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ALGORITHMIZATION OF THE EFFICIENCY ESTIMATION'S PROCEDURE OF THE AGRICULTURAL ENTERPRISES BY A DEA-METHOD

The purpose of the article. *The purpose of the paper is to develop an algorithm for estimating the efficiency of agricultural enterprises by the DEA method, the dynamics of change their efficiency.*

Research methods. *The study uses an econometric method for checking the quality of input and output parameters of the research objects, DEA - method of estimating the boundary efficiency for estimating the level of net technical efficiency of the investigated agricultural enterprises.*

Research results. *The theoretical and methodological aspects of determination of net technical efficiency of agricultural enterprises by DEA method are analyzed. The expediency of using VRS - input model for the estimation of net technical efficiency of production activity of agricultural enterprises is substantiated. The features of the analysis of the change of their efficiency in relation to the previous period by the DEA method are determined. The algorithm of estimation of net technical efficiency of agricultural enterprises and dynamics of its change is offered.*

In the proposed study on the basis of statistical information for 2016-2017, the method DEA was defined the values of net technical efficiency of agricultural enterprises of Ukrainian regions in production and sale of grain crops. The dynamics of change of efficiency for 2016-2017 is analyzed. According to calculations, for 2016-2017 the share of regions whose agricultural enterprises formed an effective front fell by 4.2% and amounted to 37.5% in 2017. Thus, 62.5% of the regions can *improve production performance by reducing the amount of resources used in production. The average value of the Malmqvist index* $Mind = 1{,}01$ *calculated for 2016-2017 indicates that the average amount of resources used in the production of the same amount of products has practically remained unchanged.*

Elements of scientific novelty. *The algorithm of estimation of net technical efficiency of agricultural enterprises and dynamics of its change is developed.*

Practical significance. *Research results can be used to rank the agricultural enterprises of Ukraine by efficiency, for estimation the dynamics of changes in their effectiveness, identify the causes of these changes. Tabl.: 5. Bibliogr.: 17.*

Keywords: *input and output parameters, net technical efficiency, DEA method, model VRS-input, Malmquist index, agricultural enterprises.*

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Formulation of the problem. For the analysis of the economic efficiency of agricultural enterprises in Ukraine, as a rule, calculate the indicators of profitability, or partial indicators of the use of resources (labor, capital, etc.). For ranking enterprises by the level of efficiency, these indicators are compared with each other. However, a large number of indicators used, does not allow making an unambiguous conclusion about the overall level of efficiency of the enterprise.

At present time, methods for estimating the boundary efficiency are widely used abroad. In accordance with these methods, the actual indicator of output is compared with the maximum possible with a certain amount of resources. Enterprises that provide maximum output per unit of resources are selected as a benchmark with which other enterprises are compared. The enterprises selected as a benchmark form the so-called a boundary of efficiency. Measurement of efficiency consists of measuring in a multidimensional space the input and output values of the distance between the enterprise, which is analyzed and the boundary of efficiency.

Among the methods for estimating boundary efficiency, one can note:

1) parametric methods: Stochastic Frontier Approach (SFA) method; Method without Distribution Free Approach (DFA); Thick Frontier Approach (TFA) method;
2) nonparametric methods: Data Envelopment Analysis (DEA); Free Disposal Hull (FDH).

These methods determine unambiguous evaluations of the level of efficiency for each enterprise, this allows ranking companies by level of efficiency. In addition, using these methods, evaluations of efficiency can be determined remotely, based on open financial information.

In this study, the DEA method of estimation the effectiveness is used. The DEA method allows evaluating the effectiveness of enterprises, and determining the values of input and output parameters, to make inefficient enterprises 100% effective. Therefore, the use of the DEA method for estimation the efficiency of agricultural enterprises in Ukraine is relevant.

Analysis of recent research and publications. There is a large list of monographs, periodicals devoted to the theory and practice of applying the DEA method in various branches of the economy. In paper [14], an analysis of more than 1400 scientific publications on the application of the DEA method is given. In paper [17], describe the history of the development and application of the DEA method over the past 20 years. Among the national researchers of the theory of the application of the DEA method for estimating the efficiency of agriculture can be noted publication Lissitsa A. [4]. However, the use of the DEA method to estimating the efficiency of Ukrainian agricultural enterprises, to analyzing of change their effectiveness is not fully explored.

The purpose of the article. The purpose of the paper is to develop an algorithm for estimating the efficiency of agricultural enterprises by the DEA method, the dynamics of change their efficiency.

Statement of the material. Here are the main provisions of the DEA method. Consider an economic subject that functions in certain socio-economic and natural conditions that are described by the vector $\xi = (\xi_1, \xi_2, ..., \xi_r)$. The result of the functioning of this economic subject is the process of transforming the resources represented by the vector of input parameters $X = (x_1, x_2, ..., x_m)$ into production of output represented by the vector of output parameters $Y = (y_1, y_2, ..., y_n)$. The combination of optimal consumption of resources $X^* = (x_1^*, x_2^*, ..., x_m^*)$ and production of output $Y^* = (y_1^*, y_2^*, ..., y_n^*)$ that are effective on the Pareto-Kupman principle [16], form the boundary of efficiency $Y^* = Q(X^*, \xi)$. To determine technical efficiency, the American scientist M. Farrell [15] proposed be fixed one of the vectors – *X* or *Y*, and the second vector should be changed proportionally to some coefficient (efficiency) until its end reaches the efficiency boundary. Subsequently, this idea was developed by A. Charns, V. Cooper and E. Roads [12]. They proposed to determine the efficiency by solving the problem of linear programming. The resulting method was called the Data Envelopment Analysis (DEA) method.

In the DEA modeling, one must make assumptions about the effect of scale. In the case of a constant effect of scale, the output parameters change in proportion to the input parameters. In the case of a variable effect of scale, changing the input parameters can lead to a disproportionate change in the output parameters. Depending on the scale-effect assumption, CRS (CCR) and VRS DEA models are distinguished. In determining the effectiveness of the CRS (constant return to scale) or CCR model, the assumption of a constant scale effect is used. R. Benker, A. Charns, and V. Cooper [11] proposed a variable return to scale (VRS) model that takes into account the variable effect of scale. The effectiveness defined by the VRS model is called net technical efficiency, and efficiency using the CRS model is technical efficiency. A feature of the production activity of agricultural enterprises is a disproportionate change in the indicators that characterize the results of production as a result of changes in the volume of expended resources. Therefore, for estimation of the efficiency of agricultural enterprises at the DEA method should use the VRS model.

There are DEA-models that oriented the input and oriented the output. In input-oriented models, the input parameters are minimized at fixed output parameters, and in output-oriented models, the output parameter vector is maximized at fixed vector of input parameters. For agricultural enterprises operating in a known demand for agricultural products, it is more expedient to use a model that minimizes resources (input-oriented model). To use of a model that maximizes production of output (output-oriented model) it is necessary to look for additional channels for marketing products and increasing costs for products storage.

In this study, we will use the VRS-input model. Efficiency measurement using a VRS - input model is based on the solution of a linear programming problem [4]:

$$\min_{E,\lambda_1,\lambda_2,\ldots,\lambda_k} E \tag{1}$$

$$EX_0 = \sum_{k=1}^{K} \lambda_k X_k + d^-, \tag{2}$$

$$Y_0 = \sum_{k=1}^{K} \lambda_k Y_k - d^+, \tag{3}$$

$$\sum_{k=1}^{K} \lambda_k = 1, \ \ \lambda_k \geq 0, \quad k = \overline{1,K}, \tag{4}$$

$$d^-, d^+ \geq 0 \tag{5}$$

where E – input-oriented net technical efficiency;

K – the number of enterprises to be compared;

λ_k – coefficients of linear combination to be defined;

$X_0 = (x_{10}, x_{20}, \ldots, x_{m0})$, $Y_0 = (y_{10}, y_{20}, \ldots, y_{n0})$ – input and output vectors of the enterprise that is estimated;

$X_k = (x_{1k}, x_{2k}, \ldots, x_{mk})$, $Y_k = (y_{1k}, y_{2k}, \ldots, y_{nk})$ – input and output vectors of the *k*-th enterprise;

d^-, d^+ – additional variables.

The nonsingularity condition for solution of problem (1) – (5) is [14]:

$$K \geq \max\{m \times n; 3(n+m)\}. \tag{6}$$

where n – number of input parameters;

m – number of output parameters.

In the analysis of the change in the efficiency of economic subjects, determined by the DEA method, it should be taken into account that the change in efficiency may be due to the change in input and output parameters of the analyzed enterprises and the change of reference enterprises that form the efficiency boundary. In the analysis of the change in the efficiency of enterprises in relation to the previous period, the Malmqvist index [13] is used, which takes into account the shift of the efficiency boundary:

$$Mind = TCng \cdot \frac{E_1^1}{E_0^0}, \tag{7}$$

where $TCng = \sqrt{\frac{E_1^0}{E_1^1} \cdot \frac{E_0^0}{E_0^1}}$ – technical shift of the boundary created by reference enterprises;

E_0^0 – the efficiency of the enterprise, analyzed in the period T_0;

E_1^1 – the efficiency of the enterprise, analyzed in the period T_1;

E_0^1 – the efficiency of the enterprise with indicators in the period T_0 relative of effective enterprises in the period T_1;

E_1^0 – the efficiency of the enterprise with indicators in the period T_1 relative of effective enterprises in the period T_0.

To evaluate the net technical efficiency of agricultural enterprises and change their efficiency, we will apply the following algorithm:

1) Selection a period of time t to determine the net technical efficiency;
2) Create a set $k = \overline{1,K}$ of enterprises that will compare. Testing them for homogeneity (uniformity, the same level of aggregation for the analysis of production activity, the same methods of calculating them as per time, etc.);
3) Define the input parameters $i = \overline{1,m}$ which characterize the activities of enterprises. Parameter refers to the input parameter x_{ik}, $i = \overline{1,m}$, $k = \overline{1,K}$, if it relates to resources and its increase leads to a decrease in efficiency. In order to determine the net technical efficiency, input parameters must be selected in physical terms;
4) Define the output parameters $j = \overline{1,n}$. The parameter refers to the output parameter y_{jk}, $j = \overline{1,n}$, $k = \overline{1,K}$, if it characterizes the result of production activity and its increase leads to an increase in efficiency. For the determination of net technical efficiency output indicators need to be selected in physical terms;

5) Check the condition of nondegeneracy (6). If condition (6) is not satisfied, then back to the items in the order. 2), 3), 4);

6) Check the parameters x_{ik}, y_{jk}, for the presence of "outliers" and elimination them [1];

7) Test availability of correlations between input parameters. For that we calculate partial correlation coefficients and test them for statistical significance. If there is a correlation between parameters, it is necessary to return to 2) and adjust the set of input parameters. The easiest way to eliminate possible correlation between indicators is to reject one of the indicators of the correlated pair. However, the exclusion of the correlated indicators without more detailed analysis is undesirable. Elimination of an important variable from the model suggests error specification. Thus, it is desirable not to exclude the input parameters x_{ik} until colinearity becomes a serious problem. To eliminate the correlation, input parameters can be converted as follows: 1) take the deviation from the average; 2) take relative values instead of absolute; 3) standardize indicators, etc.;

8) Calculate net technical efficiency of each enterprise by model VRS - input;

9) If the chosen time period $t > 1$, we apply the Malmquist index (7) to estimation the change in efficiency;

10) Analyze the obtained estimates.

In the proposed study on the basis of statistical information for 2016-2017 [2, 3, 5-10], the method DEA was defined the values of net technical efficiency of agricultural enterprises of Ukrainian regions in production and sale of grain crops. The dynamics of change of efficiency for 2016-2017 is analyzed.

In calculations, a VRS-input model was used. Input parameters of the model: 1) the area from which grain and legumes crops were harvested, thousand hectares; 2) the amount of mineral and organic fertilizers on 1 hectare, kg; 3) the number of tractors, combine machines on 1 thousand hectares, pc. Output parameters: 1) the production of grain and leguminous crops, thousand tons; 2) the realization of grain and leguminous crops, thousand tons.

In table 1 shows the values of input and output parameters of the model for 2016.

Table 1 – Input and output parameters of the model for 2016

№	Regions	Input and output parameters				
		The area from which grain and legumes crops were harvested, thousand hectares	The amount of mineral and organic fertilizers kg on 1 hectare, kg	The number of tractors, combine machines on 1 thousand hectares, pc.	The production of grain and leguminous crops, thousand tons	The realization of grain and leguminous crops, thousand tons
1	Vinnitsa	867,2	5827	13	5563,5	2714,1
2	Volynskyi	294,5	27781	9	1109,7	440,1
3	Dnipropetrovsk	1092,8	22283	11	3480,80	1734,1
4	Donetsk	543,3	31274	11	1793,40	907,8
5	Zhytomyr	391,20	18806	10	2093,9	899,6
6	Transcarpathian	92	12639	5	412,4	64,4
7	Zaporozhye	882,7	33876	12	2624,4	1624,1
8	Ivano-Frankivsk	151,3	34248	13	772,8	410,9
9	Kievsky	567,1	16123	17	3327,5	2775,9
…	……	…	…	…	…	…
20	Kherson	663,5	11973	11	2262,4	1129,5
21	Khmelnytskyi	534,8	15037	10	3085,5	1609,1
22	Cherkassy	659	22918	12	4091,7	2374,0
23	Chernivtsi	122,5	19294	11	507,4	127,7
24	Chernihiv	653,9	26746	10	3739,9	2583,5

Source: Department of Statistics in the Ukraine [2, 6, 8, 10]

Thus the number of objects under consideration: $K = 24$; the number of input parameters: $m = 3$, and the number of output parameters: $n = 2$. Condition (6) is performed.

The verification of the presence of "outliers" was carried out according to Dixon's criterion. In the Table 2 show the calculated Dixon coefficients for determining the smallest and largest "outliers" in the samples of input and output parameters. Tabular Dixon value for $K = 24$ is of significance level $\alpha = 0{,}01$: $r_{табл} = 0{,}497$. Since $r_{22} < r_{табл}$, there are no outliers in the studied samples.

Table 2 – The Dixon coefficients (r_{22}) to determine "outliers" in the parameters of model for 2016

The Dixon coefficients (r_{22})	The input parameters			The output parameters	
	x_{1k}	x_{2k}	x_{3k}	y_{1k}	y_{2k}
to determine the smallest "outliers"	0,07	0,23	0,28	0,09	0,13
to determine the largest "outliers"	0,20	0,09	0,42	0,28	0,32

Source: Own calculations

For correlation analysis of the sample, which form the values of the input parameters, was calculated partial correlation coefficients: $r_{12.3} = -0{,}017$, $r_{13.2} = 0{,}25$, $r_{23.1} = 0{,}15$. Low values of partial correlation coefficients indicate a lack of linear dependence between input parameters. To check the partial correlation coefficients for statistical significance, t- statistics are calculated: $t_{12} = -0{,}08$, $t_{13} = 1{,}18$, $t_{23} = 0{,}69$. The critical value $t_{кр} = 2{,}086$ was found for the significance level $\alpha = 0{,}05$ and degrees of freedom $K - m - 1 = 20$ in accordance with the table of critical values of the Student's t distribution for two-sided tests. Since $|t_{12}|$, $|t_{13}|$, $|t_{23}| < t_{кр}$, there is not linear correlation between input parameters.

Similarly, on the basis of statistical information [3, 5, 7, 9] the input and output parameters of the model for 2017 are formed. In the Table 3 shows the values of the calculated Dixon coefficients for the determination of "outliers" in the model parameters for 2017.

Table 3 – The Dixon coefficients (r_{22}) to determine "outliers" in the parameters of model for 2017

The Dixon coefficients (r_{22})	The input parameters			The output parameters	
	x_{1k}	x_{2k}	x_{3k}	y_{1k}	y_{2k}
to determine the smallest "outliers"	0,06	0,18	0,26	0,09	0,09
to determine the largest "outliers"	0,19	0,35	0,32	0,16	0,26

Source: Own calculations

Since $r_{22} < r_{табл}$, there are no outliers in the studied samples.

Low values of partial correlation coefficients ($r_{12.3} = 0{,}002$, $r_{13.2} = 0{,}29$, $r_{23.1} = 0{,}16$) indicate a lack of linear dependence between input parameters. To check the partial correlation coefficients for statistical significance, t-statistics are calculated: $t_{12} = 0{,}01$, $t_{13} = 1{,}36$, $t_{23} = 0{,}73$. Since $|t_{12}|$, $|t_{13}|$, $|t_{23}| < t_{кр}$, there is no linear correlation between input parameters. The quality check of the investigated parameters revealed the possibility of their use for the estimation of net technical efficiency of agricultural enterprises of the regions of Ukraine in 2017.

Estimates of net technical efficiency of agricultural enterprises at the production and sale of grain and leguminous crops by regions of Ukraine in 2016, 2017 and indicators characterizing the change in net technical efficiency for 2016-2017 can see in the Table 4.

Table 4 – The net technical efficiency of agricultural enterprises of regions of Ukraine in 2016, 2017, change of indicators of net technical efficiency for 2016-2017 years

№	Regions	Efficiency level		The coefficient of technical progress ($TCng$)	Malmquist index ($Mind$)
		2016	2017		
1.	Vinnitsa	1	1	0,96	0,96
2.	Volynskyi	0,68	0,72	0,97	1,03
3.	Dnipropetrovsk	0,78	0,85	0,76	0,84
4.	Donetsk	0,66	0,79	0,96	1,16
5.	Zhytomyr	0,88	0,86	0,98	0,96
6.	Transcarpathian	1	1	1	1
7.	Zaporozhye	0,69	0,76	0,99	1,08
8.	Ivano-Frankivsk	1	0,99	0,99	0,99
9.	Kievsky	1	1	1	1
10.	Kirovograd	0,74	0,61	0,97	0,8
11.	Lugansk	0,8	0,7	1,33	1,17
12.	Lviv	0,81	0,83	1,03	1,05
13.	Nikolayevsky	0,78	0,93	1,02	1,22
14.	Odesa	1	1	1	1
15.	Poltava	1	1	1	1
16.	Rivne	0,94	0,95	0,99	1,01

17.	Sumy	1	1	1	1
18.	Ternopil	1	1	1	1
19.	Kharkiv	0,89	0,84	0,99	0,93
20.	Kherson	0,82	0,93	1,07	1,21
21.	Khmelnytskyi	0,94	1	0,96	1,03
22.	Cherkassy	1	0,82	0,96	0,79
23.	Chernivtsi	0,87	0,97	1	1,12
24.	Chernihiv	1	1	1	1

Source: Own calculations

Table 5 and Table 6 show the indicators used to analyze the net technical efficiency of enterprises in the studied regions and its changes.

Table 5 – Indicators of net technical efficiency (NTE)

№	Indicators	2016	2017
1.	Average value NTE	0,9	0,89
2.	Standard deviation	0,12	0,12
3.	Minimum	0,66	0,61
4.	The share of regions with NTE =1, %	41,7	37,5
5.	The share of regions with NTE >0,9, %	50	58,3
6.	The share of regions with NTE <0,7, %	12,5	4,2

Source: Own calculations

Table 6 – Indicators of net technical efficiency change for 2016-2017

№	Indicators	The coefficient of technical progress ($TCng$)	Malmquist index ($Mind$)
1.	Average value	0,99	1,01
2.	Standard deviation	0,09	0,11
3.	Minimum	0,76	0,79
4.	The share of regions with $Mind$ =1, %		29,2
5.	The share of regions with $Mind$ >1, %		41,7
6.	The share of regions with $Mind$ <1, %		29,2

Source: Own calculations

According to calculations, for 2016-2017 the share of regions whose agricultural enterprises formed an effective front fell by 4.2% and amounted to 37.5% in 2017.

Thus, 62.5% of the regions can improve production performance by reducing the amount of resources used in production. The average value of the Malmqvist index $Mind = 1{,}01$ calculated for 2016-2017 indicates that the average amount of resources used in the production of the same amount of products has practically remained unchanged.

Findings from the study and the prospects for further research in this area. The DEA method allows to estimation enterprises by efficiency, estimation the change in efficiency over the period under investigation, and identifies the causes of these changes. The problems of practical application of the DEA method for estimation the values of net technical efficiency of agricultural enterprises, dynamics of changes in their efficiency were investigated in the paper. Further development of the obtained results is related to the study of the use of the DEA method for estimating the efficiency of production of crop production in general.

Долгіх Я.В. Алгоритмізація процедури оцінки ефективності сільськогосподарських підприємств методом DEA

***Мета статті** – розробка алгоритму оцінки ефективності сільськогосподарських підприємств методом DEA, динаміки її зміни.*

***Методика дослідження**. Використано економетричний метод (щодо перевірки якості вхідних та вихідних параметрів об'єктів дослідження), DEA - метод (щодо оцінки рівня чистої технічної ефективності досліджуваних сільськогосподарських підприємств).*

***Результати дослідження.** На основі статистичної інформації за 2016-2017 рр., методом DEA оцінена чиста технічна ефективність роботи сільськогосподарських підприємств регіонів України в галузі виробництва та реалізації зернових культур, проведений аналіз зміни їх ефективності.*

***Елементи наукової новизни.** Розроблено алгоритм оцінки чистої технічної ефективності сільськогосподарських підприємств та її зміни.*

***Практична значущість.** Результати досліджень можуть бути використані для ранжування сільськогосподарських підприємств України за*

ефективністю, оцінки динаміки зміни їх ефективності, виявлення причин цих зміни. Табл.: 5. Бібліогр.: 17.

Ключові слова: *вхідні та вихідні параметри, чиста технічна ефективність, метод DEA, модель VRS – input, індекс Малмквіста, сільськогосподарські підприємства.*

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Долгих Я.В. Алгоритмизация процедуры оценки эффективности сельскохозяйственных предприятий методом DEA

Цель статьи *– разработка алгоритма оценки эффективности сельскохозяйственных предприятий методом DEA, динамики изменения их эффективности.*

Методика исследования. *Использованы эконометрический метод (для проверки качества входных и выходных параметров объектов исследования), DEA - метод (для оценки чистой технической эффективности исследуемых сельскохозяйственных предприятий).*

Результаты исследования. *На основе статистической информации за 2016-2017 гг., методом DEA оценена чистая техническая эффективность работы сельскохозяйственных предприятий регионов Украины в области производства и реализации зерновых и зернобобовых культур, проведён анализ изменения их эффективности.*

Элементы научной новизны. *Разработан алгоритм оценки чистой технической эффективности сельскохозяйственных предприятий и динамики её изменения.*

Практическая значимость. *Результаты исследований могут быть использованы для ранжирования сельскохозяйственных предприятий Украины* *по эффективности, оценки динамики изменения их эффективности, выявления причин этих изменения. Табл.: 5. Библиогр.: 17.*

***Ключевые слова**: входные и выходные параметры, чистая техническая эффективность, метод DEA, модель VRS-input, индекс Малмквиста, сельскохозяйственные предприятия.*

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