MULTI AGENT SIMULATION OF SUSTAINABLE DEVELOPMENT SCENARIOS

I.E. Timchenko, E.M. Igumnova, S.M. Solodova, I.I. Timchenko

Морской гидрофизический институт
НАН Украины
г. Севастополь, ул. Капитанская, 2
E-mail:timchenko@stel.sebastopol.ua

A new Adaptive Balance of Causes (ABC) method for system modeling and new multi agent information technology for system management were applied to the problem of sustainability of socio-economic systems. Resulting simulation ABC AGENT technology was constructed on these tools and could be used for rational natural resources consumption.

1. Multi agent simulation technology based on ABC modelling. This work is aimed on fostering the implementation of a new Adaptive Balance of Causes (ABC) method for complex systems modeling, suggested in [1] and a new multi agent information technology for system management, developed in [2,3] Natural resources management problem plays extremely important role in the sustainable development of socio-economic systems. There are no simple solutions to the associated problems due to the complex interaction of huge amount of various factors: economic, social, ecological, political and others, influencing making decision on natural resources use. These common pool resources are not to be exploited by separate countries or some people groups only, but they should be profitable to all people. At various local scales exists conflict between social (state) interest in the environmental protection and private interest of firms and corporations in gaining their own benefits from the common pool resources use. There is the strong need in objective and efficient tools for making decision about a rational balance of such interests. One of them could be simulation of possible development scenarios by a new ABC method for complex systems modelling [1]. Another ones could be intelligent agents--systems that can decide what to do and do it. Simulation ABC AGENT technology, suggested in this paper, was constructed on these tools and could be used for solving the problem of rational natural resources consumption. It enables the evaluation of an industry economic benefits taking into account the costs of common pool resources for their private use.

One of the main system analysis conceptions about decomposition of a complex system on relatively independent modules could be accomplished with the use of intelligent agents [3]. We shall call them simply "agents" keeping in mind their abilities to receive and process information and to execute prescribed them actions. General diagram of simulation ABC AGENT technology is presented in fig.1.

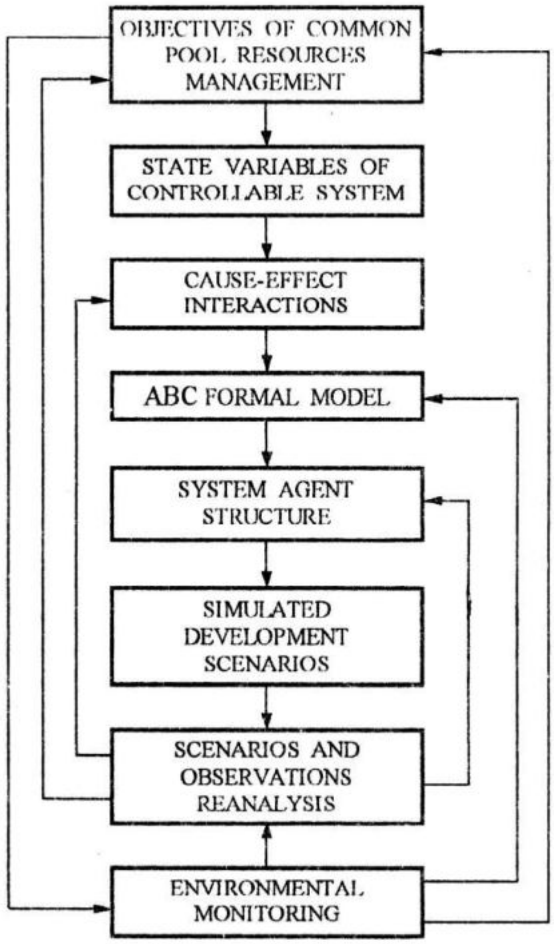

Fig. 1. General diagram of ABC agent simulation technology.

Objectives of common pool resources management generate a state variable vector of controllable system. This vector and cause-effect linkages between its components form the system model structure. Simulated development scenarios serve to make decisions about the ways of resources use and reanalysis procedure helps the model coefficients current identifications.

Simulation technology for natural resources management, that has to be constructed, forms several relatively separated multi agent models. The connection between them is shown in fig.2.

Two ABC agent models are used to be controlling the changing situations on production and resources markets. These market conditions define the profitability of an industrial production object, which input-output manufacturing agent model should be included in a gener l technology. Resources supply chains play an nportant role in industrial production and for all of them an agent model is to be presented also. Observations of common pool resources and environmental dynamics are necessary to ensure the environmental monitoring. If the information required is insufficient, appropriate dynamic models could be used to represent the possible environmental changes.

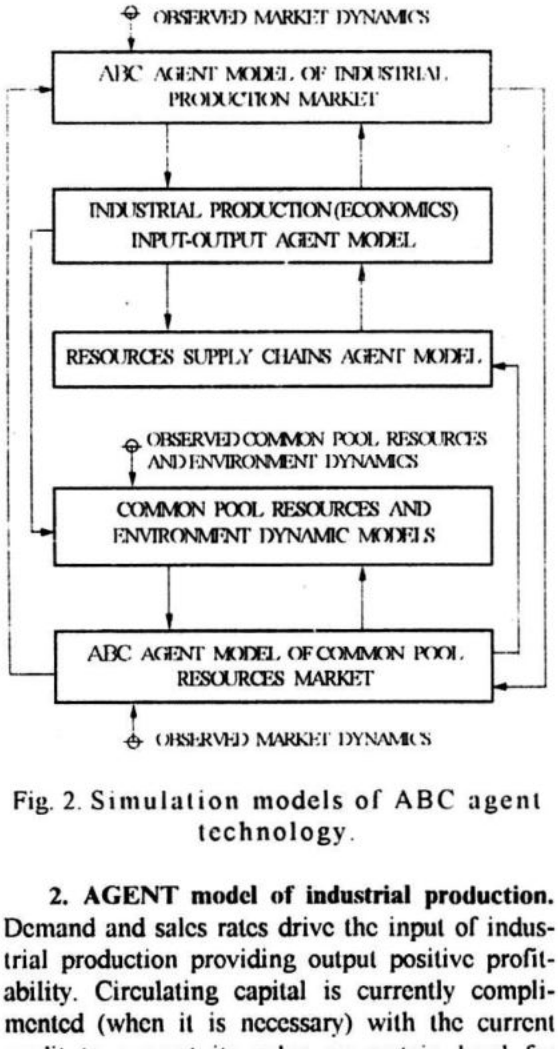

Fig. 2. Simulation models of ABC agent technology.

2. AGENT model of industrial production. Demand and sales rates drive the input of industrial production providing output positive profitability. Circulating capital is currently complimented (when it is necessary) with the current credit to support its value on certain level for baying all the various resources required. If the income grow is sufficient to avoid a total accumulated credit limitation, then the manufacture makes environmental and other resources consumption in an accordance with the current resources prices. If the accumulating credit reaches a definite threshold level, current credit is ceased and production output should be cancelled. Agents controlling industrial production model have functions of goods management, output volume planning, circulating capital distribution, accumulate credit evaluation and others. Formal algorithms for these agents could be introduced as follows.

Let us assume that one unit of industrial production (good) contains y_1 amount of ecological resources (raw materials, energy, work force and others), y_2 – of natural resources (mineral or biological resources) and y_3 of ecological resources (environmental ability to resist to the pollution contamination, to destroy them and others). Current circulating capital of an industrial object is used to be allocated to purchasing of each kind of the resources in the same proportion.

Let us designate as H_k – current volume of ready for sale production, H_{1k}^{i} - current amount of y_i resource spared in object's warehouse, H_{2k} - current circulating capital and H_{3k} - current value of accumulated credit received by the object. All these values have a general dynamic equation of the same form as for goods spare at the sale floor

$$H_k = H_j + V_k - S_k, \qquad (1)$$

where V_k - coming in and S_k – coming out amounts of goods at the time interval from moment j to moment k.

The agent making functions of a sales manager could be presented by equations

$$S_k = IF\ (N_k < 0;\ 0;\ R),$$
$$R_k = IF\ (D_k < H_j;\ D_k;\ H_j),$$
$$N_k = x_{2k} - x_{4k}, \qquad (2)$$

where D_k – current demand on the good, x_{2k} - market price and x_{4k} – production cost of it. The agent which is controlling the production output will take the following actions

$$V_k = IF\ (D_k < H_j;\ 0;\ M_{1k}),$$
$$M_{1k} = IF\ (D_k - H_j < M_j;\ D_k - H_j;\ M_j),$$
$$M_j = \min\ (m_{1j}^{1};\ m_{1j}^{2};\ m_{1j}^{3}), \qquad (3)$$
$$m_{1j}^{i} = H_{1j}^{i} / y_i,\ \ i = 1, 2, 3.$$

$$I_k = IF\ ((P_k - E_k) < 0;\ 0;\ P_k - E_k),$$
$$P_k = x'_{2k} S_k,$$
$$E_k = x'_{4k} V_k, \qquad (4)$$

where m_{1j}^{i} - minimal resource spare limiting the production output.

3. AGENT model of resources supply chain. Resources spare, which has every industrial object, could be presented as balances between coming and spending amounts. Expenditures for each kind of them are proportional to the object's output. If the current resources amounts are sufficient to supply the planning output there is no need to bay them. In the opposite case some amounts of insufficient natural and economic resources should be purchased. The controlling functions on current circulating capital are used to be made by an agent

$$H_{2k} = H_{2j} + I_{0k} - S_{3k},$$
$$S_{3k} = IF\ (H_{3j}\ \theta < H_{2j};\ H_{3j}\ \theta;\ H_{2j}),$$

where θ is the accumulated credit pay off interest.

Let it be $V_1{}^1{}_k$, $V_1{}^2{}_k$ и $V_1{}^3{}_k$ – volumes of resources which are to be purchased for credits. Then total amount of current credit will be

$$V_{3k} = p'_{1k}\ V_1{}^1{}_k + p'_{2k}\ V_1{}^2{}_k + p'_{3k}\ V_1{}^3{}_k,$$

and for accumulated credit we shall have

$$H_{3k} = H_{3j} + V_{3k} - S_{3k}.$$

Analogous balance equation takes place for the object's resources spare

$$H_1{}^i{}_k = H_1{}^i{}_j + V_1{}^i{}_k - S_1{}^i{}_k.$$

Each kind of resources spending is proportional to the industrial output volume

$$S_1{}^i{}_k = V_k\ y_1.$$

Supply chain agents determine which amount $F_1{}^i{}_k$ of insufficient resource should be purchased

$$V_1{}^i{}_k = IF((D_k - Hj\ )y_i < H_1{}^i{}_j\ ;\ 0\ ;\ F_1{}^i{}_k\ ),$$
$$F_1{}^i{}_k = IF\ (p'^i{}_j\ (y_i\ D_k - H_1{}^i{}_j\ ) < \rho_i\ H_{2j};$$
$$y_i\ D_k - H_1{}^i{}_j\ ;\ \ R_1{}^i{}_k\ ), \qquad (5)$$
$$\rho_{ik} = p'_{ik} y_i [p'_{1k} y_1 + p'_{2k} y_2 + p'_{3k} y_3]^{-1},$$
$$i = 1,2,3,$$

where p'_{ik} are prices on resources markets.

Another one agent $R_1{}^i{}_k$ is watching for total amount of accumulated credit H_{3k} and rejecting the letting of a new credits after some limited level $\rho_i H_3{}^*$. The equations for $R_1{}^i{}_k$ could be find in [2].

4. ABC-AGENT models of resources and goods markets. Let us consider a simplified ABC agent resource market model, which has cause-effect interactions, describing by the following ABC model equations

$$p^i{}_k = 2\ p^i{}_j\ (1 - c_1\ (p^i{}_j + a^i{}_{1t}\ t^i{}_j - a^i{}_{1q}\ q^i{}_j)),$$
$$t^i{}_k = 2\ t^i{}_j\ (1 - c_2\ (t^i{}_j + a^i{}_{1q}\ q^i{}_j - a^i{}_{1p}\ p^i{}_j\ )), \quad (6)$$
$$q^i{}_k = 2\ q^i{}_j\ (1 - c_3\ (q^i{}_j - a^i{}_{1t}\ t^i{}_j - a^i{}_{1q}\ p^i{}_j\ )).$$

Here are $p^i{}_k$ – prices on resources markets, $t^i{}_k$ - volumes of resources supply, $q^i{}_k$ - resources qualities.

ABC equations for goods market could be written as follows

$$D_k = IF\ (\ x_{3k} > x_3{}^0\ ;\ x_{1k}\ ;\ 0\ ),$$
$$x_{1k} = 2x_{1j}(1 - c_1(x_{1j} + a_{12}x_{2j} - a_{31}[1 - \exp\alpha_3\ x_{3j}])),$$
$$x_{2k} = 2\ x_{2j}\ (1 - c_2\ (x_{2j} - a_{24}\ x_{4j} - a_{23}\ x_{3j})),$$
$$x_{3k} = 2\ x_{3j}\ (1 - c_3\ (x_{3j} - a_{3\mu}\ \mu_j\ )), \qquad (7)$$
$$x_{4k} = 2\ x_{4j}\ (1 - c_4\ (x_{4j} - a_{4\eta}\ \eta_j\ )),$$
$$\mu_o = \rho_1 q_{1j} + \rho_2 q_{2j} + \rho_3 q_{3j},$$
$$\eta_j = p_{1j}\ y_1 + p_{2j}\ y_2 + p_{3j}\ y_3,$$

where x_{1k} – demand on production goods market, x_{2k} – price, x_{3k} – quality and x_{4k} – production cost of appropriate sale stuff. μ_o and η_j present integral estimates of resources quality and cost. Note that dimension variables A' could be presented in non dimension form A by

$$A = 5\ A'\ (\ M\ [A']\ )^{-1} \qquad (8)$$

Both ABC market models are to be coupled with the AGENT models of industrial production and resources supply chain to form general ABC AGENT technology.

5. Example of multi agent ABC model of socio-economic development. The simple and uniform structure of ABC-model equations (7) allows for significant enlargement of the systems vector-state parameters. In reference work [1] multi agent simulation model was suggested, which had the following 25 state variables: 1 - investments in social sphere, 2 - investments in industry, 3 - living standard index, 4 - social consciousness level, 5 - parliament pressure, 6 - productivity level, 7 - production general volume, 8 - corporations pressure, 9 - social stress index, 10 - crime level, 11 - state of science and education, 12 - population purchase ability, 13 - average prices level, 14 - unemployment level, 15 - total demand on goods and services, 16 - total supply, 17 - production technologies efficiency, 18 - inflation level, 19 - state budget income, 20 - public health and ecological safety, 21 - average taxes rate, 22 - central bank stock rate, 23 - public security (army and police), 24 - state budget saldo, 25 - state budget expenditures.

The extended model's causal diagram is presented in fig.3.

6. Simulation experiments with the multi agent ABC model. Simulation experiments with the model showed that it is stable and easy controllable. The model reaction of socio-economic system on money emission variation demonstrate scenarios in fig.4 and 5.

One can see from fig.4 that the inflation maximum is backward from the money emission maximum on 20 time steps. As it follows from fig.5 public living standards and social consciousness fall down sharp due to the inflation grow.

Another one simulation runs were carried out to determine the rational average taxes rate. Simulated minimum rate was located at 75 time step. Some of model development scenarios are presented at fig.6 and 7.

As it follows the best values of socio-economic system state variable parameters were at 100 time step, when the social stress level had its minimum. It should be emphasized, that average taxes rate was not minimum at 100 time step: it was at 6 % high.

Simulation experiments confirmed that multi agent ABC models have obvious advantages of simplicity, controllability and ability to changes of the model structure. These properties of the ABC-method makes it very useful in a designing of information technologies for sustainable development management.

CONCLUSION

ABC AGENT technology suggested in reference works [1-3] may be used as a practical tool for common pool resources management. It makes it possible the simulation of development scenarios in complex socio-economic-ecological systems under various paths of their resources use. Simulation is enable to ensure the important information about rational ways of natural resources consumption and conservation. Therefore ABC AGENT informational technology could be utilized in the construction of practical decision making support systems for sustainable development management.

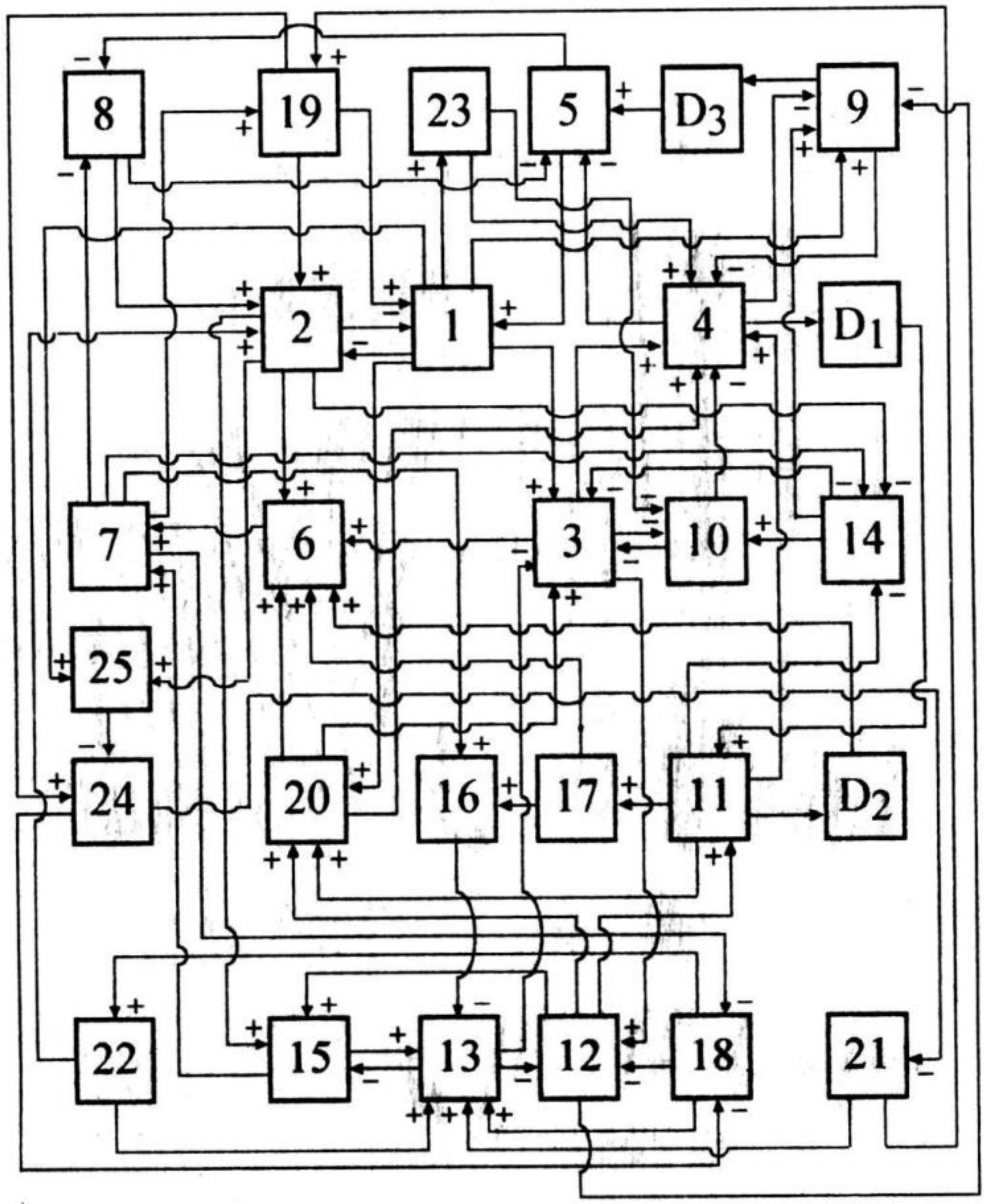

Fig. 3. Casual loops diagram of the multi agent ABC model of socio-economic system.

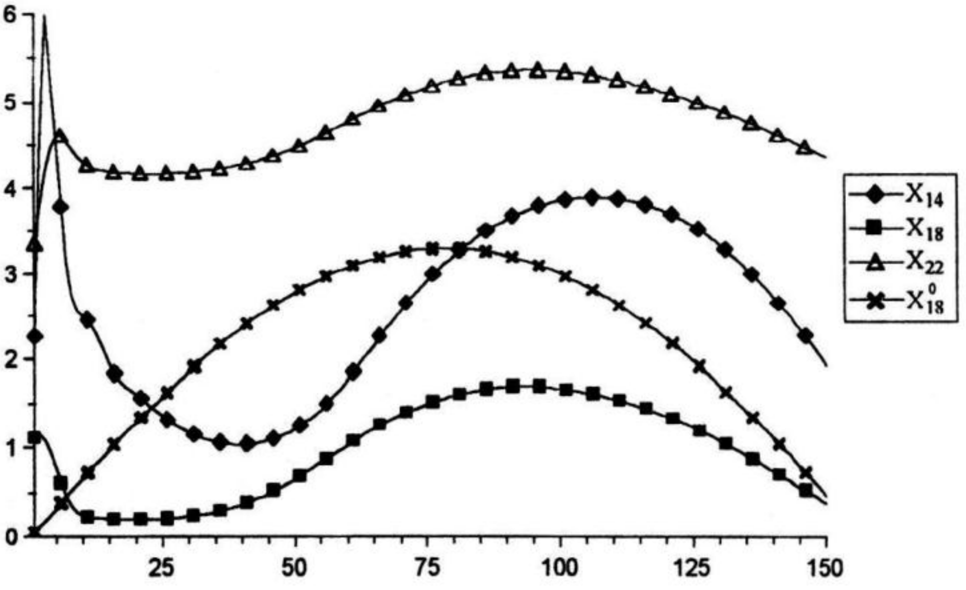

Fig. 4. Simulated money emission variation (X_{18}^{0}) and associated inflation (X_{18}).

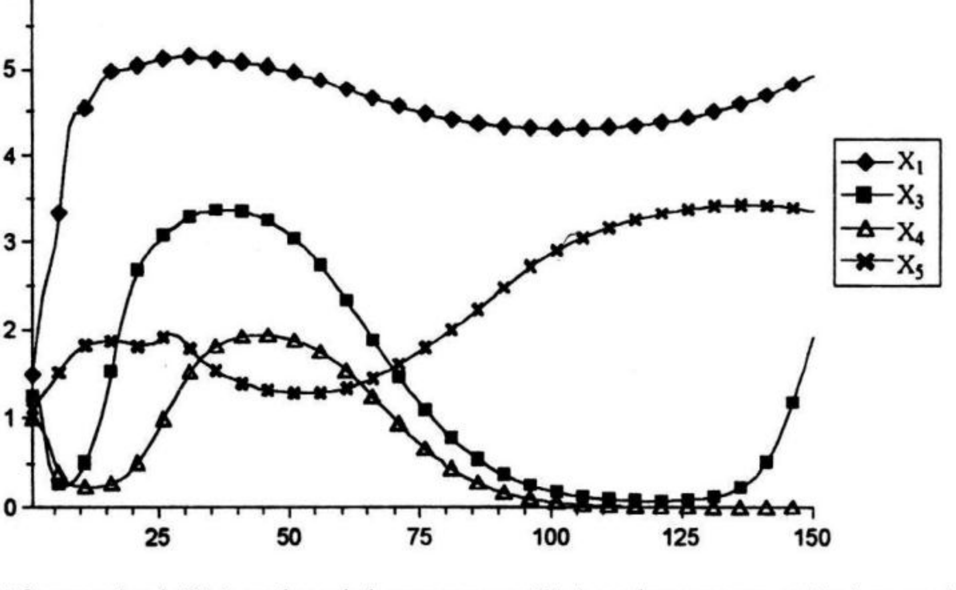

Fig. 5. Life standard (X_3) and social awareness (X_4) under money emission variation.

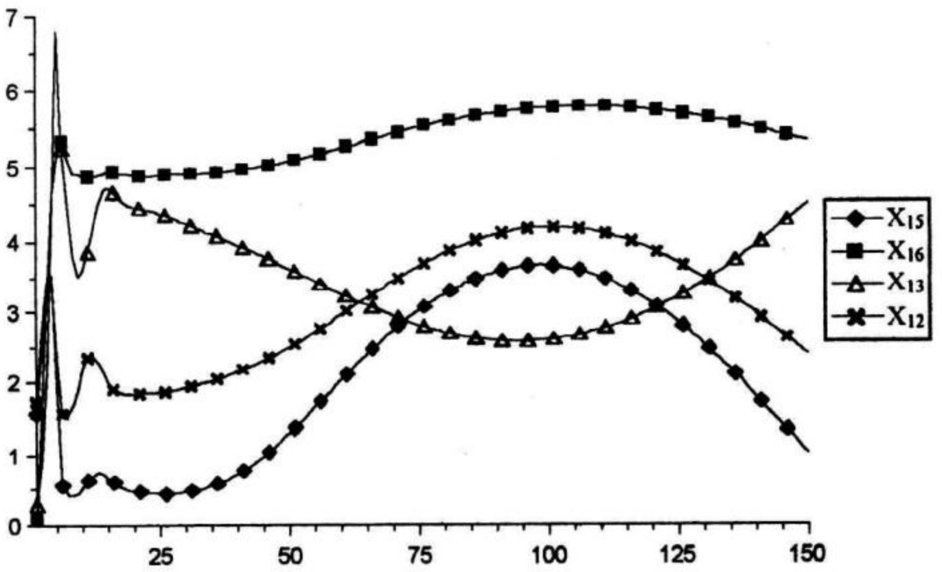

Fig. 6. Average prices level (X_{13}) and general demand (X_{15}) under taxes rate variation.

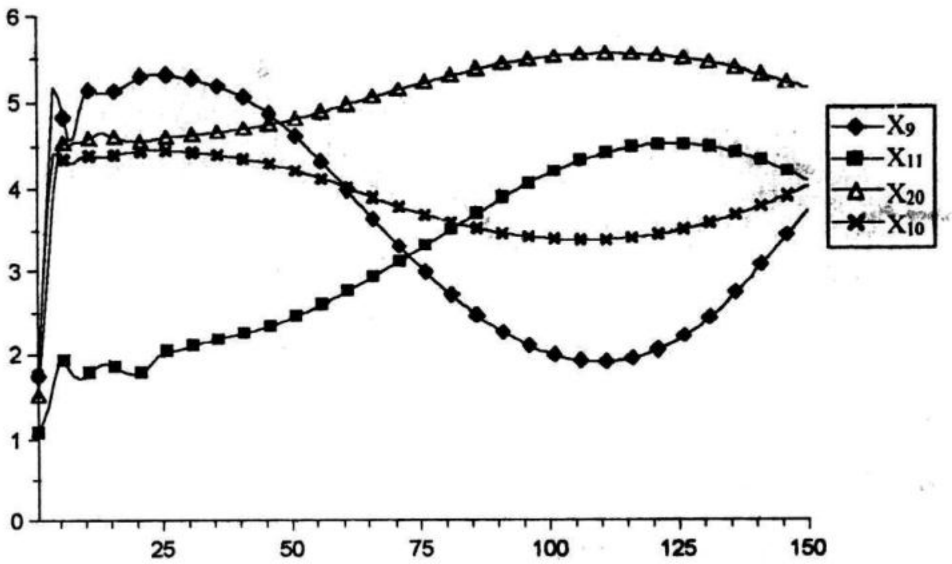

Fig. 7. Social stress level (X_9) under variation of taxes rate.

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