Environmental Shocks: Modelling the Dynamics

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Abstract. This paper reports on processes occurring within the human environment: shocks occurring in the environment; the increase in greenhouse gases from industry; the increase in greenhouse gases from agriculture; the change in global temperature; the reduction of freshwater resources; the change in area of forested land. The article also examines the impact of three groups of factors on the dynamics of environmental shocks. These factors are the history of the process, the impact of various dynamic factors of human life and the degree of influence of the processes occurring in the environment. The autoregressive distributed lags model (ADL model) is chosen as the theoretical framework for the analysis of the correlation between the environmental shocks and the influencing factors, and empirical testing of the model is performed. The exogenous variables characterising the factors of human life were analysed using the following indices: global GDP per capita; economically active global population; global merchandise exports (FOB); rail transport freight turnover (mln tons km^{-1}); the mining of coal and lignite, extraction of peat, (mln USD). The forecast of the development of environmental shocks in 2017-2018 was performed. The analysis of the model showed that the dynamics of the environmental shocks had a constant trend.

1. Introduction

The environment comprises the totality of natural conditions, the objects of animate and inanimate nature and the components of the human (as well as animal and plant) environment. In this way, the environment's form and nature can be defined [1]. The environment surrounding mankind is continuously changing. The climate is changing, pollution of the environment is taking place and both forested area and freshwater resources are declining.

The consequences of the occurrence of one of these processes, referred to as "environmental shocks", are investigated in this article. The shocks consist of those disasters that sometimes occur in the environment. The shocks occurring in the environment are estimated in terms of their economic damage. The economic damage caused by environmental shocks is growing rapidly every year. In the 1960s it amounted to about 1 bln USD, in the 1970s – up to 4.7 bln USD, in the 1980s – 16.6 bln USD, in the 1990s – 76 bln USD [2].

Economic losses from natural shocks add to the damage caused by the following factors of human activity on the planet: water pollution; soil pollution and degradation; acid rains; ozone depletion; waste; loss of biodiversity. Concerning waste production activities, significant economic damage to society is caused by the methods of waste disposal – landfilling or incineration. These methods are economically unprofitable and cause great economic losses. A pressing problem of humanity today is the loss of biodiversity. Annually about 15,000 species become extinct. Extrapolating from this information, in 50 years only half of the current biological diversity of our planet will be conserved [3]. It is impossible to use economic damage to quantify the process of biodiversity loss

The relevance of the problem under investigation is presented in the analysis of the environmental shocks. The aim of the study is to analyse the influence of various factors on the dynamics of the change in shocks, model the influence of human activities on environmental shocks and develop the exogenous variables effect model that reflect human activity on the endogenous variable that are the environmental shocks.

2. Literature Review

The study of the ecological problems is widely researched.

Classification of ecosystems is arranged according to the organisational form described in this paper [4]. It is of note that ecosystems can be defined in various ways, including or excluding humans. There are two different approaches to the classification of ecosystems: a deductive approach, based on the theoretical framework, and an inductive approach, based on the empirical data. Thus, human activities affect the ecosystems and at the same time they meet social needs.

The research, devoted to problems of origin and the evolution of ecosystems, is of interest. The study [5] introduces the concept and explores the environment from the position of the creation and assessment of ecological communities and ecosystem functions. The probabilistic scenarios of natural disasters are discussed. The paper [6] studies the impact of large-scale disasters on economic development. The night-time light intensity satellite data is chosen as a factor of economic development. It is shown that this indicator correlates strongly with income per capita. It is noted that natural disasters significantly reduce the amount of light visible from space in the short term. Climatic and hydrological disasters cause significant reduction in brightness in developing and emerging market countries. The geophysical and meteorological disasters in industrialised countries further weaken the intensity of illumination.

The factors affecting the size of the disaster are defined as the geographical location, the degree of financial development and the quality of the political institutions present. The analysis of the environmental trends alongside the development of human society is developed in this research [7-9]. Researchers formulate the endogenous growth model showing how environmental factors, corruption, public investment and military expenditure are linked [7]. This research [8] proposes a set of optimal taxes on emissions that can be used for the internalisation of external effects from environmental pollution. The study provides evidence for the proposition that production in low-income countries will be less adverse in terms of taxes on carbon emissions compared to the countries with a high level of income, whether replaced or not. The trade-off between economics and the environment is demonstrated and a management model for the sustainable development of the marine environment proposed. The adaptive management strategy in the conditions of the increasing rate of environmental change is presented [9].

This paper [10] proposes a methodological approach in order to assess the impact of economic activities on natural disasters. The article presents an input-output model of direct and indirect socio-economic impacts on natural disasters. The following indicators are considered socio-economic: population density, the level of employment and the turnover and the size of the share capital of companies.

The modelling of environmental and socio-economic effects is discussed in works [11-13]. The models describe cumulative effects that are best managed on a regional scale. However, most models of the environment presented in this set of scientific literature, provide local models for the environmental assessment at the level of different projects. Researchers justify the necessity of determining the overall risk to humans and the environment [14]. The Integrated Risk Assessment (IRA) as a combination of Environmental Exposure assessment (EEA) and Human Exposure assessment (HEA) is provided [15]. A model for uncertainty or risk assessment can also be constructed for situations when there is a danger of something having an impact on the environment. Processes occurring in the environment are primarily analysed from the position of the Earth's natural resources, which can be connected to human activities. The methodology for water resource assessment is presented as part of the planning, development and management of water resources at a national level. The factors of climate change, the global population growth and the rapidly changing patterns of land use change deep river basins. There exists an urgent need for further studies that would assess the risks of exploitation of water resources.

Demand for minerals is increasing world-wide as the population increases and the consumption demands of individual people increase. The mining of earth's natural resources is, therefore, accelerating, and it has accompanying environmental consequences [17]. Currently, companies need large amounts of various minerals, and this demand is constantly growing [18]. The issues concerning conservation of natural resources are under study. Ecohydrological modelling of water resources and land is used to assess the effectiveness of the use of water, land and forest resources for agricultural purposes [19] and forecast estimates are given.

The risks to the environment are also evaluated from the position of the life cycle of plants. This paper presents the model used to analyse the interaction between the life cycle of plants and the environment [20]. One way to understand the extent of the human impact on the Earth is the ecological footprint (EF). It is said that on a global scale EF exceeded the biocapacity of the Earth, i.e. the Earth's ability to produce resources and ecological services, in 1970. In 2012 the EF indicator increased to 1.6 times that of earth's capacity. However, the biocapacity of the Earth itself slightly increased during this period because of the increase in agricultural productivity [21].

In the current conditions of the development of the global environment it is necessary to develop a system for managing ecosystem services in the context of a sustainable global development policy [22-24], and robust monitoring mechanisms are required.

3. The influence of different factors on the development of environmental shocks

This article formulates the hypothesis that the development of environmental shocks is influenced by three groups of factors. The first group of factors is the history of the process, the second is the influence of various dynamic factors of human life and the third is the degree that the processes influence the environment.

Prehistory precedes everything

Dynamic factors of human life are the areas in which humans carry out various kinds of activities: social, productive, economic, demographic, environmental management. Human activity in these areas is estimated by the set of indicators that will be considered "exogenous indicators". Let us name some of them: global gross domestic product per capita; global employed population; global economically active population; production energy, utilities and recycling: (days sales outstanding); primary materials forestry – production (turnover); global road freight traffic; mining of coal and lignite; extraction of peat, and others.

The factors of human activities are developing to meet the needs of the inhabitants of the planet; this development generates adverse environmental consequences and initiates the development of environmental shocks.

The processes occurring in the environment affect environmental shocks. In other words, the environmental shocks depend on: the changes in the volume of CO2 in the environment; greenhouse gas emissions from industries into the environment; emissions of greenhouse gases from agriculture into the environment; changes in global temperature on the planet; freshwater resource reduction; change in forested area

4. Methodology for the mathematical modelling of correlations between environmental shocks and their influencing factors

Under the term mathematical modelling, we understand (a) the development of the mathematical model, i.e. a view in the form of a mathematical equation or a system of equations or arithmetic ratios of the most important properties of the real process, (b) the description of the algorithm for finding the mathematical model parameters, (c) the study of a real process in the model, i.e. finding the model parameters under the given change of the characteristics of the process.

As the theoretical framework of analysis of correlation between the environmental shocks and their influencing factors, the model of autoregressive distributed lags (ADL model) is chosen, in which the current values of the series depend on the past values of the series as well as on the current and past values of other time series.

The ADL model describes the hypothesis of the effects of exogenous variables upon the endogenous variable effectively. This model considers the current and prior periods and can be represented both in additive and multiplicative forms.

The model is generalised in the case of multiple exogenous variables. In the general case, it can be assumed that all exogenous variables are included in the model with the same number of lags.

The additive form of the ADL model is:

$$y_t^1 = a_0 + \sum_{i=1}^{n} a_i y_{t-i}^1 + \sum_{j=1}^{5} b_j X_t^j + \sum_{s=2}^{7} c_s y_t^s + E_t \qquad (1)$$

where $n+5+7$ is the number of exogenous variables;
n is the number of lags of the endogenous variable (i=1, 2,..*n*);
E_t - are residues that make up the process of white noise.
j=1, 2 ,..5 is the number of exogenous variables – dynamic factors of human activities;
s=2, …, 7 is the number of exogenous variables of the processes occurring in the environment;

The multiplicative form of the ADL model is:

$$y_t^1 = A_0 \prod_{i=1}^{n} y_{t-1}^{1\,\alpha_i} \bullet \prod_{j=1}^{5} X_t^{j\,\beta_j} \bullet \prod_{s=2}^{7} y_t^{s\,\delta_s} + E_t \qquad (2)$$

Taking the logarithm of the left and right part of the equation on the basis of e we obtain a linear equation of the form:

$$\ln y_t^1 = \ln A_0 + \sum_{i=1}^{n} \alpha_i \ln y_{t-i}^1 + \sum_{j=1}^{5} \beta_j \ln X_t^j + \sum_{s=2}^{7} \delta_s \ln y_t^s + E_t \qquad (3)$$

Thus, a multiplicative function can also be additive. The endogenous variable in the model (y_t^1) represents the environmental shocks. The first group of exogenous variables is the characteristic of the prehistory of the process, i.e. shocks that occurred in the environment in previous time periods (y_{t-j}^1). The second group of exogenous variables is the factors of human life activity, as measured by indicators: total global GDP per capita (USD per person) (X_t^1); the number of economically active people in the world (X_t^2), global merchandise exports (FOB) (X_t^3); the rail transport freight turnover, (mln tons km^{-1}) (X_t^4); the mining of coal and lignite, extraction of peat, USD mln (X_t^5). The third group of exogenous variables is the impact of the processes occurring in the external environment (on the shocks): a change in the content of CO2 in the environment (y_t^2); the growth of greenhouse gases from industry (y_t^3); the growth of greenhouse gases from agriculture in the environment (y_t^4); global temperature change (y_t^5);freshwater resource reduction (y_t^6); the change in forested area worldwide (y_t^7).

The algorithm for finding the mathematical model parameters involves a number of stages: collecting and processing of endogenous and exogenous primary data in the form of time series; validation of time series variables for stationarity using Dickey-Fuller test; checking the exogenous variables for multicollinearity; selection of the lags of the endogenous variable, which have a strong correlation with the variable value in the last period and testing the significance of coefficients of autocorrelation using the Ljung-Box Q-test; the choice of exogenous variables that have strong correlation with the value of the endogenous variable in the last period and testing the significance of correlation coefficients; the design of the structural form of the multiplicative form of the ADL models; working out the structural form of the ADL model in an additive form; determination of model coefficients using the least squares method; verifying the significance of the regression equation and coefficients of the regression equation.

Finding the model parameters under the given changed characteristics of the process consisted of predicting the endogenous variable for a specific set of time periods. Specifically, a forecast for the development of environmental shocks in 2017-2018 was made.

5. Empirical testing of the model

The time series data covering the time period from 1997 to 2016 is used as a source of information for developing the econometric function for statistical studies. Source: Euromonitor International, http://www.euromonitor.com/; World Bank Open Data http://data.worldbank.org/.

The indicator “change in global temperature, annual growth in %” represents the arithmetic mean value of all countries in each period. All the other parameters represent the sum value of all countries for each year. In the analysis the average values were used.

Testing the time series variables for stationarity is the solution, which is calculated independently for each variable, using the autoregressive equation in the form $y_t = ay_{t-1} + \varepsilon_t$, where y_t is a time series, ε_t is an error. If |a| <1, the series is stationary. The verification of the coefficient reliability was carried out using t - statistics for the significance level α=0.05.

For the endogenous indicator “environmental shocks” α=0.050 <1, $t_{calculate}$ =2.203 > t_{table} =1.729.

For the exogenous indicator of “global GDP per capita” α=0.961<1, $t_{calculate}$ =18.709 > t_{table} =1.729.

For the exogenous indicator “rail transport freight turnover” α=0,960<1, $t_{calculate}$ =54.096 > t_{table} =1.729.

For the exogenous indicator “economically active global population” α=0.956 <1, $t_{calculate}$ =65.611 > t_{table} =1.729.

For the exogenous indicator “global merchandise exports” α=0.412 <1, $t_{calculate}$ =1.895 > t_{table} =1.729.

For the exogenous indicator of “mining of coal and lignite, extraction of peat” α=0.409 <1, $t_{calculate}$ =1,849 > t_{table} =1.729.

For the exogenous indicator of “CO2 Emissions per production unit” α=0.935 <1, $t_{calculate}$ =47.02 > t_{table} =1.729.

For the exogenous indicator “Greenhouse gas emissions from industry” α=0.355<1, $t_{calculate}$ =1.860 > t_{table} =1.729.

For the exogenous indicator “Greenhouse gas emissions from agriculture” α=0.818<1, $t_{calculate}$ =10.709 > t_{table} =1.729.

For the exogenous measure of “Global temperature change” =0.209<1, $t_{calculate}$ = 2.462 > t_{table} =1.729.

For the exogenous indicator “Freshwater resource reduction” α=0.664<1, $t_{calculate}$ =6.429 > t_{table} =1.729.

For the exogenous indicator “Change in forested area” α=0.767<1, $t_{calculate}$ =8.509 > t_{table} =1.729.

The testing of the exogenous variables for multicollinearity was conducted by calculating the pairwise correlation coefficient between pairs of exogenous variables and removing one of the variables from the pair if the correlation coefficient was greater than |0.7|. The significance of correlation coefficients was assessed by Student’s t-criterion for the significance level α=0.05.

As a result of this verification, the variables “CO2 emissions per production unit”, “greenhouse gas emissions from agriculture” and “freshwater resource reduction” were removed from further analysis.

Choosing the endogenous variable lags, which have a strong correlation with the variable value in the current period, was carried out by computing the autocorrelation coefficients and testing the significance of coefficients of autocorrelation using the Ljung-Box Q-test. The autocorrelation analysis showed that the endogenous variable of the current period had an autocorrelation coefficient value of more than 0.7 with an endogenous variable of the previous period only. The autocorrelation coefficient is significant according to the value of Q criterion of Ljung-Box

$$Q = n(n+2)\sum_{k=1}^{m}\frac{\rho_k^2}{n-k} \qquad (4)$$

where n is the number of observations ρ_k is the autocorrelation of the k^{th} order, m is the number of tested lags $Q = 20\cdot 22\left(\frac{0.734^2}{20-1}\right) = 12.496 > \chi^2_{1-a,n} = 10.851$

Choice of exogenous variables that have a strong correlation with the value of the endogenous variable in the previous period and testing the significance of correlation coefficients.

The exogenous variables $y_t^3, y_t^5, y_t^7, X_t^1, X_t^2, X_t^3, X_t^4, X_t^5$ in the previous period have a strong impact on the endogenous variable in the previous period. The significance of the correlation coefficients was assessed by Student’s t-criterion at the significance level of α=0.05 and the number of degrees of freedom n-2=16, t table=1.746. In all cases $t_{calculate} > t_{table}$. The correlation coefficients of other exogenous variables with the endogenous variable in the previous period are less than 0.7, therefore, they will not be included in the further analysis.

The structural form of the ADL model in multiplicative form is written as

$$y_t^1 = A_0 \cdot {y_{t-1}^1}^{\alpha_1} \cdot {X_t^1}^{\beta_1} \cdot {X_t^2}^{\beta_2} \cdot {X_t^3}^{\beta_3} \cdot {X_t^4}^{\beta_4} \cdot {X_t^5}^{\beta_5} \cdot {y_t^3}^{\delta_3} \cdot {y_t^5}^{\delta_5} \cdot {y_t^7}^{\delta_7} \quad (5)$$

Taking the logarithm of both parts of the equation allows linearisation of the function’s variables and exponential model. This allows us to write the structural form of the ADL model in an additive form

$$A_t^1 = \alpha_0 + \alpha_1 A_{t-1}^1 + \beta_1 B_t^1 + \beta_2 B_t^2 + \beta_3 B_t^3 + \beta_4 B_t^4 + \beta_5 B_t^5 + \delta_3 C_t^3 + \delta_5 C_t^5 + \delta_7 C_t^7 \ (6)$$

By means of the least-squares determined coefficients model we check the significance and coefficients of the regression equation using Fisher’s F-criterion and Student’s t-criterion.

When α = 0.05, F_{table} = 30.144, $F_{calculate}$ = 52.844, the coefficient of determination equals 0.932; thus, the regression equation is significant.

The regression equation in an additive form is written as

$$A_t^1 = -30{,}935 + 0.24A_{t-1}^1 + 1{,}997B_t^1 - 2{,}867B_t^2 + 1{,}163B_t^3 + 0{,}427B_t^4 - 0{,}321B_t^5 - 0{,}380C_t^3 - 0{,}185C_t^5 + 0{,}085C_t^7 \ \text{[TB1]}(7)$$

The regression equation in a multiplicative form is

$$y_t^1 = e^{-30{,}935} \cdot {y_{t-1}^1}^{0{,}24} \cdot {X_t^1}^{1{,}997} \cdot {X_t^2}^{-2{,}867} \cdot {X_t^3}^{1{,}163} \cdot {X_t^4}^{0{,}427} \cdot {X_t^5}^{-0{,}321} \cdot {y_t^3}^{-0{,}380} \cdot {y_t^5}^{-0{,}185} \cdot {y_t^7}^{0{,}085} \ \text{[TB2]}(8)$$

6. Conclusions

For estimating the function parameters, the linear Ordinary Least Squares (OLS) method is used. OLS for the following model is:

$$A_t^1 = \alpha_0 + \alpha_1 A_{t-1}^1 + \beta_1 B_t^1 + \beta_2 B_t^2 + \beta_3 B_t^3 + \beta_4 B_t^4 + \beta_5 B_t^5 + \delta_3 C_t^3 + \delta_5 C_t^5 + \delta_7 C_t^7$$

where: e - the natural logarithm figure $Y_i (i = 1,3,5,7); X_j (j = 1,2,3,4,5)$.

$$A_1 = -30.9355 + 0.24\, A_{1_{t-1}} - 0.38026\, A_{3_t} - 0.18513\, A_{5_t} + 0.08539\, A_{7_t} +$$
$$1.99797\, B_{1_t} - 2.86778\, B_{2_t} + 1.16342\, B_{3_t} + 0.42739\, B_{4_t} - 0.32168\, B_{5_t}$$

The α_i - coefficients estimate the elasticity of environmental shocks from exogenous factors. The coefficient of elasticity of the factor shows the percentage of the function increase if the factor increases by 1%.

When $\sum \alpha_i > 1$ the function grows faster than the average, and at $\sum \alpha_i < 1$ it grows slower. In our case, $\sum \alpha_i > 1$. When $\sum \alpha_i > 1$, the average costs per unit of environmental shocks decreases with the increasing number of environmental shocks.

The cumulative impact of the considered exogenous factors for the analysed period increased, however, with a decrease in average costs, because the sum of the elasticity coefficients of the production function is more than 1.

The coefficient α_0 = - 30.935 shows that the exogenous factors had a neutral impact.

The indicator “environmental shocks” in the previous period has a positive impact on itself in the current period. It shows that the risk of shocks is increasing, which is the result of anthropogenic and natural forces.

The indicators “greenhouse gas emissions from industry” and “global temperature change” compared to the other indicators have less influence on the indicator “environmental shocks”. Despite this, with the increase in greenhouse gas emissions and global temperature change, the whole ecological system changes and environmental degradation inevitably leads to the development of natural disasters. Global temperature change contributes to the increasing number of the climate-related disasters – raising the level of the ocean and flooding coastal areas. The indicator “area of forested land” has a positive effect, demonstrating that the increase in forested land reduces the risk of climate disasters due to the absorption of greenhouse gas emissions from industry. The indicator “global GDP per capita” reflects a positive effect, i.e. by increasing the production of goods and services in the world the number of negative effects and the risk of technological disasters increases. Rail transport freight turnover and mining of coal and lignite as well as extraction of peat forces us to spend more energy, which in turn increases the release of harmful substances into the atmosphere. The indices “global merchandise exports” and “economically active global population” demonstrate a positive impact in this analysis, i.e. an increase in the export of goods due to transportation also increases the emission of harmful gases into the atmosphere.

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