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A NEURAL NETWORK MODEL OF ECONOMIC GROWTH

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Abstract. The paper deals with the research of the process of economic growth as a component of the economic development of countries and aims at developing a neural network model directed at improving the modeling of economic growth, its stabilization or recovery after the impact of globalization integration processes, crisis phenomena. During the analysis, the authors found out that the indicators used to create a model of economic growth by the countries of the world do not have a close correlation and reflect different conditions of their functioning. It is determined that in order to achieve the set goal, it is advisable to apply neural networks, which provide a possibility to build a forecast system of economic growth with greater accuracy. In the process of the analysis, the data of 77 countries of the world according to the indicator of economic growth were used, the level of economic growth of the countries was assessed, the most accurate neural network model and the optimal network architecture were determined. The authors of the paper solve the problem of approximation of experimental data using multilayer perceptron-type models and network models with radial basis functions. The dependent variable in the model is denoted by the level of economic growth, and the independent variables are the level of gross accumulation, the level of gross savings, the level of export of goods and services, the level of import of goods and services, the level of current health care expenses. The volumes of training, test and control samples, the developed neural network models and the obtained results of economic growth modeling are presented graphically in the paper. The neural network model developed by the authors is sufficiently adequate, which is confirmed by the volume of processed data and obtained results. The neural network model of economic growth is suitable for further use in the process of its forecasting in various countries of the world.

Keywords: economic growth, economic development, neural networks, modeling of economic growth, economic growth models

Introduction. Economic growth is understood in science as a dynamic process that occurs on the basis of the influence and interaction between various factors of production, economic policy and is characterized by the creation of a greater number of manufactured goods and services, which improves the well-being of the population. Factors, methods and tools of intensification of economic development (economic growth is its component) and economic growth have long been the central objects of research. Crisis phenomena in the world economy (for example, the world financial crisis of 2007-2008 and the crisis due to the pandemic of 2020), in the economies of some countries of the world due to globalization integration processes (for example, military events in Ukraine since 2022, caused economic shifts in countries and Europe) increase the relevance of the research and improvement of modeling of economic growth, its stabilization or recovery.

Literature review. Models of economic growth are researched in the papers of such scientists as Keynes, Harrod and Domar, Cobb and Douglas, R. Solow, P. Romer, R. Lucasc, Aghion and Howitt, R. Levin and D. Rene, R. Barro, B. Hussain, S. A. A. Naqvi, M. S. A. Makhdum, S. A. R. Shah, S. Omerovic, H. Friedl, B.Grün, H. Sriket, R. M. Suen and also modern Ukrainian economists: I. Irtyshcheva (2021), I. Kaleniuk, L Antoniuk, O. Kuklin, L. Tsymbal, & O. Tsyrkun (2022), V. Kovalenko, Z. Oskonbaieva (2018), S. Sheludko, M. Slatvinska, O. Serheieva & E. Kulikova (2020), V. Makohon (2021), V. Sumtsov, I. Filippova (2010), M. Petchenko (2018), A. Tuholukov (2018), H. Telnova (2016; 2019), S. Shvets (2020).
With positively evaluation of the work of scientists, it is necessary to implement modern approaches to modeling economic growth, namely through the use of neural network modeling tools.

The purpose of the paper consists in the development of a neural network model of economic growth.

Material and methods. The information base of the research includes domestic and foreign scientific periodical literature, statistical data of the World Bank and the State Statistics Service of Ukraine on indicators of economic growth of Ukraine and countries of the world, the results of the authors' own research. The paper uses methods of dialectics, a number of general scientific approaches and special methods, which together made it possible to achieve the conceptual unity of the research, in particular: abstract-logical method, generalization, coefficient method, system and structural methods, methods of comparison, grouping, analysis and synthesis, statistical analysis, economic-mathematical modeling, logical generalization.

Results and discussion. Selected indicators for the model by country do not often have a close correlation with economic growth, reflect different conditions of functioning of the countries of the world. A conclusion is made about the expediency of using neural networks, which make it possible to build a forecast system of economic growth with greater accuracy.
To solve the given task, it is necessary to perform the following actions:
formulation of the final result. For this purpose, data on the indicator of economic growth of 77 countries of the world were entered, which integrates the results of the influence of neoclassical factors, indicators of foreign trade and the level of health care expenses;
determination of the object acting as an input signal of a neural network. The input signals of the neural network are the indicators formed in the previous section;
determination of the object acting as the output signal of a neural network. The output signal is an assessment of economic growth;
determining the deviation of the neural network signal from the real input signal using correlation and determination coefficients; the most accurate neural network model, its architecture and weighting factors are determined on this basis.
So, in the process of developing a neural network, first of all, the optimal architecture of the network should be determined. Since the areas of application of the most well-known paradigms overlap, different types of neural networks can be used to solve the corresponding problem, and the results can be the same. Solving problems of approximation of experimental data is possible using the following types of neural networks: multilayer perceptron (MLP) and networks with radial basis functions (RBF).

The dependent variable in the model is denoted by Var1 – the level of economic growth (GDP growth, %).
Independent variables: Var2 – Gross capital formation, % of GDP; Var3 – Gross savings, % of GDP; Var4 – Exports of goods and services, % of GDP; Var5 – Imports of goods and services, % of GDP; Var6 – Current health expenditure, % of GDP.
The output values of neural networks are usually represented in the appropriate range or scaled. Scaling data for a neural network allows you to increase the speed and quality of the learning process. The given indicators are all measured in percentages, so it is not necessary to apply normalization and standardization procedures to the data.
The task of approximation of functions for a neural network consists in the determination of the weighting coefficients for the basic functions so that their combination should give a similar dependence that best approximates the set of values of the response function.
Consider the process of modeling using an Automated Neural Networks (SANN) package.
The determination of the output result and input data is shown in Fig. 1. (Website of the World Bank).

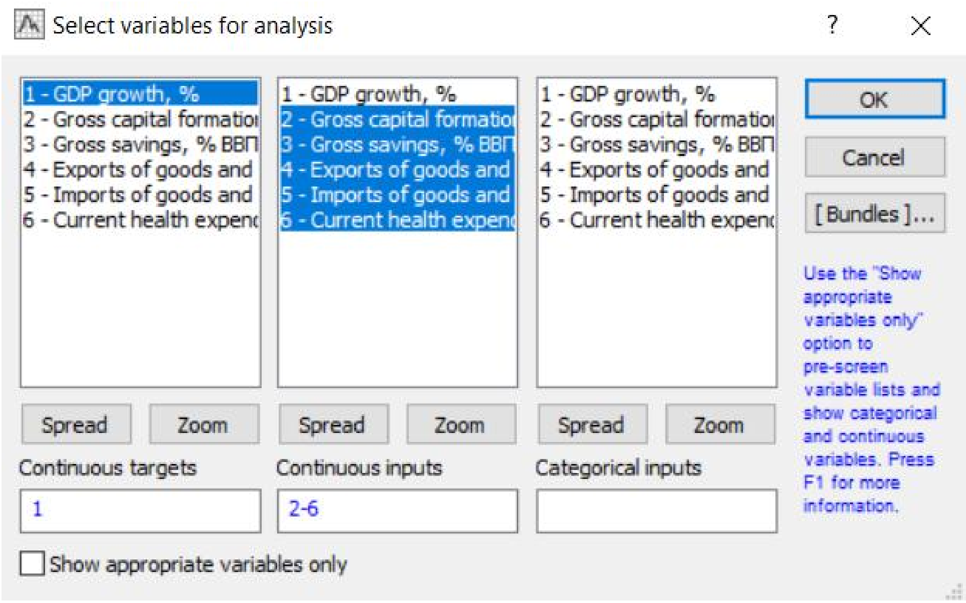


Figure 1. Determination of output and input data for neural network modeling of economic growth

The volumes of training, test, and control samples are set in proportions of 50%, 30%, and 20%, respectively (Fig. 2).

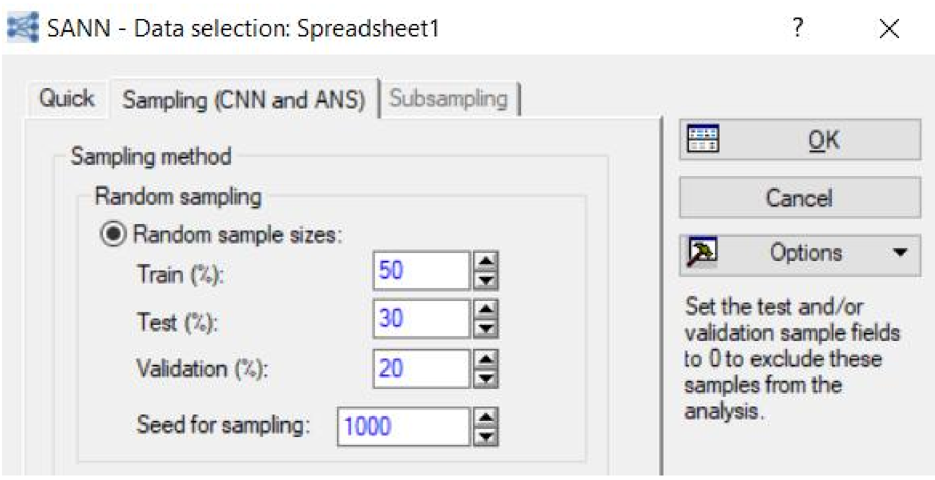
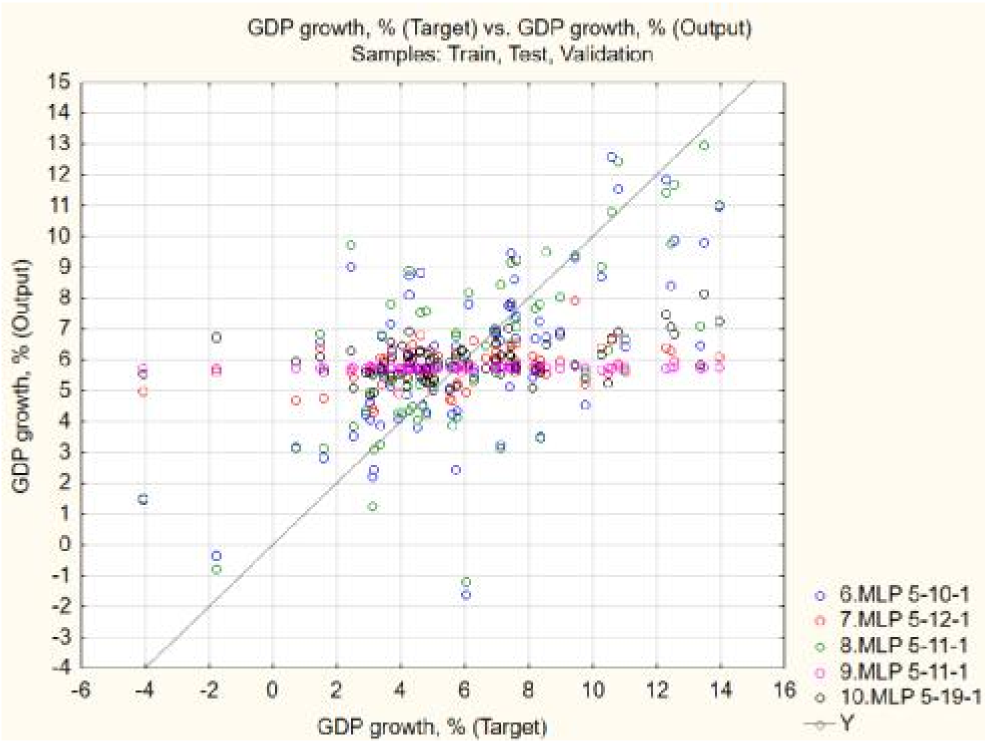
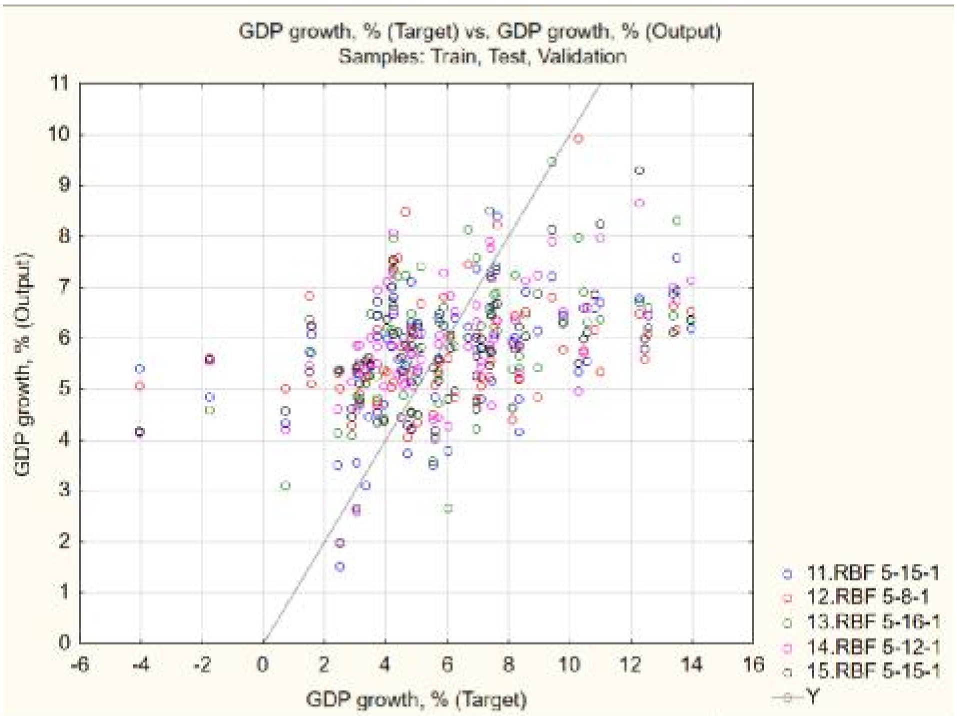


Figure 2. Volumes of training, test and control samples of neural network modeling of economic growth

To solve the set problem, a number of neural network models were developed, among which 5 models of the multilayer perceptron (MLP) type and 5 models of the network with radial basis functions (RBF) were singled out, the simulation results of which are presented in Fig. 3.



a) 5 models of the multilayer perceptron (MLP) type



b) 5 network models with radial basis functions (RBF)

Figure 3. The results of modeling economic growth, which are obtained based on the developed models

The characteristic of neural network models of economic growth is presented in Fig. 4.

Summary of active networks (Spreadsheet1)							
Net. name	Training perf.	Training error	Test error	Validation error	Training algorithm	Hidden activation	Output activation
MLP 5-10-1	0,791914	1,362560	5,714630	5,876892	BFGS 42	Tanh	Exponential
MLP 5-12-1	0,363639	3,228580	7,653566	6,007533	BFGS 32	Tanh	Exponential
MLP 5-11-1	0,810168	1,262788	4,718468	5,513622	BFGS 48	Tanh	Exponential
MLP 5-11-1	0,009073	3,628906	8,055524	7,087495	BFGS 1	Exponential	Exponential
MLP 5-19-1	0,238762	3,439552	7,034092	5,127581	BFGS 32	Logistic	Exponential

a) 5 models of the multilayer perceptron (MLP) type

Summary of active networks (Spreadsheet1)							
Net. name	Training perf.	Training error	Test error	Validation error	Training algorithm	Hidden activation	Output activation
RBF 5-15-1	0,491590	2,752168	7,421812	5,287263	RBFT	Gaussian	Identity
RBF 5-8-1	0,433128	2,948366	8,372280	5,989858	RBFT	Gaussian	Identity
RBF 5-16-1	0,555871	2,507809	7,328092	4,754519	RBFT	Gaussian	Identity
RBF 5-12-1	0,476186	2,806428	6,576552	5,141063	RBFT	Gaussian	Identity
RBF 5-15-1	0,424833	2,974196	6,438635	5,515977	RBFT	Gaussian	Identity

b) 5 network models with radial basis functions (RBF)

Figure 4. Analysis of developed neural network models of economic growth

Based on the value of the correlation coefficient (Fig. 5), we chose the best economic growth model – MLP 5-11-1, since the correlation coefficient for it was 0.81 or 81.02% on the largest training sample.

	Correlation coefficients (Spreadsheet1)		
	GDP growth, % Train	GDP growth, % Test	GDP growth, % Validation
6.MLP 5-10-1	0,791914	0,530140	0,570169
7.MLP 5-12-1	0,363639	0,226363	0,596726
8.MLP 5-11-1	0,810168	0,636055	0,616900
9.MLP 5-11-1	0,009073	0,380264	0,601086
10.MLP 5-19-1	0,238762	0,451107	0,689830

a) 5 models of the multilayer perceptron (MLP) type

	Correlation coefficients (Spreadsheet1)		
	GDP growth, % Train	GDP growth, % Test	GDP growth, % Validation
11.RBF 5-15-1	0,491590	0,291091	0,665505
12.RBF 5-8-1	0,433128	0,042215	0,703081
13.RBF 5-16-1	0,555871	0,277738	0,662167
14.RBF 5-12-1	0,476186	0,445875	0,672328
15.RBF 5-15-1	0,424833	0,489535	0,726936

b) 5 network models with radial basis functions (RBF)

Figure 5. The value of the correlation coefficient of the developed neural network models of economic growth

The scatter plot of forecast and actual data according to the MLP 5-11-1 model is presented in Fig. 6.
The weighting coefficients for the basic functions of the neural network model of economic growth of the MLP 5-11-1 type are presented in Table 1.

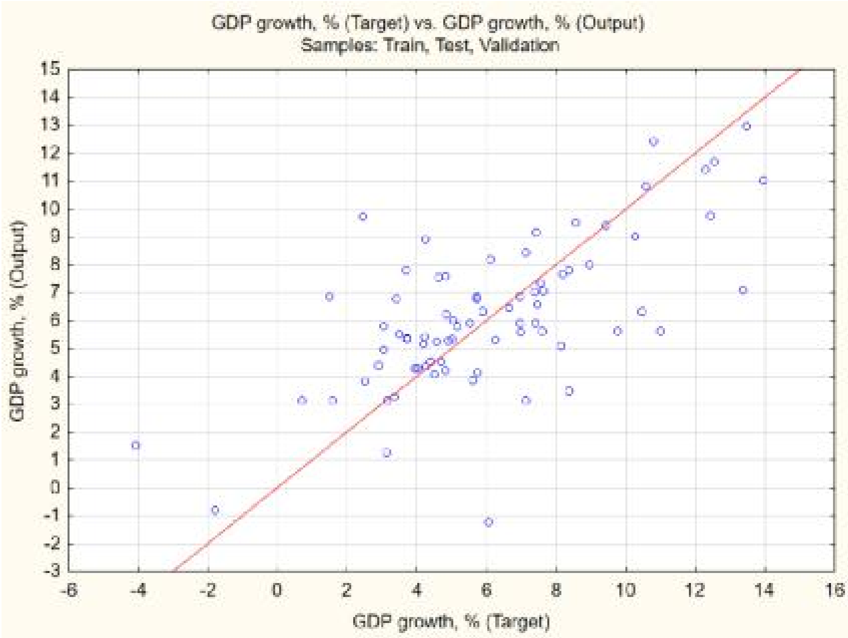


Figure 6. Scatter plot of forecast and actual data according to the MLP 5-11-1 model

Table 1. Weighting coefficients for the basic factors of the neural network model of economic growth of the MLP type 5-11-1

Connections of the MLP model 5-11-1	Weighting coefficients
1	2
Gross capital formation, % GDP --> hidden neuron 1	0.07354
Gross savings, % GDP --> hidden neuron 1	0.33426
Exports of goods and services, % GDP --> hidden neuron 1	-2.0764
Imports of goods and services, % GDP --> hidden neuron 1	1.18861
Current health expenditure, % GDP --> hidden neuron 1	-1.19579
Gross capital formation, % GDP --> hidden neuron 2	-0.30564
Gross savings, % GDP --> hidden neuron 2	-0.02399
Exports of goods and services, % GDP --> hidden neuron 2	1.45759
Imports of goods and services, % GDP --> hidden neuron 2	0.27076
Current health expenditure, % GDP --> hidden neuron 2	-0.07783
Gross capital formation, % GDP --> hidden neuron 3	-0.44753
Gross savings, % GDP --> hidden neuron 3	-0.09663
Exports of goods and services, % GDP --> hidden neuron 3	-0.91571
Imports of goods and services, % GDP --> hidden neuron 3	0.83291
Current health expenditure, % від GDP --> hidden neuron 3	-0.17425
Gross capital formation, % GDP --> hidden neuron 4	-2.21808
Gross savings, % GDP --> hidden neuron 4	-0.61427
Exports of goods and services, % GDP --> hidden neuron 4	-8.85533
Imports of goods and services, % GDP --> hidden neuron 4	3.12662
Current health expenditure, % GDP --> hidden neuron 4	-1.41092
Gross capital formation, % GDP --> hidden neuron 5	-0.49464
Gross savings, % GDP --> hidden neuron 5	-0.1503

Continuation of Table 1

1	2
Exports of goods and services, % GDP --> hidden neuron 5	-1.7426
Imports of goods and services, % GDP --> hidden neuron 5	1.94837
Current health expenditure, % від GDP --> hidden neuron 5	-0.35765
Gross capital formation, % GDP --> hidden neuron 6	0.09721
Gross savings, % GDP --> hidden neuron 6	-0.02152
Exports of goods and services, % GDP --> hidden neuron 6	2.24938
Imports of goods and services, % GDP --> hidden neuron 6	-1.19617
Current health expenditure, % GDP --> hidden neuron 6	0.11057
Gross capital formation, % GDP --> hidden neuron 7	0.58024
Gross savings, % GDP --> hidden neuron 7	-0.76943
Exports of goods and services, % GDP --> hidden neuron 7	10.34863
Imports of goods and services, % GDP --> hidden neuron 7	-6.59846
Current health expenditure, % GDP --> hidden neuron 7	1.24971
Gross capital formation, % GDP --> hidden neuron 8	0.11675
Gross savings, % GDP --> hidden neuron 8	-0.08571
Exports of goods and services, % GDP --> hidden neuron 8	1.02355
Imports of goods and services, % GDP --> hidden neuron 8	-0.58588
Current health expenditure, % GDP --> hidden neuron 8	0.22501
Gross capital formation, % GDP --> hidden neuron 9	0.02603
Gross savings, % GDP --> hidden neuron 9	-0.19227
Exports of goods and services, % GDP --> hidden neuron 9	8.37294
Imports of goods and services, % GDP --> hidden neuron 9	-2.34486
Current health expenditure, % GDP --> hidden neuron 9	1.13107
Gross capital formation, % GDP --> hidden neuron 10	0.16427
Gross savings, % GDP --> hidden neuron 10	-0.13845
Exports of goods and services, % GDP --> hidden neuron 10	2.30013
Imports of goods and services, % GDP --> hidden neuron 10	-1.19428
Current health expenditure, % GDP --> hidden neuron 10	0.01343
Gross capital formation, % GDP --> hidden neuron 11	-0.78851
Gross savings, % GDP --> hidden neuron 11	-2.13042
Exports of goods and services, % GDP --> hidden neuron 11	5.29781
Imports of goods and services, % GDP --> hidden neuron 11	-4.34966
Current health expenditure, % від GDP --> hidden neuron 11	-0.6747
input bias --> hidden neuron 1	0.11746
input bias --> hidden neuron 2	-0.34124
input bias --> hidden neuron 3	-0.10099
input bias --> hidden neuron 4	0.0366
input bias --> hidden neuron 5	0.553
input bias --> hidden neuron 6	-0.17265
input bias --> hidden neuron 7	-1.38421
input bias --> hidden neuron 8	0.10561
input bias --> hidden neuron 9	-0.9836

Continuation of Table 1

1	2
input bias --> hidden neuron 10	-0.15487
input bias --> hidden neuron 11	-2.16913
hidden neuron 1 --> GDP growth, %	-1.94601
hidden neuron 2 --> GDP growth, %	2.45087
hidden neuron 3 --> GDP growth, %	2.56834
hidden neuron 4 --> GDP growth, %	-4.09569
hidden neuron 5 --> GDP growth, %	-2.56421
hidden neuron 6 --> GDP growth, %	0.26101
hidden neuron 7 --> GDP growth, %	-1.2339
hidden neuron 8 --> GDP growth, %	0.01544
hidden neuron 9 --> GDP growth, %	-1.38706
hidden neuron 10 --> GDP growth, %	-0.11986
hidden neuron 11 --> GDP growth, %	3.22614
hidden bias --> GDP growth, %	0.00837

The correlation coefficient of the developed neural network model of economic growth (MLP 5-11-1) is 0.810168424, respectively, the value of the coefficient of determination is 0.6563, which, taking into account the amount of processed data, indicates its sufficient adequacy and the possibility of use in the process of forecasting the economic growth of countries the world.

Conclusions. Thus, summing up the above, we note that the feasibility of using neural networks is grounded on the fact that they allow building a forecast system of economic growth with greater accuracy.

In the process of modeling, a number of models of economic growth with the following factors were developed:

Var2 – Gross capital formation, % GDP;
Var3 – Gross savings, % GDP;
Var4 – Exports of goods and services, % GDP;
Var5 – Imports of goods and services, % GDP;
Var6 – Current health expenditure, % GDP, using the following types of neural networks: multilayer perceptron (MLP) and networks with radial basis functions (RBF), the most accurate of which turned out to be the MLP 5-11-1 model.

The correlation coefficient of the developed neural network model of economic growth (MLP 5-11-1) is 0.810168424, accordingly, the value of the coefficient of determination is 0.6563, which, taking into account the amount of processed data, indicates its sufficient adequacy and the possibility of use in the process of forecasting the economic growth of the countries of the world.

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Conflict of Interest

None.

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НЕЙРОМЕРЕЖНА МОДЕЛЬ ЕКОНОМІЧНОГО ЗРОСТАННЯ

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Анотація. Стаття присвячена дослідженню процесу економічного зростання як складової економічного розвитку країн з метою розробки нейромережвої моделі, спрямованої на вдосконалення моделювання економічного зростання, його стабілізацію або відновлення після впливу глобалізаційних інтеграційних процесів, кризових явищ. Під час аналізу авторами встановлено, що показники, які використовуються для побудови моделі економічного зростання за країнами світу, не мають тісного кореляційного зв'язку та відображають різні умови їх функціонування. Встановлено, що для досягнення поставленої мети доцільно застосувати нейронні мережі, що надають можливість з більшою точністю побудувати прогнозну систему економічного зростання. В процесі аналізу використані дані 77 країн світу за показником економічного зростання, проведена оцінка рівня економічного зростання країн, визначена найбільш точна нейромережна модель та оптимальна архітектура мережі. Авторами статті задачі апроксимації експериментальних даних розв'язано за допомогою моделей типу багатошарового персептрону та моделей мережі з радіально-базисними функціями, залежна змінна у моделі позначена через рівень економічного зростання, а незалежні змінні – рівень валового нагромадження, рівень валового заощадження, рівень експорту товарів і послуг, рівень імпорту товарів і послуг, рівень поточних витрат на охорону здоров'я. Обсяги навчальної, тестової та контрольної вибірок, розроблені нейромережні моделі та отримані результати моделювання економічного зростання представлені в роботі графічно. Розроблена авторами нейромережна модель є достатньо адекватною, що підтверджено обсягом оброблених даних та отриманих результатів. Нейромережна модель економічного зростання придатна для подальшого використання в процесі його прогнозування у різних країн світу.

Ключові слова: економічне зростання, економічний розвиток, нейронні мережі, моделювання економічного зростання, моделі економічного зростання.