Analysis of nonparametric methods for assessing the comparative efficiency of agro-industrial enterprises

I V Kovalev1,2,3,4, N V Zenutkin1, A A Voroshilova1,3, N A Testoyedov4,5, E N Golovenkin4,5 and A K Shatrov1,4,5

1 Siberian Federal University, 79, Svobodny pr., Krasnoyarsk, 660041, Russia
2 Krasnoyarsk State Agrarian University, 90, Mira pr., Krasnoyarsk, 660049, Russia
3 Krasnoyarsk Science and Technology City Hall of the Russian Union of Scientific and Engineering Associations, 61, Uritskogo street, Krasnoyarsk, 660049, Russia
4 Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russia
5 JSC Academician M.F. Reshetnev «ISS» Zheleznogorsk, Krasnoyarsk region, Russia

E-mail: kovalev.fsu@mail.ru

Abstract. The paper presents an analysis of nonparametric methods for assessing the comparative efficiency of agro-industrial enterprises. The authors analyzed Data Envelopment Analysis, Free Disposal Hull Analysis and Productivity Index. The most important characteristics of the models are highlighted, which are used to compare the methods. The preference was given to the DEA method, since the other described methods and their modifications do not allow taking into account the factors influencing the efficiency of agricultural enterprises. In particular, the factor of the territorial location of the enterprise. But it is the climatic zone of the location of the enterprise that has a significant impact on the efficiency of agricultural activities. When implementing the assessment method, it is necessary to take into account the fact that climatic conditions, depending on the geographical location, are always different.

1. Introduction

One of the key factors in determining the effectiveness of agro-industrial enterprises is the definition of the base model, which is used as part of the method for determining their effectiveness.

There are several common methods that can be used both for assessing objects of various industries and enterprises in the agricultural sector [1-7]. These are some of them:

- least square method;
- maximum likelihood method;
- method of Bayesian estimates.

The design quality of an object can be assessed by determining the mathematical expectation of the conditional probability [2]. There is also a method for ranking objects [3]. It is used to evaluate objects in which the parameters are determined by qualitative rather than quantitative characteristics. The described methods, in general, allow us to assess the optimality / non-optimality of the technological process. Let us consider several methods for assessing structurally complex enterprises, the type of
which includes large agro-industrial holdings for which the effectiveness of the compared objects can also be assessed by the mathematical expectation or by the ranking method, since this method is suitable for assessing the quality indicators of objects. We will consider some of the methods in details below.

2. Nonparametric methods

There are parametric and nonparametric methods for analyzing the efficiency of enterprises. In this paper, we will consider nonparametric methods in order to assess their advantages and disadvantages. This will make it possible to give recommendations on the application of methods for assessing the economic efficiency of agricultural enterprises. Let us analyze the following nonparametric methods:

- Data Envelopment Analysis (DEA);
- Free Disposal Hull Analysis (FDH);
- Productivity Index (PI).

2.1. Data Envelopment Analysis

The Data Envelopment Analysis (DEA) method was developed by American scientists A. Charnes, W. W. Cooper and E. Rhodes in 1978. This method is used to calculate the efficiency of enterprises in various economic areas. Such objects can be industrial and agricultural enterprises, banks, healthcare and educational institutions, government and justice bodies, etc. Thus, enterprises can be of any type, for example, agricultural processing enterprises, enterprises - producers of agricultural products, banks, lending to agricultural producers, educational agricultural institutions, etc.

DEA method is considered in detail in many works [8-12]. We only note that for a set of \( N \) objects \( K \) input parameters and a set of \( M \) output parameters are identified. \( K \) and \( M \) parameters are presented by \( x_i \) and \( y_i \) vector columns for each \( i \)-th object. We will define \( X \) matrix as a matrix of input parameters of \( K \times N \) dimension, and \( Y \) matrix as a matrix of output parameters of \( M \times N \) dimension. Using the data obtained, we can pass to the linear programming problem taking into account the duality theory [9].

2.2. Free Disposal Hull Analysis

The Free Disposal Hull Analysis (FDH) method was developed by Deprins, Simar, Tulkens [13] in 1984. This method is a special case of the DEA method.

The peculiarity of the method lies in the fact that the efficiency of the enterprise is calculated based on the parameters actually considered, and not hypothetical (as in the DEA method).

A set of FDH model objects using two \( x_1 \) and \( x_2 \) input resources for the production of \( y = 1 \) unit of production is shown in figure 1.

![Figure 1. Representation of FDH model.](image)
The boundary shown in Figure 1 forms the minimum set of production possibilities, and connects the evaluated objects. In formalized form, this can be represented by the following formula:

\[ P_{FDH} = \{(x, y) \mid x \geq x_i, y \leq y_i, x, y \geq 0, i = \overline{1, n}\} \]  

(1)

where \(x_i(\geq 0), y_i(\geq 0)\) are real parameters considered for \(i = \overline{1, n}\) enterprises.

According to this formula, if the input parameters of a point are not less than the input parameters of each compared \(i\)-th object \((x_i)\), and if the output parameters are not more than that of each \(i\)-th object \((y_j)\), then such a point is included in the set of production capabilities.

This method will determine the critical point \(Q'\), which is shown in figure 1. This will, however, leave the unused reserve in the segment from \(Q'\) to \(B\) unaddressed, which makes it possible to assume "free disposal", due to which the name of this model was given.

### 2.3. Productivity Index (PI)

Usually, indices are used to assess how much the indicator in some conditions exceeds the same indicator, but under other conditions. These conditions can change over time, affecting the characteristics, then we talk about dynamic indices. If conditions change depending on geographic location, then the indices are called territorial. This aspect is essential in assessing the comparative efficiency of agricultural enterprises, since the territorial location of these enterprises in different climatic conditions leads to the dependence of their indicators on the territory (for example, yield taking into account the average annual temperature, humidity, etc.). The idea of the Productivity Index (PI) for agricultural enterprises is based on the general theory of indexes [14-16].

Indexes make it easy to evaluate the performance of similar objects. Such indices are defined as the ratio of the weighted average output parameters to the weighted average input parameters.

Examples of performance indices in the analysis of the efficiency of production facilities are [15]:

- Malmquist Productivity Index, paired with DEA method;
- Tornqvist Productivity Index;
- Fisher Productivity Index.

Indices calculated on the basis of physical volume (for example, agricultural products produced) make it possible to evaluate heterogeneous objects of agricultural production. Sometimes such indices are the only way to show changes over time in parameters that are expressed through a weighted factor, for example, labor intensity.

If the objects are homogeneous, then the change in parameters over time can be calculated based on the ratio of the value of indicators for the reporting period to the baseline [12].

### 3. Results

To substantiate a suitable method for assessing the efficiency of agricultural enterprises, let us compare the features of the methods considered. Let's highlight the most important characteristics of the models described in the analysis in order to compare them with each other. Table 1 presents a comparative characteristic of the selected criteria of the considered nonparametric methods.

| Methods | Peculiarities |
|---------|---------------|
|         | efficiency frontier | input and output parameters | efficiency frontier view |
| DEA     | Determined by a set of inputs and outputs | Rearrangement possible | Connects the most efficient objects. Piecewise linear |
| FDH     | The border is defined as stepped | Interchangeability is not provided | Has a stepped appearance |
Nonparametric methods, according to the analysis and table 1, have the following features:

- random factors do not affect the efficiency of objects;
- the border is constructed with no mean errors.

Additionally, we note some advantages of nonparametric methods over parametric ones:

- there is no need to initially define the form of the efficiency frontier;
- lack of assumptions about the efficiency of objects;
- accurate calculation of the efficiency indicator for each object;
- allow comparison of large amounts of heterogeneous data (DEA).

From the above, we can conclude that the DEA method allows one to estimate a large number of input and output parameters in a vector representation, and this method is more suitable than others for assessing the comparative efficiency of agricultural enterprises. Concerning other methods, we note that the FDH method does not allow identifying objects with maximum efficiency, since it does not allow permutation of input and output indicators. The PI method allows you to evaluate the effectiveness of objects only in a certain period of time.

4. Conclusion
The DEA method has existed for a long time; therefore, a huge number of its modifications have been developed [8-20]. The main models are models with constant and variable effect of scale (Constant Return to Scale, Variable Return to Scale). Variable economies of scale make it possible to compare objects of different production capacities [15]. Other modifications assess the degree of influence of each individual parameter on efficiency [16, 17].

BCC, FGL, CTT models allow you to evaluate banks, educational institutions, hospitals, etc. taking into account the peculiarities of their functioning. DEA – BSC models were developed for multicriteria analysis of investment portfolios [10].

However, the described methods and their modifications do not allow taking into account the factors influencing the efficiency of agricultural enterprises. First of all, this is the factor of the location of the enterprise, namely the climatic zone of the location, which affects the efficiency of agricultural activities.

When modifying the DEA model, it is necessary that the selected factors are complex, take into account the characteristics of agricultural objects, which are most significant when calculating efficiency.

The climatic zone in which the object is located is a significant factor for the following reasons:

- taking into account the geographical location of agricultural enterprises, depending on each other;
- climatic conditions are always different depending on the geographic location.

It can be concluded that when taking into account the geographical location of agricultural enterprises, it is possible to more accurately take into account the peculiarities of the operation of these enterprises and, thereby, more accurately assess their comparative efficiency.

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