Olena A. Sergienko[1], Lidia S. Guryanova[2], Viktor P. Nevezhyn[3]
MODELLING OF SOCIOECONOMIC CRISES IN EARLY WARNING SYSTEMS

This paper offers a set of models of economic crises based on the catastrophe theory, which allows increasing the scientific validity of forecasts in early warning systems as an information and analytical base of decision-making in the field of stabilization policy. The activity is aimed at early recognition of crises, warning on the threats of economic catastrophes formation and promoting economic security under the conditions of markets globalization.
Keywords: economic crisis; early warning system; forecasting; catastrophe theory; bifurcation phase.

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МОДЕЛЮВАННЯ СОЦІАЛЬНО-ЕКОНОМІЧНИХ КРИЗ У СИСТЕМАХ РАННЬОГО ПОПЕРЕДЖЕННЯ

У статті запропоновано комплекс моделей економічних криз, який на основі теорії катастроф дозволяє підвищити наукову обґрунтованість прогнозу в системах раннього попередження, якість інформаційно-аналітичної бази прийняття рішень у сфері стабілізаційної політики. Остання спрямована на раннє розпізнавання криз, попередження загрози формування економічних катастроф, забезпечення економічної безпеки в умовах глобалізації ринків.
Ключові слова: економічна криза; система раннього попередження; прогнозування; теорія катастроф; фаза біфуркації.
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МОДЕЛИРОВАНИЕ СОЦИАЛЬНО-ЭКОНОМИЧЕСКИХ КРИЗИСОВ В СИСТЕМАХ РАННЕГО ПРЕДУПРЕЖДЕНИЯ

В статье предложен комплекс моделей экономических кризисов, основанный на теории катастроф, позволяющий повысить научную обоснованность прогноза в системах раннего предупреждения в качестве информационно-аналитической базы принятия решений в сфере стабилизационной политики. Последняя направлена на раннее распознавание кризисов, предупреждение угрозы формирования экономических катастроф, обеспечение экономической безопасности в условиях глобализации рынков.
Ключевые слова: экономический кризис; система раннего предупреждения; прогнозирование; теория катастроф; фаза бифуркации.

Problem statement. The formation of market economy within the global system, as well as the increase of openness of national economies has led to the growth of systemic risks.

A bright demonstration of the catastrophic level of risk is the global financial and economic crisis which was initially considered as a crisis of investment financial corporations, and, subsequently, due to the cross-border movement of capital hit a growing range of national economies and led to a significant fall in the growth rates of the world economy as a whole. Increase of the probability of formation of macroeco-

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nomic crisis situations is explained by the fact that they are interrelated, some of them resonate, which reinforces the economy decline.

The growth of uneven development of territories typical for the last years has aggravated the situation. Due to differentiated economic potentials of areas, determining the difference in speed and power of stabilizers and allowing to reduce the negative impact of external "shocks", zones of economic catastrophes have been formed which are characterized by the considerable depth of the downturn.

The package of anticrisis measures, stipulated by the countries' legislation, and related to the anticrisis policy on employment, the usage of financial instruments of economic growth regulation, demonstrated their inability to cope with emerging challenges. In this respect the problem of modelling and forecasting of macroeconomic crises in early warning systems becomes paramount.

The goal is to determine the time of the crisis onset, assessment of potential adaptation of economic systems, also selecting appropriate tools of state regulation of economy, aimed at formation of safe economic growth.

Recent research and publications analysis. Various approaches to the analysis of crisis dynamics of economic systems are considered in contemporary scientific works. Special attention deserves the classification of development indicators of economic systems on the principle of synchronization, as used by the National Bureau of Economic Research, USA. Based on this classification, leading and appropriate to the phase of economic crisis indicators are highlighted. Leading indicators are essentially symptomatic, being markers that signal the occurrence of a certain crisis phase.

Forecasting the development of economic systems based on the use of indicators system of early detection of the crises is impossible without application of economic-mathematical methods and models, as reflected in the works of V.A. Sadovnichy, A.A. Akayev, A.V. Korotayev and G.G. Malinetsky (2011), B. Hemosillo-Gozalesa (1999), Z.N. Grinyaev et al. (2010), A. Tsvetkov, K.H. Zoidov, V.A. Gubin, M.V. Ilyin and A. V. Kondrakov (2010), A. Demirguc-Kunt and E. Detragiache (1998), V.V. Mashchenko (2002), O.G. Mezentsev (2007), V.L. Pozdneev (2006), Y.V. Revenko (2007), V.G. Solovyov (2009), J.D. Sachs, A. Tornell and A. Velasvo (1996) etc. A wide range of methods of economic and mathematical modelling for predicting crises is used by these authors. In particular: recurrent charts, analysis of phase transformations in the precrisis period, the theory of random matrices, computer simulation, expert methods of forecasting, time series analysis, production functions.

Unresolved issues. Despite considerable interest in the analysis of the crisis dynamics of systems, the realities of the economy with its instability and unpredictability of crisis situations prove that used traditional methods and valuation models, analysis and prediction of crises in early warning systems provide inadequate results and forecasts, which requires improving the tools of the research crisis development dynamics of the economic systems indicators.

One of the promising approaches to analyzing and forecasting the economic crises is the theory of bifurcations and catastrophes. The catastrophe theory is a conceptual and methodological basis for the studying and forecasting the volatility of different systems (Agapova et al., 2000; Jankovskiy, Makogon and Ryabchin, 2009). Since the loss of stability of the system occurs under the action of natural develop-

ment mechanisms, the theory of catastrophes is fully applicable to the analysis of conditions under which the system stops developing in the dynamics and enters the phase of bifurcation.

Seen in this perspective, the conclusions of the catastrophe theory can be used to analyze the conditions for avoiding undesired bifurcations, the catastrophic loss of economic stability system that is taking place in the current conditions of crisis.

Forecasting the loss of stability of an economic system on the basis of the catastrophe theory is carried out in different ways. One of them is building a model of the catastrophe in the study of economic systems on the basis of data on the relationship of variables that characterize its behavior.

The purpose of the research is to develop a complex of predictive models of macroeconomic crises, enabling the catastrophe theory to determine the turning points, identify the crisis prerequisites, improve the scientific validity of predictions in early warning systems to prevent economic crises.

Key research findings. The complex of 5 models of catastrophes (fold, assembly, swallowtail, butterfly, wigwam) associated with the instability of a variable (x) with all others and umbilical catastrophes (elliptic, hyperbolic, parabolic umbilici) with instability of the relationship between the two variables (x_1) and (x_2) with all the others has been built in the study. If the value of the determination coefficient and statistical significance of the equation of one of catastrophes exceeds equation sustainable, then a catastrophe should be considered possible and a forecast can be made for it.

The study on the dynamics of economic systems identification flags, which can assume the presence of a catastrophe in the development of the system, only one of them − anomalous dispersion − is used (Alekseev, 2000). Indication of possible approximation of the catastrophe is the increase in the dispersion or amplitudes of oscillations of the quantities characterizing the system. Among other displays there should be highlighted differences in reactions of the system to the same control impacts, slow oscillation damping, increases in the frequency of oscillations.

Initial statistical data for the analysis of the instability of the relationship of the main macroeconomic indicators are chosen in such a way that you can get estimates as over a long period of time (annual cut) and short-term stages of economic development (quarterly, monthly cut). The adopted reference base on the rates of growth and absolute increments allows reducing the influence of seasonal and other temporary factors. The values of parameters of the initial time series are compiled on the basis of official data of statistic committees.

Building the catastrophe models was carried out according to the following algorithm:

1) identification of mutual influence of socioeconomic indicators for different time horizons;

2) assessment and analysis of the nature and type of catastrophe identified scorecards;

3) construction and analysis of the most probable surface catastrophes;

4) construction and analysis of bifurcation set catastrophe, analytical assessment of the points of possible balance;

5) study on the number and nature of the functions extremes with parameters change (or control variables) models catastrophes.

As a result of the research on the most relevant macroeconomic indicators in the precrisis period in the economy of Ukraine (2002–2006) the following indicators were selected: the dependence of GDP on the level of industrial production and aggregate M3. Their values are the indicators of financial security and the level of industrial activity of Ukrainian economy.

The models of umbilical catastrophe are considered. Among the obtained models the value of determination coefficient ($R^2 = 0.82$) was chosen, the parabolic umbilical model catastrophe describing the dependence of growth rate of industrial output (x_1) and aggregate M3 (x_2) from the rate of GDP growth (y), which has the following form:

$$y = x_1^2 x_2 + x_2^4 - 0.887 x_1^2 - 3.293 x_2^2 - 0.39 x_1 - 2.821 x_2. \tag{1}$$

The surface of catastrophe is defined as the set of equilibrium points (equilibrium surface) as presented in Figure 1.
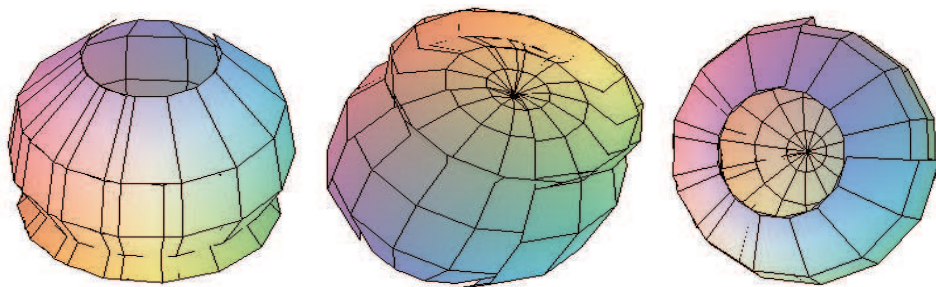

Figure 1. **The surface of catastrophe of "parabolic umbilic" type describing the relationship of industrial production and aggregate M3 of GDP (2002–2006),** *authors*

The system of equations, which describes the bifurcation set of catastrophe (projection of many singularity on the parametric space) is as follows:

$$\begin{cases} 2x_1 x_2 - 1.774 x_1 + 0.39 = 0 \\ x_1^2 + 4x_2^3 - 6.586 x_2 - 2.821 = 0. \\ x_1^2 = (x_2 - 0.887)(x_2^2 - 3.293) \end{cases} \tag{2}$$

Bifurcation set is a set of parameters' values, of which there are several different states of the system, i.e. the same value of *X* can meet a lot of *Y* values. The analysis of the system of equations describing the bifurcation set allows drawing the following conclusions:

- if the system, describing bifurcation set, approaches zero at the observed values of the variables, it is the evidence of the disaster occurrence in the specified system;

- the closer to zero the value of the system of equations is, the closer the system is to catastrophic conditions, i.e., the system loses its stability.

For the obtained model the approximation to zero the solutions of the system of equations are mostly typical for the period January-February 2006, which indicates the approach of the systems to the conditions of catastrophe.

Bifurcation set of catastrophes of "parabolic umbilic" type in three-dimensional space is graphically presented in Figure 2.
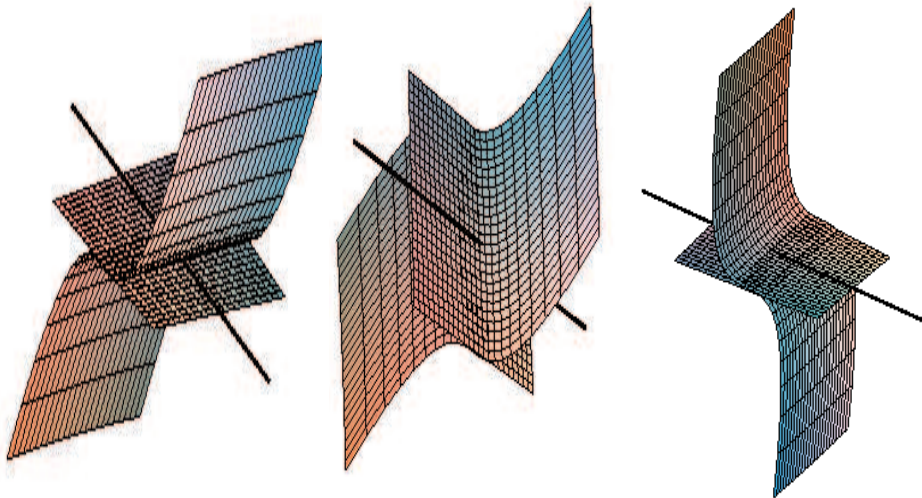

Figure 2. **Bifurcation set of catastrophes of "parabolic umbilic" type,** *authors*

The behavior of the system at the point of bifurcation, representing critical moment in the development of the system (point of branch development options, which is a catastrophe), have common patterns, many of which are disclosed on the basis of concepts of self-organization (Arnold, 1990):

1. The bifurcation points are often provoked by the changes of the control parameter or management subsystem entailing the system into a new state.

2. There are many potential trajectories of the system development and it is impossible to predict exactly what state the system will move after passing the bifurcation point. This is because the influence of the environment is random and does not exclude determinism between the bifurcation points.

3. The choice of a branch can also be connected with the stable type of system behavior. According to the principle of sustainability among the possible forms of development only stable are implemented. Unsustainable forms, if there are any, then are quickly destroyed.

4. Increasing the dimension and complexity of the system is the increase in the number of conditions that can occur leap (catastrophe), and the number of possible ways for development. Thereby, that the more heterogeneous elements of the system are and complex is its communication, the more unstable it is.

5. The more non-equilibrium is the system, the larger is the number of possible ways of development there may be at the bifurcation point.

6. Two close conditions can produce entirely different development trajectories.

7. The same branches or their types can be implemented repeatedly.

8. Temporary boundary catastrophe is determined by the "principle of maximum delay": the system makes a leap only when it has no other choice.

9. As a result of branching (bifurcation) limit cycles occur. These are periodic trajectories in the phase space, the greater the number of which is, the more structurally unstable the system is.

10. Catastrophe changes the organization of system and not always in the direction of increase.

Thus, the development of the system occurs in the process of moving from one point of bifurcation to another. At each point of bifurcation of the system chooses the path of development and the trajectory of its movement.

The onset of a catastrophic stage in the development of system (leap) is possible only when the system parameters reach threshold values (critical or bifurcation) under the influence of internal and/or external fluctuations. As a rule, the more complex a system is, the more bifurcation values of the parameters are in it, i.e. the wider is the set of states, in which instability may occur. When the values of the system parameters are close to critical, it is particularly sensitive to fluctuations: quite small impacts may cause its abrupt movement into a new state through a field of instability. For the accomplishment of the system of catastrophic transition it is necessary that its parameters as well as environment settings (control parameters) will reach the bifurcation values and will be in the field of reachability.

So, when you change the control parameters under the influence of the external environment in the catastrophe model of "parabolic umbilic" type for the period of precrisis development of Ukraine's economy (2002−2006) approximating the relationship of growth in industrial production (x_1) and the growth rate of aggregate M3 (x_2) from the rate of GDP growth (y), potential function changes the number and the nature of its extremes. Fragment of frame animation function, shown in Figure 3, confirms the structural instability of functions describing this process.
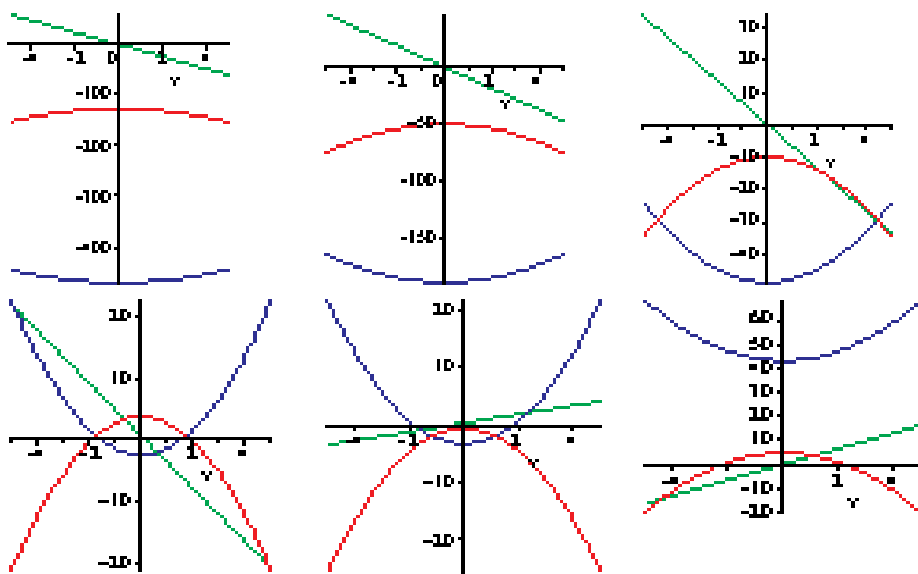

Figure 3. **Frame animation system behavior in the catastrophe model of "parabolic umbilic" type from the values of control parameters,** *authors*

As a result of the research on the systems of the most relevant macroeconomic indicators in the period of crisis development of Ukraine's economy (2007−2010), characterized by the increase of instability and nonlinearity in the relationship, the

principal possibility of bifurcations and high probability of catastrophes, the following indicators have been selected: import dependency on the level of industrial production and wages. Macroindicators are the indicators of foreign economic factors of the crisis, as well as the level of industrial activity of Ukrainian economy.

The models of umbilical catastrophe are considered. Among the obtained models of umbilical catastrophe on the criterion $R^2 = 0.943$ the catastrophe model of elliptic umbilic has been selected describing the interdependence of the growth rate of industrial output (x_1) and the growth rate of wages (x_2) from the growth rate of import (y):

$$y = x_1^3/3 - x_1 x_2^2 + 1.332(x_1^2 + x_2^2) - 1.589x_1 + 0.523x_2. \tag{3}$$

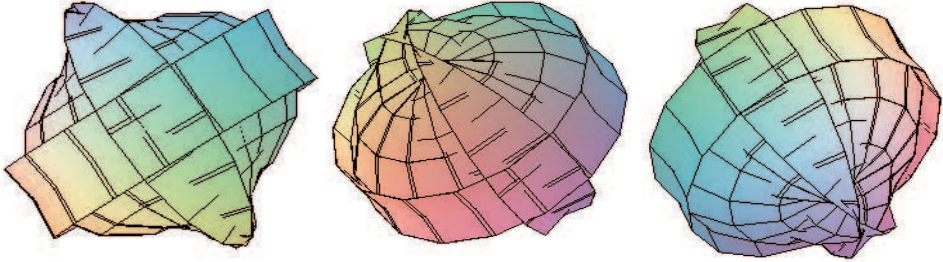The surface of catastrophe is presented in Figure 4.

Figure 4. **The surface of the catastrophe of "elliptic umbilic" type describing interdependence of industrial production, wages and imports (2007–2010),** *authors*

Bifurcation set of catastrophe is shown in Figure 5. For the obtained model the approximation to zero in the solutions of the system of equations are mostly typical for the period from August, 2007 to January, 2008, from September, 2008 to January, 2009 and the last quarter of 2010, which indicates the approach of the system to the conditions of catastrophic leap.
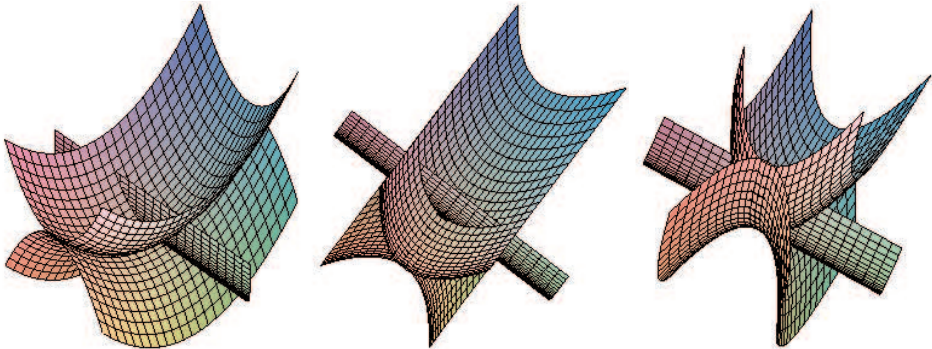

Figure 5. **Bifurcation set of catastrophe of "elliptic umbilic" type,** *authors*

Frame animation behavior of the system when you change the control parameters is presented in Figure 6. Potential function changes the number and the nature of its extremes and confirms the structural instability of functions describing this process.
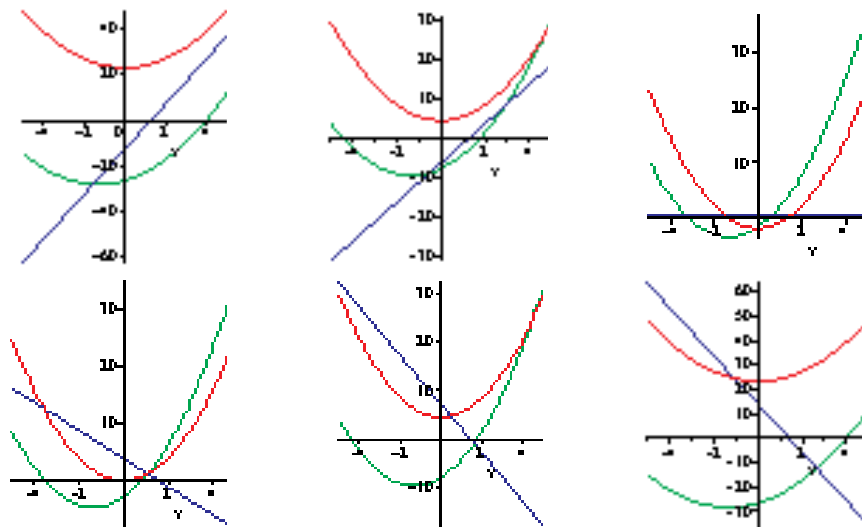
Figure 6. **Frame animation system behavior in the catastrophe model of "elliptic umbilic" type from the values of control parameters,** *authors*

Conclusion. The complex of models made on the basis of the theory of catastrophes is the tool of research of crisis processes in the dynamics of macroeconomic indicators and the basis for further development of theoretical and methodological support of stabilization policy, aimed at early recognition of crises, warning of the threat of the formation of catastrophes, economic security and sustainable economic development under the conditions of globalization of markets.

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