CDC 338.43: 519.8

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DEA METHOD FOR ESTIMATING THE KEY RESOURCE INDICATORS OF AGRICULTURAL ENTERPRISES OF THE SUMY REGION

Formulation of the problem. Recently a foreign practice widely used methods of evaluating the performance based on the concept of the effective frontiers for production capacity. Evaluation of efficacy based on the concept of effective frontiers performed parametric and nonparametric methods. By parametric methods, the effective frontier is constructed as the marginal regression function. Nonparametric methods carry out a piecewise-linear approximation of the effective frontier by methods of mathematical programming. An advantage of using a non-parametric DEA method is the ability to determine the optimal values of input and output data that allow the company to achieve 100 % efficiency. Therefore, the use of DEA method for estimating the key resource indicators of the agricultural enterprises of the Sumy region that provide their 100 % efficiency is of great importance.

Analysis of recent research and publications. There are many scientific papers devoted to the theory and practice of DEA method application in the various sectors of the economy. The paper [11] provides an overview of 4015 scientific publications on the application of DEA during last 30 years. Analysis of national scientific papers [2, 3, 5 and others] on the application of DEA method in agriculture highlighted the need for further research on improving the practical use of the method.

The purpose of the article is to determine, by DEA method, key resource indicators for the agricultural enterprises of the Sumy region to make inefficient enterprises 100 % effective when producing cereals and legumes.

Statement of the material. The idea of evaluating the efficiency based on the concept of the effective frontiers for production capacity belongs to an American scientist M. James Farrell [12]. In case a point in the input/output space which corresponds to the analyzed company is situated on the effective frontier, its activity appears 100 % effective. If the point is not on the effective frontier, the activity of the company is ineffective. To assess the cost-effectiveness, M. George Farrell offered to fix one of the input or output vectors, and to change another vector in proportion to a certain ratio (performance indicator) to achieve effective frontiers. Later this idea was developed by A. Charnes, W. Cooper, and E. Rhodes [10], who have reduced the problem of assessing the efficiency to the problem of mathematical programming. The proposed method is called Data Envelope Analysis (DEA).

DEA models can be divided according to the following criteria: 1) returns to scale: with constant returns to scale (CRS-model), and with variable returns to scale (VRS-model); 2) focus: focus on input (input-model), the output (output-model) or without orientation. In CRS-models, output parameters are changed in proportion to the input. The variable return to scale in VRS-models is characterized by disproportionate change of output parameters when changing the input. Taking into account the variable returns to scale brings to the definition of the greater number of companies as being efficient than at the constant returns to scale. The effectiveness of that model is defined by CRS called technical efficiency, and the model of VRS - pure technical efficiency. In the input-oriented models, the set of input parameters for fixed output is minimized, when in the output-oriented models, output vector is maximized with fixed input vector.

Listed DEA models allow you to use various options for measuring performance, therefore, one of the objectives of the study is the choice of the model. Let us choose a model to assess the relative efficiency of agricultural enterprises and identify the key resource indicators that allow inefficient companies to become 100 % effective. In agriculture the increase in the use of resources leads to decreasing rates of crop production. Therefore, VRS-model should be used when assessing the effectiveness of crop production.

Efficiency measurement using a VRS-input model is based on the solution of a linear programming problem [7]:

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

$$EX_0 = \sum_{k=1}^{K} \lambda_k X_k + d^-, \; Y_0 = \sum_{k=1}^{K} \lambda_k Y_k - d^+ \tag{2}$$

$$\sum_{k=1}^{K} \lambda_k = 1, \; \lambda_k \geq 0 \quad k = \overline{1,K} \tag{3}$$

$$d^-, d^+ \geq 0, \tag{4}$$

where E - input-oriented net technical efficiency;

λ_k - coefficients of linear combination to be defined;

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

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

K – the number of enterprises to be compared;

d^-, d^+ - additional variables that characterize the resources spent inefficiently and insufficient productions respectively.

The nonsingularity condition for solution of problem (1)-(4) is [11]:

$$K \geq \max\{m \times n; 3(n+m)\}. \tag{5}$$

The Malmquist productivity index is used to analyze the dynamics of productivity changes for several years [8, 9].

Along with the selection of the DEA model type, important tasks for investigators are the formation of the variety of objects to be compared and a set of input and output parameters. Let us create an algorithm of statistical database that forms input and output parameters for DEA model:

1) Formation of a variety of objects being evaluated by $k = \overline{1,K}$. 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.), and the presence of heterogeneity of the modalities. If there are so-called uncontrolled defined conditions over the system, then we classify objects $k = \overline{1,K}$ into homogeneous groups;

2) Referring the index to input parameter x_{ik}, $i = \overline{1,m}$, $k = \overline{1,K}$ if it relates to resources, and its growth brings to reduced efficiency;

3) Referring the index to output parameter y_{jk}, $j = \overline{1,n}$, $k = \overline{1,K}$ if it describes the result of production activity and its growth brings to increased efficiency;

4) Condition (5) test. If condition (5) is not satisfied, then back to the items in the order. 1) 2) 3);

5) Elimination of mixing volume indicators and index numbers. All activities must be expressed either in volume indicators, or in index number;

6) Taking into account inflation. If you plan to estimate relative performance for different periods of time and there are cost parameters among x_{ik}, y_{jk}, it is necessary to list them adjusted for price index;

7) Testing indicators x_{ik}, y_{jk} for outliers and their rejection [1, 6]. The presence of outliers leads to displacement of the efficiency frontier;

8) Testing 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.

On the basis of statistical information for 2015 [4], the method of DEA and the VRS-input model, the proposed research offers an estimate of pure technical efficiency of agricultural enterprises of the Sumy region in production of grain and leguminous crops and suggests such calculated input values according to which the Sumy region economy will be 100 % effective.

Evaluation of the productive efficiency of the agricultural enterprises is carried out for 13 districts of Sumy region ($K = 13$), belonging to the same natural-climatic zone - woodland. Thus the companies under consideration belong to a homogenous group (the same climatic conditions and soil structure). Iinput parameters of the model: 1) x_{1k} - the area from which grain and leguminous crops were harvested per 1 worker, hectare; 2) x_{2k} - the amount of mineral and organic fertilizers on 1 hectare, quintal; 3) x_{3k} - the number of tractors, units. Output parameter of the model: 1) y_{1k} - the production of grain and leguminous crops, quintal. Table 1 shows input and output parameters of the model for estimating net technical efficiency of grain and leguminous crops production by district agricultural enterprises of the Sumy region [4].

Table 1 – Model input and output parameters for estimating net technical efficiency of grain and leguminous crops production by district agricultural enterprises of the Sumy region in 2015

No	District	Input			Output
		Area per 1 worker, hectare	Amount of mineral and organic fertilizers on 1 hectare, quintal	Number of tractors, unit	Production of grain and leguminous crops, quintal
1	Bilopilsky	69,25	128	276	3322944
2	Burynsky	139,71	106	207	2699540
3	Velykopysarivsky	39,15	106	232	1280322
4	Konotopsky	47,61	110	339	2345788
5	Krasnopilsky	30,77	89	332	1456610
6	Krolevetsky	35,94	141	221	1125531
7	Lebedynsky	49,93	76	247	2751500
8	Lypovodolynsky	22,45	74	425	1548971
9	Nedryhailivsky	57,24	109	85	2068885
10	Okhtyrsky	19,46	102	358	1465406
11	Romensky	44,83	128	363	4567523
12	Sumsky	27,72	112	480	2997482
13	Trostyanetsky	37,20	114	125	1463806

Source: Department of Statistics in the Sumy Region [4]

Thus the number of objects under consideration: $K = 13$; the number of input parameters: $m = 3$, and the number f output parameters: $n = 1$. Condition (5) is performed.

Testing for availability of outliers was carried out by means of Dixon's ratio test [1]. Table 2 shows the calculated Dixon ratios to determine the least outliers in the sample values of input parameters x_{1k}, x_{2k}, x_{3k} and major outliers in the sample output parameter y_{1k}.

Table 2 - Estimated Dixon ratios

Estimated values for Dixon ratio (r_{21}) to determine the following:			
least outliers in the samples of the input parameters			major "outliesr" in the samples of the output parameter
x_{1k}	x_{2k}	x_{3k}	y_{1k}
0,166	0,278	-0,216	0,478

Source: Own calculations

Tabular Dixon ratio for $K = 13$ is of significance level $\alpha = 0,05$: $r_{табл} = 0,521$.. Since $r_{21} < r_{табл}$, there are no outliers .in the studied samples.

Partial correlation coefficients: $r_{12.3} = 0,05$, $r_{13.2} = -0,39$, and $r_{23.1} = -0,18$ were designed for correlation analysis of samples that form the input parameters of the study. Low values of partial correlation coefficients show no linear relationship between input parameters. The t- statistics: $t_{12} = 0,17$, $t_{13} = -1,04$, $t_{23} = -0,51$ are designed to test partial correlation coefficients for statistical significance. The critical value $t_{кр} =$ 2,23 was found for the significance level $\alpha = 0,05$ and degrees of freedom $n - m$ =10 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 no linear correlation between input parameters.

According to calculations, in 2015 agricultural enterprises of Lebedinsky, Lypovodolynsky, Nedryhailivsky, Akhtyrsky, Romensky, Sumsky, and Trostyanetky regions had net technical efficiency equal to 1. Estimates of net technical efficiency of other districts of the Sumy region one can see in the Table 3.

Table 3 - Recommended values of key resource indicators for the agricultural enterprises of the Sumy region in the production of grain and leguminous crops

No	District	Efficiency level	Input			Recommended input		
			Area per 1 worker, hectare	Amount of mineral and organic fertilizers on 1 hectare, quintal	Number of tractors, unit	Area per 1 worker, hectare	Amount of mineral and organic fertilizers on 1 hectare, quintal	Number of tractors, unit
1	Bilopilsky	0,87	69,25	128	276	50,29	111,49	240
2	Burynsky	0,92	139,71	106	207	52,47	97,85	191
3	Velykopysarivsky	0,93	39,15	106	232	36,22	98,07	215
4	Konotopsky	0,82	47,61	110	339	39,06	90,25	278
5	Krasnopilsky	0,96	30,77	89	332	29,64	85,71	320
6	Krolevetsky	0,89	35,94	141	221	31,82	110,36	196

Source: Department of Statistics in the Sumy Region [4] and own calculations

DEA method allows finding the target values of input and output variables that helps inefficient economy to become effective. Table 3 shows the calculated recommended values of the input parameters by which the agricultural enterprises of the Sumy region will be 100 % effective.

Findings from the study and the prospects for further research in this area. DEA method allows finding the target values of input and output variables that helps inefficient company to become 100 % effective. The paper investigates the practical use of DEA method in order to determine such input parameters that improve the efficiency of the company and raise it up to 100 %. Further studies are planned for analyzing allocative efficiency of crop production among agricultural enterprises of the Sumy region.

Долгіх Я.В.

Метод DEA при оцінці основних ресурсних показників сільськогосподарських підприємств Сумської області

Ціль статті – визначити за методом DEA основні ресурсні показники сільськогосподарських підприємств Сумської області, що дозволять неефективним підприємствам стати 100 відсотків ефективними в галузі виробництва зернових та зернобобових культур.

Дослідження виконано методами економіко-математичного моделювання.

Проаналізовано теоретичні та методологічні аспекти методу DEA. Обґрунтовано доцільність використання моделі VRS – input методу DEA для оцінки ефективності сільськогосподарського виробництва. Розроблено алгоритм створення бази статистичних даних, що формують вхідні та вихідні параметри моделі DEA. На основі статистичної інформації здійснено обчислення рівня чистої технічної ефективності виробництва зернових та зернобобових культур сільськогосподарських підприємств районів Сумської області за 2015 р. Розраховані значення ресурсних показників, що дозволять неефективним підприємствам стати 100 відсотків ефективними в галузі виробництва зерна та зернобобових культур.

Бібліогр.: 12.

Ключові слова: основні ресурсні показникі, вхідні та вихідні показникі, чиста технічна ефективність, метод DEA, сільськогосподарське виробництво.

Долгих Я.В.

Метод DEA для определения основных ресурсных показателей сельскохозяйственных предприятий Сумской области

Цель статьи – методом DEA определить значения основных ресурсных показателей сельскохозяйственных предприятий Сумской

области, позволяющие неэффективным предприятиям стать 100% эффективными в области производства зерновых и зернобобовых культур.

Исследование проведено методами экономико - математического моделирования.

Проанализированы теоретические и методологические аспекты метода DEA. Обоснована целесообразность применения модели VRS – input метода DEA для оценки эффективности сельскохозяйственного производства. Разработан алгоритм создания базы статистических данных, формирующих входные и выходные параметры модели DEA. На основе статистической информации оценена чистая техническая эффективность производства зерновых и зернобобовых культур сельскохозяйственными предприятиями районов Сумской области за 2015 г. Рассчитаны значения ресурсных показателей, позволяющие неэффективным предприятиям стать 100% эффективными в области производства зерновых культур.

Библиогр.: 12.

Ключевые слова: основные ресурсные показатели, входные и выходные показатели, чистая техническая эффективность, метод DEA, сельскохозяйственное производство.

Dolgikh, Yana V.

DEA Method for Estimating the Key Resource Indicators of Agricultural Enterprises of the Sumy Region

The purpose of the article is to work out values of the key resource indicators for agricultural enterprises of the Sumy region by DEA, allowing inefficient enterprises be 100% effective in the production of grain and grain legumes.

The study was conducted by methods of economic and mathematical modeling.

The author has analyzed theoretical and methodological aspects of DEA method, and substantiated the expediency of using the VRS-input model of DEA to evaluate relative efficiency of the agricultural production. The algorithm for creating a statistical database that forms inputs and outputs of the DEA model has been developed. On the basis of statistical information for 2015, the author has estimated net technical efficiency of grain and leguminous crops production by agricultural enterprises of the Sumy region for 2015.

The author has calculated the resource indicators that allow inefficient enterprises be 100% effective in the field of grain and grain legumes production.

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Keywords: key resource indicators, inputs and outputs, net technical efficiency, DEA, agricultural production.

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