

# Simulation of the Crisis Contagion Process Between Countries with Different Levels of Socio-Economic Development

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**Abstract.** The paper contains a detailed analysis of the occurrence and contagion of crisis phenomena in countries with different levels of economic development. As part of the study, a correlation analysis of classification characteristics was carried out for the preliminary division of countries into classes. The usage of neural networks tools for the mathematical modelling of the processes of transboundary contagion of crisis is substantiated. A general scheme of the system of models of transboundary distribution of crisis phenomena between countries has been built. At the first level of the scheme for dividing countries into separate groups according to types of reaction to crisis phenomena, it was proposed to cluster them using self-organizing maps. At the second level of the scheme it was decided to use a perceptron-type neural network to predict the effects of crisis transfers.

**Keywords:** crisis contagion, financial market, macroeconomic indicators, classification, perceptron, self-organizing map

## 1 Introduction

Since the 90s of the twentieth century, the world economy has experienced several waves of economic crises, covered all countries of the world. Such universality and speed of crisis contagion is predetermined, first of all, from expansion of Internet network and accelerated rates of switch to electronic money.

Specific features of modern economic crises are: the existence of a source country, in the economy of which the systemic infringements in the functioning of one or several economy sectors (financial for the most part) are born and recorded; and the time-dispersed processes of transboundary contagion of negative trends between countries.

The experience of studying the consequences and coverage of the latest world economic crises suggests that reviews of economic systems with different levels of development and initial conditions differ significantly.

Given all this, there is an urgent problem of rethinking and supplementing the existing methodology for assessing the country's economic security. In particular it's

necessary to take into account and assess the consequences of the crisis transfer to the national economy.

## **2 Purpose and Objectives of the Study**

The purpose of this study is to build a generalized scheme of a system of models of transboundary contagion of crisis between countries with different levels of socio-economic development. The purpose of the study calls for the following tasks:

1. analysis of the subject area and definition of the object of study;
2. analysis of existing approaches to modelling the processes of crisis contagion;
3. identification of features that are important for the selection of modelling tools;
4. substantiation of the choice of mathematical tools for describing the transboundary contagion of crisis between countries with different levels of socio-economic development;
5. selection of a set of criterion for preliminary separation of domain objects into classes;
6. construction of a generalized scheme of the system of models of transboundary distribution of crisis phenomena between countries with different levels of socio-economic development based on the chosen mathematical tools;
7. implement the developed system of models in specialized software module in MATLAB.

## **3 Study Summary**

As the direction of the study, the contagion of crisis between the elements of a particular closed system is not new. The task of a formal description of the contagion processes of certain properties or regularities from one object to another has been sufficiently studied in the natural sciences: physics, biology, medicine. In particular, the mathematical models of the dynamics of epidemics, models of wave propagation in various environments, and equations of the reaction-diffusion type are justified and constructed.

In economic theory, the study of such phenomena is focused on identifying the hidden mechanisms for launching sharp negative changes in the financial markets and is aimed at predicting their subsequent appearance. To date, only a small number of studies focus on the study and formal description of the other side of the crisis: the transboundary contagion of a significant deterioration in the economy functioning of one country to other countries.

Among the fundamental studies in this trend, it is necessary to single out the works of S. Schmukler and J. Franklin [1], S. Calvo and C. Reinhart [2], J. Sachs, A. Tomell and A. Velasco [3]. V. Danich [4] is an important contributor to the study of avalanche processes in the economy.

To determine the boundaries of the object of study, let us consider the basic provisions of the main theoretical concepts of this trend.

Within the W. Kermack and A. McKendrick Susceptible-Infected-Removed model (SIR), the infection "spreads either directly or indirectly from an infected to a suscep-

tible individual through discrete time and is divided into periods of occurrence and contagion" [5]. According to the theory of wave propagation, the process of fluctuation transfer is accompanied by movement of matter in time through an oscillatory medium [6].

V. Danich defines the socio-economic avalanche process as "the spread of a certain property or state in the environment of subjects of socio-economic relations with the help of socio-psychological mechanisms of infection, imitation, suggestion, which leads to a change in the economic situation or environment (demand, supply, methods of management) in a certain market segment" [4].

Taking into account the common features inherent in the phenomena of the transfer of certain regularities and properties between the elements of one system in the space, in the future, according to the purpose and objectives, object of study shall be considered as "the processes of transboundary contagion of crisis between countries with different levels of economic development from the country-sources through accessible channels of infection, which lead to a significant deterioration of the economic situation in the country".

The process of crisis contagion between countries during time can be schematically represented as follows. Let's introduce the concept: period of occurrence ( $l$ ) is the time interval from the beginning of the crisis in the source country ( $t_0$ ) until the time when the crisis begins in the country under study ( $t_p$ ), and the response period ( $v$ ) is the time interval from the moment  $t_p$  to the moment of time when recorded a reduction in the rate of economic decline ( $t_k$ ).

To date, the most well-known theoretical and methodological approaches to analyzing and predicting crises in the economy (in particular, financial crises) are the following:

1. Classic Theory of Cyclical Fluctuations in economics: developed in the works of J. Sismondi (explaining the emergence of economic crises by the fact that too much of the income is saved and a very small part of it is spent on consumer goods, as a result of which the balance between the production and sale of the produced product is violated), J. Keynes [7] (considered the variable nature of investment as the main cause of economic fluctuations, among the root causes of distrust of the market and readiness for panic, he called "instability of the business psyche of a significant part of market participants"), J. Hicks [8] (according to whom, economic fluctuations are due to the impact of the investments on the change in output), N. Kondratiev [9] (considered long periods of disruption and recovery of economic equilibrium in close relationship with the processes of depreciation of fixed capital and cyclical nature of investment), J. Schumpeter, S. Kuznets and others.

2. Balance of Payment Deficit Theory. For the first time the model was formalized in the works of P. Krugman: [10] he described that under the conditions of a fixed exchange rate, the main cause of the crisis is the financing of the budget deficit by increasing public debt. Over time, this leads to a critical reduction in gold and foreign exchange reserves, and once their level reaches the limit, the Central Bank of the country is no longer able to maintain a fixed rate. Subsequently, the Krugman model was complicated, additional variables were introduced: mistrust of the existing currency regime, the level of price flexibility, the likelihood of speculative attacks, the change in public debt, the state policy, etc.; alternative regimes were considered after abandoning a fixed rate [11].

3. Monetary Model of Exchange Market Pressure. Used to analyze and isolate the moments or periods when a speculative attack on the national currency leads to a sharp depreciation and / or a significant reduction in gold and foreign exchange reserves. To determine similar periods, the index of exchange market pressure (IEMP) is calculated as a weighted average of the degree of change in the exchange rate of the currency and the volume of gold and foreign currency reserves [12].

4. Self-fulfilling Crises Theory. It is the newest concept in the list of assumptions regarding the causes of financial shocks. Proposed for the first time by M. Obstfeld [13] it considers the behaviorist approach in explaining the causal relationships of the "avalanche" growth of negative trends in the economy. The very term "self-fulfilling" is borrowed from sociology, where it has been used since 1948 to explain the mechanism of autosuggestion [14]. The Theory of Self-fulfilling Crises suggests that sharp negative trends in the economy are preceded by an unjustified growth of negative expectations among market participants. Thus, a biased information wave, spreading among investors, causes capital outflow and in leads to devastating consequences for the country's economy a short period of time, even in the absence of initial objective conditions for their occurrence.

According to the purpose and objectives of the study and taking into account the features of the object of the study, we formulate a list of requirements for mathematical tools:

1. To model the uneven consequences of cross-border contagion of economic shocks at the stage of introduction of explanatory variables it's necessary to consider the differentiation of the set of initial conditions that significantly affect the course of the crisis within the national economies.

2. It is necessary to take into account the nonlinear relationships inherent in the object of the study.

3. In order to classify the initial information within the same system of models and predict the consequences of the contagion of economic shocks, it is necessary to ensure parallel use of several types of computing subsystems for implementing advanced approaches to processing the input data.

4. For ease of operation, the model must have the ability to adapt in case of initial data change and dynamically adjust the parameters.

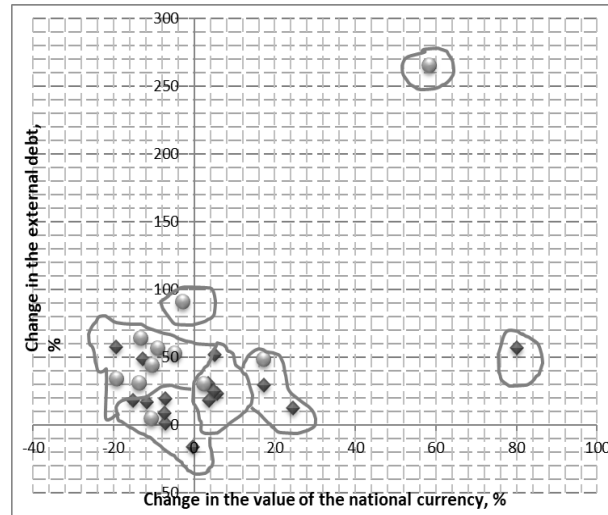
5. The practical significance of the constructed model directly depends on the possibility of an economic interpretation of the results obtained.

It is understandable that the consequences of the contagion of economic shocks, which result in the fall of the gross domestic product, the value of the national currency or the price of government bonds, are different for different countries. Therefore, the objective is to classify the countries under study in accordance with a certain set of criteria.

To simplify this stage, we can try to use the already developed system used by the IMF and the UN. It covers 181 member countries of the institution and divides countries according to the level of a market economy development to: developed market economies; emerging economies.

Let us estimate the possibility of using this classification system within this study. Based on statistical information on the course of the global crisis of 2007-2009, we construct a data field where the location of each point is determined by the coordi-

nates 'x' (percentage change in the value of the national currency) and 'y' (percentage change in the external debt). We denote seven conditional types of countries with different levels of response of economic on global crisis using markers of two types: a black rhombus – developed market economies and grey circle – emerging economies (Fig. 1).



**Fig. 1.** Point diagram of the 2007-2009 crisis impact on the economy of different countries

Interestingly, that the countries of each of the two groups on the IMF typology fell in the most zones. This makes it clear that this classification system is not convenient and universal for modeling the transboundary contagion of crisis between countries with different levels of economic development and does not correspond to the objectives of the study.

For the selection of classification criteria we use a statistical sample of economic indicators of 36 countries of the world. The sample included all two types of countries in the IMF classification:

1. Advanced economies (Austria, Italy, Netherlands, Belgium, Spain, France, Germany, United States, Japan, Greece);
2. Emerging economies (Ukraine, Hungary, Poland, Russian Federation, Kazakhstan, Bulgaria, Vietnam, Colombia, Malaysia, Philippines, Peru, South Africa, China, Argentina, Jamaica, Ghana, Sri Lanka, Indonesia, Pakistan, El Salvador, Brazil, Chile, Tunisia, Ecuador, Egypt, Turkey).

We calculate the correlation index between each classification criterion (the corruption perceptions index, the index of competitiveness, the globalization index, the economic freedom index, and the exchange rate flexibility index) and the level of GDP change, the national currency rate, the external debt. The results of the calculations are given in Table. 1.

**Table 1.** Values of the correlation indexes between the classification criterion of countries and the indicators of the crisis contagion consequences

Indicator of the crisis contagion consequences	Classification Criterion				
	Corruption Perceptions Index, points	Index of Competitiveness, points	Globalization Index, points	Index of Economic Freedom, points	Index of Exchange Rate Flexibility
GDP Growth Rate, %	-0.2436	-0.2378	-0.2764	-0.4253	-0.4522
National Currency Rate, %	0.3873	0.3875	0.1625	0.238	0.575
<b>External debt, %</b>	<b>-0.3613</b>	<b>-0.419</b>	<b>-0.2661</b>	<b>-0.1065</b>	<b>-0.3911</b>

Information for calculating the correlation indexes for the first four indexes can be found on available websites [15-18]. Index of Exchange Rate Flexibility (*ERF*) is calculated by the following formula [19]:

$$ERF_t = \frac{ME_t}{MR_t} = \frac{\sum_{k=0}^{11} |E_{t-k} - E_{t-k-1}| / E_{t-k-1}}{\sum_{k=0}^{11} |R_{t-k} - R_{t-k-1}| / H_{t-k-1}}, \quad (1)$$

where  $E_{t-k}$  – nominal exchange rate for  $k$  months till the current time  $t$ ,  $R_{t,k}$  – net foreign exchange reserves excluding gold reserves in  $t-k$  month,  $H_{t,k}$  – money supply in  $t-k$  month.

Based on the results of the correlation analysis, we assume that there is an interrelation between the selected classification criterion and indicators, reflecting the consequences of the crisis contagion between countries. We note that in this particular case the use of the Pearson correlation index is rather arbitrary and does not purport to directly estimate the coupling density between the variables.

However, the correlation indexes obtained low values. It can be explained by the nonlinearity of the relationships between the indices. This once again testifies to the futility of constructing linear models and makes it expedient to use mathematical tools that can effectively detect nonlinear regularities, in particular, neural networks.

The neural network is a mathematical tool that realizes the idea of processing information on the principle of the nervous system. The optimized network is able to build approximations for a wide class of dependencies between input parameters and the result. One of their advantages is no need for a strict mathematical specification of the model (this property is especially valuable for an adequate description of the object of study that belongs to the class of weakly formalized processes). Also, neural networks are robust, that is, they are resistant to changes in external conditions and can work with a large volume of inconsistent and incomplete information.

Among the variety of types of neural networks, the architecture known as the Kohonen Self-Organizing Map (SOM) [20] is better suited for the classification task, which is a single layer of neurons organized in the form of a two-dimensional matrix. This arrangement of neurons makes it possible to obtain a visual display of multidimensional input data. This allows to cluster the objects of study on the neurons of the

map, to carry out further analysis of the weights of the neurons and the results of the distribution of examples across clusters.

When you configure the map, its examples are provided with case studies. At each step, a neuron that has a minimal scalar product of the weights of the bonds and the input vector is defined. Such a neuron is designated as the winner in the competition of map neurons and becomes the center when adjusting the weights of both its and neuron neighbors connections.

To carry out the procedure of countries preliminary classification on the basis of the Kohonen map, we will use all five characteristics: the corruption perception index, the index of competitiveness, the globalization index, the economic freedom index, and the index of exchange rate flexibility. Taking them into account when dividing countries into classes allows us to describe the characteristics and initial conditions with which each country enters to latent period of occurrence of the crisis.

The next stage in modeling the process of transboundary crisis contagion is the construction of a neural network to predict the depth of the economic downturn in the country. The analysis of macroeconomic indicators and their testing made it possible to formulate a list of indicators of crisis processes contagion between financial sectors of different countries by the one of type of contagion channel – financial or trading (see Table 2).

**Table 2.** Indicators of transboundary contagion of crisis processes between the financial sectors of different countries

Group and Name of the Indicator	Calculation Methodology
<b>Macroeconomic indicators for assessing economic security</b>	
Ratio of the official international reserves volume to the gross external debt, %	In accordance with the methodological recommendations of relevant international financial organizations and funds
Ratio of M2 money supply to gold and foreign exchange reserves, %	
Spread of the real interest rate in the country to the same indicator abroad, % of points	
M2 money supply, %	
Deposits of commercial banks, adjusted for the consumer price index, % to the previous period	
Index of exchange market pressure (IEMP)	Weighted average of three components: changes in the exchange rate, changes in the nominal interest rate and the volume of reserves
<b>Indicators assessing the level of liberalization and integration of the stock market</b>	
Index of stock market liberalization	global index (IFCG) / investment index (IFCI)
Index of international financial integration (IFI), %	(foreign assets + financial liabilities of a country) / GDP
Net foreign assets (NFA)	By the International Monetary Fund
Corruption perception index (CPI)	By Transparency International
<b>Indicators assessing the relationship between the real and financial sectors of the economy</b>	
Tobin's index (elite enterprises shares of which are included in the stock indexes), %	market value of the company's assets / balance sheet capital
Monetization factor, %	M2 money supply (cash, cash on the accounts of enterprises and household deposits in banks) / GDP

Export of goods and services, % compared to the previous period	In accordance with the methodological recommendations for assessing the level of economic security of Ukraine
Terms of trade index (price), %	
Import of goods and services, % compared to the previous period	
Share of exports in total GDP, % compared to the previous period	[export income / GDP (previous period)] / [export income / GDP (previous period)]
Share of raw materials export income, %	raw materials export income / GDP

Let us consider a system consisting of economies of  $N$  countries ( $E=1, \dots, N$ ). Each economy is characterized by a set of macroeconomic indicators that record the spread of economic crises through financial ( $f$ ) or trade ( $tr$ ) channel ( $I_f^E, f=1, \dots, M; I_{tr}^E, tr=1, \dots, L$ ). According to the conditions inherent in each particular economy at time  $t$ , it can be assigned to a certain class ( $CL=1, \dots, D$ ). The consequences of the crisis for the economy of an arbitrary country can be estimated on the basis of a set of three indicators: changes in GDP, the rate of the national currency, the value of external debt ( $RES_k^E, k=1, \dots, 3$ ). Then the processes of transboundary contagion of crisis can be described by a scheme of system of models based on neural networks, as shown in Fig. 2.

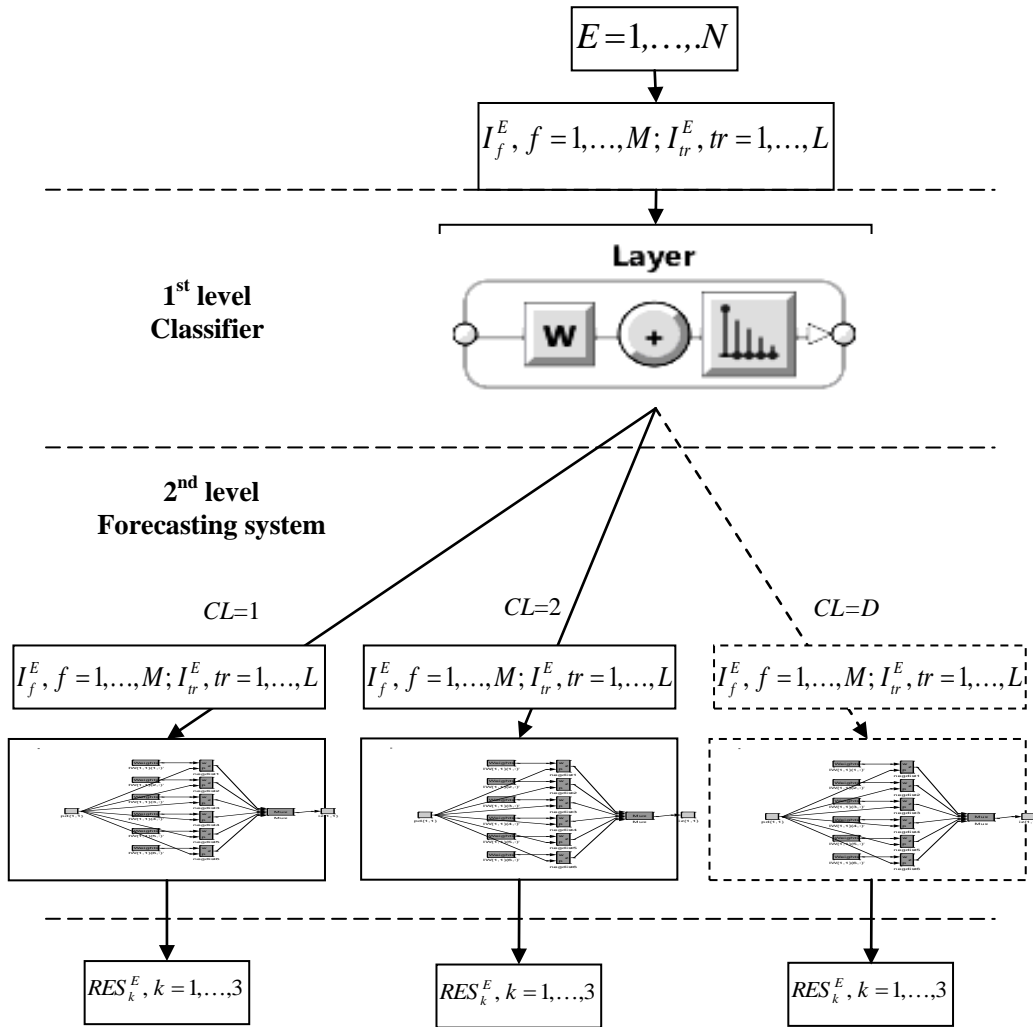
As can you see from Fig. 2, the scheme of calculations consists of two levels. Each level implements one of the modeling tasks – classification or forecasting. At the first level, countries are divided into clusters according to the system of classification criterion (corruption perceptions index, exchange rate flexibility index, competitiveness index, etc.). At the second level, the task of forecasting the main macroeconomic indicators of the economy shrinks due to the crisis contagion is being solved.

The system of models presented in Fig. 2 is implemented as a separate software module in the MATLAB system and consists of two subsystems. The calculation was made based on statistical information on the course of the global crisis of 2007-2009.

The first model, based on the Kohonen map, implements the classification of researched countries by the type of reaction to the processes of cross-border transfer of crisis phenomena in financial markets. As a result of the algorithm it's obtained the Kohonen map, consisting of six clusters. Each of them is associated with a particular scenario of economic behavior of countries belonging to it:

1. Euro Area, Estonia, Lithuania, Czech Republic, Denmark, Israel, Singapore, Switzerland, United States, Brunei Darussalam, Malaysia, Myanmar, Philippines, Thailand, Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Latvia, Macedonia, Montenegro.
2. Australia, Canada, New Zealand, Norway, Sweden, Indonesia, Kiribati, Samoa, Tonga, Vanuatu, Hungary, Poland, Serbia Republic.
3. Bangladesh, Armenia, Georgia, Moldova.
4. Iceland, South Korea, United Kingdom, Bhutan, India, Nepal, Solomon Islands, Romania, Turkey.
5. Special administrative region of China Hong Kong, China, P.R.: Macao, Japan, China P.R.: Mainland, Lao People's Democratic Republic, Papua New Guinea, Azerbaijan.
6. Cambodia, Fiji, Mongolia, Sri Lanka, Vietnam, Kazakhstan, Belarus, Kyrgyz Republic, Russian Federation, Tajikistan, Ukraine.



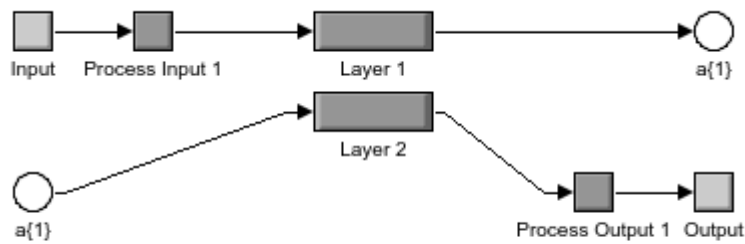


**Fig. 2.** Generalized scheme of the system of models of transboundary contagion of crisis between countries with different levels of socio-economic development

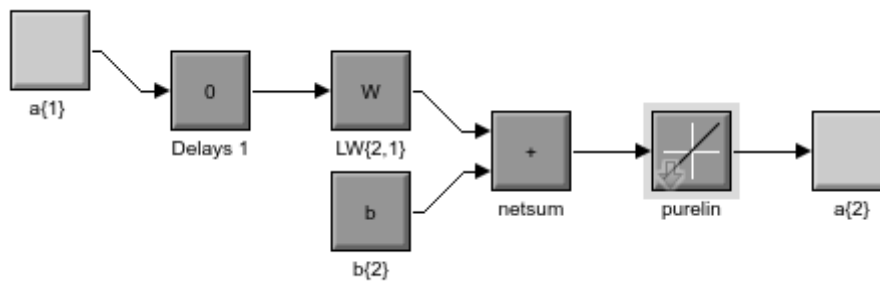
Clusters #1 and #2 combine countries characterized by a short economic recovery period and a fairly rapid return of key macroeconomic indicators to pre-crisis levels. The longer period of recovery and the higher volatility of exchange rates, gross domestic product and the reduction of export-import operations are characterized the third and fourth cluster of the Kohonen map. As for the countries from the last two clusters (including Ukraine), as a result of the crisis the average estimate of macroeconomic indicators dropped is more than 15% for the sixth cluster and by 9% for cluster #5. It is also important to note that the SOM has included in one group the countries, which are geographically neighbors with historically established close economic ties.

The second subsystem that implements the forecasting process was built on the basis of the neuron network of the perceptron type. The trained neural network performs the forecasting of the scenario of the studied country economic development under the impact of transboundary transfer processes of crisis phenomena in financial markets by establishing a correspondence between the pre-crisis level of macroeconomic indicators characterizing financial and trading channels of crisis contagion (see Table 2) and one of the six clusters obtained on the previous stage.

A detailed structure of the neural network for predicting the scenarios of response of studied economics in terms of basic macroeconomic indicators fall shown in Figures 3-4.



**Fig. 3.** A detailed structure of a two-layer neural network of perceptron type. Source: built by authors in SIMULINK



**Fig. 4.** A detailed structure of second layer of neural network of perceptron type. Source: built by authors in SIMULINK

The obtained results of carried out experiments indicate the high level of reliability of the obtained model. Constructed perceptron-predictor with a probability of 77% determines the scenario of the behavior of the studied economy in the processes of cross-border transfer of crisis phenomena in financial markets through available distribution channels.

## 4 Conclusions and Outlook

As a result of the research, weaknesses in the study of crises were identified and the need for analysis and modeling of the processes of crisis transboundary contagion in countries with different levels of economic development is emphasized. The essence of the object of study is revealed and its definition is formulated. According to the purpose, objectives and the object of study, a theoretical substantiation of the usage of neural networks as a mathematical tool is given.

Note that a separate transfer scenarios not addressed the crisis between the two countries, such as between developed and developing countries or between developing countries, etc. The problem of this type does not seem expedient to the authors, because isolate pairwise relations between countries in terms of transnational corporations and the electronic money is not possible. In this study, the transfer of the crisis is considered by analogy with the contagion of epidemics in natural sciences [5].

For the purpose of the primary division of the totality of countries into classes, a correlation analysis of the classification characteristics is carried out. Conclusions on the inadequacy of common approaches to the goals of modeling are made.

A generalized scheme of a system of models of crisis transboundary contagion between countries with different levels of socio-economic development based on neural networks is constructed. At the first level of the scheme, it is suggested to use Kohonen self-organizing maps to divide countries into separate groups according to the types of reaction to crises. To predict the consequences of crisis contagion at the second level of the scheme it was decided to use a perceptron type neural network.

An important advantage of the built system of models based on neural networks, besides the ability to forecast the scenarios of behavior of the national economy during the crisis on world capital markets, is the possibility of determining the elasticity of each of the indicators of the transmission channels to form an adequate situational policy of adaptation to imbalances in the source country's economy and mitigate its effects.

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