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Neural Network Approximation in Forecasting Economic Risks

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Abstract

The article aims to assess the level of the economic systems development in the context of the accuracy of forecasts in unpredictable socio-economic conditions, taking into account the impact of unforeseen environmental risks and disasters. The authors used methods of neural networks in order to evaluate the sustainable development process. To date, a large number of mathematical forecasting methods are known, and experts in the world economy use appropriate risk assessment criteria, but the neural network is used when the exact type of connections between inputs and outputs is unknown, which allows us to create a more accurate and flexible forecast model. The modeling takes into account the main weights that determine the degree and the priority of the impact on each component of the economic system and characterizes the complex macroeconomic relationships to determine the aggregate indices. The developed model is used when assessing the level of economic security of the national economy. Especially, such an important component as environmental security is evaluated with the help of this model.

Keywords: sustainable development, functional indexes, economic security, risk assessment criteria, environmental security.

JEL: C4, G32, F5, O11.

1. Introduction

Economic security of a State is an integral part of national security and is a closed system of mutually related factors. Considering the world economy development ways, it is important to consider structural transformations in the world economy and determine the conditions which will ensure a proper level of economic security of a State (Reznik et al., 2020). The formation of an

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expert assessment of the level of economic security is what the works of such leading scientists of economics, as Abalkin (1994), Arkhireiska (2012), Horbulin and Vlasiuk (2015), Hubarieva and Pinchuk (2015), Tymoshenko (2016) are devoted to. Despite a significant number of research pieces in this area, the expert assessment of the level of economic security of the national economy requires further development and is vital in case of an unstable situation in the world.

The article aims to assess the level of the economic systems development in the context of the accuracy of forecasts in unpredictable socio-economic conditions, taking into account the impact of unforeseen environmental risks and disasters. Elaboration of the economic security level of the State`s national economy and its main functional components assessment model, will allow to predict the economic state of the country, accurately assess the impact of each component on the integral index, identify the critical zones and develop solutions to create an effective mechanism to ensure economic security. In the writings of Tymoshenko (2016) the author has identified the following functional indexes as the main indexes of influence on the economic security:

- macroeconomic index;
- food supply component;
- production component;
- energy component;
- socio-demographic index;
- financial component;
- external economic condition;
- investment and innovation index;
- environmental sustainability index.

These indexes affect the formation of the integral index in economic security of national economy of the State. Rapid development of mathematical modeling methods covers a wide variety of areas of human activity, involving modern scientific technologies (Tymoshenko & Kotsiubivska, 2016). One of the integration models can be the use of artificial intelligence elements for economic research, in particular to predict risks using a mathematical apparatus, which, unlike classical methods, is adapted to take into account the nonlinearity of economic processes and irrationality of market entities (Khomutenko et al., 2019).

2. Materials and methods

These functional indexes of the economic security index generally affect the sustainable development of the country. A major problem of modern researchers is to develop an informative and adequate system of indexes to evaluate the sustainable development process (Arkhireiska, 2012). Sustainable development provides implementation of survival and reproduction of the gene pool, intensification of the role of each society individual, ensures one`s rights and freedoms, preserves the environment, forms conditions for restoration of the biosphere and its local ecosystems, and ensures harmony of human-nature relations. As any other process, the process of sustainable development and its procedure conditions can be assessed by means of qualitative and quantitative parameters, which are called ecological marks and indexes (Hubarieva & Pinchuk, 2015). Formation and use of ecological marks and indexes allows:

- to identify the current or achieved level of harmony of relation between anthropo-technogenic and natural systems;
- identify the range of problems arising from such relations;
- create possible solutions for current problems and define a set of adequate means to implement the solutions;

- choose the best set of means among the selected alternatives;
- control the progress and effectiveness of the means being implemented (Karyntseva, 1997).

Use of traditional macroeconomic indexes, such as gross domestic product (GDP), gross national product (GNP), national income, etc. as indexes while evaluating the sustainable development of the country, unfortunately, does not allow to fully cover and adequately take into account social and environmental phenomena. Regarding this problem, international organizations are working on development of marks and indexes of sustainable development, which will contain a complex system of criteria for development assesment. Such innovation is a complex procedure that requires processing a large amount of information (Karyntseva, 1997).

The ecological component is characterized by the state of the environment. The general state of the environment depends on quality of atmospheric air, surface water bodies and waste presence. The following indexes can be used to assess the ecological status:

- pollutants emissions into air;
- surface water bodies pollution rate;
- industrial waste creation;
- natural disasters;
- technological disasters.

Economic consequences from pollution impact certain economic activity entities, they are manifested on the efficiency of their functioning and proceedings (Terianyk, 2015). The effect of the ecological component on economic activity entities can be defined by the following means:

- number and quality of economic resources operating in the economic system reduction;
- assignment of economic resources to prevent and compensate for the negative consequences caused to the ecosystem.

In both cases, each economic entity increases the cost of functioning, decreases the number of final product, and, as a result, it all leads to a decrease of income (Terianyk, 2015).

In general, sustainable development means economically, socially and environmentally balanced development of certain areas, aimed at the coordinated formation and functioning of their economic, social and environmental components based on rational use of all kinds of resources (natural, labor, industrial, scientific, technogenic, informational, etc.). Three components of sustainable development are allocated. These are: economic, social and ecological. Economic and social components should cause a high quality of life of the population by increasing production volumes, effective development of social, industrial, transport, engineering, communication and information and environmental infrastructure (Abalkin, 1994).

3. Results and discussion

3.1. Ecology component of economic stability

The ecological crisis is determined by the level of environmental safety, which covers a range of environmental problems that potentially or actually affect the pace of evolution of modern civilizations. It is based on the position of carrying capacity, which is understood as the total consumption of natural resources, which the natural system is able to withstand without degradation and depends on the total population, number of technologies and lifestyle (Khvesyk & Stepanenko, 2014). The ecological situation and the level of development of the national environmental system can be assessed by means of indexes of the international index of ecological dimension – EPI (Environmental Performance Index). The primary causes of environmental problems are as follows: deterioration of the main industrial and transport infrastructure funds; existing system of authoritative administration in the field of environmental protection and regulation of natural resources use; absence of a clear distinction between environmental and economic functions; insufficient formation of civil society institutions; insufficient society understanding of environmental priorities and benefits of sustainable development; non-compliance with current environmental legislation (Aleksandrova et al., 2018).

Excessive burden on the environment is associated with excessive material and energy capacity and a large amount of waste as a result of the national economic complex technologies. It is accompanied by harmful pollutants and compounds emissions to the air that cause changes in the chemical composition and physical state of the atmosphere. For examnple, the contamination of surface water bodies and groundwater by industrial and household discharges leads to a decrease in quality and exhaustion of water resources. The same is true for the pollution, depletion and reduction of land resources quality suitable for use (Tymoshenko & Kotsiubivska, 2016).

For its part, ecology significantly affects the economy. According to the Ministry of Ecology and Natural Resources of Ukraine, the average annual loss of GDP due to the deterioration of the environment is 10-15%. At the same time, according to estimates of the International Institute of Environmental Management (Switzerland), the level of environmental damage in Ukraine reaches at least 15-20% of GDP and is one of the highest in the world. It should be noted that the environmental crisis is not an accidental phenomenon isolated from the state of general economic development, but on the contrary – as a regularity and a significant factor for the deep systemic crisis (Grebennik et al., 2019).

The consequences of environmental disasters are becoming increasingly devastating, and countries alone are incapable of effectively overcoming them without coordinated assistance of the world community. At the same time, international experts of the UN point out that the current international projects are more aimed at overcoming the consequences of destruction than at preventing them and strategically managing the risks (Guliyeva et al., 2018). According to US experts, every million dollars invested in disaster prevention, saves a seven times bigger value. The national economy suffers significant losses from natural and technological disasters. The losses, caused by disasters, significantly depend on the distribution of hydrometeorological and geological disaster cases with serious consequences by regions (Khvesyk & Stepanenko, 2014).

3.2. Prediction of economic risks using neural networks

The use of neural networks in forecasting, unlike regressive methods, allows to take into account asymmetry of information, presence of nonlinear connections, uncertainty of economic processes. Neural networks are used in solving complex nonformalized problems, which analytical algorithms cannot help with, and inputs can be incomplete and contradictory (Evergreen, 2021). When modeling the processes of economic development, neural networks allow to take into account a large number of independent inputs when modeling forecasts, and determine the most significant indexes (Horbulin & Vlasiuk, 2015). When formalizing and identifying the preconditions of the crisis, unlike regression models, which are limited by the assumption of preserving the development of the main trends of the past in the future, neural networks take into account the asymmetry of information, uncertainty and influence of various factors in the crisis scenarios, and reveal nonlineary relationships (Haleshchuk, 2016).

The most flexible and effective at working with economic data are neural networks of reverse error spread. They are structures that approximate any continuous function with several variables. The architecture of the neural network is implemented on a three-layer perseptrone that has three input level neurons, a hidden layer of neurons, and an output neuron. This structure of the neuronet has two main advantages – its simplicity and the provision of the necessary generalizing properties (Haleshchuk, 2016). The schematic image of the structure of the three-layer perceptron is presented in Figure 1.

The output value of the three-layer perceptron is calculated by expression (Haleshchuk, 2016):

$$y = F\left(\sum_{j=1}^{n} v_j h_j - b_3\right) \tag{1}$$

Given:

n – number of neurons in the hidden layer;

v_j – weight of communication from the output of j–th neuron of the hidden layer to the output neuron;

h_j – output value of j-th neuron of the hidden layer;

b_3 – threshold of the output neuron;

F is the output neuron activation function.

The output value of the j–th neuron of the hidden layer is calculated by the formula (Haleshchuk, 2016):

$$h_j = F\left(\sum_{i=1}^{n} w_{ij} x_i - b_{2j}\right) \tag{2}$$

Given:

w_{ij} - the weight of communication between i-th input neuron and j-th hidden layer neuron.

x_i - input values;

b_{2j} – threshold of the j-th neuron of the hidden layer.

The hidden layer and output neurons activation function:

$$F(x) = \frac{1}{\left(1 + e^{kx}\right)} \tag{3}$$

Given:

x - the weighted sum of input values;

k – the index that determines the curvature of the function, its change rate from values close to zero, to values close to one (k>0).

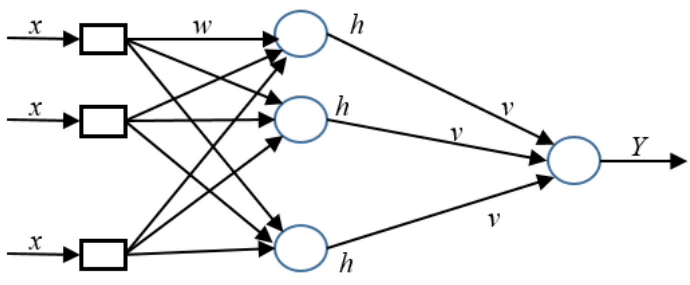

Figure 1. Structure of three-layer perceptron.
Source: developed by the authors.

The use of the reverse error spread algorithm allows one to train not only a single-layer, but also multilayered perceptrons. Training is conducted in several iterations (Singularuty U.Kyiv, 2017). The average offset for each training iteration when learning a vector p is calculated according to the formula:

$$E^p(t) = \frac{1}{2}\left(y^p(t) - d^p(t)\right)^2 \quad (4)$$

Given:

t – iteration number;

$y^p(t)$ – calculated output value of the multilayered perceptron;

$d^p(t)$ – expected output value of the multilayered perceptron.

In the course of training for all vectors, a generalized offset is calculated according to the formula:

$$E(t) = \sum_{p=1}^{P} E^p(t) \quad (5)$$

Output neuron offset while training with the vector p is calculated according to the formula (Haleshchuk, 2016):

$$\gamma_3^p(t) = y^p(t) - d^p(t) \quad (6)$$

And the expression for the offset of the j-th neuron of the hidden layer looks like:

$$\gamma_i^p(t) = \sum_{j=1}^{n} \gamma_3^p \cdot v_i(t) \cdot h_j^p(t) \cdot \left(1 - h_j^p(t)\right) \quad (7)$$

The reverse error spread algorithm for multilayered perceptron training consists of the following steps (Haleshchuk, 2016; National Mining University, 2011):

- initialize the weights and thresholds of neurons by random values between 0 and 1 using a random number generator;
- bring the initial data to a single scale, they must be normalized using one of the transformations (National Mining University, 2011)

$$x_{ij}^k = \frac{x_{ij} - \min\limits_i(x_{ij})}{\max\limits_i(x_{ij}) - \min\limits_i(x_{ij})}\ x_{ij}^k =$$

$$= \frac{\max\limits_i(x_{ij}) - x_{ij}}{\max\limits_i(x_{ij}) - \min\limits_i(x_{ij})}\ x_{ij}^k =$$

$$= \frac{x_{ij} - x_j}{\max\limits_i(x_{ij}) - \min\limits_i(x_{ij})}$$

$$x_{ij}^k = \frac{1}{1 + e^{-x_{ij}}}$$

- set learning step a
- each input neuron x_i receives the input signal and propagates it to all neurons of the hidden layer;
- each hidden layer neuron adds its own weighted input signals:

$$h_j = \sum_{i=1}^{n} w_{ij} x_i \quad (8)$$

applies to the received sum the activation function, forming an output signal (2), which is sent to all neurons of the output layer.

- each output neuron adds weighted signals:

$$h_k = \sum_{j=1}^{q} w_{jk} x_j \quad (9)$$

- forming after application of function of activation an output signal of a network;
- to set the minimal average multilayered perceptron training offset to be achieved in the training process;
- calculate the output multilayer perceptron value for the training vector p, using formulas (1), (2);
- calculate output neuron offset with the formula (5);
- each output neuron compares its output value with the desired target function and calculates $\delta_k = (t_k - y_k) \cdot f'(h_k)$, then the correcting member of the scales is determined $\Delta w_{ik} = \eta \delta_k v_j$, and parameters δ_k are sent to the neurons of the hidden layer;

- calculate the offset of neurons of the hidden layer according to the expression (6);
- each neuron of the hidden layer vj adds its δ- inputs from neurons of the output layer:

$$h_k = \sum_{k=1}^{m} \delta_k w_{jk}$$

- the result is multiplied by the differential of the activation function to determine δ_j:

$$\delta_j = F'(x) \cdot \sum_{k=1}^{m} \delta_k w_{jk}$$

- and the correcting member is calculated:

$$\Delta w_{ij} = \eta \delta_k w_{jk}$$

- calculate a generalized medium-defective multilayer perceptron offset according to formula (4)
- if the generalized mid-quadratic offset is still greater than the defined minimal, training should be continued.

3.3. Forecasting the level of economic security based on the neuro-network model

The use of neural network to predict the level of economic security of the state makes it possible to identify the impact of the main index components on stability of the national economy. The most important functional indexes of influence on the integral level of economic security were used to create the model: macroeconomic index; food supply component; production component; energy component; socio-demographic index; financial

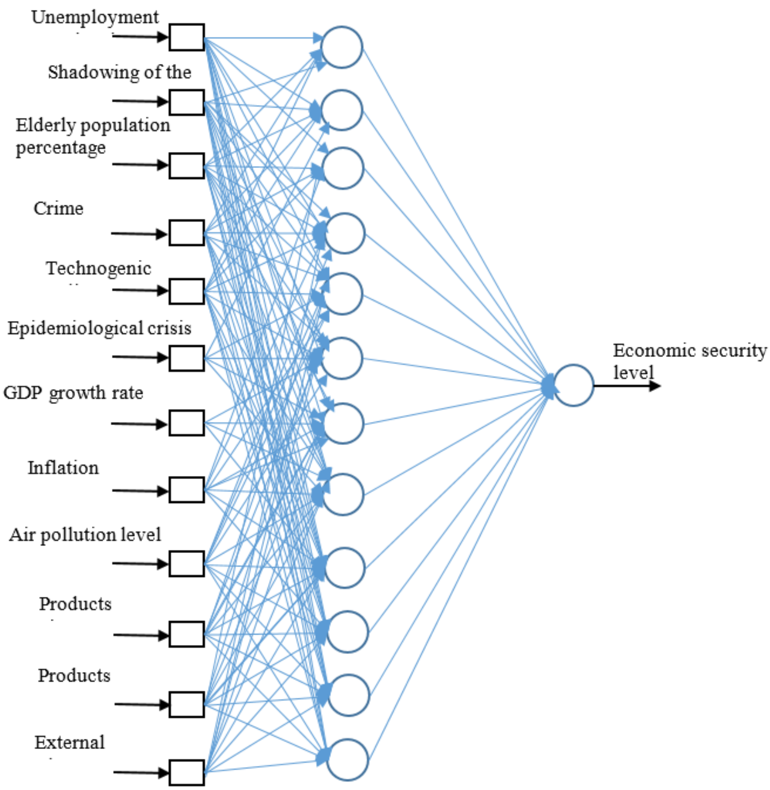

Figure 2. Structure of neural network model to predict the level of economic security
Source: developed by the authors

component; external economic condition; investment and innovation index; index of environmental sustainability (Codeguida, 2017). But in addition to that, impact of natural disasters, technological disasters, state of environment, epidemiological threats to life or health of citizens was taken into account (National Mining University, 2011). During the training, the neural network with the reverse error spread, the most significant indexes of influence on the destabilization of the economic situation were selected: economy shading, unemployment, elderly population percentage, crime rate, technogenic disasters, epidemiological crisis, GDP growth rate, inflation (Lagodiienko et al., 2019). The structure of the neural network model for level of economic security prediction is presented in Figure 2.

All economic and mathematical models based on neural networks are built to avoid the effect of overtraining, which occurs if the number of parameters of the model is bigger than the volume of the training sets. In order to avoid inaccuracy of the predictions, all input indexes of the perceptron have to be reduced to normalized values (Chaika, 2020).

4. Conclusion

Neural networks are a universal method for simulating different continuous and nonlineal functions that do not set any limitations for input information. In order to create a model, numerical data needs to be presented as its face value. In such a way, neural networks work with a step-by-step method that allows the use of new data to teach the network in order to improve previous results and to build a neuronet prediction model. Therefore, the data is divided into three categories, namely: for training, validation, and testing.

The training set, accordingly, includes 70% of collected data, validation set – 20%, testing – 10%. Different methods of sets creation are used every time before starting a training session, for example, filtering based on the information theory or methods based on assessment of a certain index significance by rating the sensitivity of the output information with respect to different input neurons. These groups of methods are used to solve complex problems with numerous inputs and a number of hidden neuron layers, as they help simplify the architecture of a neural network. After grouping the data, the network structure is set with the choice of number of hidden layers of neurons, input neurons and conversion function, which affects the efficiency of the neural network.

The choice of neural network parameters is based on certain criteria: the number of input and output variables, the complexity and structure of the information available, theoretical knowledge and facts about the predicted activities, etc. Signals from the input layer of neurons are transmitted to the hidden layers, where they are processed and usually converted by means of logistical approximation by a step or threshold function. Then the received signal is transmitted to the output layer of neurons, where the information is processed again to receive the final result. A fully connected neural network is one where each input neuron is connected to all of the hidden-level neurons, and each of the hidden ones is connected to subsequent output neurons. Since the modern stage of the world economy is characterized by increasing uncertainty, unpredictable economic changes and trends that make it difficult to establish linear dependencies between the main macroeconomic factors, there is a need to use flexible tools of system analysis. Neural networks allow using a simple mathematical apparatus to simulate complex nonlineal processes that can intensify in the conditions of globalization of the world economy.

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