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Model substantiation of strategies of economic behavior in the context of increasing negative impact of environmental factors in the context of sustainable development

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Abstract. The concept of sustainable development considers environmental, social and economic issues in general. And the goals of resource conservation and socio-economic development do not contradict each other, but contribute to mutual reinforcement. The purpose of this study is to build and test an economic and mathematical model for the formation of strategies for the behavior of an economic entity with an increase in the impact of negative environmental factors. The proposed strategies and their models are based on the income-expenditure balance equation, which takes into account both quantitative and qualitative characteristics. The constructed models are considered in the state space. The research methodology is based on building models in the form of linear combinations of functions of a homogeneous external impact and various spatial combinations of economic sources (sinks). The study makes it possible to assess the dependence of the amount of resources used for life support on the chosen adaptive strategy. Within the framework of the proposed model, it was found that the criterion for the effectiveness of the applied strategy can be an indicator of satisfaction with the state, the preservation of which, simultaneously with the preservation of the size of resources used, corresponds to the direction of optimization. This approach is consistent with the concept of sustainable development.

1. Introduction

Many modern problems of a global nature are primarily related to the exhaustibility of non-renewable natural resources, their irrational use, environmental pollution, and deterioration of environmental factors. As a result, it became necessary to develop strategies for the development of mankind that would prevent the deterioration of the quality of the environment, eliminate the consequences of such deterioration, and contribute to the formation of conditions for providing resources not only to the current generation, but also to the future.

The concept of sustainable development has become a priority model for the development of most countries. Its appearance was a requirement of the time for solving pressing acute



problems of both socio-economic and resource-environmental nature. The most progressive concept today is the triune concept of sustainable development. Within the framework of such an understanding of sustainable development, environmental, social and economic issues are considered as a whole, and the goals of resource conservation and socio-economic development not only do not contradict each other, but can also contribute to mutual reinforcement [1]. This understanding of sustainable development implies the achievement of a high standard of living, a prosperous economy and the conservation of resources. Within the framework of this concept, an important factor in the effective solution of environmental problems is the development of environmental awareness in the process of performing by economic entities of their main functions, the use of appropriate forms of economic behavior.

The authors of the study [2] draw attention to the need for changes in values, attitudes and behavior for the transition to global sustainability, linking them with such subcomponents of sustainable development as the environment, population, consumption, technology, etc.

Thus, the study of economic behavior strategies in the context of sustainable development and the development of a methodology for qualitative assessment of the result of their use are relevant.

The emergence of the concept of sustainable development as a direction of economic analysis is associated with the 1972 report "The Limits to Growth" [3], the main idea of which was to assess the natural and environmental limits of the development of the world economy and the development of society. At the same time, in the article [4], the formulation of the core of the modern concept of sustainable development under the name "tectological general scientific concept" is attributed to A. Bogdanov and dates back to the beginning of the 20th century. It was only in 1987 that the concept of sustainable development received the status of a scientific phenomenon.

We agree with the definition of G. H. Brundtland [5] that sustainable development involves meeting the needs of the subject in the current cycle without harm to meet the needs in the next cycle.

At the present stage of development of the concept of sustainable development, there is a tendency to transfer the problem from the global and macroeconomic levels to the level of enterprises and households, which both take an active part in causing harm to the environment and become subjects of its elimination (reduction) [6]. The sustainability of an individual microeconomic entity is not just a concept, but also an object of sustainable development, which opens up opportunities for modeling, design, organization and management [7].

The study [8] proposes a model for optimizing the economic and environmental factors of the logistics system of enterprise management, which allows assessing and taking into account the impact on the environment.

The article [9] proposes a multi-agent simulation model of the feedback mechanism of dynamic interaction between the behavior of residents when making decisions and the safety of life in the city under the influence of the environment and politics. But the social sustainability of the city is at the forefront. The study [10] proposes an evolutionary game model with four participants, including governments, financial institutions, businesses, and consumers. Analog modeling provided an analysis of the impact of each parameter on the changes and development of the green financial market. It should be noted that the articles [9,10] primarily studied the features of organizational management on the part of state structures.

In the article [11] it is noted that sustainable development belongs to the category of concepts that, in a generalized form, reflect some ideal model that is difficult to represent using accurate quantitative calculations. But this only expands the possibilities of its interpretation and the use of interdisciplinary approaches. An example of such an approach is a generalized analytical model of economic behavior under the conditions of an internal income-cost balance [12], built on the basis of a phenomenological assumption about an isomorphic relationship between the

processes of production-consumption in the economy and emission-absorption in continuum mechanics, mentioned by W.B. Zhang [13]. The proposed method was used to analyze economic behavior under the established influence of exogenous factors and with their strengthening [14], but the environmental component was not taken into account in these studies.

The aim of the study is to substantiate the formation of economic behavior strategies as a response to the deterioration of environmental performance. To achieve this goal, it is necessary to complete the following tasks: within the framework of existing methods of economic and mathematical modeling, build a model for adapting an economic entity to changes in the state of the ecological environment; conduct model experiments to identify cause-and-effect relationships between the motives for the formation of a strategy of economic behavior, its form and results.

2. Presentation of the basic research

Classical economic theory traditionally interprets economic behavior as a rational desire to control resources and minimize costs while achieving the goals set by the economic entity. Instead, institutional economics provides for bounded rationality [15]. The institutional economy is characterized by such a type of management as self-organization [16] and a synergistic approach to management [17]. The main goal of the functioning of the economic entity in this case is equilibrium. At the same time, the motives of economic behavior are determined by the level of satisfaction of the economic subject, which depends on social, cognitive or emotional factors [18]. In this case, the equilibrium is ensured by the implementation of the law, which in the article [12] was called the “law of conservation of motivation”

$$M(r, \theta) + \frac{V^2}{2} = M_0, \tag{1}$$

where M_0 is a constant value that characterizes motivation in a state of equilibrium (satisfaction). Taking into account the understanding of sustainable development, we will set it by the value $M_0 = 0$. The term $M(r; \theta)$ in equation (1) is called motivating, the term $\frac{V^2}{2}$ in equation (1) is called compensating.

Note that the proposed model is built in the space of states, which in the spherical coordinate system $(r; \theta; \varphi)$ are described by the quantitative coordinate r (corresponds to the magnitude of the deviation from the balanced state), qualitative coordinate θ (characterizes improvement-deterioration), innovation coordinate φ (development indicator). The origin of coordinates $(0; 0; 0)$ corresponds to the equilibrium state of the system under study. These coordinates are related to the Cartesian rectangular coordinate system $(x; y; z)$ by the equalities

$$x = r \sin\theta \cos\varphi; \quad y = r \cos\theta; \quad z = r \sin\theta \sin\varphi. \tag{2}$$

Equation (1) shows that the motivation $M(r; \theta)$ depends on the quantitative and qualitative changes in the state of the economic entity. The component $V = V(r; \theta; \varphi)$ determines the speed and direction of changes in economic behavior. The spatial components of the velocity $V = V(r; \theta; \varphi)$ are given by the expressions

$$v_r = \frac{1}{r^2 \sin\theta} \frac{d\Omega}{d\theta}; \quad v_\theta = -\frac{1}{r \sin\theta} \frac{d\Omega}{dr}; \quad v_\varphi = \frac{C_0 \Omega}{r \sin\theta}. \tag{3}$$

The flow function $\Omega(r; \theta)$ in its meaning coincides with the concept of an economic action, as a reaction of a microeconomic entity to its economic state [19]. The coefficient C_0 will be called the “innovation coefficient”.

Taking into account the previously formulated phenomenological assumption, taking into account formulas (1), (3) and using the models available in continuum mechanics [20], the model for the formation of economic behavior can be represented as follows

$$\frac{\partial^2 \Omega}{\partial r^2} + \frac{\sin \theta}{r^2} \frac{\partial}{\partial \theta} \left(\frac{1}{\sin \theta} \frac{\partial \Omega}{\partial \theta} \right) + C_0^2 \Omega = 0. \tag{4}$$

If $C_0 = 0$, then equation (4) is simplified

$$\frac{\partial^2 \Omega}{\partial r^2} + \frac{\sin \theta}{r^2} \frac{\partial}{\partial \theta} \left(\frac{1}{\sin \theta} \frac{\partial \Omega}{\partial \theta} \right) = 0. \tag{5}$$

Note that equations (4), (5) are partial differential equations [21]. Some of the solutions to equation (5) were proposed and described in articles [14, 22], as models of constructs, combinations of which can be used to build models of economic behavior:

1. Economic source (sink)

$$\Omega_{ES} = (1 - \cos \theta) \Omega_0, \tag{6}$$

where $\Omega_0 = \pm \frac{P}{4\pi}$ (P is the intensity of the economic source (sink)).

2. Economic dipole

$$\Omega_{ED} = \frac{m \sin^2 \theta}{4\pi r}, \tag{7}$$

where m is the moment of the economic dipole [22], the absolute value of which characterizes the ability (potential) of an economic agent to improve the condition or to counter the factors that tend to worsen it. The moment of economic dipole should be considered as a characteristic of potential economic energy [19].

3. Uniform external influence

$$\Omega_{EI} = -\frac{1}{2} V_\infty r^2 \sin^2 \theta, \tag{8}$$

where V_∞ is a characteristic of the intensity of external influence (EI).

Often the triune concept of sustainable development is illustrated by the Wett diagram, in which ecological, social and economic processes are considered equivalent, and the relationship between them provides weak stability [23]. But the authors of this article believe that the image of these components of sustainable development in the form of concentric circles is more accurate: the environment is represented by the outer circle, since it is of paramount importance; secondary is society; the economic component is located inside the specified construction, the existence of which in the article [23] is associated with strong stability.

It should be noted that the environment in this case is not only a supporting component, but also a limiting one. That is, socio-economic development, which is provided by environmental resources, is limited by the objective capacity of the environment. The negative value of function (8) in the presented study is consistent with such a limiting influence of environmental factors.

Returning to the meaning of the flow function $\Omega(r; \theta)$, we note that in the state space their combinations can reflect cognitive-reflexive and information-communicative processes that form an assessment of the state of an economic entity in the context of sustainable development with a concentric structure of interaction.

A typical example is an economic dipole (see figure 1c), which is formed as a result of the balance of quantitative and qualitative characteristics of an economic entity, as a combination of an economic source (point of production) (see figure 1a) and an economic sink (point of consumption) (see figure 1b) with the same intensities and located at an infinitesimal distance from each other in the state space [22]. In the absence of external restrictions, the flow lines corresponding to the flow functions (5), (6), (7) form an infinite field (see figure 1a, figure 1b, figure 1c). Flow directions are shown in figure 1a, figure 1b, figure 1c. Figure 1a shows the relationship between polar coordinates $(r; \theta)$ and Cartesian coordinates (x, y) . On figure 1c

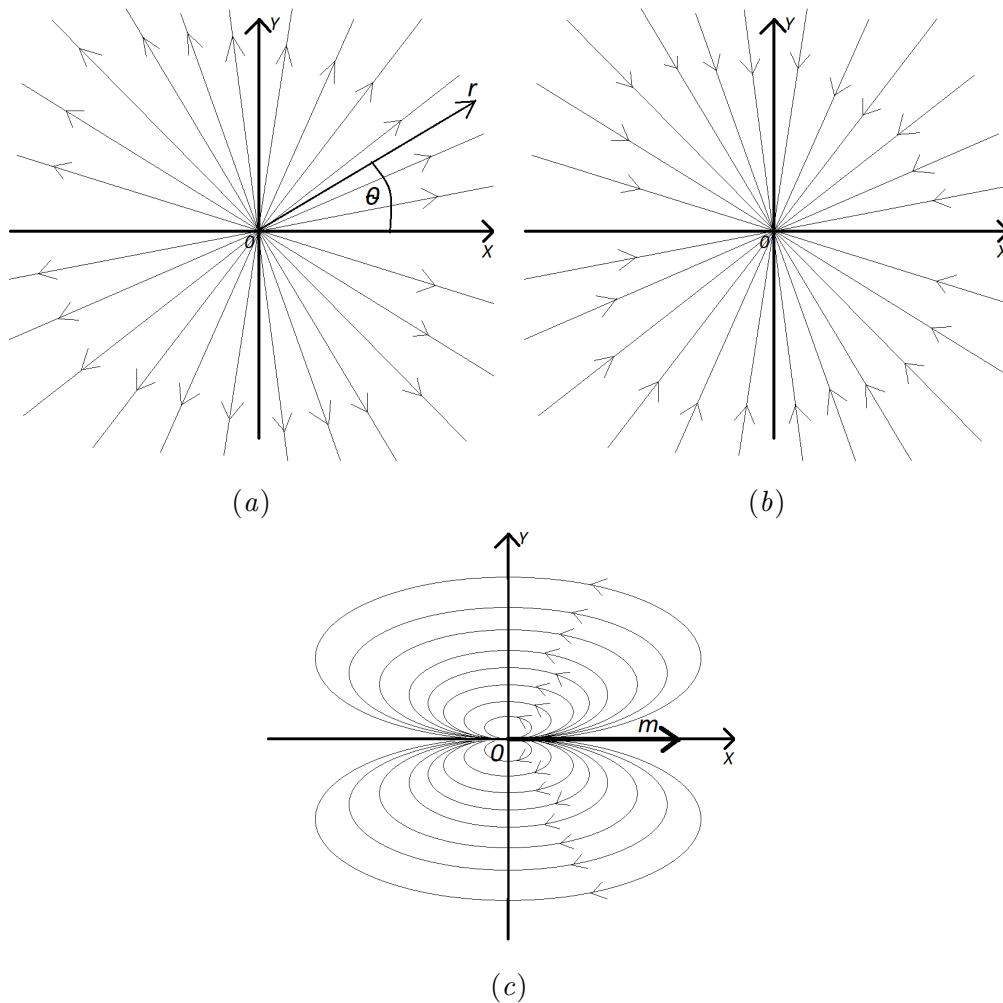


Figure 1. Flow structure: economic source (a), economic sink(b) and economic dipole (c).

shows the direction of the economic dipole moment m . The circulation structures of the economic dipole (see figure 1c) can be classified as a soliton (stable non-linear wave), which was the result of the internal interaction of the microsubject to ensure a stable form of the socio-economic state [19].

As an object of a model experiment, it is proposed to use households, which are social phenomena and one of the most important subjects of economic activity with clearly defined relations of production, distribution, exchange and consumption. Using the example of a household, article [22] introduced the concept of “economic dipole”.

Taking into account the theoretical foundations of the spatial interaction of flows [20], the interaction model of an economic entity satisfied with the level of its state and the external influence limiting this level is represented by a linear combination of the economic dipole flow function (7) and the external influence flow function (8)

$$\Omega_0 = \Omega_{ED} + \Omega_{EI} = \frac{m \sin^2\theta}{4\pi r} - \frac{1}{2}V_\infty r^2 \sin^2\theta . \tag{9}$$

The moment of the economic dipole m in this case is aimed at meeting the flow, which corresponds to the external influence.

The purpose and result of such interaction is to establish a balance corresponding to the sustainable development of the system as a whole. So, adapting to the established influence of the external environment, the economic entity seeks to be satisfied with the balance of its income and expenses to ensure life.

Such a balance in the case under consideration corresponds to the condition

$$\Omega_0 = 0. \tag{10}$$

Using condition (10), the relationship between the parameters of the flow function (9) can be represented by the expression

$$r_s = \sqrt[3]{\frac{m}{2\pi V_\infty}}. \tag{11}$$

Analysis of expression (11) allows us to conclude that the balance of internal and external flows occurs on the surface of a spherical shape, the radius of which is $r = r_s$.

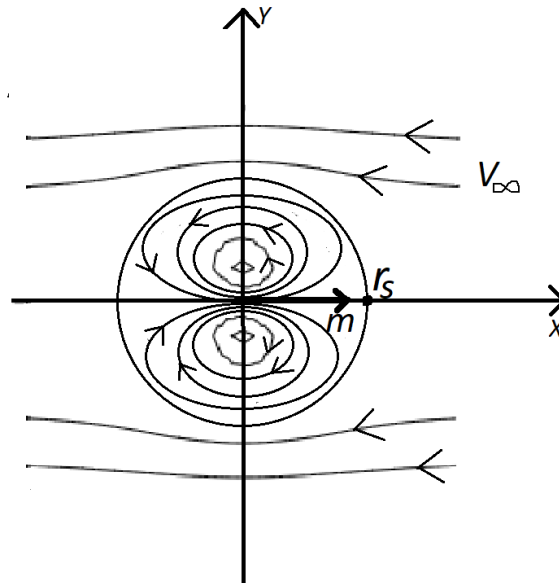


Figure 2. Flow structure of flow function (9).

The inner region, which is formed by the flow of the economic dipole, will be called the “stability zone” [12] (see figure 2).

Its size is difficult to give a clear qualitative and quantitative characteristic. Our study used the following principles:

1. The size of the “stability zone” corresponds to the opportunities that an economic entity has to carry out economic activities. For the flow function (9) this is the area of a circle of radius $r = r_s$ (see figure 2).
2. The quantitative indicator of satisfaction with the available opportunities corresponds to the coordinate of the point of the “stability zone”, which lies on the horizontal axis in the positive direction. In figure 2 it is r_s .
3. The qualitative indicator of satisfaction *SAT* (satisfaction) with the available opportunities is determined from the ratio

$$SAT = \frac{S_R}{S_L}, \quad (12)$$

where S_L is the area of the part of the “stability zone” located in the left half-plane relative to the vertical axis; S_R is the area of the part of the “stability zone” located in the right half-plane relative to the vertical axis. For the flow function (9) (see figure 2) $S_L = S_R$; $SAT = 1$.

Dependence (11) allows us to consider such situations of the ratio of possible values of the economic dipole moment m and the parameter of external influence V_∞ :

1. The economic dipole moment m is much larger than the parameter of external influence V_∞ (external influence can be neglected).
2. The moment of the economic dipole m is much less than the parameter of external influence V_∞ (leads to the destruction of the economic entity).
3. The moment of the economic dipole m and the parameter of external influence V_∞ are commensurate values (as a result of the adaptation of the economic entity to external influence, a structure similar to figure 2).

2.1. *Passive reaction to the deterioration of environmental factors*

Consider a situation where the negative impact of environmental factors increases (the external impact parameter increases V_∞). The most trivial in this case is the passive strategy, which is characterized by the fact that the economic dipole moment m remains unchanged. With such a strategy of economic behavior, it is obvious that the greater the external influence, the smaller the size of the “stability zone”, the fewer opportunities.

There are several reasons for this decrease. One of the consequences of the deterioration of the state of the environment is the deterioration in the quality of the usual set of food products. As part of ensuring the stability of the internal socio-economic state, the change in the economic behavior of households is expressed in attempts to restore the loss of quality. This can be expressed in the transition to more environmentally friendly products [24]. While maintaining the economic dipole moment m , the implementation of such a strategy of economic behavior requires the use of additional resources and a decrease in available opportunities.

Another reason is related to the fact that the “stability zone” limits not only the possibilities of using material resources, but also the available human capital, which is provided by education, qualifications, health, etc. [25]. For a household, this is also a decrease in the opportunities for the implementation of the reproductive function.

Let us consider as model initial data the values: $r_s = 1$, $m = 1$, $V_\infty = 0,16$, which satisfy relation (11).

In our study, first of all, it is not absolute changes in indicators that are important, but relative ones. So, if environmental indicators deteriorate by 2 times relative to the initial value $V_\infty = 0,16$, then the use of a passive strategy will lead to a decrease in satisfaction by almost 21 percent ($r_s = 0,7924$). The “stability zone” in this case will decrease from the initial 3,1416 will decrease to 1,977. That is, the available opportunities will decrease by 37 percent.

But the attitude towards such changes will remain neutral: $SAT = 1$.

The natural consequences of such economic behavior is the gradual depletion of available resources, the amount of which may decrease to a level capable of providing only basic needs. In our opinion, the strategy under study can be identified as irrational.

2.2. Reactive response to the deterioration of environmental factors

In an effort to maintain the amount of available resources, the reactive strategy for adapting an economic entity to the deterioration of environmental factors provides for a change in the structure of consumption. In the framework of the proposed model, this means that in the face of increased negative external influence, the balanced state in the form of an economic dipole is being transformed. Keeping equal absolute values of the intensities of the economic source and economic sink, their relative position in the state space is corrected. This reflects the behavior of an economic entity aimed at compensating for the deterioration of environmental factors.

The flow structure in this case in the Cartesian coordinate system (x, y) is described by the function:

$$\Omega_1 = -\frac{1}{2}V_\infty y^2 + m\left(1 - \frac{x}{\sqrt{x^2 + y^2}}\right) - m\left(1 - \frac{x+a}{\sqrt{y^2 + (x+a)^2}}\right). \tag{13}$$

Obviously, as a result of a change in the habitual structure of consumption in the direction of a deterioration in its quality level, the topology of the “stability zone” will also change - it will take on the shape of an ellipse.

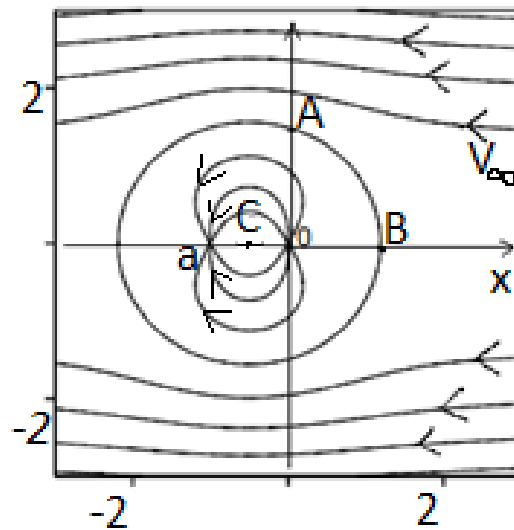


Figure 3. Flow structure of flow function (13).

On figure 3 the flow structure of the flow function (13) is presented at $V_\infty = 0,5$; $m = 1$ and $a = 1$ (the value $a = 1$ is illustrative).

To assess changes in the internal socio-economic structure and the size of the “stability zone”, we use the formulas [20]

$$V_\infty = \frac{m}{\left(L - \frac{a}{2}\right)^2} - \frac{m}{\left(L + \frac{a}{2}\right)^2}, \tag{14}$$

$$V_\infty = \frac{2ma}{h^2 \sqrt{h^2 + \left(\frac{a}{2}\right)^2}}. \tag{15}$$

L, h is major and minor semi-axes of the ellipse (“zones of stability”) (see figure 3). These ratios make it possible to determine the level of consumption adjustment while maintaining

internal resources, the value of which for the elliptical shape of the “stability zone” is calculated by the formula

$$SZ_1 = \pi Lh. \tag{16}$$

Recall that at $r_s = 1$, $m = 1$, $V_\infty = 0,16$ the “stability zone” is estimated by the value

$$SZ_0 = \pi r_s^2 \approx 3,1416. \tag{17}$$

Using relations (14)-(17), it was found that when the negative influence of external factors doubles relative to the initial value $V_\infty = 0,16$ and the value of $m = 1$ is maintained, the value of a should be equal to $a \approx 0,159$. That is, the correction is such that satisfaction with the structure of consumption decreases by almost 16 percent.

The quantitative indicator of the overall satisfaction of the economic entity with its state after applying the described reactive strategy is estimated by the length of the segment of the OB (see figure 3).

$$OB = L - \frac{a}{2} \approx 0,92. \tag{18}$$

The value of the qualitative assessment of the overall satisfaction of the economic entity with its state after applying the described reactive strategy is carried out according to the formula (12). In the situation under study, S_R is defined as the area of the segment perpendicular to the major axis of the ellipse (see figure 3).

$$S_R = L \arccos\left(\frac{CO}{L}\right) - CO \times OA =$$

$$= 1,003 \times 0,997 \times \arccos\left(\frac{0,008}{1,003}\right) - 0,008 \times 0,992 \approx 1,4115.$$

$$S_L = SZ_1 - S_R \approx 3,1416 - 1,4115 \approx 1,73$$

$$SAT = \frac{S_R}{S_L} = \frac{1,4115}{1,73} \approx 0,816. \tag{19}$$

2.3. Active response to the deterioration of environmental factors

An active form of economic behavior in the face of an increase in the negative impact of external factors involves actions aimed at eliminating the consequences of such an impact while maintaining overall resources and the level of satisfaction. Such economic behavior ensures the sustainable development of the system as a whole.

Such economic behavior implies an active participation in reducing the deterioration of environmental factors. For households, this implies direct participation in the use and promotion of such technologies for individual use as home treatment facilities [26], household biogas systems [27], etc.

From the point of view of the proposed economic and mathematical model, an active form of economic behavior leads to an increase in the value of the moment of the economic dipole m , at which the shape and size of the “stability zone” is preserved.

To quantify the change in the economic dipole moment m , we use relation (11). When the negative impact of external factors doubles relative to the initial $V_\infty = 0,16$ and $r_s = 1$, the moment of the economic dipole m should also double and equal $m = 2$. Such an increase implies the use of technologies that allow more efficient use of available resources, innovative technologies.

3. Conclusions

1. The proposed approach to modeling the formation of economic behavior has been successfully tested in the space of states, in which the state of the socio-economic system is determined by a combination of spatial and energy indicators. The formation of flows is provided by motivation to maintain a stable balance between the processes of interaction of the socio-economic system with the external environment.
2. Models of economic behavior are built in the form of linear combinations of such elements as economic source, economic sink, economic dipole, external influence. Models of economic behavior are built for various states of the internal and external environment, in conditions of stability and the strengthening of the negative influence of environmental factors, the formation of passive, reactive and active forms of economic behavior.
3. A study of the properties of the proposed models showed that the adaptation of an economic entity is accompanied by the emergence of processes of self-organization of material and information flows.
4. It is shown that the most effective in terms of satisfaction and availability of resources is the active economic behavior of responding to the deterioration of environmental factors. This is consistent with the concept of sustainable development.
5. The constructed model is normative and does not allow studying transient processes in the formation of economic behavior. But the proposed method allows us to evaluate the relative changes in such quantitative and qualitative indicators as opportunities, motivation, satisfaction. It also makes it possible to establish and investigate cause-and-effect relationships in the formation of economic behavior in the context of sustainable development.

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