DOI 10.1007/s10559-020-00217-w
*Cybernetics and Systems Analysis, Vol. 56, No. 1, January, 2020*

# MODELING THE CONTROL EFFECTS OF THE BANKING SYSTEM ON THE FUNCTIONING OF THE ECONOMY. I. DYNAMICS AND ADJUSTMENT OF CRISIS SITUATIONS

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UDC 519-7/339.9

**Abstract.** *The paper examines mathematical modeling of the dynamics of the global financial and economic system. The features of the full mathematical model of the financial-economic system are indicated. The choice of the mathematical apparatus that is optimal for the study of this class of models is justified.*

**Keywords:** *financial and economic system, mathematical modeling, control optimization, "splashing out" effect, Tikhonov's systems, analysis of large systems, Khilenko's theorem.*

The problem of predicting crisis situations in the economy and the banking system remains relevant. A lot of articles have been dedicated to this problem and to the development of ideas and methods for crisis management. However, every crisis situation that follows is a testament to the fact that the suggested recommendations and methods are de facto ineffective. The main reasons for it may be the following:

1. Insufficient mathematization of the problem, unclear statement of the problem. These factors result in ambiguity and lack of clarity in determining the correctness of the proposed solutions and recommendations.

2. Problem parameters vary with time, development of society, development of banking and economic systems. The lack of a clear, mathematical statement of the problem and, accordingly, of mathematical models, makes it impossible to adjust the formulation of the problem in a way that would consider transformations that have occurred, and time-adaptive changes in constraints and parameters.

3. Dependency (often ungrounded) of the decision-making process (illustrated by the Federal Reserve System, FRS, and the "splashing out" effect [1]) on human performance [2]. Making managerial decisions under astronomical multifactorality of the problem, even (theoretically) in case of utmost professionalism of the chair of the managing structure, requires a greater emphasis on the computational, computer-mathematical choice of control actions (considering the mixed valuations of the degree of optimality of the decisions made by the former Chairman of the FRS and by some of his colleagues, including Nobel Laureates).

A direct result of human performance is that a number of economic, financial, social, and other factors, as well as ongoing processes, may end up ignored because of physiological limits of the human brain to grasp and process colossal amounts of information on accounting and predicting its influence on further dynamics of the system. The "splashing out" effect demonstrates that, for instance, an informed decision for the US economy may require consideration of a large number of exernal parameters that are outside of the scope of the daily focus (forecasts of Asian economic processes caused by previous decisions by the FRS). In case that this condition is ignored, the expected results of the managerial decisions may be ineffective.

Let us examine in greater detail the grounds for including the above-mentioned reasons in the list.

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Translated from Kibernetika i Sistemnyi Analiz, No. 1, January–February, 2020, pp. 26–34. Original article submitted February 5, 2019.

The need for mathematization of control of financial and economic system (FES) stems from attempts to apply the research of renown economists practically. For example, even though the works of J. Keynes are regarded as highly significant [3], his theoretical provisions do not give a clear algorithm for defining practical (numerical values) control actions. The relevance of this provision is supported by information from the IMF in 2016 on factors that were harbingers of the crisis [4, 5], etc. A lot of time passed between [3] and the publications [4, 5]; however, the abovesaid about the work of J. Keynes is also true for the aforementioned articles.

The second reason is obvious and requires no further explanation.

The third reason is traditionally debatable. Defining the borders of optimality when choosing between "machine suggestions" and human opinion is a complicated task. To what extent a human making the decision must take into account the optimal machine solution — that is determined by the point of view of the individual and depends on a particular situation. However, an approach that requires that a limited set of acceptable "machine solutions" in a Pareto region be formed, and the limits of this region set by specialists, is not unsound.

In order to overcome the difficulties caused by the reasons indicated above, it is necessary to form a mathematical model that describes the dynamics of the FES in a way that is standard for computational mathematics. At the same time, this model must account for various factors, which influence the economies of particular countries and regions, and the connections between them. This model, along with random variables and parameters that have deterministic values, must also contain social and psychological factors that characterize the behavior (financial and economic actions) of large groups of people. Such factors cannot be easily formalized in the terminology of systems analysis and operations studies [6, 7].

It is an applied problem of the highest difficulty to create, while keeping the aforementioned factors in consideration, a full, global, mathematical model (SM model) of the FES. However, conceptual foundations of such model can be defined clearly, even if the SM model is adjusted to the permanent changes as they take place in the global FES. The difficulty level of the problem of SM model creation correlates with modern capabilities for its solution and the lack of alternatives to this approach, because, in this case, to paraphrase A. Poincare, science begins where mathematical models begin. The creation of SM models of the FES will facilitate, according to A. Lyapunov's thesis, the move from a "physical problem" to a "purely mathematical" problem, which, in turn, enables the use of well-developed and appropriate instruments of computational mathematics [8–12].

The characteristics of an SM model of the FES are as follows:

1) large dimension of the vector of state variables;
2) wide range of the rates of variation of state variables (the system is classified as static);
3) presence of a single, common for all state variables, control parameter;
4) quasi-stationarity of the total value of the single control parameter (closed system).

Overall, the FES can be presented as a system that is variable in structure and consists of micro- and macro-clusters. All clusters function on the border of the bifurcation region, or, in the terminology of Tikhonov's systems, the boundary layer region. The clusters are connected to each other by the banking system that regulates the financial flow. The supply of the flow depends on a number of factors, starting with the consumers (population, households, according to the terminology of J. Keynes) and businesses, as well as suppliers of components that are necessary for production of goods by businesses producing the final product for households.

The FES model is to be examined structurally as a system of closed vessels, which are entities in the system, all connected with a common "ring," which is the physical realm where the common financial resource is transferred (can be regarded as a single circulatory system of a biological entity). The entities in the system (businesses and households) use resources from the common "ring." Financial ("feeding") resource is associated with a sort of liquid of fixed (quasi-fixed) volume, which circulates in some closed space. This space, in addition to the main flow that is common to all the elements of the system, has branches with outflow and subsequent return of the consumed resource into the main flow. The movement of the financial resource determines the normal functioning of the entire system. Clearly, if the consumers (households, other businesses) have a need for the product of business $L$, then it thrives, if not, then it becomes ineffective and unprofitable. In case of the latter, a part of the financial flow is freed up and moves to other clusters or is "preserved" in the banking system. Households receive some resources from the common flow and spend a part of them on consumption, which creates financial flow for businesses. By allocating another part of resources for savings, they also increase the "volume of the flow" and participate indirectly, through the banking system, in building up resources for businesses.

The closed-loop, closed nature of the FES as a single unit is an important factor that defines the specifics of the dynamic processes that take place in the system. The main (financial) resource (the same as all other resources that are subjects to the system) takes on final, clearly defined values. As a result, the exponential development of any cluster (industry, sub-industry) creates imbalance in the system. After a certain period, this process may lead to a “bubble burst” if the “bubble” is not backed by real results that are productive for the system. Alternatively, the process may lead to normal, non-exponential dynamics if the development of the cluster was caused by technological and revolutionary changes.

Steady state is a natural property of the full mathematical model of the FES because there are slow processes (occurring at significantly different “slow” speeds) in the economy and the banking system that go on for months, years, even decades, as well as fast processes, when, in a matter of weeks (sometimes even days), there are abrupt changes in share prices, currency exchange rates, etc.

The most acceptable mathematical apparatus for describing systems (of objects) that considers the above-listed factors are Tikhonov and quasi-Tikhonov systems [8].

In order to describe the dynamics of certain fragments of the FES, we are using a special type of model: the Lotka–Volterra (predator–prey), which, unlike the traditional model, considers a certain final set of “predators” (according to the established terminology) that are fighting for a single, shared resource $\theta_{f(i)}$, from this particular fragment $f(i)$ of the FES:

$$\dot{X}_1 = f_1(x_2, \theta_{f(i)})x_1, \qquad (1)$$
$$\dot{X}_2 = f_2(x_1, \theta_{f(i)})x_2 .$$

The complexity of creating and calculating an SM model is due to having to account for the relationship (interaction) of separate fragments of the FES, when values $\theta_{f(i)}$ change in correlation without compromising the equation $\sum_i \theta_{f(i)} = \Delta$, where $\Delta$ represents the value of the total financial resource of the FES.

The FES SM model that accounts for the development dynamics of individual fragments and their mutual influence, according to [1], will be examined as a system of ordinary differential equations

$$\dot{Z}_1 = f_1(z_1, \ldots, z_n, t), \qquad (2)$$
$$\dot{Z}_n = f_n(z_1, \ldots, z_n, t).$$

A number of renown specialists [1] have remarked on the importance of accounting for not only the direct influence that powerful and economically developed clusters have on the other fragments of the FES, but also for the (reverse, coming with a certain delay) “splashing out effect” response, which affects the dynamics and stability of the FES as a whole. The accounting is complex because the mathematical formalization and modeling of these processes are labor-intensive tasks.

Considering the static characteristic of the model, we will state it in a standard form of a system with explicit small parameters

$$\varepsilon \dot{y}_1 = f_1(y, t), \qquad (3)$$
$$\dot{y}_2 = f_2(y, t),$$

where the small parameters $\varepsilon$ account for the dynamics of the common resource coming from the main flow.

In case of creation of the SM model in the form of (2), the small parameter $\varepsilon$ is hidden but, just as in (3), when it is visible, it sets the speed (the fast component) that determines the oscillation of the financial flow (inflow and outflow of the common resource) into separate businesses (clusters) and households. Wherein $\varepsilon$ can be considered as the control action that defines the stability of the system. When $\varepsilon$ increases, certain businesses will not be able to develop at the same speed as they did with small $\varepsilon$.

A full, applied model of the FES may contain hundreds of thousands of equations that describe the dynamics of financial flow movements for businesses and households. The dynamics of individual businesses can be regarded as quick fluctuations against the backdrop of slow development of the entire system.

Variations of $\varepsilon$, which show the overall state of the economic system, are, first and foremost, connected to the dynamics of the banking system. The dynamics of $\varepsilon$ are controlled and changed by the banking system. Changes in $\varepsilon$ in the common “supply flow” simply provoke a total collapse of the system. Adequate management of the banking system should slow (stop) the development of crisis situations. Influence of governing structures (governments, central banks, and other organizations) on the dynamics of the values of $\varepsilon$, exercised through the banking system, allows adjustment of the dynamics of the FES and not let the FES move into unwanted sections of the trajectory.

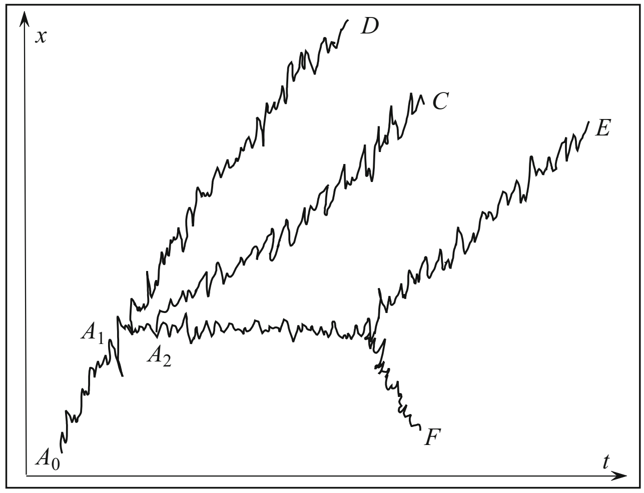


Fig. 1

Naturally, the full model of the object under study will be nonlinear. Analyzing and calculating large and super large models is a problem in and of itself. Controlling the dynamics of such model requires finding solutions to not just one highly complex problem, but to a whole range of complex and highly complex problems. However, the transformation of a nonlinear model into the quasi-stationary type and the linearization of a model simplify the analysis. In this case, we will use large and super large matrices. Assessment of the dynamics of ongoing processes in the intervals of linearity will allow us to determine the eigenvalues in such matrices. The numerical algorithm that provides a solution to the problem of determining the eigenvalues of large and super large matrices is the algorithm proposed in [9], which is based on (Khilenko's) theorem [10]. In the context of this work, source [9] agrees, in concept, with the claim that the formulation and solution of the problem of "technocratic control and regulation of the global FES" is currently realistic if the following factors are considered:

— high level of development of methods of computational mathematics and systems analysis (operations research);

— modern computing power of supercomputer clusters;

— high level of infocommunication technologies and digitalization of the world, which makes it possible to collect and accumulate statistical data and to build necessary data bases (bases of knowledge, data storage).

The combination of the listed-above factors is a supporting argument for special attention to be paid by the governing structures of the FES to technocratic calculations in the decision-making process.

The object, described by the system of equations (1), has its normal state, which is in the interest of the majority of the "FES users," i.e., businesses, households, and other structures, as the trajectory of $A_0D$, illustrated by Fig. 1, which is the state of dynamic equilibrium. Elements of the system are in a constant state of micromotion (in relation to the dynamics of the entire system).

In the beginning period of the crisis, the dynamics of separate fragments of the FES can be described using one of Thom's catastrophes, when the process takes on the characteristics of a landslide, "a fall off a cliff" with a negative angle of reverse ascension along the dynamic trajectory. At the same time, the use of Thom's theorem to examine the class of FES models under consideration is impossible in general, as the value of $k$ is limited to ($k < 5$) [11]. Also, the classical definition of a catastrophe in the terminology of the catastrophe theory may not mean a collapse in the functioning of the FES. The concept of a crisis (collapse) in this case does not mean fast transition of the system from one state to another, but falling into a state of "anabiosis," a "coma."

For the sake of the chosen approach to modeling FES dynamics, the term "crisis of an object (system)" is to be understood as the minimization ("freezing") of the dynamic processes of the "FES users." Considering the state of collapse, the trajectory of the system (dynamics of financial processes of "FES users") will look like the illustration in Fig. 1, where the intervals $A_1A_2$, $A_2B$, and $BF$ correspond to the crisis state of the FES.

It is evident from the analysis of the dynamics of the examined model, that, for the stability of the entire system, the movement of its elements must occur within a limited range: the zone of stability and attraction of a bifurcation point. Such dynamics correspond to the evolution periods of the FES's development, which are characterized by a slow, average movement of the system along a "slow" trajectory. In case of the opposite, the entire system may move into the attraction zone of another solution, which has to do with changes in the nature of the average dynamic process. The fundamental question here is to determine the types of exponentially growing business processes and whether their nature is creative or speculative. In case of the former, the system is very likely to switch to another, average "slow" trajectory. In case of the latter, it is expected that the phase trajectory of the system will switch to interval $A_2B$, i.e., sliding into crisis. Correct choice of control actions should ensure that the control goal is reached, namely, prevent the system from going into interval $A_2B$.

The matter of determining and accounting for parameter $\varepsilon$ is a problem in and of itself. It is complicated by the fact that its solution must be based on the analysis of the functioning of a number of banks in separate regions (countries), and take into account the system of risks that assumes the reported data may be distorted [12]. The need for further mathematization of the problem and the importance of taking factors into account, which, according to the terminology of Tikhonov's systems, determine the dynamics of "small" parameters, can be illustrated by the example of one country. According to a number of renown economists, it is difficult to anticipate the consequences of a crisis in one country and to assess their impact on the economy of other countries. Yet, the consequences of such "local" crises carry risks for the global economy.

Based on the description (mathematical model) of the system dynamics, following the analysis of steady functioning of the system, two groups of changes in the dynamics of oscillations (problems) of the FES can be distinguished as follows: local problems and problems common to the entire systems. The first group are oscillations (which correspond to the dynamics and functioning problems) of individual businesses. The probability of them causing a total collapse of the system is low. The second group consists of system-wide oscillations, connected to the changes that are defined by $\varepsilon$, and dynamic changes in the common resource and control action.

Cataclysms of separate businesses (industries) cannot provoke a system-wide crisis ("the Great Depression") on their own without a number of additional conditions, while processes and actions within the banking system can cause (and have in the past) the "domino effect" and a total crisis. Therefore, at the dawn of a crisis, such as the crisis of a separate cluster, correct and immediate reaction of the banking and governing systems can correct the situation. Adequate actions on the part of the governing structures, carried out through the banking system at the beginning stages of the development of adverse factors, namely, in some borderline area of point $A_1$ of interval $A_1A_2$, which necessitates the proper functioning of the system monitoring the state of the FES.

With further development of this approach and a deeper detailing of the formed, simplified, mathematical model, the use of the mathematical apparatus of systems analysis and operations research leads to the conclusion that it is not the slowdown in individual sub-industries and businesses that causes financial and economic crises, but the functioning of the banking system, namely, ineffective and situation-inappropriate management are the main reasons for crises.

The crises of separate businesses (industries) may create prerequisites for a global crisis. However, they can be mitigated by the proper management of the banking system and a number of additional control actions. On the contrary, a crisis that is conceived in the banking system is impossible (with the exception of using a combination of specialized, systematic actions) to neutralize with particular industries or businesses. This type of crisis has all the preconditions to create a global recession of the entire system. The question of whether the given model corresponds to the object it models (real FES), and whether it requires detailing, needs further study and development. Firstly, the functioning of the global FES must be studied as a single object (taking into account the factor that there are market economies, which function according to clear market principles, as well as economies of the authoritarian type, which do not follow normal market logic, etc.). Further research is required for the clarification of the model, its detailing, and construction of a fan of sub-models necessary for solving practical problems of producing concrete numerical values for control actions.

The speed of reaction on the part of the governing elements to the prerequisites of a crisis, or to its first symptoms (in the banking system), is an important factor in averting the crisis, i.e., neutralizing deviations of the system trajectory from the average "slow" trajectory.

Parameter $\varepsilon$ is the aggregate value, determined by central banks of economies of clusters that comprise the global FES. Coordinated actions of central banks of leading global economies can ensure that a crisis is "put out" in its beginning stages. Because of mutual influence of financial and economic clusters, if the governing structures do not exercise sufficient control over the actions of commercial banks, allowing them to receive super profits that are not supported by creation of material (intellectual) resources, then the crisis will spread rapidly from one country to another and across industries. By coordinating their actions, central banks can exert significantly stronger influence on parameter $\varepsilon$ and, accordingly, on the stability of the entire system. The efforts of one economy (even if it is as powerful as the US economy) may not be sufficient for the entire system.

Development of economic theories is an important factor in forming a full, applied mathematical model of the FES. Further to the discussion about the significance of J. Keynes' theory, let us note at this stage that, following the chosen approach to FES modeling, Keynesianism did not become obsolete, but demonstrated that, without exact calculations in the Pareto region and full mathematization of the FES control, it is impossible to determine the "correct" control actions that ensure the systems functioning without deep, total crises.

The following conclusions can be drawn from the suggested approach to formulating and examining the FES dynamics model.

1. Mathematical description of the FES and modeling of its dynamics should be done on the basis of a mathematical apparatus of systems analysis and operations research, in particular Tikhonov's and quasi Tikhonov's systems.

2. FES crises (primarily their beginnings, and not the basic, underlying reasons for them) are provoked by actions in the banking system. The main prerequisite for the "start" and developent of financial-economic crises is the unfocused on goals ("not goal-oriented", "ill-considered") management of the banking system (insufficient control of its activity, lack of information about the markers of a pre-crisis state of the FES and, as a result, not taking preventative measures in a timely manner). A pre-crisis state of the FES, which is a multi-factor result of an aggregate of economic (and not only) processes, is initially "pushed" into a crisis state (section $A_1B$ corresponds to a crisis period in the functioning of the FES) by problems in the banking system. Control actions in this system can prevent the development of a crisis (going from a pre-crisis state, or the beginning stages of a crisis, into a crisis state), or, on the contrary, provoke it.

Terms "ill-considered management of the banking system," or "insufficient control of banking activity" mean the following. For instance, a bank is on the verge of bankruptcy, but salaries, bonuses, and other forms of material incentives for the management are not only not contingent upon the results of the performance of the institution, instead they exceed reasonable limits. This increases the share of the "non-productive" money and raises the "degree of readiness" of the FES for a crisis.

3. When the FES is in intervals $A_1B$ (in a state of crisis), which, from a mathematical point of view, correspond to the near disappearance in solution of the terms of the equation, which have to do with accounting for $\varepsilon$, the recovery of individual small parameters that have been "lost" in the collapse will help "launch" the economy. Given the mathematical description of the FES dynamics, the recovery of the economic system can be done by introducing calculated control actions, executed in the banking system, into the right side of the equations. This provision can be implemented in the economic system by launching individual, fast-growing businesses.

4. When the system is in interval $A_1A_2$, i.e, in pre-crisis mode, as opposed to the situation in p. 3, generating exponential growth for a particular group of businesses by varying parameter $\varepsilon$ is one of the ways of keeping the system from going to interval $A_2B$. Switching the FES, using a banking system control factor (parameter $\varepsilon$), to another, "slow" trajectory $A_2C$ will avoid the predicted transition of the FES into a state of crisis. Naturally, businesses that are under consideration here do not belong to the group of businesses with concentration of "non-productive" (speculative) of capital.

5. Determining the numerical values and control action parameters can be done by implementing the numerical model (SM model) of the FES, which requires particular applied efforts. Its implementation is currently a priority for structures that manage or are, in part, responsible for the functioning of the global FES.

Formally, in the dynamics of the full FES model, which takes into account fast and slow movements, two types of crises can be distinguished. The first type includes microcrises, which are crises in individual industries. The second type is a crisis of the entire system. Prerequisites for crises of the first type are new technological processes, technological revolutions and other evolutionary processes taking place in individual businesses (clusters, industries), as well as changes in consumer needs of the society. Crises of the first type are natural fragments of the system's dynamics. Whether they turn into the crises of the second type, that depends on the actions of the banking system first and foremost. It is clear from the well-known studies of Tikhonov's and quasi-Tikhonov's systems that changing the control parameter, the intensity of the "supply" financial flow, can bring on the collapse, or, on the contrary, correct a malfunction situation in the system. Intentional actions to "artificially" cause (evoke) crises of the first type in the FES may be a way to prevent a global crisis (of the second type). In the overall case, the chosen method of transitioning the dynamics of the FES to another, "slow" trajectory with the help of control actions, the dynamics of parameter $\varepsilon$ (implemented by the banking system) should ensure the transition of the system to interval $A_2C$ (or $BE$) and neutralize the crisis.

The implementation of these actions requires capability to influence the entire FES, and not just its individual fragments. It is evident that there is a need for a common world center for managing economic and banking systems. Presently, while the lack of such center significantly complicates optimal (quasi-optimal) management of the FES, the decision-making vector of governments and central banks of leading world economies must shift towards technocratic decisions, calculated with the inter-element and inter-cluster connections in mind. In this case, the formation of an appropriate Pareto set, which is a range of possibilities of predicted FES dynamics, will allow the minimization of the non-optimality of the “human performance” in management decision making.

This article does not lay claim to offering an already implemented practical solution or an applied model that allows the calculation of values of optimal or quasi-optimal control actions for managing the dynamics of the FES, but is an announcement of the results of research, which meet the challenges of the current times in terms of management decisions adequate for the globalized FES.

Development of super powerful hardware for the new generation computing technology makes the calculation and analysis of full mathematical models of the FES realistic, even when they have large dimensions, which increases the significance of “machine” predictions and of consequently suggested management decisions. In this case, the significance of collecting objective information and protecting it from distortion is increased [13, 14]. The development of possible solutions to these problems, which have significant practical value, goes beyond the scope of this article. It can be implemented using new approaches [15].

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