

UDC 332.146:316-036.21

**Kuzmenko O.***Doctor of Economics, Professor,  
Head of the Department of Economic Cybernetics,  
Sumy State University, Ukraine;**e-mail: o.kuzmenko@uabs.sumdu.edu.ua; ORCID ID: 0000-0001-8575-5725***Lieonov S.***Doctor of Economics, Professor,  
Director of the Business Processes Department,  
Sumy State University, Ukraine;**e-mail: s.lieonov@uabs.sumdu.edu.ua; ORCID ID: 0000-0001-5639-3008***Kashcha M.***Ph. D. student of the Department of Economic Cybernetics,  
Sumy State University, Ukraine;**e-mail: m.kascha@uabs.sumdu.edu.ua; ORCID ID: 0000-0001-9055-8304***FINANCIAL, ECONOMIC, ENVIRONMENTAL AND SOCIAL DETERMINANTS  
FOR UKRAINIAN REGIONS DIFFERENTIATION  
BY THE VULNERABILITY LEVEL TO COVID-19**

**Abstract.** According to the COVID-19 pandemic, the Ukrainian regions significantly differ in the population's vulnerability to this infection. Specific patterns (combinations) of factors identify the reasons for regional differentiation of morbidity and mortality from COVID-19. They were accumulated over a long period and formed the so-called «retrospective portraits of the region's vulnerability to COVID-19» for each region. The main purpose of the study is to define such combinations of financial, economic, environmental and social factors causing many deaths and morbidity from COVID-19 among the population of different Ukrainian regions. The study is based on a constructed spatial nonlinear model. According to the step-by-step algorithm, individual factor variables are gradually added / removed from the model specifications by the Aitken method depending on their correlation with morbidity and mortality from COVID-19 in the region until the model's specification with the highest adequacy by p-value and t-statistics is formed. The nonlinear multifactorial regression equations regarding the dependence of the resulting indicator (the level of morbidity and mortality of the region from COVID-19) on variables — 23 indicators of social, economic, environmental and financial development of each Ukrainian region and Kyiv are built for the creation of the «retrospective portraits of the region's vulnerability to COVID-19». Besides, the correlation matrices and correlation pleiades are formed. Based on a correlation matrix, the multicollinearity test is performed using the Farrar — Glauber algorithm. The Durbin — Watson method checks residuals for autocorrelation. The heteroskedasticity test is performed using the Spearman rank correlation test. The empirical analysis results show that migration, population size, the environmental situation in the region, a significant index of medical institutions readiness for qualitative patient care during the pandemic and citizens' income dynamics mostly affect the incidence of COVID-19 and the number of deaths. The retrospective research results can help create road maps of individual regions to overcome the future epidemiological influence effects.

**Keywords:** COVID-19, epidemiological threats, retrospective portraits of regional vulnerability to COVID-19, step-by-step nonlinear regression, morbidity, regional morbidity differentiation, pandemic, multicollinearity, heteroskedasticity.

**JEL Classification** C21, C51, C 31, C12, I15, I18, R58, R11

Formulas: 17; fig.: 3; tabl.: 2; bibl.: 36.

**Кузьменко О. В.***доктор економічних наук, професор,  
завідувач кафедри економічної кібернетики,  
Сумський державний університет, Україна;**e-mail: o.kuzmenko@uabs.sumdu.edu.ua; ORCID ID: 0000-0001-8575-5725*

**Леонов С. В.**

доктор економічних наук, професор,  
директор департаменту бізнес-процесів,  
Сумський державний університет, Україна;  
e-mail: s.lieonov@uabs.sumdu.edu.ua; ORCID ID: 0000-0001-5639-3008

**Каца М. О.**

аспірант кафедри економічної кібернетики,  
Сумський державний університет, Україна;  
e-mail: m.kascha@uabs.sumdu.edu.ua; ORCID ID: 0000-0001-9055-8304

## **ФІНАНСОВІ, ЕКОНОМІЧНІ, ЕКОЛОГІЧНІ ТА СОЦІАЛЬНІ ДЕТЕРМІНАНТИ ДИФЕРЕНЦІАЦІЇ РЕГІОНІВ УКРАЇНИ ЗА РІВНЕМ ВРАЗЛИВОСТІ ДО COVID-19**

**Анотація.** Як свідчить перебіг пандемії COVID-19, регіони України суттєво відрізняються за рівнем вразливості населення до цієї інфекції. Причини регіональної диференціації захворюваності та смертності населення від COVID-19 ідентифікуються певними патернами (комбінаціями) факторів, які кумулятивно накопичуються протягом тривалого періоду часу, сформувавши так звані «ретроспективні портрети вразливості регіону до COVID-19» для кожного регіону. Основною метою дослідження є визначення таких комбінацій фінансових, економічних, екологічних і соціальних факторів, які обумовили різну кількість летальних випадків та захворюваності серед населення різних регіонів України від COVID-19. Дослідження здійснено на основі побудованої просторової нелінійної моделі, у якій за ступінчастим алгоритмом окремі факторні змінні додавалися / вилучалися зі специфікацій моделі покроково методом Ейткена залежно від їхньої кореляції з показниками захворюваності та смертності від COVID-19 у регіоні, доти, доки не була сформована специфікація моделі з найвищим рівнем адекватності за  $p$ -значенням і  $t$ -статистикою. Для побудови індивідуальних «ретроспективних портретів вразливості регіону до COVID-19» для кожного регіону побудовані нелінійні багатофакторні регресійні рівняння залежності між результативною ознакою (рівень захворюваності та смертності населення регіону від COVID-19) від змінних — 23 індикаторів соціального, економічного, екологічного та фінансового розвитку кожного регіону України і міста Києва, сформовані кореляційні матриці та побудовано кореляційні плеяди. Перевірку на мультиколінеарність здійснено на основі кореляційної матриці з використанням алгоритму Фаррара — Глобера, перевірку залишків на наявність автокореляції здійснено методом Дарбіна — Уотсона, перевірку на гетероскедастичність здійснено за допомогою тесту рангової кореляції Спірмена. Результати емпіричного аналізу засвідчили, що на рівень захворюваності від COVID-19 і кількість смертельних випадків найбільше впливає показники міграційного руху, кількісний склад населення та екологічна ситуація в регіоні, але також суттєвим є індикатор готовності медичних закладів до якісного обслуговування хворих у період пандемії та динаміка доходів населення. Використання ретроспективних результатів дослідження можуть бути корисними при створенні дорожніх карт окремих регіонів, для подолання наслідків епідеміологічних впливів у майбутньому.

**Ключові слова:** COVID-19, епідеміологічні загрози, ретроспективні портрети вразливості регіонів до COVID-19, покрокова нелінійна регресія, захворюваність, регіональна диференціація захворюваності, пандемія, мультиколінеарність, гетероскедастичність.

Формул: 17; рис. 3; табл.: 2; бібл.: 36.

**Introduction.** As of the end of September, the number of deaths in the world caused by COVID-19 infection reached 1 million (1,006,467). The high effective reproduction coefficient of COVID-19 pandemic (2.5—2.9) shows that the peak of this infection in Ukraine and around the world has not been overcome. This indicator is the main factor in describing any outbreaks of infectious disease and predicting the development of epidemics. When it is greater than 1, the

infection is statistically able to spread among citizens. Under opposite conditions ( $\leq 1$ ), the chain of the virus spread is broken). By comparison, during the first wave of the so-called «Spanish flu» pandemic in 1918, the index was significantly lower (1.7—2.09), but the virus claimed the lives of about 50 million people in the world. These impressive data provoked a rapid and large-scale response from international institutions and governments, which take unprecedented measures, including «non-pharmaceutical intervention», aimed primarily at slowing the spread of COVID-19 or «smoothing the exponential morbidity curve». It means closing schools, banning mass gatherings, and introducing social distancing and travel restrictions on various scales, border closures, etc.

The growing pandemic has not only had an unprecedented impact on human health, but has also caused significant changes in the economic development in all regions. These aspects emphasize the relevance of the study regarding the impact of the current regional features on the vulnerability of the population to COVID-19, in particular — on the infected patients' mortality rate. In Ukraine as of the end of September, the population vulnerability level from infection, i.e. the number of infected / dead people per 100,000 citizens was the highest in Chernivtsi (1586 / 40) and Ternopil regions (1283 / 16), and the smallest — in Kherson (106 / 2) and Poltava (152 / 3) regions. It is particularly relevant to identify financial, economic, environmental and social factors that have accumulated over the years and eventually formed the so-called «retrospective vulnerability portrait of the population from different regions to COVID-19» and at what combinations of these factors this impact will be most statistically significant. Obviously, the incidence and mortality of patients with COVID-19 depend on many factors, namely the medical reform in the region (the active signing of declarations with family doctors determines the speed of diagnosing virus infections and providing qualified care); regional indices of population morbidity (diseases which cause complications in the case of infection with COVID-19, or lead to mortality are of particular importance); the environmental pollution in the region, which determines the severity of the disease and the speed of recovery, given the infection combination with other environmental diseases; the regional economic development, which determines the financial capacity of local medical institutions to provide patients with all necessary procedures, the ability of the local business environment and government to accumulate economic resources to counteract epidemiological threats, etc; the well-being of households in the region, which determines their ability to withstand the «economic burden» of quarantine, etc.

**Literature review and the problem statement.** The worldwide problem caused by the COVID-19 virus has intensified many scientists in various fields. Medical workers and pharmacists are trying to create a quality vaccine; specialists in technical fields are rapidly trying to re-equip buildings into hospitals to treat people. Economists are also looking for causal links between the differentiated spread of the disease and financial, environmental and social determinants, trying to develop recommendations for counteracting the harmful effects of quarantine worldwide to help the world economy overcome the crisis.

Over the past year, the world scientific community carried out fundamental research to find ways to slow the spread of infection. For example, the authors [35] found out that in China, different regions have different levels of health care funding and, as a result — a differentiated regional vulnerability to the epidemic. Researchers [27] developed three scenarios of the country's events, given the quarantine bans in the state. One of the extreme cases is total quarantine, but then there is a risk of growing public discontent and reducing household income and crimes. The abolition of all travel bans increases the risk of the rapid spread of COVID-19 and makes the public health system disable to withstand it. Scientists [25] also paid particular attention to the regional distribution, having built an exponential model regarding the number of seriously ill patients. Researchers [10; 23; 34] looked for a relationship between the speed of virus spread and belonging to a racial/ethnic age group. The work [2] analyzes the European economy losses from the pandemic, which are compared with the costs during the crisis in 2009.

*The environmental* factors and their effects on the economy's overall resilience to systemic crises are analyzed in [16; 18; 31] and others. The work [32] theoretically substantiates that the

regional ecological state is a driving force for the stable growth of the overall nation health [33]; the authors of [12] systematize the theoretical aspects in the analysis of the environment in the regional context; researchers [12] substantiate the green investment impact on regional stability.

*The financial factors* for differentiation of regional vulnerability to systemic crises are studied in [12]. The works [9; 21; 13] consider these issues in terms of the investment policy, and [20; 22] — in terms of financial support of small and medium enterprises affected by quarantine restrictions. [36] emphasizes the need for impact investment in health care as a means of economic recovery in the post-pandemic period. Researchers [1] focus on improving regional planning mechanisms to ensure the region's resilience to pandemic threats; scientists [19] — on the improvement of government regulation mechanisms. The authors [24] proposed a Bass model to predict innovative changes in the region. [17] considers the principles of regions' differentiation by several indicators and step-by-step exclusion of several factors from the final model.

The works [8; 11] investigate the *social factors* for differentiation of regional vulnerability to systemic crises in terms of the social responsibility increase for consequences of actions acquiring particular urgency with the distribution of restrictive quarantine measures; [5] — in terms of «social rules», which are built into the state's institutional structure; in [15] — in terms of inequality among the population. The authors [4] empirically prove the direct relationship between the index of institutional quality of the social sector and the state's health level by regression analysis. The scientists [3] use regression analysis to define the relationship between gross capital accumulation, investment and country's economic growth to overcome poverty and inequality among the population. The study [26] is of special attention too. It examines the risk perception among medical specialists regarding professional activities. They believe that the organizational structure and policies of the medical institution and the state are the most significant danger.

The works [9; 30] define information transparency as the key to quickly overcoming the pandemic consequences, and [30] — the importance of public informing and public opinion consideration. The authors [6] emphasize the crucial role of public confidence in stabilizing economic and social processes in the post-pandemic period.

In [29], authors assess the level of transformations using the bifurcations theory in the state social and economic sphere and the negative influence consequences, including quarantine restrictions.

Based on this, *the purpose of this work* isto find the most essential factors, causing he regional differentiation of morbidity and mortality rates from COVID-19.

**Research results.** The reason for different consequences of the pandemic impact on the Ukrainian regions may include different age structure of the population, population distribution indices by age, health care development level, environmental pollution in the region, economic development, income, migration, etc. A set of parameters is defined to describe each of these areas. They summarize the statistical data for each Ukrainian region and separately Kyiv for 2019-2020 (*Table 1*) [28].

Table 1

### The least of independent variables

	Parameter	Year
Age structure of the population	Population in total, thousand people	2020
	Population aged 0—15, thousand people;	2020
	Population aged 15—64, thousand people	2020
	Population aged 64+, thousand people	2020
Indicators of health system development	Population per one hospital bed, persons	2019
	Number of doctors of all specialties per 10,000 people	2019
	Number of declarations	2019
	Population who signed the declaration, %	2019
Indicators of environmental pollution	Number of pollutant emissions per 1 person, thousand tons	2019
	Emissions from mobile sources of pollution, kg / person	2019
	Investments in environmental protection, thousand UAH	2019
The level of economic development in the region	Gross regional product per 1 person	2019

Table 1 (continued)

	Parameter	Year
Incomes of the population	Incomes, UAH million	2020
	Disposable income of households, UAH million	2020
	Household expenditures, mln.	2020
	Wage arrears, thousand UAH	2020
	% to debt	2020
	Average monthly salary, UAH	2020
	The level of population participation in the labor force	2020
Migration movement of the population	Migration growth (all flows)	2019
	Migration growth (interstate migration)	2019
	Number of comers	2020
	Number of leaving people	2020

We use the following indices as target parameters of the nonlinear spatial model with step-by-step exclusion to identify the factors affecting the regional vulnerability to the effects of a pandemic:

- 1) The level of morbidity from COVID-19 of each Ukrainian region from the beginning to the moment of calculations (05.03.2020—05.09.2020) [7];
- 2) The number of deaths caused by the COVID-19 virus (05.03.2020-05.09.2020) [7].

It is necessary to conduct a preliminary analysis of the data to avoid factors that affect the resulting variable for constructing a multiple regression model through the least square method (LSM) (1):

$$y = a_0 + a_1x_1 + a_2x_2 + \dots + a_{23}x_{23}. \tag{1}$$

Taking quite a few indicators and from one group of data, we test the hypothesis for the presence of a linear correlation between several independent variables — multicollinearity. The greater the number of variables, the more detailed the study of this problem. Therefore, we apply the Farrar — Glauber algorithm for input data at three levels:

- a) the multicollinearity in the whole data set is checked using the  $\chi$ -square criterion;
- b) the linear correlation of each independent variable with the rest variables — using Fisher’s test;
- c) the paired multicollinearity — using Student’s t-test.

First, it is necessary to normalize the data:

$$x_{ij}^* = \frac{x_{ij} - \bar{x}_j}{\sigma_{xj}}, \tag{2}$$

where  $x_{ij}^*$  — normalized value of each variable;  $\bar{x}_j$  — the average value of the variable,  $\sigma_{xj}$  — standard deviation,  $i = 1..25$  — number of regions and Kyiv,  $j = 1..23$  — number of independent variables.

We construct a correlation matrix of even coefficients:

$$r^* = X^{*T} \cdot X^*, \tag{3}$$

where  $X^*$  — a matrix of normalized values of independent variables formed by the formula (2);  $X^{*T}$  — the matrix transposed to  $X^*$ .

We calculate the critical value of the criterion  $\chi$ -square (5), at the significance level of 95% and number of the freedom degrees  $v$ , if  $m = 23$ ,  $n = 25$  (4):

$$v = \frac{1}{2}(m - 1)m = 253, \tag{4}$$

$$\chi_{tab}^2(0,05; 253) = 217. \tag{5}$$

The empirical value of the  $\chi$ -square is found by the formula:

$$\chi_{emp}^2 = - \left[ n - 1 - \frac{1}{6}(2m + 5) \right] \ln(\Delta r^*). \tag{6}$$

The result  $\chi_{emp}^2 = 6488$  exceeds the critical value that confirms the multicollinearity hypothesis in the input data set.

The next step is to find the correlation for each variable. For this purpose, we see the matrix  $C$  inversed to the correlation matrix of even coefficients  $r^*$ . For each diagonal element  $c_{jj}$  in this matrix, we see the empirical Fisher's criterion value, which will enable to confirm or refute the hypothesis regarding the multicollinearity of the studied indicator with others:

$$F_{jemp} = (c_{jj} - 1) \frac{n-m}{m-1}. \quad (7)$$

The critical value of  $F_{tab}(0.95; 2; 22)$  is 0.05. Each Fisher criterion value exceeds the tabular one, so there is a linearly correlated variable for each independent variable.

So, we calculate even correlation coefficients, which will indicate the relationship density between two independent variables:

$$r_{kj} = \frac{-c_{kj}}{\sqrt{c_{kk} \cdot c_{jj}}}. \quad (8)$$

Having the results of paired correlation coefficients (8), we calculate the practical values of Student's  $t$ -criteria

$$t_{kj} = \frac{r_{kj} \sqrt{n-m}}{\sqrt{1-r_{kj}^2}}. \quad (9)$$

At the final stage of multicollinearity determination by the Farrar-Glauber method, we compare the obtained coefficients with the critical value  $t(0,95; 25 - 23) = 0.07$ . If the hypothesis of the multicollinearity by the indicator  $r_{kj}$  is confirmed, there is a linear correlation between the  $k$  and  $j$  factors, affecting the dependent variable almost equally. Having found the multicollinearity, we remove from the study such indicators as household expenditures, population in total, the population aged 0—15, the population aged 15—64, disposable income, number of leaving people and the average monthly salary in the regions of Ukraine. Thus, we reduce the number of indicators from 23 (1) to  $m = 16$  (10):

$$y = a_0 + a_1x_1 + a_2x_2 + \dots + a_{16}x_{16}. \quad (10)$$

We construct an input data matrix to calculate the coefficients of the multiple regression model:

$$X = \begin{pmatrix} 1 & x_{1,1} & \dots & x_{1,16} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_{25,1} & \dots & x_{25,16} \end{pmatrix}, Y = \begin{pmatrix} y_1 \\ \dots \\ y_{25} \end{pmatrix}, X^t = \begin{pmatrix} 1 & \dots & 1 \\ x_{1,1} & \dots & x_{16,1} \\ \vdots & \ddots & \vdots \\ x_{1,25} & \dots & x_{16,25} \end{pmatrix}.$$

Matrix  $X$  is a dimension matrix of  $25 \cdot 17$ , formed by the values of 16 independent variables in 24 regions and Kyiv, supplemented by a column of units to obtain a free member in the model. The matrix  $Y$  is a column-matrix of dimension  $25 \cdot 1$ , which consists of empirical values of the objective function, in our case — the number of deaths by region. The matrix  $X^t$  — dimension  $17 \cdot 25$  is obtained by transposing the input matrix  $X$ .

We perform the actions on the matrices to obtain the regression model coefficients (10):

$$A = (X^t X)^{-1} \cdot X^t \cdot Y = \begin{pmatrix} a_0 \\ \dots \\ a_{16} \end{pmatrix}. \quad (11)$$

Having performed a preliminary analysis of the linear regression model, we obtain a satisfactory result in terms of its quality: the coefficient of determination is 0.68, and the actual value of the Fisher criterion is 1.09 that is less than in the *Table 2*. So, the regression equation is not statistically reliable, and the coefficients may not be significant. Each step, excluding the least significant factor, will significantly worsen the adequacy situation. For further study, we will use a nonlinear regression model.

Table 2

**The result of a nonlinear regression model, with the number of independent variables  $n = 16$**

	$a_i$	$\epsilon_i$	$t$	$P$
$a_0$	1,863	44,702	0,042	0,968
$a_1$ Population aged 64+	-2,906	3,812	-0,762	0,468
$a_2$ Population per one hospital bed	1,691	2,771	0,610	0,559
$a_3$ Number of doctors of all specialties	0,435	1,301	0,334	0,747
$a_4$ Number of declarations	1,236	3,275	0,377	0,716
$a_5$ % of the signed declarations	0,572	3,581	0,160	0,877
$a_6$ Number of pollutant emissions per 1 person, thousand tons	-0,094	0,310	-0,304	0,769
$a_7$ Emissions from mobile sources of pollution	-2,814	2,035	-1,383	0,204
$a_8$ Investments in environmental protection	-0,003	0,263	-0,010	0,992
$a_9$ GRP	0,663	2,738	0,242	0,815
$a_{10}$ Incomes	1,226	2,225	0,551	0,597
$a_{11}$ Wage arrears	-0,215	0,270	-0,794	0,450
$a_{12}$ % to debt	0,927	3,193	0,290	0,779
$a_{13}$ The level of population participation in the labor force	0,603	9,466	0,064	0,951
$a_{14}$ Migration growth (all flows)	-0,094	0,300	-0,315	0,761
$a_{15}$ Migration growth (interstate migration)	0,183	0,238	0,768	0,464
$a_{16}$ Number of comers	1,226	1,161	1,057	0,321

Logarithmization is impossible since such data as migration peculiarities are negative. In our opinion, one of the ways to take the value by the module is not appropriate since the difference between population growth and reduction is leveled. We determine the smallest value and add it to all data:

$$\ln y = a_0 + a_1 \ln x_1 + a_2 \ln x_2 + \dots + a_{16} \ln x_{16}. \tag{12}$$

We repeat the previous step of calculations, but for the new data received by logarithmization. We build a model for the first dependent indicator «Mortality from COVID-19 by the Ukrainian regions». The initial review of the results shows a large value of the determination coefficient:  $R^2 = 0,8867$ ; Fisher’s test  $F = 3.91 > F_{tab} (0.05; 16; 8) = 3.2$ . It means that the determination coefficient is statistically significant, and indeed there is a relationship between the dependent variable and 16 independent variables.

Having analyzed the results of the constructed logarithmic model, we can see that although there are good indicators of sufficiency and significance, most of them have a high estimate of the coefficient difference from zero ( $P$ -value). On the contrary, the value of  $t$ -statistics goes to zero. It means that the independent variable has almost no effect on the dependent variable (see Table 2). Therefore, we consider the most influential values, observing the  $t$ -statistics and  $P$ -values:

Indicators «Population participation in the labor force (15—70 years)» and «Capital investment in environmental protection» show the lowest level of impact on the number of deaths among the population from COVID-19, so we reject them from the total indices. In the same way, we gradually remove such parameters as the number of doctors of all specialties; % of the population who signed the declaration; the number of pollutant emissions per person; gross regional product; % to debt; migration growth (all flows); migration growth (interstate migration); wage arrears; population per hospital bed. We remain five factors that show the most significant importance, according to the preliminary result.

As a result of constructing a nonlinear logarithmic model, the following factors determining the regional differentiation of the death number ( $S$ ) from COVID-19 among the population include:

- 1) Population over the age of 64 ( $P$ );
- 2) Number of declarations signed by citizens with family doctors ( $D$ );
- 3) Emissions of pollutants into the atmosphere from mobile sources of pollution ( $E$ );
- 4) Household income ( $I$ );
- 5) Number of comers in the region ( $M$ ):

$$\ln S = -3,82 \ln P + 1,76 \ln D - 2,19 \ln E + 1,59 \ln I + 0,97 \ln M + 32,98. \tag{13}$$

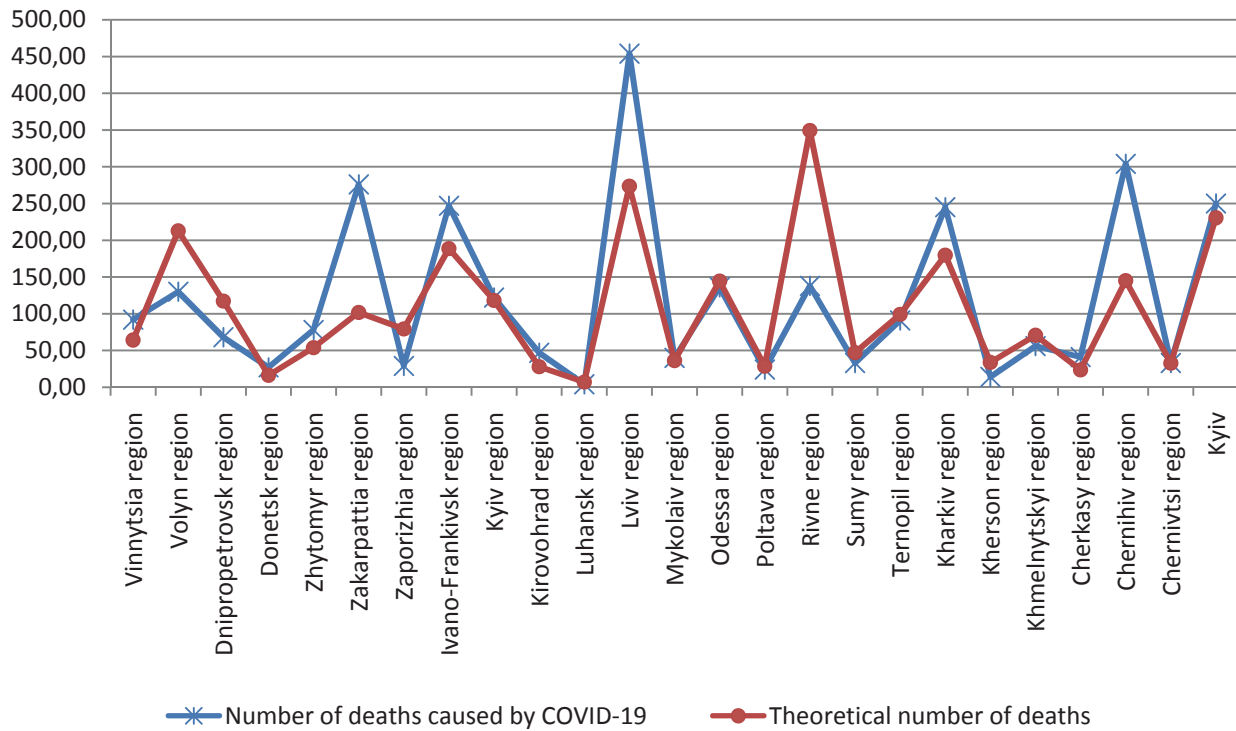


Fig. 1. Comparison of experimental data with the theoretical number of deaths caused by COVID-19

First, we check the significance of the model:

1) Determination coefficient 0.76, which indicates a strong relationship between the dependent and independent variables.

2) The actual value of the Fisher index  $F = 12.68$  is greater than the critical  $F_{kr}(0.05; 5; 19) = 2.74$ . So, the regression equation is statistically significant; the constructed model is relevant.

Thus, analyzing the obtained result (13), we can see a positive relationship between the number of deaths among the population from COVID-19 ( $S$ ) and the number of declarations signed by the citizens with family doctors ( $D$ ), household income ( $I$ ) and the number of comers to the region ( $M$ ). Conversely, there is a negative correlation with the volume of pollutant emissions into the atmosphere from mobile sources of pollution ( $E$ ) and the population aged 64+ ( $P$ ). We can conclude that the popular myth in society that the elderly come through the illness harder and the higher the percentage of the population aged 64+, the higher the mortality rate, has not been statistically confirmed. There is also an indicator of the regional ecological state (the amount of emissions from mobile sources), which is negatively correlated with the resulting variable. Such assumption as the more emissions, the lower mortality is illogical in this case. Thus, we can conclude that these factors are not interconnected. Variables that need attention and really affect the mortality rate include household income, the number of comers to the region and the active signing of declarations with family doctors by the population.

An essential step in validating the model is to verify the absence of the relationship between random deviations and residuals in other observations, i.e., the autocorrelation. We apply the Darbin — Watson test to check it (14):

$$DW = \frac{\sum(e_i - e_{i-1})^2}{\sum e_i^2}, \tag{14}$$

where  $e_i$  — difference between theoretical and empirical level of  $i$  observation. After the calculation, we receive  $DW = 2,27$ . The critical values of this criterion for the significance level  $\alpha = 0,05, n = 25, m = 5$  are  $d_1 = 0,95, d_2 = 1,89$ . The obtained result lies outside the critical values



that confirms the autocorrelation of the residuals. Given that we do not have a dynamic model, but a spatial one, we can neglect a little autocorrelation.

We analyze the graphs of the residuals dependence  $e$  on the variables included in the final model (Fig. 2) to define the presence or absence of heteroskedasticity. There is no linear relationship between the residuals and each indicator, so we presuppose that there is no heteroskedasticity in the model.

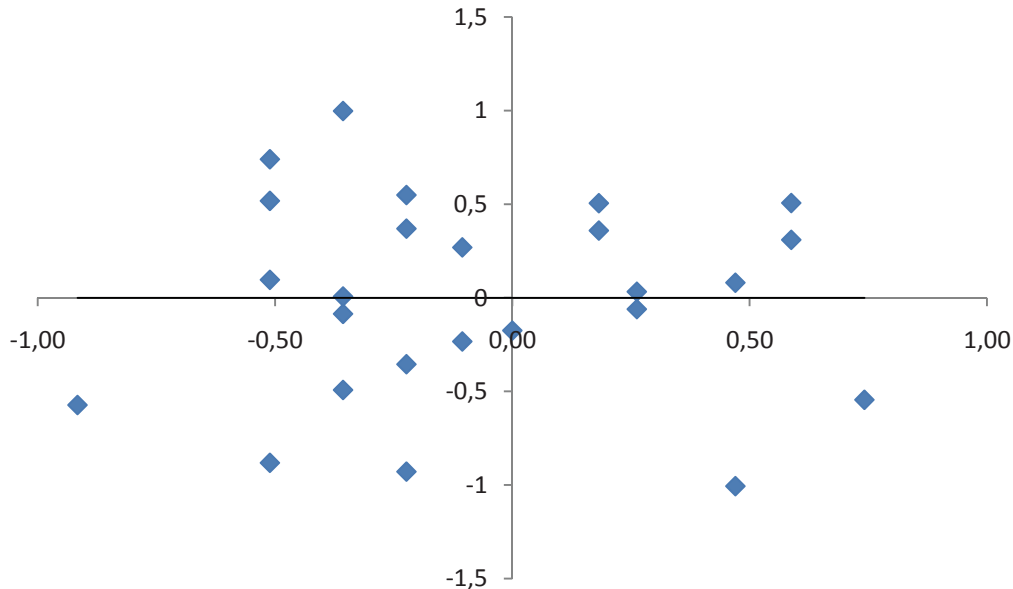


Fig. 2. Number of declarations signed with family doctors, residual plot

We use the Spearman’s test to verify the hypothesis. First, we rank the residuals ( $e_i$ ) and variables ( $x_i$ ). We will check each one separately since there are several variables in the model. Then we find the even coefficients of rank correlation (6):

$$r_i = 1 - 6 \frac{\sum d_i^2}{(n^2 - 1)n}, \tag{15}$$

where  $d_i$  — difference between the ranks of each level,  $n = 25$  — number of observations.

We will check the results through the Student’s test (16):

$$t = \frac{r_i \sqrt{n-2}}{\sqrt{1-r_i^2}}, t_{kp}(0,05; 23) = 2,07. \tag{16}$$

All values from the Student’s test are higher than the critical one — the rank correlation is insignificant, so the hypothesis regarding the absence of heteroskedasticity in the model is accepted.

The above technique helps us repeat the reasoning for another dependent variable:  $Y$  — the number of infected by COVID-19 from the beginning of the epidemic to the time of calculations (05.09.2020). For this factor indicating the vulnerability of the region to the spread of the virus, the most influential indicators include the number of comers to the region ( $M$ ), % of wage arrears ( $W$ ), air pollutant emissions from mobile sources by region ( $E$ ), number of doctors of all specialties by regions per 10,000 people ( $L$ ), the population aged 64+ ( $D$ ):

$$\ln Y = -1,6 \ln D + 2,3 \ln L - 1,3 \ln E + 2,4 \ln W + 1,6 \ln M - 1,2. \tag{17}$$

We check the significance of the model:

1) Determination coefficient 0.76, which indicates a strong relationship between the dependent and independent variables.

2) The actual value of Fisher’s index  $F = 12.12$  is greater than the critical  $F_{kr}(0.05; 5; 19) = 2.74$ , so the regression equation is statistically significant; the constructed model is relevant.

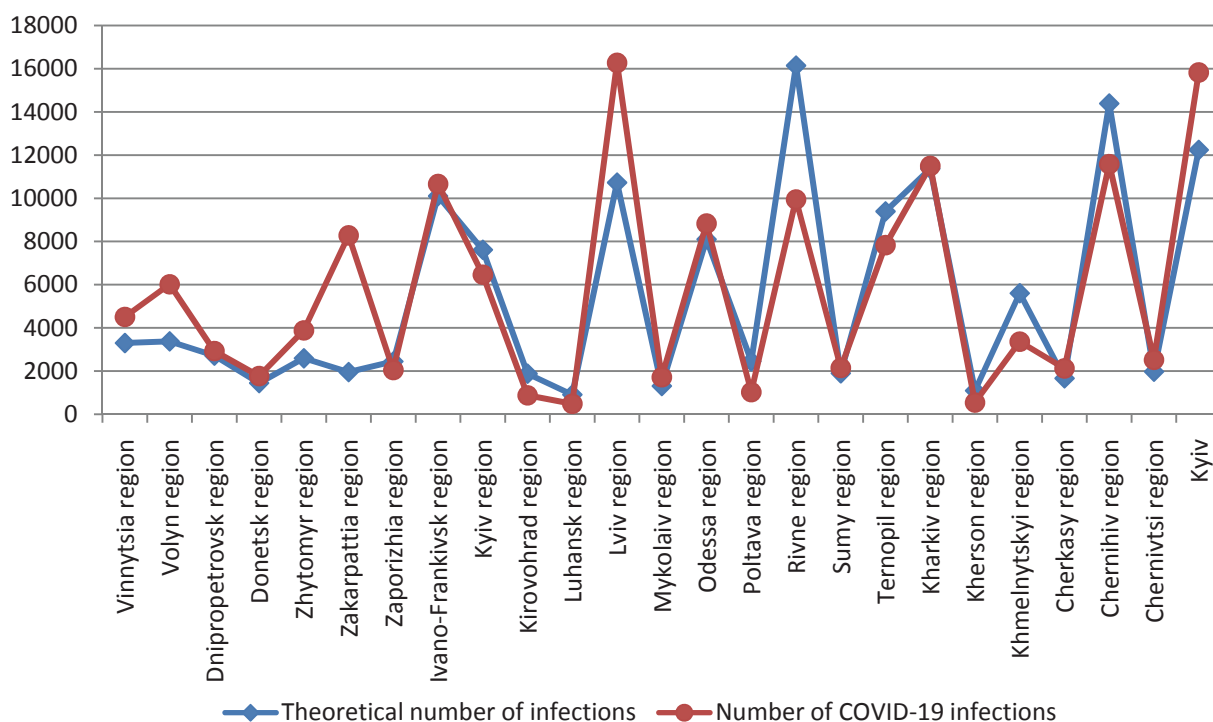


Fig. 3. Comparison of experimental data with the theoretical number of COVID-19 infections

Analyzing the obtained result (17), we can see a direct relationship between the number of infections from COVID-19 among the population from the beginning of the pandemic ( $Y$ ) and the number of doctors of all specialties by region per 10,000 people ( $L$ ), % to wage arrears ( $W$ ) and the number of comers to the region ( $M$ ). On the contrary, the negative correlation is similar to the previous one — the volume of pollutant emissions into the atmosphere from mobile sources of pollution ( $E$ ) and the population aged 64+ ( $P$ ). Thus, the readiness of medical institutions to respond to the pandemic, the general level of citizens’ welfare and perhaps, most importantly, the migration movement, affect the differentiated vulnerability of the Ukrainian region to COVID-19. Therefore, we believe that the introduction of restrictive quarantine measures helps slow down the spread of infection, and the country’s division into four zones can reduce the negative impact on the country’s economy.

**Conclusion.** Thus, the financial, environmental, social and economic determinants that differentiate regions in terms of their vulnerability to COVID-19 indicate that the most crucial factor is the migration dynamics, directly related to the number of deaths and the incidence rate. Therefore, we believe that introducing restrictive quarantine measures, considering the regional differentiation, really helps slow down the spread of infection and minimize losses in the economic sector. The ecological situation in the region (for example, the volume of pollutants into the atmosphere from mobile sources of pollution), the medical institutions’ readiness, and citizens’ incomes influence regions’ vulnerability to coronavirus infection. The study results can be useful in creating road maps of any region to overcome the consequences of epidemiological effects. The current Economic Incentive Program to overcome the impact of COVID-19 provides the use of «adaptive quarantine». Its mechanism is based on the principle of «Post Factum», i.e., relates to the number of infected and dead people from COVID-19. At the same time, the Government and local governments need a scientifically sound and statistically proven foundation to respond to Ante Factum, based on combinations of many factors formed in each region, which will be either catalysts or inhibitors of the subsequent epidemics. It will enable to make appropriate adjustments in advance to the national and regional programs to mobilize the economy and medical system to carry out reactive and preventive regulation. With the emergence of new parameters and changing trends, it lets to adjust the quarantine measures trajectory diversified without stopping the economy in all regions, to apply restrictive steps in priority order. Targeted introduction of certain quarantine restrictions will reduce economic losses and social risks. A systematic review of the structural

relationships of the financial, economic, environmental and social factors will identify patterns of parameters that determine risk groups for future epidemiological challenges. It creates a basis to prioritize initiatives of the Ministry of Health and regional health departments to establish a list of diseases that in the host region, in combination with COVID-19, increase the risk of infection or mortality. Besides, it provides for the Ministry of Infrastructure of Ukraine to make prompt and targeted decisions to limit the population's movement in case of a second pandemic wave and adjust government programs stimulating the creation of the new jobs in the relevant regions. Consideration of many regional economic parameters and their connection with the vulnerability level of the population to COVID-19 in the first pandemic wave will enable the Ministry of Community and Territorial Development of Ukraine to adjust sectoral and functional support initiatives to increase financial and economic self-sufficiency.

**Acknowledgements and research funding.** This article was prepared within the project «Economic and mathematical modeling and forecasting the impact of COVID-19 on Ukraine's development in national and regional contexts: public health factors and socio-ecological and economic determinants», implemented with the financial support of the National Research Fund of Ukraine.

#### Література

1. Abdalla M. The Role Of Regional Planning In Achieving Economic Development And Social Justice In Sudan. *SocioEconomic Challenges*. 2018. Vol. 4. № 2. P. 101—113.
2. Albert E., Boutelet C., Piquer I., Hivert A. F., Bonnel O. Comment l'Europe tentedesaivers on économie. *LeMonde*. 2020.
3. AUgbaka M., Awujola A., Shcherbyna T. Economic Development, Foreign Aid and Poverty Reduction: Paradigm in Nigeria. *SocioEconomic Challenges*. 2019. Vol. 3. № 4. P. 5—12.
4. Bagmet K. V., Haponova O. Assessing the Impacton Social Sector: A Macroeconomic Approach. *Socio Economic Challenges*. 2018. Vol. 3. № 2. P. 103—108.
5. Bilan Yu., Vasilyeva T., Lyeonov S., Bagmet K. Institutional complementarity for social and economic development. *Business: Theory and Practice*. 2019. Vol. 20. P. 103—115.
6. Brychko M., Kuzmenko O., Polách J., Olejarz T. Trust cycle of the finance sector and its determinants: The case of Ukraine. *Journal of International Studies*. 2019. Vol. 12. № 4. P. 300—324.
7. Центр медичної статистики МОЗ України. Статистичні дані. 2009. URL : <http://medstat.gov.ua/ukr/main.html>.
8. Dave H. The X-ray report of «Economic growth». *Financial Markets, Institutions and Risks*. 2019. Vol. 3. № 4. P. 89—93.
9. Dutta P., Dutta U., Hasan S., Sarkar N., Sana T. Educate, Empower And Protect People Through Timely Authentic Information: Explore How Bangladesh Newspapers Response To COVID-19 Pandemic. *Socio Economic Challenges*. 2020. Vol. 4. № 3. P. 94—104.
10. Faust S. N., Munro A. P. S. It's Time to Put Children and Young People First During the Global COVID-19 Pandemic. *JAMA Pediatr*. 2020. September 25.
11. Harafonova O., Zhosan G., Akimova L. The substantiation of the strategy of social responsibility of the enterprise with the aim of providing efficiency of its activities. *Marketing and Management of Innovations*. 2017. Vol. 3. P. 267—279.
12. Hasan S., Dutta P. Coverage of Environmental Issues in Local Dailies of Chattogram Centering World Environment Day. *Socio Economic Challenges*. 2019. Vol. 3. № 4. P. 63—71.
13. Hrytsenko L., Roienko V., Boiarko I. Institutional background of the role of state in investment processes activation. *Financial And Credit Activity: Problems Of Theory And Practice*. 2018. Vol. 1. № 24. P. 338—344.
14. Ibragimov Z., Lyeonov S., Pimonenko T. Green investing for SDGS: EU experience for developing countries. *Economic and Social Development: Book of Proceedings*. 37th International Scientific Conference on Economic and Social Development «SocioEconomic Problems of Sustainable Development». 2019. Vol. 37. P. 868—877.
15. Jafarzadeh E., Shuquan He. The Impact of Income Inequality on the Economic Growth of Iran: An Empirical Analysis. *Business Ethics and Leadership*. 2019. Vol. 3. № 2. P. 53—62.
16. Kashyap G. C., Puri P., Singh S. K. Respiratory Health Upshots due to Contaminated Living Environment: A Cross-Sectional Study of the Industrial Belt of Kanpur City, India. *Socio Economic Challenges*. 2020. Vol. 4. № 1. P. 17—27.
17. Kaya H. D. The Efficiency of the Financial System: A Comparison of Developed and Less Developed Countries. *Financial Markets, Institutions and Risks*. 2020. Vol. 4. № 2. P. 16—24.
18. Lyeonov S., Pimonenko T., Bilan Yu., Streimikiene D., Mentel G. Assessment of Green Investments' Impact on Sustainable Development: Linking Gross Domestic Product Per Capita. *Greenhouse Gas Emissions and Renewable Energy*. 2019. Vol. 12. P. 1—12.
19. Levchenko V., Boyko A., Bozhenko V., Savchenko T., Humenna Y., Pilin R. State regulation of the economic security by applying the neoteric approach to its assessment. *Marketing and Management of Innovations*. 2019. Vol. 4. P. 364—372.
20. Musa H., Musova Z., Sliacky P. Financial Support to Small and Medium-Sized Enterprises in Slovakia. *Financial Markets, Institutions and Risks*. 2017. Vol. 1. № 4. P. 47—52.
21. Marcel D. T. Am. Impact of the Foreign Direct Investment on Economic growth on the Republic of Benin. *Financial Markets, Institutions and Risks*. 2019. Vol. 3. № 2. P. 69—78.
22. Masharsky A., Azarenkova G., Oryekhova K. Anti-crisis financial management on energy enterprises as a precondition of innovative conversion of the energy industry: case of Ukraine. *Marketing and Management of Innovations*. 2018. Vol. 3. P. 345—354.

23. Moore J. T., Ricaldi J. N., Rose C. E. (et al.). Hone in Disparities in Incidence of COVID-19 Among Underrepresented Racial, Ethnic Groups in Counties Identified as Hotspots. *Ethnic Groups in Counties Identified as Hotspots*. 2020. Vol. 69. № 33. P. 1122—1126.
24. Oliinyk V., Wiebe I., Syniavska O., Yatsenko V. Optimization model of Bass. *Journal of Applied Economic Sciences*. 2018. Vol. 8. № 62. P. 2168—2183.
25. Papo D., Righetti M., Fadiga L., Biscarini F., Zanin M. A minimal model of hospital patients' dynamics in COVID-19. *Chaos Solitons and Fractals*. 2020. Vol. 140. P. 1—6.
26. Rajan D. Personal and Social Perception of Occupational Hazards by Health Care Workers: A Study among Radiographers. *Business Ethics and Leadership*. 2018. Vol. 2. № 4. P. 46—63.
27. Shammi M., Bodrud-Doza M., Islam A., Rahman M. M. Strategic assessment of COVID-19 pandemic in Bangladesh: comparative lockdown scenario analysis, public perception, and management for sustainability. *Environment Development and Sustainability*. 2020. Vol. 7. P. 1—44.
28. Державна служба статистики України. Статистичні дані. URL : <http://ukrstat.gov.ua>.
29. Vasilyeva T., Kuzmenko O., Bozhenko V., Kolotilina O. Assessment of the Dynamics of Bifurcation Transformations in the Economy. *Modeling & Management of Emergent Economy*. 2019. M3E2. P. 134—146.
30. Vasilieva T., Leonov S., Makarenko I., Sirkovska N. Sustainability information disclosure as an instrument of marketing communication with stakeholders: markets, social and economic aspects. *Marketing and Management of Innovations*. 2017. Vol. 4. P. 350—357.
31. Vasylieva T., Vorontsova A., Bilan Yu., Ostasz G., Mayboroda T. The influence of state regulation of education for achieving the sustainable development goals: case study of Central and Eastern European countries. *Administratives Management Public*. 2020. Vol. 34. P. 6—26.
32. Vasilyeva T., Mentel G., Samusevych Ya., Pryymenko S. Regional differentiation of electricity prices: social-equitable approach. *International Journal of Environmental Technology and Management*. 2018. № 21. P. 354—372.
33. Vasylieva T., Lyeonov S., Lyulyov O., Kyrychenko K. Macroeconomic Stability and Its Impact on the Economic Growth of the Country. *Montenegrin Journal of Economics*. 2018. Vol. 14. № 1. P. 159—170.
34. Viner R. M., Mytton O. T., Bonell C. (et al.). Susceptibility to SARS-CoV-2 Infection Among Children and Adolescents Compared With Adults: A Systematic Review and Meta-analysis. *JAMA Pediatr*. 2020. September 25.
35. Yunpeng J., Zhongren M., Maikel P., Qiuwei P. Potential association between COVID-19 mortality and health-care resource availability. *The Lancet Global Health*. 2020. Vol. 8. P. 480—481.
36. Yelnikova J., Kwilinski A. Impact-Investing in The Healthcare in Terms of the New Socially Responsible State Investment Policy. *Business Ethics and Leadership*. Vol. 4. № 3. P. 57—64.

Статтю рекомендовано до друку 31.08.2020

© Кузьменко О. В., Леонов С. В., Кауца М. О.

#### References

1. Abdalla, M. (2018). The Role Of Regional Planning In Achieving Economic Development And Social Justice In Sudan. *Socio Economic Challenges*, 4 (2), 101—113. doi:10.21272/sec.2(4).101-113.2018.
2. Albert, E., Boutelet, C., Piquer, I., Hivert, A. F., & Bonnel, O. (2020). Comment l'Europe tente de sauver son économie. *Le Monde*. Retrieved from [https://www.lemonde.fr/economie/article/2020/08/31/comment-l-europe-tente-de-sauver-son-economie\\_6050464\\_3234.html](https://www.lemonde.fr/economie/article/2020/08/31/comment-l-europe-tente-de-sauver-son-economie_6050464_3234.html).
3. AUgbaka, M., Awujola, A., & Shcherbyna, T. (2019). Economic Development, Foreign Aid and Poverty Reduction: Paradigm in Nigeria. *Socio Economic Challenges*, 3 (4), 5—12. doi:10.21272/sec.3(4).5-12.2019.
4. Bagmet, K. V., & Haponova, O. (2018). Assessing the Impact on Social Sector: A Macroeconomic Approach. *Socio Economic Challenges*, 3 (2), 103—108. doi:10.21272/sec.3(2).103-108.2018.
5. Bilan, Yu., Vasilyeva, T., Lyeonov, S., & Bagmet, K. (2019). Institutional complementarity for social and economic development. *Business: Theory and Practice*, 20, 103—115. doi:10.3846/btp.2019.10.
6. Brychko, M., Kuzmenko, O., Polách J., & Olejarz, T. (2019). Trust cycle of the finance sector and its determinants: The case of Ukraine. *Journal of International Studies*, 12 (4), 300—324. doi:10.14254/2071-8330.2019/12-4/20.
7. Tsentri medychnoi statystyky MOZ Ukrainy. (2009). *Statystychni dani [Statistics]*. Retrieved from <http://medstat.gov.ua/ukr/main.html>.
8. Dave, H. (2019). The X-ray report of «Economic growth». *Financial Markets, Institutions and Risks*, 3 (4), 89—93. doi:10.21272/fmir.3(4).89-93.2019.
9. Dutta, P., Dutta, U., Hasan, S., Sarkar, N., & Sana, T. (2020). Educate, Empower And Protect People Through Timely Authentic Information: Explore How Bangladesh Newspapers Response To COVID-19 Pandemic. *Socio Economic Challenges*, 4 (3), 94—104. doi:10.21272/sec.1(3).94-104.2020.
10. Faust, S. N., & Munro, A. P. S. (2020, September 25). It's Time to Put Children and Young People First During the Global COVID-19 Pandemic. *JAMA Pediatr*. doi:10.1001/jamapediatrics.2020.4582.
11. Harafonova, O., Zhosan, G., & Akimova, L. (2017). The substantiation of the strategy of social responsibility of the enterprise with the aim of providing efficiency of its activities. *Marketing and Management of Innovations*, Vol. 3, 267—279. doi:10.21272/mmi.2017.3-25.
12. Hasan, S., & Dutta, P. (2019). Coverage of Environmental Issues in Local Dailies of Chattogram Centering World Environment Day. *SocioEconomic Challenges*, 3 (4), 63—71. doi:10.21272/sec.3(4).63-71.2019.
13. Hrytsenko, L., Roienko, V., & Boiarko, I. (2018). Institutional background of the role of state in investment processes activation. *Financial And Credit Activity: Problems Of Theory And Practice*, 1 (24), 338—344. doi:10.18371/fcaptop.v1i24.128465.
14. Ibragimov, Z., Lyeonov, S., & Pimonenko, T. (2019). Green investing for SDGS : EU experience for developing countries. *Economic and Social Development: Book of Proceedings*, 37th International Scientific Conference on Economic and Social Development «SocioEconomic Problems of Sustainable Development», 868—877.
15. Jafarzadeh, E., & Shuquan, He. (2019). The Impact of Income Inequality on the Economic Growth of Iran: An Empirical Analysis. *Business Ethics and Leadership*, 3 (2), 53—62. [http://doi.org/10.21272/bel.3\(2\).53-62.2019](http://doi.org/10.21272/bel.3(2).53-62.2019).

16. Kashyap, G. C., Puri, P., & Singh, S. K. (2020). Respiratory Health Upshots due to Contaminated Living Environment: A Cross-Sectional Study of the Industrial Belt of Kanpur City, India. *Socio Economic Challenges*, 4 (1), 17—27. doi:10.3139/124.110800.
17. Kaya, H. D. (2020). The Efficiency of the Financial System: A Comparison of Developed and Less Developed Countries. *Financial Markets, Institutions and Risks*, 4 (2), 16—24. doi:10.21272/fmir.4(2).16-24.2020.
18. Lyeonov, S., Pimonenko, T., Bilan, Yu., Streimikiene, D., & Mentel, G. (2019). Assessment of Green Investments' Impact on Sustainable Development: Linking Gross Domestic Product Per Capita. *Greenhouse Gas Emissions and Renewable Energy. Energies*, Vol. 12, 1—12. doi:10.3390/en12203891.
19. Levchenko, V., Boyko, A., Bozhenko, V., Savchenko, T., Humenna, Y., & Pilin, R. (2019). State regulation of the economic security by applying the neoteric approach to its assessment. *Marketing and Management of Innovations*, 4, 364—372. doi:10.21272/mmi.2019.4-28.
20. Musa, H., Musova, Z., & Sliacky, P. (2017). Financial Support to Small and Medium-Sized Enterprises in Slovakia. *Financial Markets, Institutions and Risks*, 1 (4), 47—52. doi:10.21272/fmir.1(4).47-52.2017.
21. Marcel, D. T. Am. (2019). Impact of the Foreign Direct Investment on Economic growth on the Re-public of Benin. *Financial Markets, Institutions and Risks*, 3(2), 69—78. doi:10.21272/fmir.3(2).69-78.2019.
22. Masharsky, A., Azarenkova, G., & Oryekhova, K. (2018). Anti-crisis financial management on energy enterprises as a precondition of innovative conversion of the energy industry: case of Ukraine. *Marketing and Management of Innovations*, Vol. 3, 345—354.
23. Moore, J. T., Ricaldi, J. N., & Rose, C. E. (et al.). (2020). Disparities in Incidence of COVID-19 Among Underrepresented Racial, Ethnic Groups in Counties Identified as Hotspots. doi: 10.15585/mmwr.mm6933e1.
24. Oliinyk, V., Wiebe, I., Syniavska, O., & Yatsenko, V. (2018). Optimization model of Bass. *Journal of Applied Economic Sciences*, Vol. 8, 62, 2168—2183.
25. Papo, D., Righetti, M., Fadiga, L., Biscarini, F., & Zanin, M. (2020). A minimal model of hospital patients' dynamics in COVID-19. *Chaos Solitons and Fractals*, 140, 1—6. doi:10.1016/j.chaos.2020.110157.
26. Rajan, D. (2018). Personal and Social Perception of Occupational Hazards by Health Care Workers: A Study among Radiographers. *Business Ethics and Leadership*, 2 (4), 46—63. doi:10.21272/bel.2(4).46-63.2018.
27. Shammi, M., Bodrud-Doza, M., Islam, A., & Rahman, M. M. (2020). Strategic assessment of COVID-19 pandemic in Bangladesh: comparative lockdown scenario analysis, public perception, and management for sustainability. *Environment Development and Sustainability*, Vol. 7, 1—44. doi:10.20944/preprints202004.0550.v1.
28. Derzhavna sluzhba statystyky Ukrainy. (n. d.). *Statystychni dani [Statistics]*. Retrieved from <http://ukrstat.gov.ua>.
29. Vasilyeva, T., Kuzmenko, O., Bozhenko, V., & Kolotilina, O. (2019). Assessment of the Dynamics of Bifurcation Transformations in the Economy. SHS Web of Conferences 2422 The 8th International Conference on Monitoring. *Modeling & Management of Emergent Economy, M3E2*, 134—146. doi:10.1051/shsconf/20196504006.
30. Vasilyeva, T., Lyeonov, S., Makarenko, I., & Sirkovska, N. (2017). Sustainability information disclosure as an instrument of marketing communication with stakeholders: markets, social and economic aspects. *Marketing and Management of Innovations*, 4, 350—357. doi:10.21272/mmi.2017.4-31.
31. Vasilyeva, T., Vorontsova, A., Bilan, Y., Ostasz, G., & Mayboroda, T. (2020). The influence of state regulation of education for achieving the sustainable development goals: case study of Central and Eastern European countries. *Administrative Management Public*, 34, 6—26. doi:10.3390/SU11061528.
32. Vasilyeva, T., Mentel, G., Samusevych, Ya., & Pryymenko, S. (2018). Regional differentiation of electricity prices: social-equitable approach. *International Journal of Environmental Technology and Management*, 21, 354—372. doi:10.1504/IJETM.2018.100583.
33. Vasilyeva, T., Lyeonov, S., Lyulyov, O., & Kyrychenko, K. (2018). Macroeconomic Stability and Its Impact on the Economic Growth of the Country. *Montenegrin Journal of Economics*, 14 (1), 159—170. Retrieved from <https://ideas.repec.org/a/mje/mjejnl/v14y2018i1p159-170.html>.
34. Viner, R. M., Mytton, O. T., & Bonell, C. (et al.). (2020, September 25). Susceptibility to SARS-CoV-2 Infection Among Children and Adolescents Compared With Adults: A Systematic Review and Meta-analysis. *JAMA Pediatr.* doi:10.1001/jamapediatrics.2020.4573.
35. Yungpeng, J., Zhongren, M., Maikel, P., & Qiuwei, P. (2020). Potential association between COVID-19 mortality and health-care resource availability. *The Lancet Global Health*, Vol. 8, 480—481. doi:10.1016/S2214-109X(20)30068-1.
36. Yelnikova, J., & Kwilinski, A. (2020). Impact-Investing in The Healthcare in Terms of the New Socially Responsible State Investment Policy. *Business Ethics and Leadership*, 4 (3), 57—64. doi:10.21272/bel.4(3).57-64.2020.

The article is recommended for printing 31.08.2020

© Kuzmenko O., Lyeonov S., Kashcha M.