APPLICATION OF DATA ENVELOPMENT ANALYSIS TO MEASURE THE EFFICIENCY OF THE METAL PRODUCTION SECTOR IN EUROPE

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Abstract

The main purpose of this paper is to compare the efficiency of sector manufacturing base metal in 25 European countries. The study applies Data Envelopment Analysis (DEA), which is a non-parametric method based on production theory and the principles of linear programming. It enables one to assess how efficiently a firm, organization, country, or such other Decision Making Unit (DMU) uses the available inputs to generate a set of outputs relative to other units in the data set. This article presents the use the input-oriented CCR and BCC model, to determine overall technical efficiency, pure technical efficiency and scale efficiency of sector manufacturing base metal in European countries. The analysis gives a possibility to create a ranking of counties. The results point out the reasons of the inefficiency and provide improving directions for the inefficient Decision Making Units.

Keywords: efficiency, manufacture of base metal, Data Envelopment Analysis

1. INTRODUCTION

Against the backdrop of the economic slowdown observed in recent years, it is necessary to increase productivity of the manufacturing industry and associated services in order to support economic growth and a favorable labor market situation, as well as to restore the sound condition and sustainable development of the EU economy. Industry is therefore in the foreground of the new growth model for the EU economy, which has been unveiled in the "Europe 2020" strategy.

Efficiency is the main criterion for a comprehensive assessment of activities of an entire industry sector [1] and individual economic operators [2]. Efficiency is considered to be one of the sources of wealth for nations and at the same time various ways of defining and measuring it are proposed. A macro-economic approach to economic efficiency refers to how well the economy allocates scarce resources to meet the needs and demands of consumers [3]. In turn, a microeconomic approach to efficiency is linked to individual enterprise and defined as the relation between the effects obtained by a particular economic operator and its input [4]. Fried, Lovell and Schmidt refer to such a relation between effects and input as productivity, while defining efficiency as the relation between the productivity of a given entity and the maximum productivity achievable in certain technological circumstances [5]. In this context, efficiency is a relative measure, while productivity is an absolute measure.

2. LITERATURE REVIEW

In economic literature methods for testing the efficiency of economic entities can be classified as: parametric, non-parametric and indicator-based.

Parametric methods are based on the function of production known in microeconomic theory, which defines the relationship between input and effects. The parameters of this function are determined by means of standard econometric estimation tools. This function determines the efficiency curve, while deviations from this curve are treated as being caused by random errors and inefficiency. The parametric method group - apart from the production function - includes, inter alia: Thick Frontier Approach - TFA [6], Stochastic Frontier Approach - SFA [7], [8], Distribution Free Approach - DFA [9].

Non-parametric methods do not take into account the impact of random factors on the efficiency of the tested elements and do not include potential measurement errors. Also, non-parametric methods do not require the adoption of any assumptions regarding the functional relationship between expenditure and effects. The efficiency curve is determined on the basis of empirical data using linear programming. Non-parametric methods include Data Envelopment Analysis - DEA [4] and Free Disposal Hull - FDH [6].

In turn, establishing efficiency in the case of indicator methods consists in the comparison of economic-financial indicators between businesses, e.g. indicators of profitability, productivity and work efficiency [10].

Other multi-criteria based assessment methods for entities and, in particular, ones for the creation of rankings, are methods derived from operational research. The following are examples of such methods: AHP [11], ELECTRE [12], PROMETHEE [13], [14], and ORESTE [15].

Parametric and non-parametric methods were used to evaluate and create rankings of various entities, such as hospitals [16], educational bodies (schools, universities) [17], [18], banks [19], farms [20], agribusiness companies [21], [22].

The use of non-parametric methods for the assessment of the effectiveness of European industry is not a very popular direction of research. The issue of efficiency in industry is usually considered in literature from a one-dimensional perspective, using conventional economic and financial indicators, such as: labor productivity, asset productivity or profitability, based on both sectorial data and an analysis of individual companies.

The purpose of this article is to use the Data Envelopment Analysis method to compare the technical efficiency of the metal production sector in 25 European countries. The assumption is that as a result of the research a ranking would be created, countries with a high efficiency of metal-producing sectors would be indicated and, based on the principles of benchmarking, the directions for efficiency improvements would be indicated for individual national sectors deemed to be ineffective.

3. THE METHODOLOGY OF DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis (DEA) is a non-parametric mathematical programming approach for measuring relative efficiencies of comparable DMUs with respect to multiple inputs and outputs [4]. The DEA models may be categorized based on two criteria: model orientation and type of returns to scale. Depending on the model orientation a calculation is made of technical efficiency focused on the input minimization or of technical efficiency focused on the output maximization. But taking into account the type of returns to scale the following models are distinguished: the CCR model providing for constant returns to scale (the name derives from the authors of the model: Charnes-Cooper-Rhodes [4]) and the BCC model providing for changing return to scale (the name derives from the authors of the model: Banker-Charnes-Cooper [23]). The CCR model is used to calculate the overall technical efficiency (Technical Efficiency - TE) and the BCC model is used to calculate pure technical efficiency (Pure Technical Efficiency - PTE).

3.1 CCR-model

Charnes, Cooper and Rhodes [4] introduced a measure of efficiency for each DMU that is obtained as a maximum of a ratio of weighted outputs to weighted inputs. The weights for the ratio are determined by a restriction that the similar ratios for every DMU have to be less than or equal to unity, thus reducing multiple inputs and outputs to single "virtual" input and single "virtual" output without requiring preassigned weights. The efficiency measure is then a function of weights of the "virtual" input-output combination. Formally the efficiency measure for the DMUo can be calculated by solving the following mathematical programming problem [24]:

$$\max_{u,v} h_0(u,v) = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{1}$$

subject to

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \quad (j = 1,2,\ldots,j_{0,}\ldots,n) \tag{2}$$

$$u_r, v_i \geq 0; \quad r = 1, 2, \ldots, s; \; i = 1, 2, \ldots, m \tag{3}$$

where

x_{ij} - the observed amount of input of the i_{th} type of the j_{th} DMU ($x_{ij} > 0$, $i = 1, 2, ..., n$, $j = 1, 2, ..., n$)

y_{rj} - the observed amount of output of the r_{th} type for the j_{th} DMU ($y_{rj} > 0$, r = 1, 2, ..., s, $j = 1, 2, ..., n$).

The variables u_r and v_r are the weights to be determined by the above programming problem. However, this problem has infinite number of solutions since if (u^*, v^*) is optimal then for each positive scalar α (αu^*, αv^*) is also optimal. Following the Charnes-Cooper transformation, one can select a representative solution (u, v) for which

$$\sum_{i=1}^{n} v_i x_{io} = 1 \tag{4}$$

to obtain a linear programming problem that is equivalent to the linear fractional programming problem (1) - (4). The problem (5) - (8) is so-called "input-oriented CCR model", in which the maximization is oriented toward the choice of "virtual multipliers" (i.e. weights) u and v which produces the greatest rate of "virtual output" per unit of "virtual input". Thus, denominator in the above efficiency measure h_o is set to equal one and the transformed linear problem for DMU_0 can be written:

$$\max_{u} z_0 = \sum_{r=1}^{s} u_r y_{ro} \tag{5}$$

subject to

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1,2,\ldots,n \tag{6}$$

$$\sum_{i=1}^{n} v_i x_{io} = 1 \tag{7}$$

$$u_r, v_i \geq 0; \quad r = 1, 2, \ldots, s; \; I = 1, 2, \ldots, m \tag{8}$$

For the above linear programming problem, the dual can be written as:

$$\min_{\lambda} z_o = \Theta_0 \tag{9}$$

subject to

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0}, \quad r = 1,2,\ldots,s \tag{10}$$

$$\Theta_0 x_{i0} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0, \quad i = 1,2,\ldots,m \tag{11}$$

$$\lambda_j \geq 0, \quad j = 1,2,\ldots,n \tag{12}$$

The value of Θ is the technical efficiency score for the particular DMU_0. The value of Θ is always less then or equal unity. DMUs for which Θ < I are relatively inefficient and those for which Θ = I are relatively efficient, having their virtual input-output combination points lying on the frontier. The frontier itself consists of linear facets spanned by efficient units of the data, and the resulting frontier production function (obtained with the implicit constant returns-to-scale assumption) has no unknown parameters.

3.2 BCC-model

Banker et al. [23] extended the earlier work of Charnes at al. [4] by providing for variable returns of scale and thus mitigates the impact of economies of scale on operational efficiency. The BCC model adds an additional variable u_0 to identify the returns of scale of the target DMU. The input-oriented BCC-model for the DMU_0 can be written formally as [24]:

$$\min_{\lambda} z_o = \Theta_0 \tag{13}$$

subject to

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0}, \quad r = 1,2,\ldots,s \tag{14}$$

$$\Theta_0 x_{i0} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0, \quad i = 1,2,\ldots,m \tag{15}$$

$$\sum_{j=1}^{n} \lambda_j = 1 \tag{16}$$

$$\lambda_j \geq 0, \quad j = 1,2,\ldots,n \tag{17}$$

The BCC-efficiency scores have similar interpretation as in the CCR model. With the overall technical efficiency and pure technical efficiency calculated, it is possible to determine the object scale efficiency (Scale Efficiency - SE). The scale efficiency is defined as a ratio of DMUs overall technical efficiency score (measured by the CCR-model) and pure technical efficiency score (measured by the BCC model), according to the formula: SE = TE/PTE [25]. Scale efficiency (SE) calculated in this manner denotes the degree to which the object is efficient in relation to the optimum enabling the maximal use of inputs.

4. RESULTS

The study was based on source data for 2010 collected in the databases of Eurostat regarding the metal manufacturing sector in 25 European countries. The CCR and BCC models were used to determine the relative efficiency of metal production industries across Europe. Models aimed at minimizing inputs (*input - oriented*) were chosen, which was based on the strong pressure from managers to reduce costs and thus expenditure on production as a result of the still ongoing economic slowdown. The following variables were set for DEA models:

- output y_1 - turnover (million Euro)
- input x_1 - gross investment in tangible goods (million Euro)
- input x_2 - number of employees (people)
- input x_3 - total purchases of goods and services (million Euro)

As a result of the study a ranking of countries was created according to the efficiency index for the metal manufacturing sector (see **Table 1**). The average technical efficiency of the metal production sector in Europe in 2010 achieved a fairly high level. The DEA efficiency indicator in the CCR model was 0.84 and 0.92 in the BCC model.

It was found that among the 25 studied countries, 4 countries (CCR model) and 10 countries (BCC model) had a metal production sector that was effective, i.e. the efficiency ratio stood at 1. The group of efficient DMUs in both models included the following countries: Norway, Austria, Ireland and Cyprus. In addition, the BCC model deemed the following as efficient: Belgium, Germany, Estonia, Italy, Netherlands, and United Kingdom.

Table 1 The technical efficiency, scale efficiency and returns to scale of sectors manufacturing base metal in European countries in 2010

DMU (Country)	CCR-model Technical efficiency	BCC-model Pure technical efficiency	SE Scale Efficiency	RTS Return to Scale
BE	0.94	1.00	0.94	Decreasing
BG	0.71	0.76	0.95	Decreasing
CZ	0.71	0.85	0.83	Decreasing
DK	0.91	0.95	0.95	Constant
DE	0.92	1.00	0.92	Decreasing
EE	0,76	1.00	0.76	Increasing
IE	1.00	1.00	1.00	Constant
ES	0.90	0.96	0.94	Decreasing
HR	0.62	0.74	0.84	Constant
IT	0.90	1.00	0.90	Decreasing
CY	1.00	1.00	1.00	Constant
LV	0.68	0.80	0.85	Constant
LT	0.66	0.69	0.95	Increasing
HU	0.73	0.91	0.80	Decreasing
NL	0.97	1.00	0.97	Decreasing
AT	1.00	1.00	1.00	Constant
PL	0.70	0.86	0.81	Decreasing
PT	0.82	0.86	0.95	Decreasing
RO	0.66	0.82	0.81	Constant
SI	0.75	0.93	0.81	Constant
SK	0.78	0.92	0.85	Decreasing
FI	0.90	0.90	1.00	Constant
SE	0.94	0.96	0.98	Decreasing
UK	0.94	1.00	0.94	Decreasing
NO	1.00	1.00	1.00	Constant
Average	**0.84**	**0.92**	**0.91**	

Among inefficient countries the lowest rate of technical efficiency in the metal production sector was seen, both in the CCR and BCC model, in: Croatia and Lithuania (see **Table 1**).

Taking into account economies of scale, it has been found that the metal production sector deemed efficient in 10 countries is characterized by constant economies of scale, in 2 countries (Lithuania and Estonia) the metal production sector sees increasing economies of scale, while the metal production sector in the remaining 13 countries is characterized by decreasing economies of scale.

Based on the DEA method benchmarks have been defined for countries with an inefficient metal production industry. On the basis of these benchmarks for inefficient sectors (DMU), it is possible to determine a combination of technologies that allows the same results to be achieved with less input. Calculations were made based on the values of coefficients of the linear combination of common technology, as shown in **Table 2**. Based on these coefficients, it is possible to construct an optimal technology modelled on the industry from regions defining benchmarks for them (see **Table 2**). For example, for the Polish metal production industry benchmarks would consist of metal production in Cyprus and Austria. For the Polish metal production industry the following combination is therefore optimal: 10772.4% Cyprus' technology and 11.5% Austria's technology. In order for the Polish metal production industry to be efficient, it should achieve the present day revenues from sales of 9147.6 million Euro on the basis of the following inputs:

x_1 - gross investment in tangible goods: 107.724 x 0,8 + 0.115 x 558.5 = 150.407 (million Euro)

x_2 - number of employees: 107.724 x 357 + 0.115 x 32948 = 42247 (people)

x_3 - total purchases of goods and services: 107.724 x 43.5 + 0.115 x 9300,1 = 5755.5055 (million Euro)

The resulting inputs are far below those used in the production of metals in Poland in 2010. Metal production in Poland could therefore be classified among efficient sectors if, in order to achieve unchanged revenues, it employed 30% less people, reduced investment in tangible goods by 50%, lowered costs of purchases of products and services by 30%. **Table 3** shows potential changes that should be made within the scope of inputs in inefficient metal production sectors in individual countries. The results suggest how much smaller should the use of inputs be in inefficient metal production sectors in order to achieve the current value of effects (revenue).

Table 2 The values of coefficients of the linear combination of common technology for inefficient metal production industry

Inefficient DMU	Efficient DMU				Inefficient DMU	Efficient DMU			
	Ireland	Cyprus	Austria	Norway		Ireland	Cyprus	Austria	Norway
BE		35.103	0.072	1.299	HU		32.325	0.010	
BG		18.195	0.049	0.120	NL		41.602	0.012	0.470
CZ		73.098	0.161		PL		107.724	0.115	
DK		4.761	0.059		PT		10.123	0.085	0.045
DE		354.615	1.798	4.367	RO		56.167		
EE		0.569			SI		17.707		
ES		60.601	0.616	1.644	SK		39.237	0.111	
HR		4.868			FI			0.378	0.331
IT		20.450	2.431	2.263	SE		18.953	0.550	0.581
LV		5.504	0.003		UK	16.481	73.735		0.575
LT		0.898							

Table 3 Projections values

DMU	Total purchases of goods and services	Gross investment in tangible goods	Number of employees	DMU	Total purchases of goods and services	Gross investment in tangible goods	Number of employees
BE	-6%	-6%	-6%	HU	-27%	-58%	-27%
BG	-29%	-29%	-29%	NL	-3%	-3%	-3%
CZ	-29%	-37%	-29%	PL	-30%	-50%	-30%
DK	-9%	-35%	-9%	PT	-18%	-18%	-18%
DE	-8%	-8%	-8%	RO	-34%	-83%	-47%
EE	-24%	-49%	-47%	SI	-25%	-79%	-26%
ES	-10%	-10%	-10%	SK	-22%	-28%	-22%
HR	-38%	-89%	-68%	FI	-10%	-14%	-10%
IT	-10%	-10%	-10%	SE	-6%	-6%	-6%
LV	-32%	-89%	-32%	UK	-6%	-6%	-6%
LT	-34%	-45%	-64%				

CONCLUSIONS

The paper presents the application of the DEA methodology to the evaluation of efficiency of sector manufacturing base metal in European countries. From the methodological point of view the proposed approach for ranking and benchmarking of DMU has a universal character and can be applied in different industries. It allows comparing relative efficiency of DMU by determining the efficient DMUs as benchmarks and by measuring the inefficiencies in input combinations in other units relative to the benchmark.

From the practical point of view the results of this analysis can be summarized as follows:

- The CCR model proved to be more restrictive than the BCC model. However, the same four countries had the highest scores in both the CCR and BCC models.
- The countries with the most efficient sector manufacturing base metal are Norway, Austria, Ireland and Cyprus.
- Detailed analysis of the efficient DMUs as a benchmark for other evaluated units point out the reasons of the inefficiency and provide improving directions for the inefficient DMU.

Given that efficiency is a complex economic phenomenon and individual methods used for its analysis have their advantages and limitations, it is difficult to clearly state the superiority of the presented non-parametric approach. According to the authors, assessments of efficiency of industry sectors should be performed by means of an integrated approach - based on different methods that complement each other, as well as help to achieve a better understanding and explain the situation of assessed sectors, and formulate reliable conclusions. In turn, awareness of the shortcomings and limitations of each method used for measuring efficiency should lead to their further refinement, in order to ultimately achieve objective results of the measurement itself and provide clear recommendations for continuous improvement of industrial efficiency in Europe.

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