ADAPTIVE BALANCE OF CAUSES IN SOCIAL ECOLOGICAL-ECONOMIC SYSTEMS

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INTRODUCTION.

Any separate part of the populated world territory represents a social ecological-economic system, which sustainable development depends on natural, economic, humanitarian and others resources use. Since the system is being in a dynamic balance with the complex and changing environment, it is necessary to have predicted development scenarios as the system possible reactions on changing environmental conditions. That is the reason why dynamic models of complex socio-ecological-economic systems became a core instrument of the sustainable development management. Along with these models the informational technologies should be constructed for the decision making support on rational ways of management.

In this paper we use the Adaptive Balance of Causes (or ABC) method of complex systems modeling [1], which one could consider as a specific version of the system dynamic approach [2,3]. To begin with the proposed modeling we need to formulate several main concepts of system analysis due to their significance for sustainable development management[1]. These concepts are: relativity of development goals,
integrity of controllable system, casualty, subordination, dynamic balance and information unity.

Relativity concept means that development objectives of any system have uncertainties due to the lack of information about the real and anticipated system's states. Therefore a part of development resources should be directed to the clarification of development goals. Integrity concept requires the choice of a minimal set of state-variable vector parameters describing the system's goal-seeking movement. Subordination concept introduces the hierarchy of systems in order of their submission and makes it possible to link the short-term development scenarios with the long-term ones. Dynamic balance concept postulates the stability of general controllable system and their subordinates, which means that a system must return to its balance state after external influence on it is ceased. And finally, information unity concept points out the importance of current adaptation of predicted development scenarios to the observed system's states.

Keeping in mind these concepts one could develop a dynamic model of any system in three main steps:

1. Concept model construction by selection of minimal set of most important purpose-oriented processes in the system, determination of cause-effect linkages between them and establishing of external driving forces,
2. Concept model formalization, which means writing a set of differential equations describing selected processes dynamics and revealing their prognostic scenarios,
3. Determination of model coefficients and developing an agent-based technique for taking into account specific features of inner processes in the system and its relations with external forcing.

The ABC method was suggested to perform all these steps. In this paper we demonstrate how it works on an example of a social macroeconomic-ecological system.

1. CONCEPT MODEL CONSTRUCTION.

Consider a macroeconomic system of national economy and define a set of following processes as the most important scenarios for the system sustainable development.

1. Capital investments in social sphere,
2. Capital investments in industries,
3. Population living standards,
4. Public consciousness,
5. Parliament pressure on government on social issues,
6. Production efficiency,
7. Gross industrial output,
8. Corporations pressure on government on industries capital investments,
9. Public social stress,
10. Criminal activity,

11. Education and research,
12. Population purchasing capacity,
13. Average prices,
14. Unemployment,
15. Total demand on goods and services,
16. Total supply,
17. Technological net efficiency of production ,
18. Inflation,
19. Total budget income,
20. Health and ecological safety,
21. Taxes,
22. Central bank interest,
23. External (army) and internal (police) security,
24. Budget saldo,
25. State expenditures,
26. Capital investments in environment protection,
27. Ecologists pressure on parliament, government and corporations
28. Environmental quality
29. Efficiency of new ecologically approved technologies,
30. Pollutants concentration in environment
31. Public ecological consciousness.

We assume, that this set of processes will be sufficient for sustainable development management, provided that each of them could be presented with the aid of some numerical index. The main purpose of modeling will be reaction of these processes on external forcing simulating various changes in governmental policies on taxes, inflation, social investments and others.

Due to the large amount of parameters in the system state-variable vector we begin from the socio-economic part of general concept model, which will contain the first 25 model variables from the general list above. In ABC modeling each of the selected 31 parameters should be checked on the existence of influences on it from others 30 processes. The check-up results for the first 25 parameters are summarized in fig. 1, presenting cause-effect interactions inside the socio-economic part of the system. Numbers in rectangular correspond to the numbers of processes. For instance, the arrow, connecting block 7 with block 19 and marked with sign “+”, means that the process ¹ 7 “Gross industrial output” has a positive influence on the process ¹ 19 “ Total budget income”.

To simplify the explanation of this diagram we could designate the positive influence, coming from total budget income as +19. Equally considering, for instance, influences directed to the block ¹ 3 “population living standards” we could listed them as follows: +1 “ Capital investments in social sphere”, - 10 “ Criminal activity”, - 14 “Unemployment”, - 13 “ Average prices”, + 20 “ Health and ecological safety”. Public consciousness (8), is caused by + 3 “population living standards”, - 9 “ Public social stress” - 10 “ Criminal activity”, + 20 “ Health and ecological safety”, + 23 “ External (army) and internal (police) security” and others.

Parliament pressure on government on social issues (5) depends on: - 4 “ Public consciousness”, - 8 “ Corporations pressure on government on industries capital investments”, + 9 “ Public social stress”. Since the public social stress is used to be accumulated gradually, the parliament reaction on it will have some time to pass. Therefore, on the way from + 9 to 5 the time delay block D_3 has been placed in fig 1. Another one time delay D_1 was placed to take into account a finite time, which is need to rise the education and research levels. Time delay D_2 put off the gross industrial output rise as a result of the education and research levels improvements.

The similar explanation could be done to all other linkages shown in fig.1. Note, that an overall set of positive and negative feed backs, controlling the system, has been formed in a self-acting way by taking into account all possible influences inside the system.

The socio-ecological part of the general model contains processes from 26 to 31. Cause-effect diagram for this part of the model is shown in fig.2. The underlying idea of ecological economic systems expresses a general balance condition between economic profitability of natural resources use and the ecological protection of environment. This could be done by a necessary allocation of state capital investments between industrial production development and environmental condition recovering and conservation. Since the industrial output makes the main impact on environmental pollution contamination, some part of its investments should be oriented on natural recovering measures. That is the reason why the two parts of total capital investments: 2 and 26 are connected by negative influences.

While the decreasing investments in industries may have a short-term negative effect on production output, in a long-term perspective it could lead to the development of new ecologically friendly and efficient production technologies. We consider also the public ecological consciousness as a part of the public consciousness with positive interconnections between them. The higher public ecological consciousness, the stronger public and ecologists pressure on parliament, government and corporations resulting in the increasing of capital investments on environmental protection aims .

Two factors make the concern of ecologists and the society as a whole: environmental quality 28 and environmental pollution concentrations 30. Environmental quality improvement could be achieved only with some time delay D_4. Two others delays, which were introduced on the diagram in fig. 2, are connected with the decreasing of pollution concentrations by the development of ecologically friendly industrial technologies (D_5) and their implementation (D_6).

2. CONCEPT MODEL FORMALIZATION.

To produce a dynamic model of the social ecological-economic system one should exploit some method for balancing rates of changes of all the processes with these processes itself. It should be taken into account also the influences on these processes coming from inner and external sources. The system dynamics (or SD) method has been successfully applied to solve this problem in numerous works [2,3]. The SD approach gave rise to the development of a variety of standard sub models ("molecules") which are separate blocks of complex stocks and flows diagrams [4]. The overall idea of SD approach is to find out and use in a model construction a general balance of positive and negative feed backs, which results in chains of different equations, derived for temps and auxiliary information transforms.

In a contrast with SD approach in Adaptive Balance of Causes (ABC) method we have suggested a standard module equation, which could be currently used for all of the modeling processes. We assumed, that any process in the system is being in a state of local dynamic balance with influences applied to it from neighboring processes and external forcing.

Consider a system with n-component state-variables vector, presenting the processes x_1, x_2, ... , x_n , which are to be controlled. The standard equation for the process x_1 has the following form in ABC method [1]

$$dx_1 /dt = x_1[1 - 2F^{(+)}(x_1 + a_{12}x_2 + a_{13}x_3 + ... + a_{1n} x_n + y_1)] \qquad (1)$$

where $F^{(+)}$ is co-called "basic influence function" - a positive rising function of the process x_1 itself and all influences applied to it. Influence coefficients a_{pq} (p,q = 1, 2, ... , n) present the rates $a_{1q}x_q$ of internal cause effects on x_1. The item y_1 means external forcing on x_1.

As it was shown in our reference works [1,5] the standard equation (1) has two important features:

1. It keeps a stable balance state in the absence of external influences,
2. It enables to follow for the external influences by an adaptation to them.

One could choose in (1) a various types of basic influence functions. For instance, the most simple one choice is

$$F^{(+)}(x_1 + a_{12}x_2 + a_{13}x_3 + ... + a_{1n} x_n + y_1) = x_1 + a_{12}x_2 + a_{13}x_3 + ... + a_{1n} x_n + y_1.$$

It leads to the non-linear Bernoully equation [1], which is used to be exploit in some economic and ecological case studies (see, for instance, the Lotka-Volterra equations in "predator-prey" models [5]). In our case the standard equation takes the form

$$dx_1 /dt = x_1[1 - 2(x_1 + a_{12}x_2 + a_{13}x_3 + ... + a_{1n} x_n + y_1)] \qquad (2)$$

With the use of equation (2) the problem of dynamic model construction could be solved in rather easy and straightforward way.

Let us apply the standard module equation sequentially to all of the processes x_i (i = 1, 2, ... , 31) introduced above for the social ecological-economic system. In accordance with the system concept model shown in fig. 1 and fig.2 we shall have the set of 31 equations of the similar form

$dx_1 /dt = x_1[1 - 2(x_1 + a_{1\,2}x_2 - a_{1\,5}x_5 - a_{2\,19}x_{19} - y_1)]$,

$dx_2 /dt = x_2[1 - 2(x_2 - a_{2\,8}x_8 - a_{2\,19}x_{19} - a_{2\,22}x_{22} - y_2)]$,

$dx_3 /dt = x_3 [1 - 2(x_3 - a_{3\,1}x_1 + a_{3\,10}x_{10} + a_{3\,13}x_{13} + a_{3\,14}x_{14} - a_{3\,20}x_{20} - y_3)]$,

$dx_4 /dt = x_4 [1 - 2(x_4 - a_{4\,9}x_9 - a_{4\,11}x_{11} + a_{4\,10}x_{10} - a_{4\,20}x_{20} - a_{4\,3}x_{3j} - a_{4\,23}x_{23} - y_4)]$,

$$dx_5/dt = x_5[1 - 2(x_5 + a_{5\,4}x_4 + a_{5\,8}x_8 - a_{4\,9}D_3x_9)],$$
$$dx_6/dt = x_6[1 - 2(x_6 - a_{6\,2}x_2 - a_{6\,3}x_3 - a_{6\,11}x_{11} - a_{6\,17}x_{17} - a_{6\,20}x_{20})],$$
$$dx_7/dt = x_7[1 - 2(x_7 - a_{7\,6}x_6 - a_{7\,15}x_{15} - y_7)],$$
$$dx_8/dt = x_8[1 - 2(x_8 + a_{8\,7}x_7 - y_8)],$$
$$dx_9/dt = x_9[1 - 2(x_9 + a_{9\,1}x_1 + a_{9\,4}x_4 - a_{9\,14}x_{14} - y_9)],$$
$$dx_{10}/dt = x_{10}[1 - 2(x_{10} + a_{10\,3}x_3 + a_{10\,23}x_{23} - a_{10\,14}x_{14} - y_{10})],$$
$$dx_{11}/dt = x_{11}[1 - 2(x_{11} - a_{11\,12}D_2x_{12} - a_{11\,1}D_1x_1 - y_{11})],$$
$$dx_{12}/dt = x_{12}[1 - 2(x_{12} - a_{12\,3}x_3 + a_{12\,18}x_{18} + a_{12\,13}x_{13} - y_{12})],$$
$$dx_{13}/dt = x_{13}[1 - 2(x_{13} + a_{13\,16}x_{16} - a_{13\,18}x_{18} - a_{13\,21}x_{21} - a_{13\,22}x_{22} - a_{13\,15}x_{15} - y_{13})],$$
$$dx_{14}/dt = x_{14}[1 - 2(x_{14} + a_{14\,2}x_2 + a_{14\,11}x_{11} + a_{14\,7}x_7 - y_{14})],$$
$$dx_{15}/dt = x_{15}[1 - 2(x_{15} - a_{15\,2}x_2 - a_{15\,12}x_{12} + a_{15\,13}x_{13} - y_{15})],$$
$$dx_{16}/dt = x_{16}[1 - 2(x_{16} - a_{16\,7}x_7 - a_{16\,17}x_{17} - y_{16})],$$
$$dx_{17}/dt = x_{17}[1 - 2(x_{17} - a_{17\,11}x_{11} - y_{17})],$$
$$dx_{18}/dt = x_{18}[1 - 2(x_{18} + a_{18\,7}x_7 + a_{18\,24}x_{24} - y_{18})],$$
$$dx_{19}/dt = x_{19}[1 - 2(x_{19} - a_{19\,7}x_7 - a_{19\,21}x_{21} - y_{19})], \qquad (3)$$
$$dx_{20}/dt = x_{20}[1 - 2(x_{20} - a_{20\,1}x_1 - a_{20\,11}x_{11} - a_{20\,12}x_{12} - y_{20})],$$
$$dx_{21}/dt = x_{21}[1 - 2(x_{21} + a_{21\,24}x_{24} - y_{21})],$$
$$dx_{22}/dt = x_{22}[1 - 2(x_{22} - a_{22\,18}x_{18} - y_{22})],$$
$$dx_{23}/dt = x_{23}[1 - 2(x_{23} - a_{23\,1}x_1 - y_{23})],$$
$$dx_{24}/dt = x_{24}[1 - 2(x_{24} - a_{24\,19}x_{19} + a_{24\,25}x_{25} - y_{24})],$$
$$dx_{25}/dt = x_{25}[1 - 2(x_{25} - a_{25\,1}x_1 - a_{25\,2}x_2 - y_{25})],$$
$$dx_{26}/dt = x_{26}[1 - 2(x_{26} + a_{26\,2}x_2 - a_{26\,27}x_{27} - y_{26})],$$
$$dx_{27}/dt = x_{27}[1 - 2(x_{27} - a_{27\,30}x_{30} - a_{27\,31}x_{31} - y_{27})],$$
$$dx_{28}/dt = x_{28}[1 - 2(x_{28} - a_{28\,26}D_4x_{26} - a_{26\,29}x_{29} + a_{26\,30}x_{30} - y_{28})],$$
$$dx_{29}/dt = x_{29}[1 - 2(x_{29} - a_{29\,26}D_5x_{26} - y_{29})],$$
$$dx_{30}/dt = x_{30}[1 - 2(x_{30} - a_{30\,7}x_7 + a_{30\,29}x_{29} + a_{30\,28}x_{28} - y_{30})],$$
$$dx_{31}/dt = x_{31}[1 - 2(x_{31} - a_{31\,4}x_4 - a_{31\,30}x_{30} + a_{31\,28}x_{28} - y_{31})],$$
$$D_j = [1 - \exp(-d_j t)], \qquad (j = 1, 2, 3, 4, 5, 6).$$

The dynamic model (3) has the obvious uniform structure. It could be used for prognostic scenarios calculation in the considered social ecological-economic system.

3. DETERMINATION OF THE MODEL COEFFICIENTS.

The model (3) has an advantage of the ABC modeling method, because it allows for an objective determination of all coefficients a_{pq} by reanalysis of past (archival) scenarios of the processes observed. Moreover, the current evaluation of coefficients is possible and hence these coefficients could be made variable. That means that linear approximation of cause-effect interactions inside a system, which was assumed above, becomes in fact more realistic non-linear.

To achieve the current coefficients evaluation on observed scenarios one should make an assumption that cause-effect linkages inside a system are changing more slowly than the scenarios itself. Then the correlations between archival scenarios x_p and external forcing y_q must be introduced as follows: $K_{pq} = E\{x_p x_q\}$ and $N_{pq} = E\{x_p y_q\}$. By applying the Kolmogorov's optimal interpolation scheme [6,7] one could obtain a set of linear equations for determination of coefficients in each of equations (3). These sets of equations take the following general form [1]

$$\sum_n K_{mn} a_{rn} = K_{lm} + N_{lm}, \quad (l, m, n = 1, 2, ..., 31), \quad (n \neq m, n \neq l \text{ in } \sum_n). \qquad (4)$$

Examples of this technique implementation could be find in our reference works [1,5].

Another one opportunity to make the model (3) more realistic consists in an introducing of intelligent agents controlling cause-effect interactions inside the system. First of all agents may be watching for external conditions when the system cames on the edge of destroy of its structure. For instance, the unemployment grow may be followed by the fall of public consciousness x_4 much low the some threshold level x_4^* resulting in general economic disorder, ceasing the total demand on goods and services x_{15}, and stopping the gross industrial output x_7. This situation could be accounted for by the simple agent elements controlling influences of the total output $a_{p\,7}x_7$ on unemployment x_{14}, total supply x_{16} and inflation x_{18}

$$a_{p7} = \text{IF}[x_4 > x_4^*;\text{ then } a_{p7};\text{ otherwise } a_{p7}\exp(-\alpha_p t)], \quad (p = 14, 16, 18).$$

More complicated multi-agents control structures were suggested in our reference works describing the information technology ABC AGENT [5,8]. This technology implies standard operations taking place in any economic system, which input depends on the situation at resources markets and output is forced by the situation at goods and services markets.

The implementation of variable influence coefficients and addition of agent-based coefficients control results in the much more complicated ABC model for the system under consideration. But the complication of model based on the original set of equations (3) is justified by the more adequate model representation of the social ecological-economic system, which is very much complex in reality.

4. SIMULATION EXPERIMENTS WITH THE MODEL

Simulation experiments with the finite-difference version of the model (3) showed that it has properties of robustness to the variations of coefficients and rapid convergence to the balance state from an arbitrary initial condition. The model was used to study reactions of the social ecological-economic system on different management operations.

Socio-economic parts of such systems are used to be very sensible to the capital investments in social sphere x_1, inflation x_{18} , total budget income x_{19}, taxes x_{21} and central bank interest x_{22}. Calculations were made on 150 steps in time and influence coefficients were chosen to meet the required sensibility. Time delays D_p (p = 1, 2, ... , 6 system) were ranged between 10 and 40 time steps. We cite below only two of simulation runs result, which could be called “pessimistic” and “optimistic” development scenarios. More information could be find in our work [1].

To study pessimistic development scenarios the external forcing $y_{18} = x_{18}^0$ was applied to the inflation index x_{18}. That was done to simulate an unjustified high level of the money emission with the maximum on 75 time step. The resulting inflation scenario is shown in fig. 3 along with the unemployment level x_{14} and central bank interest x_{22}. Noteworthy, that maxima of inflation and unemployment have backwards in attitude on the money emission maximum. Fig. 4 demonstrates a big rise of public social stress x_9, caused by the unemployment, and associated grow of criminal activity x_{10}, decreasing of education and research x_{11} and worsening of health and ecological safety index x_{20}.

For an “optimistic” way of socio-economic development the lowering of taxes index x_{21} has been chosen. The external management function $y_{21} = x_{21}^0$ presented in fig. 5. One can see that the minimum of the resulting central bank interest values scenario has a time lag in comparison with the management forcing. That is an evidence of the system’s resistance to the changes of its dynamic balance state. In accordance with the decreasing of the central bank interest the economic parameters grow was achieved and inflation and unemployment were downed. Scenarios of population living standards x_3 and public consciousness x_4 demonstrate the great improvement. That is the reason why the parliament pressure on government on social issues x_5 was weakened during this time period.

CONCLUSION.

In this paper we tried to expose the innovated approach to the system dynamic method which we have called Adaptive balance of causes (ABC). This method is based on the assumption that any complex system consists of many local balances, which could be presented by a standard module equation in the system model. The main property of the module is the prompt adaptation of its balance state to the changing influences coming from neighboring modules and external forcing applied to the system. In our view point a complex socio ecological-economic system consists of the standard modules expressing an adaptive balance of causes.

An obvious advantage of such representation is the simple and direct construction of a set of dynamic equations for socio ecological-economic processes based on a cause-effect diagram of the system. We believe, that this property of ABC modeling was well illustrated by the transition from concept model presented in fig. 1 and 2 to the set of equations (3).

Another one advantage consists in objective evaluation of the model coefficients by the reanalysis of archival scenarios of the system behavior. That allows for to introduce in a model not only objective, but variable coefficients and hence to ensure more realistic non-linear modeling. We convinced, that this opportunity of the ABC modeling could be very useful in the processing of archival information about the socio ecological-economic dynamics in geo information systems (GIS).

The ABC modeling approach supposes also the use of intelligent agents for executing necessary control operations with the model influence coefficients. While standard modules ensure the adaptation of development scenarios to the currently changing situation inside and outside of the social ecological-economic system, intelligent agents are watching the changes and making prescribed them actions. That is a farther way to more realistic and reliable scenarios prediction in such systems.

We have discussed the implementation of the ABC method to the model construction of a social ecological-economic system. This case study served only to illustrate in brief three main steps of ABC modeling outlined in the introduction to the paper. More information about this study one could find in our reference works.

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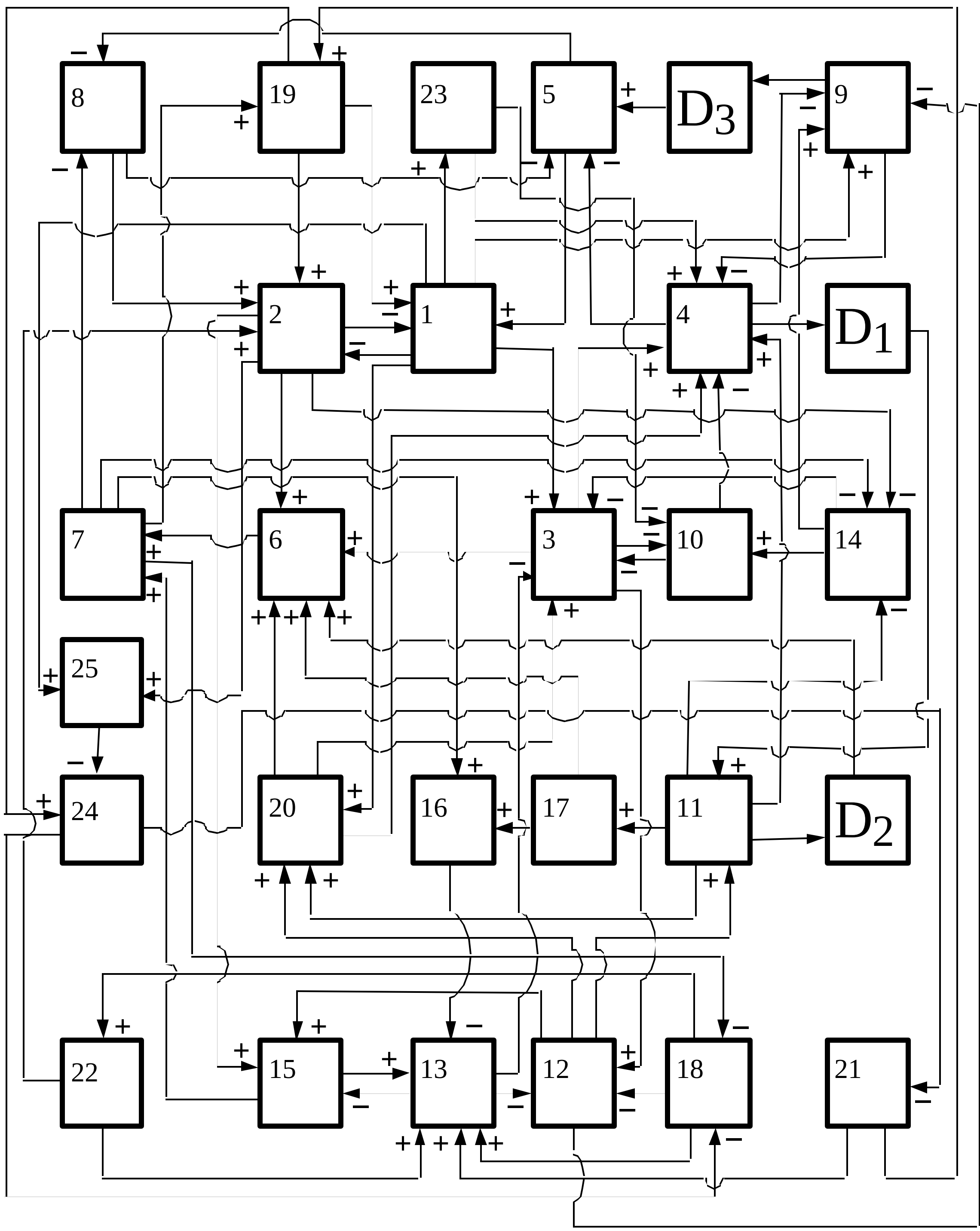

Fig. 1. Concept model of the system's socio-economic part.

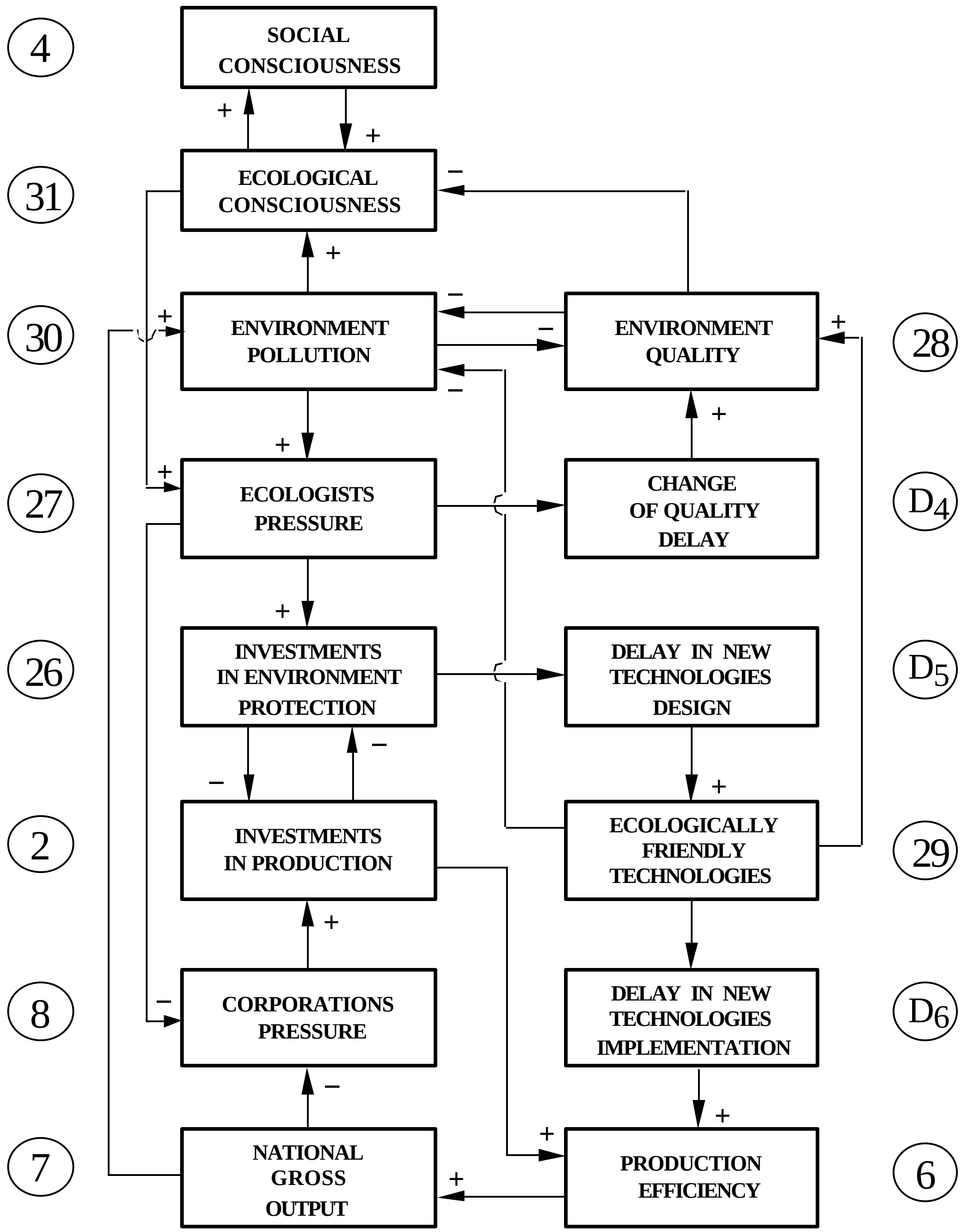

Fig. 2. Concept model of ecological-economic subsystem.
Numbers of model parameters are in circles.

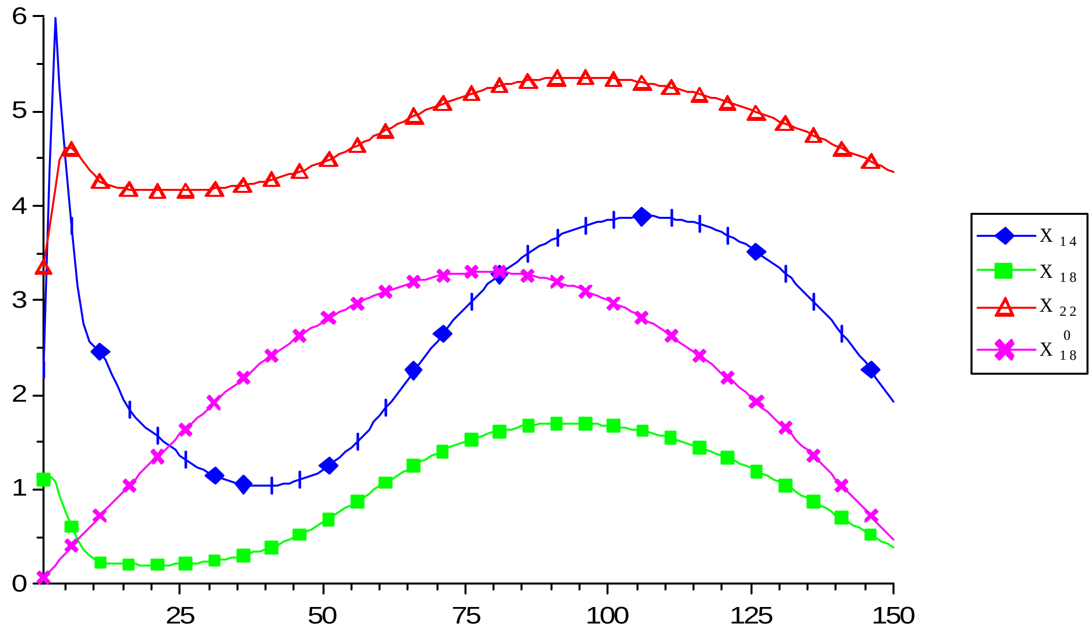

Fig. 3. Simulated money emission variation (X_{18}^{0}) and associated inflation (X_{18}).

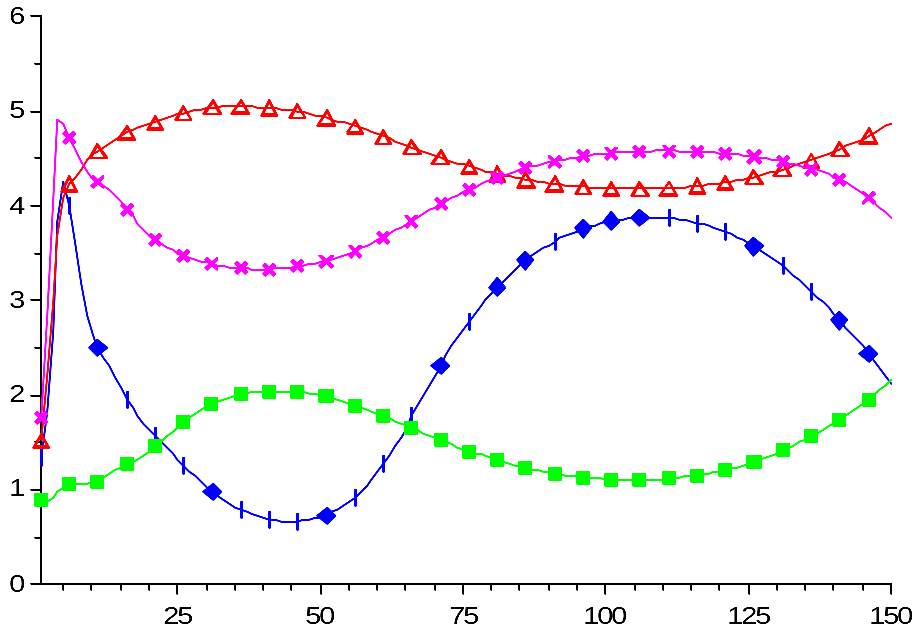

Fig. 4. Social stress scenario (X_9) under money emission variation.

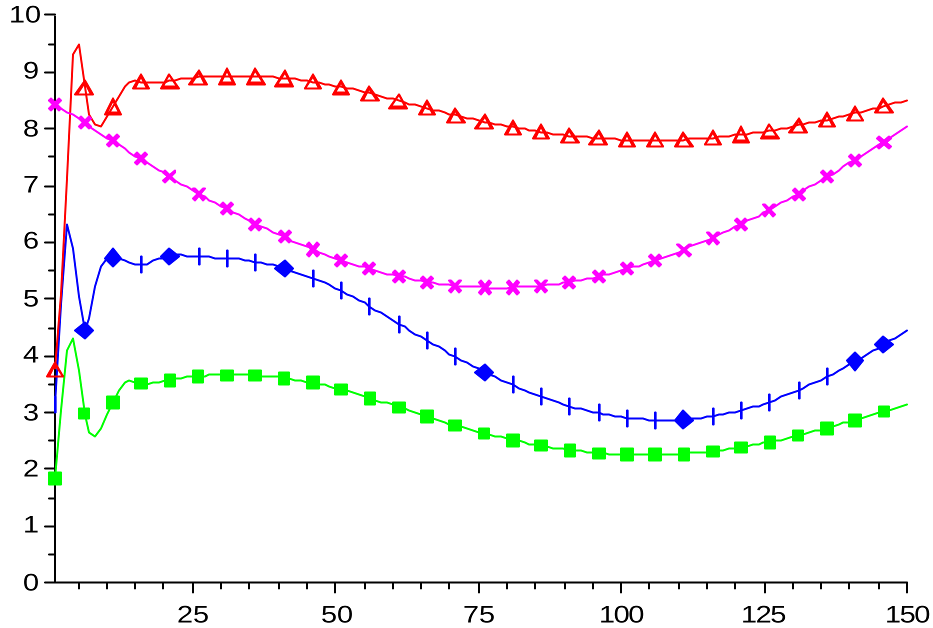

Fig. 5. Simulated variation of average taxes rate (X_{21}^{0}).

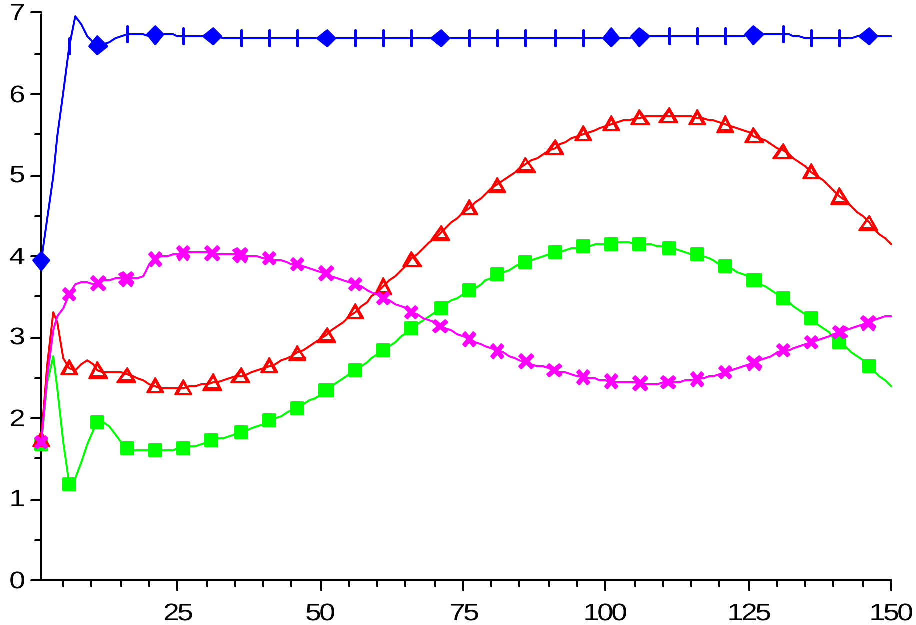

Fig. 6. Living standard (X_3) and social awareness (X_4) under taxes rate variation.

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