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A nonlinear model for evaluating the impact of internally displaced persons dynamics on the level of regional socio-economic development

Abstract

The consequence of the military aggression of the Russian Federation is the loss of control over part of the territory of Donetsk and Luhansk regions in Eastern Ukraine and the annexation of the Crimean peninsula. The events are accompanied by the objective processes of migration of persons who were forced to leave their permanent residence and move to other regions of Ukraine or abroad. As a result, a new category of citizens who are the internally displaced persons (IDPs) has arrived in the country counting for millions of people. In such circumstances, the study of the interdependence between gross regional product (GRP) and the IDP migration is topical and reflects the ongoing social and economic processes in a big European country.

As a result of the study, a two-layer neural network with an error back-propagation model that simulates the nonlinear impact of the number of internally displaced persons on the dynamics of gross regional product has been constructed.

According to the number of IDPs, regions such as Donetsk, Luhansk, Kharkiv, Zaporizhzhia and Kyiv, including Kyiv city, are among the first ten regions of Ukraine. Based on the data from the abovementioned regions, we have formed a statistical sampling in order to formulate and test the prospective economic and mathematical model.

The study of mutual correlation function graphs by regions has allowed justifying the value of the time lag, which shifts an array of explanatory variables along the time axis, on average, into nine periods (three quarters). According to the results, only for Kharkiv, Donetsk, Luhansk, Zaporizhzhia and Kyiv regions, there is a significant correlation between the studied indicators. This conclusion is substantiated in view of the fact that the number of IDPs, in the structure of which only about 23% represents the working age population, impacts the size of the gross product growth in the regions. The abovementioned regions account for 75% of the total number of internally displaced persons.

The estimation of the forecast reliability, based on the 2017 data for Dnipropetrovsk region, points to the high accuracy of the developed model. The author of the article has identified specific features that accompany the processes of internal migration of the able-bodied population. In particular, based on the correlation function, the value of the time lag, which is shifted by the effect of IDP movement into a separate region, has been substantiated. The author has developed a neural network which establishes nonlinear regression dependence between the number if IDPs and the dynamics of GRP with high reliability.

Keywords: Internally Displaced Persons; Gross Regional Product; Mutual Correlation Function; Time Lag; Nonlinear Model; Neural Network

JEL Classification: B49; R58; J18; O15

DOI: https://doi.org/10.21003/ea.V171-07

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Побудова нелінійної моделі оцінки впливу динаміки внутрішньо переміщених осіб на рівень соціально-економічного розвитку регіонів

Анотація. Наслідком військової агресії Російської Федерації стала втрата контролю над частиною території Донецької та Луганської областей на сході України та анексія Кримського півострова. Ці події супроводжуються об'єктивними процесами міграції людей, які були змушені залишити своє постійне місце проживання та переїхати в інші регіони України або за кордон. Як наслідок, в країні сформувалася нова категорія населення – внутрішньо переміщені особи (ВПО), кількість яких перевищує мільйон осіб. За таких обставин вивчення взаємозалежності між валовим регіональним продуктом (ВРП) та міграцією внутрішніх переміщень є актуальним і відображає поточні соціальні та економічні процеси у великій європейській країні.

В результаті проведеного дослідження було побудовано двошарову нейронну мережу зі зворотнім розповсюдженням помилки, що моделює нелінійний вплив кількості внутрішньо переміщених осіб (ВПО) на динаміку валового регіонального продукту (ВРП).

Серед перших десяти регіонів України за даними ВПО провідні позиції займають Донецька, Луганська, Харківська, Запорізька та Київська області, а також місто Київ. На підставі даних цих регіонів сформовано статистичну вибірку з метою формулювання та перевірки перспективної економіко-математичної моделі.

Вивчення графіків взаємно кореляційної функції по регіонах дозволило обґрунтувати величину часового лагу, що зсуває масив пояснювальних змінних вздовж часової вісі в середньому на дев'ять періодів (три квартали). Відповідно до отриманих результатів лише для Харківської, Донецької, Луганської та Запорізької областей, а також міста Києва, існує помітний взаємозв'язок між досліджуваними показниками. Даний висновок є закономірним, оскільки від числа ВПО, в структурі яких лише близько 23% складають особи працездатного віку, залежить величина зростання валового продукту в регіонах. На зазначені вище регіони припадає 75% від загальної кількості внутрішньо переміщених осіб.

Оцінка достовірності побудованого прогнозу за даними 2017 року для Дніпропетровської області вказує на високу точність побудованої моделі. Визначено особливості, що супроводжують процеси внутрішньої міграції працездатного населення. На основі взаємно кореляційної функції обґрунтовано величину часового лагу, на яку зсувається ефект від переміщення ВПО до окремо взятого регіону. Автором статті побудовано нейронну мережу, що з високо достовірністю встановлює нелінійну регресійну залежність між кількістю ВПО та динамікою ВРП.

Ключові слова: внутрішньо переміщені особи; валовий регіональний продукт; взаємно кореляційна функція; часовий лаг; нелінійна модель; нейронна мережа.

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Построение неленейной модели оценки влияния динамики внутренне перемещенных лиц
на уровень социально-экономического развития регионов

Аннотация. Последствиями военной агрессии Российской Федерации стали потеря контроля над частью территории Донецкой и Луганской областей на востоке Украины, а также аннексия полуострова Крым. Эти события сопровождаются объективными процессами миграции людей, вынужденных покинуть свое постоянное место жительства и переехать в другие регионы Украины или за границу. В результате в Украине сформировалась новая категория населения – внутренне перемещенные лица (ВПЛ), которых насчитываются миллионы. При таких обстоятельствах изучение взаимозависимости между валовым региональным продуктом (ВРП) и миграцией ВПЛ актуально и отражает текущие социально-экономические процессы в большой европейской стране.

В результате проведенного исследования было построено двухслойную нейронную сеть с обратным распространением ошибки, которая моделирует нелинейное влияние количества внутренне перемещенных лиц (ВПЛ) на динамику валового регионального продукта (ВРП).

Среди первых десяти регионов Украины по числу ВПЛ – Донецкая, Луганская, Харьковская, Запорожская, Киевская области и г. Киев. На основе данных из этих регионов была сформирована статистическая выборка для формулирования и проверки экономическо-математической модели.

Изучение графиков взаимно корреляционной функции по регионам позволило обосновать величину временного лага, что сдвигает массив объяснительных переменных вдоль временной оси в среднем на девять периодов (три квартала). Согласно полученным результатам, только для Харьковской, Донецкой, Луганской, Запорожской областей и города Киев существует заметная взаимосвязь между исследуемыми показателями. Данный вывод является вполне обоснованным, так как от численности ВПЛ, в структуре которых только около 23% составляют лица трудоспособного возраста, напрямую зависит величина роста валового продукта в регионах. На указанные выше регионы приходится 75% от общего количества внутренне перемещенных лиц.

Оценка достоверности построенного прогноза по данным 2017 года для Днепропетровской области указывает на точность построенной модели. Определены особенности, которые сопровождают процессы внутренней миграции трудоспособного населения. В частности, на основе взаимно корреляционной функции обоснованно величину временного лага, на которую сдвигается эффект от перемещения ВПЛ в отдельно взятом регионе. Автором статьи построена нейронная сеть, которая с высокой достоверностью устанавливает нелинейную регрессионную зависимость между количеством ВПЛ и динамикой ВРП.

Ключевые слова: внутри перемещенные лица; валовой региональный продукт; взаимно корреляционная функция; временной лаг; нелинейная модель; нейронная сеть.

1. Introduction

The consequence of the military aggression of the Russian Federation is the loss of control over part of the territory of Donetsk and Luhansk regions in Eastern Ukraine and the annexation of the Crimean peninsula. The events are accompanied by the objective processes of migration of persons who were forced to leave their permanent residence and move to other regions of Ukraine or abroad. In accordance with the definition stated in the «Guiding Principles on Internally Displaced Persons Issues» developed by the United Nations, such persons receive the status of internally displaced persons (IDPs), given that «internally displaced persons are individuals or groups of persons forced to leave their homes or places of permanent residence as a result, or to avoid the consequences, of an armed conflict, manifestations of violence, human rights violations, natural or industrial disasters, and who did not cross international recognized frontiers» (ECOSOC, 1998).

The importance of these processes has led to the appearance of relevant scientific works. However, the majority of them are focused on studying the age and social structure of IDPs, issues of regional labour markets and real estate, which are short-term effects of internal migration. However, four years have passed since the beginning of mass internal displacement; there has been an accumulation of statistical information, and it has become possible to assess middle-term effects of the process. In particular, the growth of the able-bodied population in certain regions is expected to be reflected in the size of gross regional product (GRP).

The study of nonlinear and interspaced time changes of GRP, impacted by the IDP migration, is essential for the formation of regional economic policies, as well as for the introduction of perspective plans for the development of private entrepreneurship, housing market, social infrastructure, etc.

2. Brief Literature Review

A complex analysis of the modern trends in the migration in Ukraine, covering its impact on the country's demographic and socio-economic development, has been done by a significant number of Ukrainian scholars, including A. Gladun, T. Hnatyuk, T. Dragunova, O. Ivankova-Stetsyuk, E. Libanova, I. Maydanik, I. Mostovaya, A. Ovchinnikova, A. Pozniak, I. Prybytkova, M. Romaniuk, A. Khomra and P. Shuspanova.

Among foreign scholars, a significant contribution to the study of regional migration theory has been made by P. Pedersen (2004), M. Pytlikova (2004), N. Smith (2004). The studies by G. Borjas (1992; 1995; 1999), D. Levhari (1982) and O. Stark (1982; 1998) are devoted to the economic issues of immigration processes.

Taking into the account the cessation of peak processes of internal migration, there are objective prerequisites for a post-stage analysis and assessment of the middle-term effects of the relevant processes. The assessment of the impact of the number of IDPs on the size of GRP is of particular importance for regional economic development.

The analysis of research publications in this area gives grounds to consider the results of assessing the impact of domestic forced migration on the dynamics of the gross product in certain regions extremely insufficient.

3. The purpose

The research aims at the study of effects of the internal migration of persons from temporarily occupied territories on the dynamics of GRP, taking into account the peculiarities of the time distribution of the relevant effects in order to make a scientific justification of time lags, which are considered when constructing a nonlinear mathematical model of such dependence.

The main objectives of the research are to construct a nonlinear model of the dependence of the number of IDP on the dynamics of GRP in selected regions; to pre-substantiate the need of taking into account certain inertia of these effects and determining the magnitude of the corresponding time lag, to select mathematical tools that meet the research objectives and the specifics of the available statistical information as well as to ground the obtained findings.

4. Results

Considering issues relating to the internally displaced persons in Ukraine, it is necessary to realise that currently the matter is one of the most acute global problems, since the number of IDPs worldwide has grown to almost 40 million people who were forced to become migrants due to wars or natural disasters in 2017. According to the IDMC, armed conflicts have caused the

resettlement of 11.8 million people, doubling more than in 2016, and about 19 million people were left without a roof over 2017 due to the disaster - most of them are from China, the Philippines, Cuba and the United States.

In the EU member states, there are 2.5 to 2.8 million internally displaced people: there are about 1 million people in Turkey, about 600 thousand in Azerbaijan, 274 thousand in Georgia, 225 thousand in Serbia, 113 thousand in Bosnia and Herzegovina; others are in the Balkan countries, Armenia and Russia.

The increase in the number of internally displaced people, as a result of protracted wars has been noted in the following countries: Iraq, South Sudan, Syria, the Democratic Republic of the Congo and Nigeria. The five countries account for 60% of the world's internal displacement. Over the past four years, Ukraine has also joined the group of these countries.

According to the data of the Ministry of Social Policy, departments of social protection of the population of regional and Kyiv City state administrations, the number of internally displaced persons in Ukraine, as of the beginning of May 2018, was 1,502.019 persons. The largest number of IDPs lives in Donetsk region - 548,144 people, Luhansk region - 292,191 people and in Kyiv City - 162,334 people. About 60% of the IDPs are retired, 23.1% are able-bodied, 12.8% are children and 4.1% are disabled persons (Ministry of Social Policy of Ukraine, 2018).

It is essential to add that the lowest number of IDPs is registered in the western regions of Ukraine, i.e. in Volyn region (2,892 persons), Chernivtsi region (2,503 persons) and Ternopil region (2,123 persons).

The pattern of territorial resettlement of internally displaced persons in the regions of Ukraine is shown in Table 1.

According to the number of IDP, Kyiv, Dnipropetrovsk, Poltava, Odesa and Sumy are among the first ten regions. Correspondingly, based on the statistic information from the regions, we form a statistical sampling in order to formulate and test the prospective economic and mathematical model (see Figure 1).

It is necessary to formulate requirements for mathematical tools so as to construct the model showing interconnection between the number of IDPs and GRP. The following should be considered.

1. The mathematical model should describe the nonlinear effects peculiar to the investigated processes. In particular, there is a noticeable asymmetry between the number of IDPs and the dynamics of GRP, which is explained by the social age structure of IDPs, in which only about 23% of persons are of
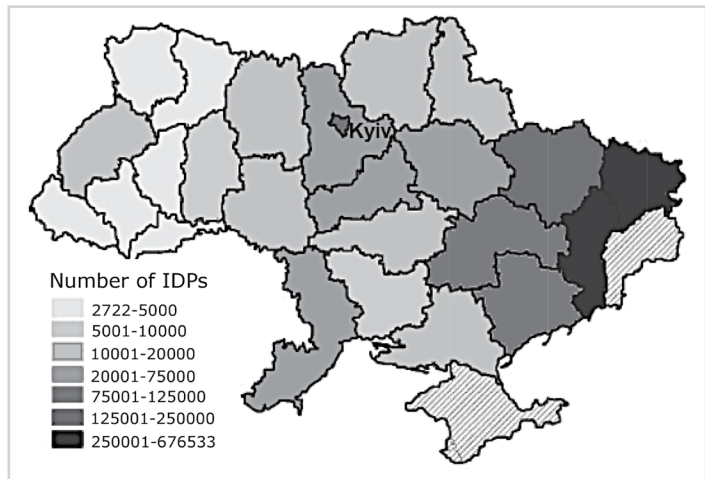

Fig. 1: **Number of IDPs by regions of Ukraine as of the end of 2017**
Source: Compiled by the author based on data
by the Ministry of Social Policy of Ukraine

working age. Inversely to the purposeful labour migration processes from the territory of Ukraine to neighbouring Poland, it causes almost a direct proportional effect on GDP growth.
2. The mathematical model should take into account certain time inertia between the emergence of the able-bodied population in the regional labour market and the reflection of the results of their labour in the GRP amount.
3. The mathematical model ought to be flexible to changes in output data and to adjust with the emergence of relevant information or changes in external conditions.

In accordance with the requirements for developing a nonlinear model of the relationship between the IDP number and the GRP dynamics, the author used the mathematical apparatus of the neural networks theory.

Compared with other mathematical tools designed to support decision-making process under uncertainty and the availability of small-size accessible databases, neural networks have a number of specific advantages (Strelchenko, 2011). They:
1) allow to effectively model nonlinear processes;
2) do not require strict mathematical specification of the model during the resolving of non-formalised or poorly formalised tasks;
3) are adaptive to changes of the affecting factors;
4) allow performing parallel processing of information;
5) are effective when working with incomplete or noisy data;
6) provide the possibility of classification on many grounds;
7) are effective in predicting time series that depend on many factors;
8) effectively work in the task of finding hidden patterns in data arrays.

First of all, it is important to create a learning sample in order to configure the parameters of the neural network. Previously, it has been noted that it is expedient to include statistics in the learning sample from ten areas, where the number of IDPs is statistically significant for the GRP dynamics. The data forming the learning sample must have the same periodicity. According to the available publicly, accessible statistical information on the distribution of the number of IDPs by regions (State Migration Service of Ukraine, 2018) and the amount of GRP (State Statistics Service of Ukraine, 2018), the sample included monthly data for selected areas over the four-year period of 2014-2017. The total amount of the learning sample (N) is:

$$N = 2 \times 4 \times 12 \times 10 = 960 . \qquad (1)$$

One half of the data is the meaning of the explanatory $\{X_i\}$ variable. However, in order to justify the potential structure of the neural network, it needs to be verified. For this purpose, the testing of the neural network is carried out on the basis of known arrays of input indicators $\{X_i\}$ and resultant $\{Y_i\}$ values. Therefore, before the formation and testing the neural network, the output data array will be shortened to rows that correspond to

Tab. 1: **Distribution of internally displaced persons by regions of Ukraine in May 2018**

	Territorial unit, region	Number of internally displaced persons, people
1	Cherkasy	11,391
2	Chernihiv	8,492
3	Chernivtsi	2,503
4	Dnipropetrovsk	74,036
5	Donetsk	548,144
6	Ivano-Frankivsk	3,563
7	Kharkiv	125,132
8	Kherson	13,959
9	Khmelnytskyi	6,582
10	Kirovohrad	6,630
11	Kyiv	63,857
12	Kyiv City	162,334
13	Luhansk	292,191
14	Lviv	11,768
15	Mykolaiv	8,416
16	Odesa	40,786
17	Poltava	25,406
18	Rivne	3,244
19	Sumy	11,215
20	Ternopil	2,123
21	Vinnytsia	11,416
22	Volyn	2,892
23	Zakarpattia	3,606
24	Zaporizhzhia	55,078
25	Zhytomyr	7,255

Source: Ministry of Social Policy of Ukraine, 2018

information in Kharkiv and Dnipropetrovsk regions. Finally, the size of the learning sample of the elements $N = 768$ is obtained.

Let us consider the second requirement to the mathematical model that was formulated earlier. The effect of inertia in reflecting the influence of the IDP quantity on the GRP dynamics is analytically taken into account as a time lag. That is, the shift of the array of explanatory variables is relative to the time axis of the previously known value τ. To determine the time lag, the correlation function R_{yx} is used.

The mutually correlative function characterises the tightness of the each dependent function element connection $\{Y_i\}$, with the element of an independent variable $\{X_i\}$ shifted to the time lag τ, one relatively to the other. The values of the mutual correlation function R_{yx} lie in the range from -1 to 1. The largest value $\{R_{yx}\}$ taken by the module (closest to one) determines the time lag. If some of the $\{R_{yxi}\}$ values are several units closer to one, then it means that the late effect of the variable occurs over a period of time, and as a result, there are several time lags for the interrelated time series (Matviichuk and Strelchenko, 2015).

The correlation function R_{yx} between $x(t)$ and $y(t-\tau)$ is mutually determined by the formula (2):

$$R_{yx}(t) = E\left[(x(t) - \mu_x)(y(t-\tau) - \mu_y)\right],\qquad(2)$$

where μ_y and μ_x are mathematical expectations of random processes $y(t)$ and $x(t)$ respectively.

It is essential to construct graphs of the correlation function between the number IDPs and the GRP by the data of the ten regions that are characterised by the largest number of internally displaced persons. In the process of creating the database, an additional restriction was found on the length of the initial series of data on the number of IDP. The official statistics of this indicator have been determined since July 2014. Consequently, it reduces the learning sample on the elements (six for each region).

In order to determine the statistically significant values of the time lag τ on the graph, one has to denote confidence intervals calculated in the form of double inequalities:

$$\mu(R_{xy}) \pm t_\alpha \cdot \frac{\sigma}{\sqrt{n}},\qquad(3)$$

where (μR_{yx}) is the selective meaning equal to the arithmetic mean of the correlation function; t_α is the argument of the Laplace function for a given probability α (in this case α is the assumed value; σ is the selective quadratic deviation; n is the sample size).

The results of calculations are shown in Figures 2-5.

It is necessary to note that according to the obtained results, there is a significant correlation between the studied indicators only for Kharkiv, Donetsk, Luhansk, Zaporizhzhia regions and Kyiv city. This conclusion is substantiated in view of the fact that the number of IDPs, in which structure there is only approximately 23% represents the working age population impacts the size of the gross product growth in the regions. These regions account for 75% of the total number of internally displaced persons.

According to the data, it is possible to determine the average value of the time lag τ, that is $\tau = 9$ (periods).

Consequently, the final learning sample consists of an array of explanatory variables shifted along the time scale for 9 periods for each resulting variable (4):

$$Y_i = f(X_{i-9}, X_{i-8}, ..., X_i).\qquad(4)$$

The analytical nonlinear model (4) was implemented on the basis of the NeuroNetwork toolbox of the MatLab package.

In particular, a two-layer neural network with error back-propagation for the solution of the nonlinear regression task is constructed.

In accordance with the method of error back-propagation, in order to determine the synaptic weights of a multilayer neural network, a gradient method of finding the minimum of the error function in the direction opposite to the signal propagation in the normal operation mode is used. Taking into the account

the computational characteristics of the gradient optimisation methods, the derivative of the activation function must be determined throughout the abscissa (Strelchenko, 2011).

The training of the neural network has been carried out according to the Levenberg-Marquardt method. The algorithm successfully combines the method of steepest descent (i.e. minimisation along the gradient) and the Newton method (i.e. use of a quadratic model to accelerate the search for the function minimum). The method of steepest descent gives the algorithm the working stability, the Newton method influences as accelerated convergence in the neighborhood of minimum. The Levenberg-Marquardt's algorithm implements optimisation with simple constraints, that is limitation of the $l_i \le X_i \le u_i$ form.

The error function is to be calculated using the modified formula (5) as follows:

$$e = \frac{1}{2}\sum_{p=1}^{n}(y_p - y_p^*)^2,\qquad(5)$$

where y_p and y_p^* are the output signal of the neuron and the reference index for this neuron, respectively.
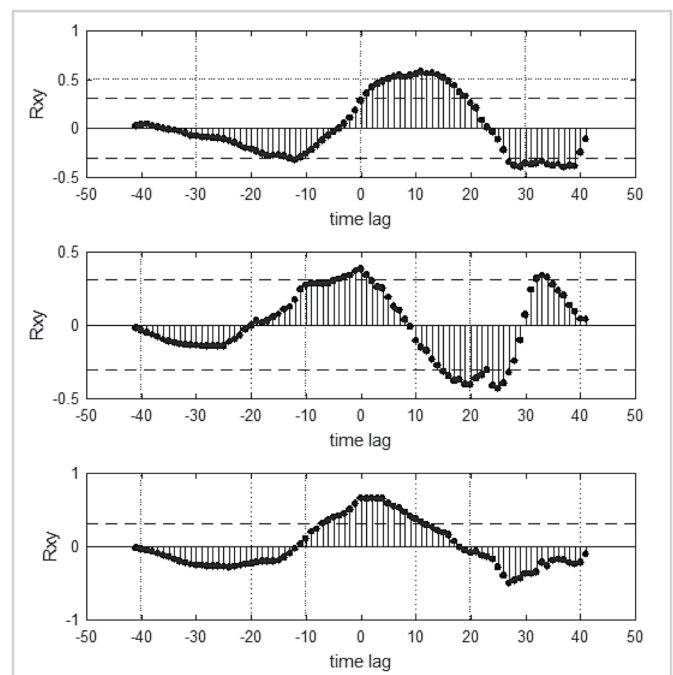

Fig. 2: **Mutually correlated function of selected indicators for Kharkiv, Luhansk and Zaporizhzhia regions for the period of July 14 - December 17 2017**
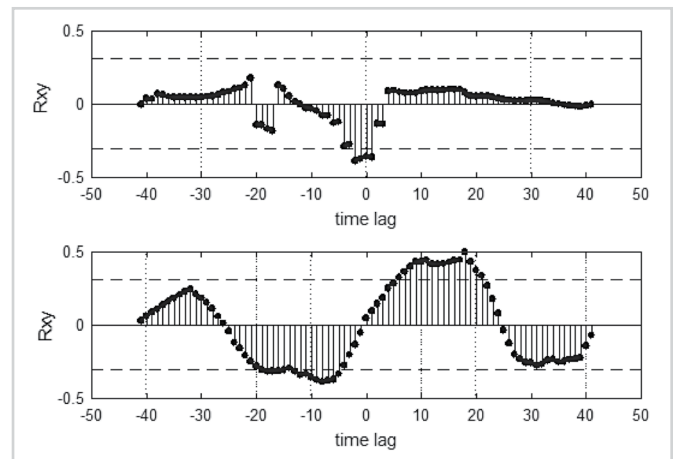Source: Compiled by the author

Fig. 3: **Mutually correlated function of selected indicators for Donetsk region and Kyiv City for the period of July 2014 - December 2017**
Source: Compiled by the author

The adjustment of the matrix of synaptic weights by the gradient descent method is given by the formula:

$$\Delta w_{pq}^h = -\eta \frac{\partial e}{\partial w_{pq}},\qquad(6)$$

where w_{pq}^h is the coefficient of synaptic connection from neuron p of layer $h - 1$ to neuron of layer;

η is the coefficient of learning rate, $0 < \eta < 1$.

Applying the rule for differentiating a complex function and entering a new variable

$$\delta_p^h = \frac{\partial e}{\partial y_p} \cdot \frac{dy_p}{dS_p},$$

where S is the argument of the activation function of the corresponding neuron, allows the expression (6) to be written in a more usual form:

$$\Delta w_{pq}^h = \eta \cdot \delta_q^h \cdot y_p^{h-1}.\qquad(7)$$

The value δ_p^h is calculated according to the recursive formula for each layer h based on the values δ_p^{h+1} of the following layers $h + 1$:

$$\delta_p^h = \left[\sum_r \delta_r^{h+1} \cdot w_{pr}^{h+1} \cdot \frac{dy_p}{dS_p}\right].\qquad(8)$$

As well as individually for the last layer H of the neural network:

$$\delta_p^H = (y_p^H - y_p^*)\frac{dy_p}{dS_p}.\qquad(9)$$

The expanded structure of the neural network for modeling the nonlinear regression dependence between the IDP number and the GRP dynamics is presented in Figures 6-8.

The results of the realised neural network training are shown in Figure 9.

The determination coefficients shown in Figure 6 correspond to the results of each stage of the neural network training: learning ($R = 0.765$), verification ($R = 0.946$), testing ($R = 0.865$), complete sample ($R = 0.773$).

The obtained results indicate a high level of reliability of the obtained model. The constructed neural network makes it possible to describe the existing nonlinear relationship between the indicators by 77%.
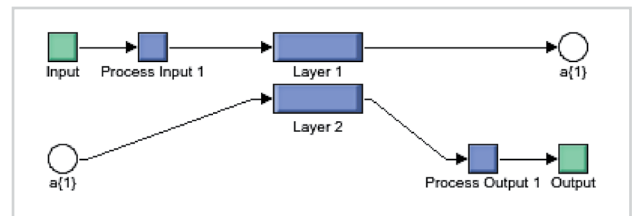

Fig. 4: **Mutually correlated function of selected indicators for Dnipropetrovsk, Poltava and Sumy regions for the period of July 2014 - December 2017**
Source: Compiled by the author

Fig. 6: **The expanded structure of a two-layer neural network, modeling the nonlinear relationship between the investigated indicators**
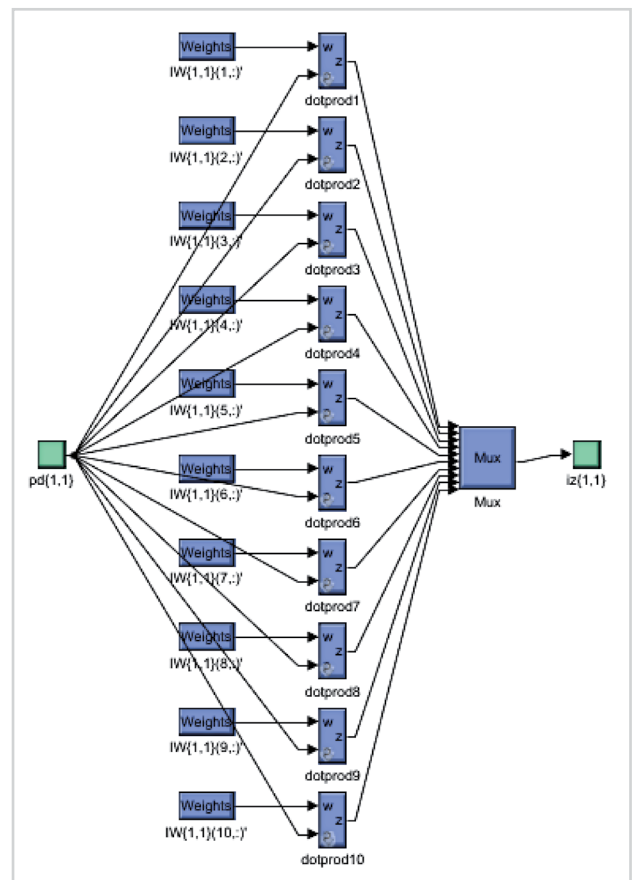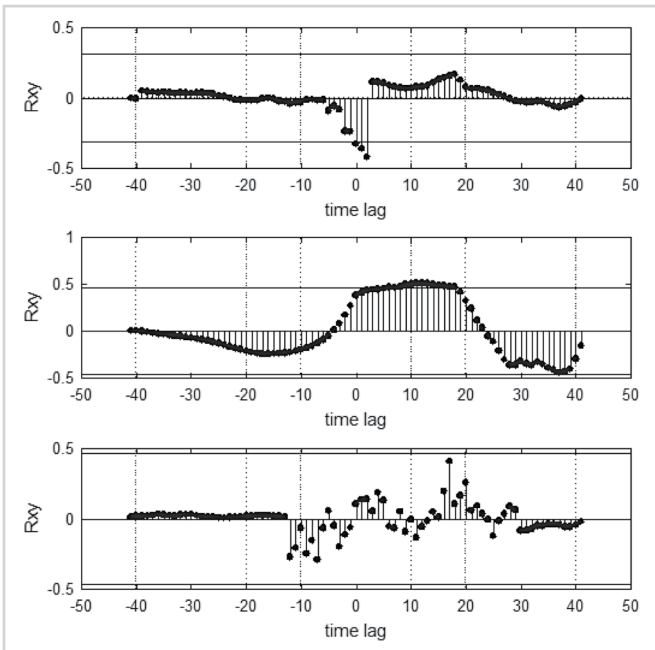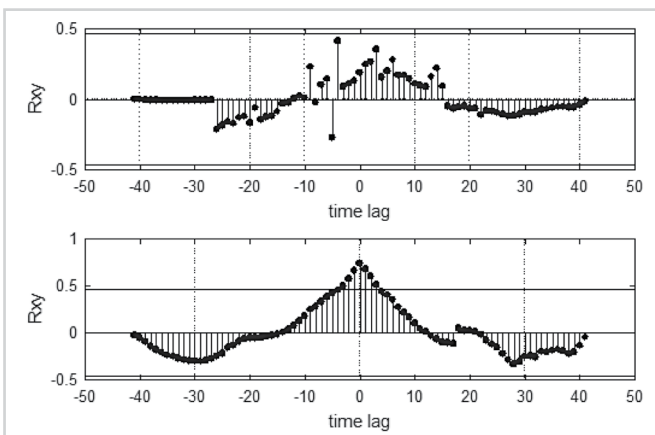Source: Compiled by the author

Fig. 5: **Mutually correlated function of selected indicators for Kyiv and Odessa regions for the period of July 2014 - December 2017**
Source: Compiled by the author

Fig. 7: **The deployed structure of the first layer of the neural network**
Source: Compiled by the author

It is possible to make a forecast for the GRP in 2017 for Dnipropetrovsk region and compare it with the actual data. The results are presented in Table 2.

The average absolute error of the forecast is UAH 1,046.208 million or 2.65%, the average square error is 3.1%. It testifies to the high quality of the obtained nonlinear model.

5. Conclusions

As a result of the study, a neural network that simulates the nonlinear influence of the IDP number on the dynamics of the GRP has been developed. The preliminary analysis of the learning sample has confirmed the assumption of the existence of a certain time lag in the formation of a noticeable effect on the able-bodied population growth in the regions. It is
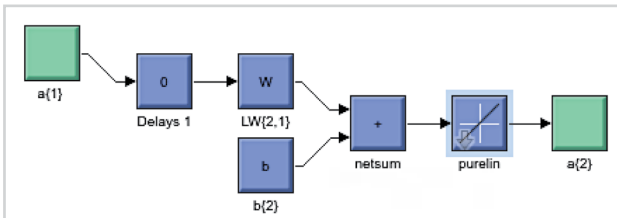

Fig. 8: **The deployed structure of the second layer of the neural network**
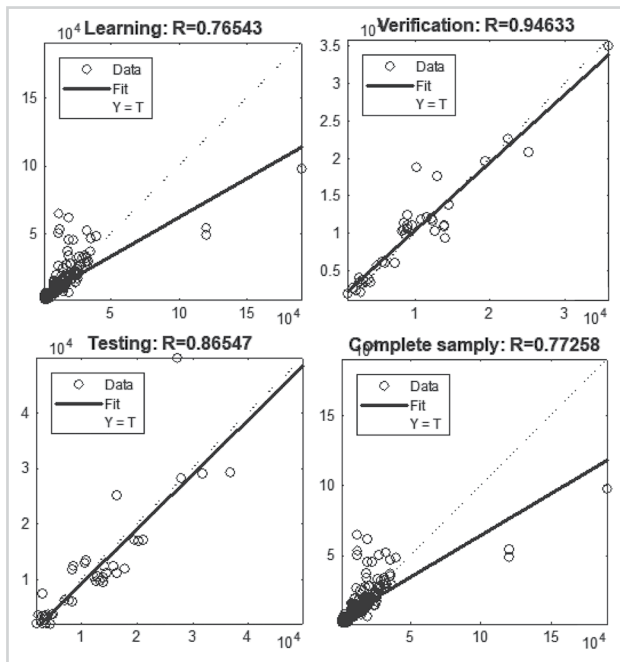Source: Compiled by the author

Fig. 9: **Results of training of the neural network**
Source: Compiled by the author

Tab. 2: **Estimation of the constructed nonlinear model quality**

No	Actual values of GRP, UAH million	Value of GRP, calculated on the basis of the model, UAH million	Absolute deviation, UAH million	Average absolute error	Averaged square error
1	31,874.7	31,056.3	818.4		
2	33,527.9	32,253.6	1,274.3		
3	36,825.5	35,442.0	1,383.5		
4	32,242.8	32,304.5	-61.7		
5	28,969.1	29,912.1	-943		
6	31,770.6	31,022.4	-748.2	1046.208	1184.706
7	31,164.7	32,215.1	-1,050.4		
8	35,816.4	33,948.5	18,67.9		
9	35,427.2	36,429.3	-1,002.1		
10	35,566.5	36,554,3	-987.8		
11	39,580.7	37,453.4	2,127.3		
12	32,346.7	32,056.8	289.9		

Source: Compiled by the author

logical to confirm the conclusion that the magnitude of the effect depends directly on the number of domestic migrants of working age, accounting for an average of 23% of the total. The study of graphs of the mutually correlated function by region allowed justifying the value of the time lag, which shifts the array of explanatory variables along the time axis, on average, into nine periods (three quarters). From the point of view of the socio-economic conditions that IDPs face with, this result is quite expected and indicates a long period of adaptation and identification of migrants in the labour market.

Given the present inertia in the model, its general appearance is as follows:

$$Y_i = f(X_{i-9}, X_{i-8}, ..., X_i).$$

This analytical nonlinear model (4) was implemented on the basis of the NeuroNetwork toolbox of the MatLab package.

In particular, a two-layer neural network with back-propagation error for resolving the issue of nonlinear regression has been developed.

The results of the training of the neural network are: training ($R = 0.765$), verification ($R = 0.946$), testing ($R = 0.865$), complete sample ($R = 0.773$).

The reliability of the estimation of the developed forecast according to the data of 2017 for Dnipropetrovsk region points to the high accuracy of the constructed model: the average absolute error of the forecast is 2.65%, the average square error is 3.1%.

The constructed model can be used for planning and operational assessment of the migrant workforce impact on socio-economic development of regions.

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