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DETERMINATION OF THE ENVIRONMENTAL TAX ON THE BASIS OF MODIFIED INPUT-OUTPUT LEONTIEF-FORD MODEL

Об'єктом дослідження є планування виробничої діяльності, яке ставить за мету узгодити екологічні та економічні критерії розвитку «природа-виробництво». Одним з найбільш проблемних місць у виробництві є врахування екологічного фактору, оскільки виробнича діяльність чинить негативний вплив на навколишнє середовище. Особливо важливим є зменшення частки парникових газів у викидах виробничих підприємств.

В ході дослідження використовувалися підходи до моделювання виробничої діяльності на основі міжгалузевого балансу з урахуванням екологічної складової.

Отримано модифіковану еколого-економічну модель Леонтьєва-Форда для випадку розширення міжгалузевого балансу з урахуванням нової галузі, що здійснює переробку парникових газів. Запропонована модель має, зокрема, особливість, що дозволяє розглядати процес знищення парникових газів як окрему галузь виробництва, нерозривно пов'язану міжгалузевими зв'язками з іншими галузями.

Проведено розрахунки за реальними даними на основі таблиці міжгалузевого балансу за 2016 рік. Сформовано агреговану матрицю прямих витрат з виділенням 8 основних галузей.

Завдяки цьому забезпечується можливість отримання у явному вигляді формули для відшукання або оцінки величини екологічного податку в залежності від забрудненості технології. У дослідженні зведено модифіковану модель Леонтьєва-Форда, що враховує появу та функціонування нової галузі, яка здійснює знищення парникових газів, до статичної моделі міжгалузевого балансу. В результаті розрахунків були отримані матриця прямих технологічних витрат та матриця приростів прямих витрат при введенні нової галузі. Розраховано ціну основної продукції і вартість знищення забруднювачів. У порівнянні з аналогічними відомими моделями можна зробити висновок, що запропонована модель забезпечує переваги при вирахуванні плати за забруднення. В результаті визначено величину ставки екологічного податку, яка враховує забрудненість виробництва. Це сприятиме більш раціональному природокористуванню та, відповідно, зменшенню викидів парникових газів у атмосферу.

Ключові слова: *еколого-економічне моделювання, сталий розвиток, міжгалузевий баланс, модель Леонтьєва-Форда, емісія парникових газів.*

1. Introduction

Problems of rational environmental management and environmental protection remain actual for many years. The economic activity has a negative influence on the environment that is why there are questions about taking into account the ecological factor at planning of productive activity. At present considerable money on preventing of negative influence on an environment is spent, in particular it touches building of sewage treatment plants. One of the major factors influencing the environment of human existence, as well as the nature in general is the pollution of the air, thus considerable part in emissions have greenhouse gases. For example, emissions of certain pollutants and greenhouse gases into the atmosphere in 2016 amounted to 3078.1 thousand tons, which was 107.7 % compared to 2015, that is, there is a tendency to emissions increase.

According to the Paris Climatic Agreement [1], the main objective is to:

– strengthen the implementation of the Framework Convention on Climate Change by maintaining the increase of the average world temperature;
– support of climate change counteractions, development of low greenhouse gas emissions in a way that does not threaten the production of food;
– harmonization of financial streams from development with climate change counteractions and low greenhouse gas emissions.

It is possible to mark, taking into account the stated higher, that a theme of this research is actual.

2. The object of research and its technological audit

The object of the research is determination of the ecological tax rate at planning of production activities, which aims to harmonize the ecological and economic criteria for the development of «nature-production».

One of the most problematic places in production is taking into account the ecological factor, as the economic activity has a negative influence on the environment. Particularly important is the reduction of the part of greenhouse gases in emissions from industrial enterprises.

In order to form an effective rate of ecological tax, research was conducted on the basis of input-output ecological-economic Leontief-Ford model. The introduction of a tax rate that takes into account the pollution of production will contribute to a more rational use of the environment and, accordingly, to reduce greenhouse gas emissions into the atmosphere.

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3. The aim and objectives of research

The aim of research is creation of an effective ecological tax rate. To achieve this goal, the following scientific tasks have been identified:

1. To modify Leontief-Ford's model taking into account new greenhouse gas-destroying industry.
2. To make calculations based on the inter-branch balance for 2016.
3. To determine the size of the ecological tax.

4. Research of existing solutions of the problem

Problems of ecological-economic modeling and taking into account the negative influence on the environment interested many scientists. For example, in the proceedings [2] it is proposed to examine a new separate branch in an inter-branch ecological-economic model that recycles waste. At the proceedings [3] the methodological issues of the economic-mathematical modeling of steady development are investigated. They include the systematic consideration of economic and ecological problems, and economic growth, which are associated with the state of the environment, first of all, with the use of exhaustive natural resources and the purification of the environment from the pollution. The inter-branch models that develop and generalize the Leontief-Ford model are described. The following are macro models of sustainable development. The aggregated dynamic models of ecologically friendly technologies based on the kinetic model of Mono-Jerusalimsky have been constructed. Market mechanism of ecological-economic interaction is proposed. A wide spectrum of questions and methods is surveyed that allow taking into account the influence of the environment on economic development.

In the proceedings [4], which is devoted to the estimation of the ecological economy, including greenhouse gas emissions per person and unit of GDP it is offered to include the index of productive costs on an environment. The authors assume the modernization of the Leontief-Ford inter-branch balance model by means of an economic evaluation of the influence of environmental pollution.

The proceedings [5] explore the potential of combining of two ecological and economic methods: the analysis of inter-branch balance and the using of decision support systems. Firmness of investments in various sectors of the economy in order to minimize the use of resources and emissions generation is evaluated.

In [6], Leontief ecological model is surveyed. It is the model of inter-branch balance that is increased due to sectors that create and reduce pollution. In literature, it is possible to find two formulations of this model. In one formulation, an exogenously introduced vector of permissible level of pollutants (ecological standards) as the negative variable on the right side of the model is surveyed. Another formulation implies that each branch excludes a specific proportion of the pollution it creates, so that the proportions of gross pollutants to be processed by each sector are introduced as given parameters. Even if levels of production and emission reductions in the two different formulations of the model are the same, the solution of the dual or price model is different in cases where some pure pollution remains indestructible. Analytical relations between two price models are established. Both models, formulated in the form of linear programming problems, are expanded by calculating the costs of emissions into untreated pollution.

At the proceedings [7–10] modification of the Leontief model is surveyed. It takes into account pollution, its systematic formulation and its surveyed properties. And [11] proposes methodology that defines the main productive links between the activity industries that deal with CO_2 emissions and are used in the Spanish economy. This indicates that emissions are related to productive interconnections in an economy, the intensity of CO_2 emissions sectors and the structure of the final demand of different sectors. Formal analysis of these factors is carried out using the system «cost-release» in connection with the analysis of sensitivity and linear programming methods. It is shown that the most intense industrial relations in Spain are connected with CO_2 emissions. Such review of key relationships contributes to identifying key sectors of economy and contributes to the development of effective political measures to reduce emissions.

[12] argues that waste utilization reduces the amount of waste that is burned and/or collected at landfills and also reduces emissions from these sources, but it generates waste and emissions from its own sources. A static inter-branch model is surveyed for the analysis of the economic and ecological consequences of waste recycling that takes into account different kinds of waste processing. Waste can be divided into two main categories, depending on the method of their formation:

1) those which are formed as «unwanted» by-products during the production process, such as waste water or sludge;

2) those that were originally manufactured as goods but returned as waste over time, for example, waste paper or discarded consumer goods of long-term use.

In this proceeding, considerable attention is paid to the second category of waste. This category of waste is usually distributed across a wide geographic area, since it is formed at the place of final consumption, while the first is produced at the place of production. Collection and recycling of waste are considered as separate activities. As an empirical illustration, a numerical example is presented for recycling waste paper based on the data for Denmark, and analyzed the effects of alternative scenarios for the processing of industrial activities and CO_2. emissions. Each scenario consists of a set of parameters related to the proportion of processed goods in the total volume, the efficiency of waste collection and the efficiency of the processing technology.

In [13] it is marked that emissions of waste in the economy are largely determined by models of technologies, institutions and lifestyles. The mathematical model (cost-release of waste) is presented, which gives a simple analytical representation of this interdependence. This model was used to assess the influence of alternative methods of waste disposal and recycling at the level of industrial production, landfill consumption and carbon dioxide emissions, as well as to analyze the overall dependence of individual industries. It has been found that a systematic combination of options can be effective in reducing overall carbon dioxide emissions.

Thus, the results of the analysis allow to make a conclusion that the expansion of existing models in terms of ecological balance is necessary to find effective solutions for the management of ecological and economic systems.

5. Methods of research

To achieve the set aim, in determining the formulated tasks, their formulation and resolution, the following general scientific and special methods of research were used:

– the method of theoretical generalization – to clarify the conceptual apparatus, the essence of the modeling of inter-branch relations and the identification of its features;
– methods of analysis and synthesis – to identify the individual factors that affect the production activities and construction of the inter-branch model;
– monographic method – to study existing solutions to the problem;
– methods of analogies and comparative comparisons – for the consideration of the classical Leontief-Ford model and its modification;
– method of system analysis – for establishing structural relations between elements of the investigated ecological-economic system;
– matrix analysis method – for studying the interrelations between branches of the economy using matrix modeling.

6. Research results

The classical model of Leontief-Ford, as a rule, is considered as:

$$x_1 = A_{11}x_1 + A_{12}x_2 + y_1, \quad x_2 = A_{21}x_1 + A_{22}x_2 - y_2, \tag{1}$$

where $x_1 = (x_1^1, x_1^2, ..., x_1^n)^{\mathrm{T}}$ – vector-column of production volumes of the main group of industries; $y_1 = (y_1^1, y_1^2, ..., y_1^n)^{\mathrm{T}}$ – vector-column of final production of the main group of industries; $A_{11} = (a_{ij}^{11})_1^n$ – square matrix of the coefficients of the products direct costs i on the output of the product unit j; $x_2 = (x_2^1, x_2^2, ..., x_2^m)^{\mathrm{T}}$ – vector-column of the destroyed pollutants volumes; $y_2 = (y_2^1, y_2^2, ..., y_2^m)^{\mathrm{T}}$ – vector-column of the undestroyed pollutants volumes; $A_{12} = (a_{il}^{12})_{i,l=1}^{n,m}$ – a rectangular matrix of direct products costs i the destruction of the pollutant unit l; $A_{21} = (a_{tj}^{21})_{t,j=1}^{m,n}$ – a rectangular matrix of direct pollutant products t per unit of production j; $A_{22} = (a_{tl}^{22})_1^m$ – square matrix of the direct pollutants output t when destroying the pollutant unit l.

Let's suppose that there is only one pollutant – greenhouse gases in the equivalent CO_2. Let's introduce a new industry – an industry that eliminates greenhouse gases. At the same time, in the process of production, that is, during the destruction of greenhouse gases, a new pollution can be created. Then instead of the vector $x_2 = (x_2^1, x_2^2, ..., x_2^m)^{\mathrm{T}}$ in the corresponding model, we will consider x_{n+1} – the amount of destroyed greenhouse gases, y_{n+1} – the amount of indestructible greenhouse gases. Then the corresponding Leontief-Ford model will be the next:

$$x = Ax + ux_{n+1} + y, \quad x_{n+1} = vx + wx_{n+1} - y_{n+1}. \tag{2}$$

On the basis of inter-branch balance data for 2016 the corresponding aggregate matrix of direct costs was formed. There are 8 branches selected in this matrix:

1 – agriculture, forestry and fisheries;
2 – mining and quarrying;
3 – processing industry;
4 – supply of electricity, gas, steam and air conditioned;
5 – water supply, sewage, waste management;
6 – construction;
7 – transport, warehousing, postal and courier activities;
8 – other types of economic activity. In the notation of the classical model.

In symbols of the classical model $A_{11} = A$ (square matrix 8×8), $x_1 = x$, $y_1 = y$. In the role of matrix A_{12} (size 8×1) will be the vector-column of the cost of each type of product that is required to destroy the unit of pollution (greenhouse gases) $u = (u_1, u_2, ..., u_n)^{\mathrm{T}} \geq 0$. The matrix A_{21} (size 1×8) acts $v = (v_1, v_2, ..., v_n) \geq 0$ – the vector-row of greenhouse gas emissions at producing units of each type of products. In the role of matrix A_{22} (size 1×1) there will be a matrix of greenhouse gas emissions when the unit of pollution is destroyed $0 \leq w < 1$.

Using the methodology offered in the proceedings [2], let's reduce this Leontief-Ford model, taking into account the appearance and functioning of a new industry – the destruction of greenhouse gases, to a static model of inter-branch balance. In this case, the matrix of direct costs A will increase ΔA, respectively, the matrix of full costs $B = (E - A)^{-1}$ will gain ΔB. As it is known that for matrixes A and B is fair correlation $A = E - B^{-1}$, we can find a formula for calculating the increment ΔB. For this purpose it is necessary to write down correlation for $B + \Delta B$: $B + \Delta B = (E - (A + \Delta A))^{-1}$, where we have $\Delta B = (E - (A + \Delta A))^{-1} - B$ or $\Delta B = (B^{-1} - \Delta A)^{-1} - B$. For easiness to use of this formula for calculation let's write it in the next form $\Delta B = \left((E - \Delta AB)^{-1} - E\right)B$.

According to [14], in case where D is a non-singular matrix, for which the inverse matrix is known, u – a certain column, v – a certain line, $C = D + uv$ is a fair formula:

$$C^{-1} = D^{-1} - \frac{1}{\gamma} D^{-1}uvD^{-1}, \tag{3}$$

where $\gamma = 1 + vD^{-1}u$. Accordingly let's assume that $\gamma \neq 0$.

Firstly let's denote x_{n+1} from the second equalization of model (2):

$$x_{n+1} = \frac{1}{1-w}(vx - y_{n+1}), \tag{4}$$

and substitute in the first equalization of system:

$$x = Ax + \frac{u}{1-w}(vx - y_{n+1}) + y, \tag{5}$$

obtain:

$$x = \left(A + \frac{uv}{1-w}\right)x + y - \frac{u}{1-w}y_{n+1}. \tag{6}$$

Let's consider that:

$$\Delta A = \frac{uv}{1-w}, \ \Delta y = -\frac{u}{1-w}y_{n+1}. \tag{7}$$

In [2] wit is possible to see that for the given model calculations can be done according to the formula:

$$\Delta B = \frac{BuvB}{1-w-vBu}. \tag{8}$$

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Let's make the corresponding calculations according to the data of the inter-branch balance of Ukraine for 2016 [15]. For this purpose, a matrix of direct technological losses (matrix A) was constructed, which is given in Table 1.

The coefficients of the cost matrix of each of the 8 industries per unit of greenhouse gas utilization in the equivalent of CO_2 are calculated on the basis of [16]:

$$u = (0;\ 0.00302;\ 0.09870;\ 0.03457;\ 0.00031;\ 0;\ 0;\ 0)^{T}.$$

The coefficients of the matrix of emissions per unit of manufactured products of each of the 8 branches:

$$v = \begin{pmatrix} 0.00182;\ 0.01754;\ 0.03779;\ 0.46950; \\ 0.01074;\ 0.00064;\ 0.01988;\ 0.00309 \end{pmatrix}.$$

Coefficient of CO_2 emissions per unit of CO_2 utilization $w = 0.07735$.

As a result of calculations, the matrix of full costs B (Table 2) and the matrix of incremental direct costs were introduced when introducing a new industry ΔB (Table 3).

The dual model of inter-brunch price dependencies for the Leontief-Ford model in the classical formulation has the next form:

$$\begin{aligned} p_1 &= p_1 A_{11} + p_2 A_{21} + r_1, \\ p_2 &= p_1 A_{12} + p_2 A_{22} + r_2, \end{aligned} \qquad (9)$$

where $p_1 = (p_1^1, ..., p_n^1)$ – vector row of prices of basic products; $p_2 = (p_1^2, ..., p_n^2)$ – vector row value of destroyed units of pollutants; $r_1 = (r_1^1, ..., r_n^1)$ – vector row of coefficients of conditional clean production of the main production; $r_2 = (r_1^2, ..., r_n^2)$ – vector row of coefficients of conditional clean production of auxiliary production.

For model (2) the corresponding dual model of price dependencies will have the form:

$$\begin{aligned} p &= pA + p_{n+1} v + r, \\ p_{n+1} &= pu + p_{n+1} w, \end{aligned} \qquad (10)$$

where $p = (p_1, ..., p_n)$ – the vector row of prices of basic products; p_{n+1} – cost of destruction of a unit of greenhouse gases; $r = (r_1, ..., r_n)$ – vector-row of coefficients of conditionally-clean production of the main production.

The vector-row of conditionally cleaner coefficients can be found from the condition:

$$z_j = r_j x_j,$$

where z_j is the coefficient of value-added of products of the j-industry basic production that includes depreciation, remuneration of labor and additional product. It is worth noting that in this model prices for basic products are shown in non-monetary items, but are price indexes.

Let's consider that elimination of pollutants takes place in an indissoluble technological process «producing of products + elimination of pollutants». In this case, the depreciation of equipment of auxiliary production, the salary and the additional product of this production, is the result of the elimination of pollutants consisting of only material costs. Therefore, the conditionally clean production coefficient of auxiliary production equals 0. Such supposition allows expecting from a model (10) both the cost of basic products and the cost of eliminating pollutants.

Table 1

The coefficients of the matrix of direct costs

Producers-industries \ Consumers-industries	1	2	3	4	5	6	7	8
1	0.21560	0.00163	0.06723	0.00100	0.00065	0.00096	0.01395	0.01533
2	0.00664	0.08883	0.07750	0.35295	0.00742	0.03355	0.08066	0.00395
3	0.22237	0.15696	0.28876	0.12082	0.29897	0.46075	0.18372	0.09215
4	0.01223	0.09155	0.03500	0.08966	0.14216	0.00972	0.05329	0.02095
5	0.00047	0.00122	0.00125	0.02731	0.03786	0.00155	0.00169	0.00252
6	0.00150	0.00563	0.00192	0.00505	0.00639	0.18023	0.01269	0.01140
7	0.03751	0.07150	0.03610	0.00362	0.01341	0.00476	0.05926	0.01917
8	0.11654	0.14243	0.23064	0.06444	0.18482	0.07430	0.12261	0.26698

Table 2

The coefficients of the matrix of full costs

Producers-industries \ Consumers-industries	1	2	3	4	5	6	7	8
1	1.3307	0.0475	0.1538	0.0468	0.0675	0.0958	0.0647	0.0522
2	0.0897	1.2053	0.1923	0.5032	0.1576	0.1698	0.1804	0.0548
3	0.5337	0.4052	1.6308	0.4185	0.6342	0.9659	0.4328	0.2588
4	0.0631	0.1551	0.1049	1.1840	0.2213	0.0854	0.1104	0.0542
5	0.0045	0.0078	0.0072	0.0359	1.0482	0.0074	0.0069	0.0060
6	0.0119	0.0178	0.0160	0.0182	0.0207	1.2321	0.0255	0.0228
7	0.0893	0.1181	0.0962	0.0687	0.0659	0.0706	1.1043	0.0468
8	0.4197	0.4064	0.6037	0.3634	0.5378	0.4982	0.3803	1.4810

Table 3

The coefficients of the matrix $B + \Delta B$

Producers-industries \ Consumers-industries	1	2	3	4	5	6	7	8
1	1.3318	0.0497	0.1561	0.0579	0.0703	0.0748	0.0665	0.0530
2	0.0923	1.2104	0.1976	0.5295	0.1642	0.1735	0.1847	0.0568
3	0.5451	0.4277	1.6544	0.5345	0.6631	0.9826	0.4516	0.2674
4	0.0665	0.1617	0.1118	1.2180	0.2298	0.0903	0.1159	0.0567
5	0.0047	0.0081	0.0075	0.0374	1.0486	0.0076	0.0072	0.0061
6	0.0121	0.0181	0.0163	0.0197	0.0211	1.2323	0.0257	0.0229
7	0.0901	0.1197	0.0979	0.0768	0.0679	0.0718	1.1056	0.0474
8	0.4245	0.4158	0.6135	0.4116	0.5498	0.5051	0.3881	1.4846

Finding prices from correlations (10), it is possible to come to the conclusion that the cost of eliminating pollutants can be found following:

$$p_{n+1} = r\left(E - A - \frac{uv}{1-w}\right)^{-1} \cdot \frac{u}{1-w} \tag{11}$$

or according to (3):

$$p_{n+1} = r\left(B + \Delta B\right) \cdot \frac{u}{1-w}. \tag{12}$$

Using the data of the inter-branch for 2016 it is possible to calculate p_{n+1}:

$$p_{n+1} = r\left(B + \Delta B\right)\frac{u}{1-w} \approx 0.12264. \tag{13}$$

According to [3] it is possible to assume that the output of indestructible pollutants y_{n+1} is «technological emissions» and in some sense proportional to destroyed pollutants x_{n+1}, where a coefficient of proportion k is an indicator of the of technology pollution:

$$y_{n+1} = kx_{n+1},\ k \geq 0. \tag{14}$$

The ecological tax can be calculated in particular as a fee for «technological emissions»:

$$e = p_{n+1}y_{n+1} = kp_{n+1}x_{n+1}. \tag{15}$$

Substituting the corresponding expressions, found beforehand, it is possible to come to the conclusion that the value of the environmental tax can be found the following way:

$$e = kr\left(B + \Delta B\right)\frac{uv}{(1-w)(1+k-w)} \cdot x \tag{16}$$

or

$$e = kr\left(B + \Delta B\right)\frac{uv}{(1-w)(1+k-w)} \times \left(E - A - \frac{uv}{1+k-w}\right)^{-1} \cdot y. \tag{17}$$

This expression, using the formula (3), can be written like this:

$$e = kr\left(B + \Delta B\right)\frac{uv}{(1-w)(1+k-w)} \times \left(B - \frac{BuvB}{1+k-w-vBu}\right)y. \tag{18}$$

It is obviously, that:

$$\left(B + \Delta B\right) \cdot \frac{uv}{(1-w)(1+k-w)} > \frac{uv}{1+k-w},$$

that is why:

$$e > kr\frac{uv}{1+k-w}y, \tag{19}$$

what can be considered the lower limit of ecological tax To reduce the ecological tax, the enterprise is interested in reducing its indicator of technology pollution k.

So, in particular, when the limiting case of the pollution indicator of technologies is equal to 1, it corresponds to 100 % pollution, the calculation of the size of ecological tax according to the formula (16) can be carried out the next way:

$$e = r\left(B + \Delta B\right)\frac{uv}{(1-w)(2-w)} \cdot x. \tag{20}$$

Counting the size of ecological tax after this formula, according to the data of 2016, it is possible to find that in the limit case, the amount of ecological tax revenues would be 6 billion 691 million 466 thousand 436 UAH 69 coins. At the rate of pollution $k = 0.5$ the amount of revenues would be 4 billion 521 million 613 thousand 870 UAH 07 coins. At $k = 0.2$ – 2 billion 291 million 960 thousand 618 UAH 98 coins. At $k = 0.1$ – 1 billion 258 million 40 thousand 184 UAH 28 coins. In 2016, the tax rate for CO_2 emissions was 0.41 UAH per ton. Thus, in case of emissions from stationary sources in the amount of 150581 thousand tons, we find the amount of tax revenues in the amount of 61 million 738 thousand 210 UAH. It can be concluded that taking into account the contamination of technologies, it is possible to increase tax revenues to the state budget.

7. SWOT analysis of research results

Strengths. The strong point in the research is the explicit formulation of a formula for finding or evaluating of ecological tax size depending on the pollution of the technology.

Weaknesses. The weak point is that not all of the statistical data required for calculations after the models are available. Some of them need to be calculated on the basis of available statistical data, which may lead to certain errors in the results of the calculations.

Opportunities. Opportunities for further research are the calculation of the value of ecological tax on the basis of real prices that will allow taxing companies in various sectors of the economy efficiently. This will increase tax revenues to the state budget due to a more adequate calculation of the ecological tax.

Threats. Threats for the results of the carried researches are that the ecological tax rate depends on a large extent on inter-branch balance data and ecological balance indicators. These indicators change every year, so the amount of environmental tax will change.

8. Conclusions

1. The research of the modified Leontief-Ford model was conducted taking into account the new greenhouse gas elimination industry. It is possible to conclude that the proposed model provides benefits when calculating the payment for pollution. After all, when calculating the environmental tax is considered that it comes forward as a fee for «technological emissions».

2. Calculations based on the inter-branch balance table for 2016 are made. As a result of the calculations, the coefficients of the cost matrix of products of each of the

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8 industries per unit of greenhouse gas utilization in the equivalent of CO_2, were obtained, as well as the full cost matrix B and the matrix of incremental direct costs in the introduction of a new industry ΔB. The size that can be considered as the lower ecological tax is found.

3. Explicit formulas for finding or estimating the value of the ecological tax depending on the contamination of the technology and the introduction of the tax rate are obtained. It also takes into account the pollution of production, contributes to a more rational use of the environment and, accordingly, reduction of greenhouse gas emissions into the atmosphere. After all, in order to reduce the ecological tax, the company is interested in reducing its indicator of technology pollution.

References

1. Paris Agreement: Essential Elements // United Nations Framework Convention on Climate Change. 2018. URL: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
2. Tadeiev Yu. P. Rozshyrennia modeli Leontieva v umovakh ekolohichnoi zbalansovanosti // BiznesInform. 2012. No. 4. P. 132–136.
3. Liashenko I. M. Ekonomiko-matematychni metody ta modeli staloho rozvytku: monograph. Kyiv: Vyshcha shkola, 1999. 234 p.
4. Modification of the Leontief-Ford Input-Output Model for the Green Economy Goals and Environment Protection / Potravny I. et al. // Journal of Geoscience and Environment Protection. 2017. Vol. 5, No. 11. P. 15–23. doi: http://doi.org/10.4236/gep.2017.511002
5. Shmelev S. E. Economic Models and the Environment: Input-Output Analysis // Ecological Economics. Springer: Dordrecht, 2011. P. 87–114. doi: http://doi.org/10.1007/978-94-007-1972-9_6
6. Luptacik M., Bohm B. A Consistent Formulation of the Leontief Pollution Model // Economic Systems Research. 1999. Vol. 11, No. 3. P. 263–276. doi: http://doi.org/10.1080/09535319900000018
7. Arrous J. The Leontief Pollution Model: A Systematic Formulation // Economic Systems Research. 1994. Vol. 6, No. 1. doi: http://doi.org/10.1080/09535319400000008
8. De Mesnard L. The Asynchronous Leontief Model // Economic Systems Research. 1992. Vol. 4, No. 1. P. 25–34. doi: http://doi.org/10.1080/09535319200000002
9. Qayum A. A Reformulation of the Leontief Pollution Model // Economic Systems Research. 1991. Vol. 3, No. 4. P. 428–430. doi: http://doi.org/10.1080/09535319100000033
10. Leontief W. Environmental Repercussions and the Economic Structure: An Input-Output Approach // The Review of Economics and Statistics. 1970. Vol. 52, No. 3. P. 262–271. doi: http://doi.org/10.2307/1926294
11. Tarancon Moran M. A., del Rio Gonzalez P. A combined input-output and sensitivity analysis approach to analyse sector linkages and CO_2 emissions // Energy Economics. 2007. Vol. 29, No. 3. P. 578–597. doi: http://doi.org/10.1016/j.eneco.2006.02.004
12. Nakamura S. An interindustry approach to analyzing economic and environmental effects of the recycling of waste // Ecological Economics. 1999. Vol. 28, No. 1. P. 133–145. doi: http://doi.org/10.1016/s0921-8009(98)00031-7
13. Nakamura S., Kondo Y. A waste input-output life-cycle cost analysis of the recycling of end-of-life electrical home appliances // Ecological Economics. 2006. Vol. 57, No. 3. P. 494–506. doi: http://doi.org/10.1016/j.ecolecon.2005.05.002
14. Waugh F. V., Dwyer P. S. Compact Computation of the Inverse of a Matrix // The Annals of Mathematical Statistics. 1945. Vol. 16, No. 3. P. 259–271. doi: http://doi.org/10.1214/aoms/1177731089
15. Tablytsia «vytraty-vypusk» za 2016 rik (v tsinakh spozhyvachiv) // Derzhavna sluzhba statystyky Ukrainy. URL: https://ukrstat.org/uk/operativ/operativ2006/vvp/vitr_vip/vitr_u/arh_vitr_u.html (Last accessed: 24.04.2018).
16. Ukraina v tsyfrakh 2016: statystychnyi zbirnyk. Kyiv: Derzhavna sluzhba statystyky Ukrainy, 2017. 240 p.

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