MEASURING THE RELATIVE EFFICIENCY OF ECONOMIC SECTORS
ADVICES FOR POLICY MAKERS IN POLAND

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Abstract

The main goal of the paper is to present an idea of the Data Envelopment Analysis model and its potential as a method of evaluation of economic sectors efficiency. An empirical part is concentrated on the use of the DEA model to assess efficiency of the construction industry in Poland from 1999 to 2007.
The first part of the article addresses the concept of DEA (CCR model) and the next section presents data and results of the analysis. To obtain the outcomes DEA solver software was applied.

Key words: *efficiency, regional policy planning, Data Envelopment Analysis, construction sector.*

Introduction

Recently, one can observe a tendency to measure various aspects of human activities. In the European Union (EU) such an interest has its roots in aspiration of the EU members to raise competitiveness of the European economy, compared to the US and Far East countries. One of the most important issues for comparing the competitiveness level is the problem of objective measuring and assessing the entities which are confronted. In the case of national economy such a comparison can be made with reference to various sectors, parts of economy, regions, branches, etc. and can be conducted dealing with different criteria. From the economists' point of view there are many different evaluation criteria that can be examined for such a purpose, for example utility, coherence, relevance, and effectiveness. Efficiency seems to be a particularly important and hard to evaluate criterion

In the praxeological sense, the entity's efficiency[4] can be defined as its productiveness or economy (Kotarbiński, 2000). The entity is more productive if it produces the bigger total output (its value) with given investment. On the other hand, the entity may also be called more efficient when it produces the given output with the smaller input. Generally speaking, efficiency can be defined as a ratio of total outputs to total inputs. This feature of the entity is gradable, which means that the entity can be more or less efficient.

Measuring the entity's efficiency is especially difficult when it has a multidimensional structure of inputs and outputs. One of the methods that attempt to address that problem is a relatively new method of Data Envelopment Analysis (DEA).

Considering all of the above, the purpose of this article is to present the main idea of the DEA model and use it to assess efficiency of the construction industry in Malopolska voivodship[5] in relation to other regions from 1999 to 2007. Such an analysis (DEA) may be especially useful for regional planners. Measuring efficiency seems to be very important in Poland during a period of a great absorption of EU funds. The paper is organised as follows:

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[4] We can also evaluate efficiency of action undertaken by the entities or human beings.
[5] In this paper the terms: „voivodship" and „province" will be used interchangeable and will refer to the II level units (NUTS nomenclature) of territorial division in Poland.

the next sections cover the fundaments of the DEA methodology, application of the model to assess the performance of the chosen sector and finally, conclusions.

The DEA model

Data Envelopment Analysis (Charnes, Cooper, Rhodes, 1978) is an approach for measuring the relative efficiency of various decision-making entities (called here decision-making units -DMUs) with multiple outputs and multiple inputs structure. Moreover, an important strength of the method is that it doesn't require functional relations between inputs and outputs and data may be multi-dimensional. So far, it has been used for assessing a broad range of various DMUs, for instance countries (Malhotra, Malhotra, 2009), banks (Brockett, Charnes, Cooper, Huang, Sun, 1997), sectors (Dinc, Haynes, Tarimcilar, 2003), hospitals (Matawie, Assaf, 2010), etc.

The DEA calculates the efficiency of a DMU relative to the best performing DMU or DMUs (when more than one DMU are the most efficient). Moreover, the DEA assigns an efficiency score of one (100 percent) to the most efficient unit, and the low-performing DMUs efficiency can vary between 0 and 100 percent in comparison to the most efficient DMU(s).

In order to describe the basics of the DEA model, some notations and definitions are to be made. Let n be the number of DMUs, j be the index referring to the given DMU, i be the index referring to the input variables and r be the index of output variables.

The DEA method measures the efficiency of each DMU as the ratio of weighted outputs to the weighted inputs. Charnes et al. (1978), calculate the efficiency measure as one that allocates the most favourable weights to each unit. Generally, each unit does have different weights. If a unit is inefficient (comparing to the others) and most favourable weights are chosen, then it is inefficient, independent of the choice of weights. Having a set of weights, we define the efficiency with which a DMU_o transforms the inputs into the outputs as the ratio of the weighted sum of output to the weighted sum of inputs:

$$E_o = \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \qquad (1)$$

where:
E_o – efficiency of the DMU_o (observed DMU)
x_{io} – amount of input i for the unit o, i = 1; 2; . . . ,m and o = 1; 2; . . . ,n.
y_{ro} – amount of output r for the unit o, r = 1; 2; . . . ,s and o = 1; 2; . . . ,n.
u_r – weight assigned to the output r, r = 1; 2; . . . ,s.
v_i – weight assigned to the input i, i = 1; 2; . . . ,m.

Taking the above considerations, the assessment of the weights is a very important issue in the DEA applications. A mathematical programming can be used to calculate a set of weights that maximize the efficiency of a DMU subject to the condition that the efficiency of other DMUs (computed using the same set of weights) is restricted to values between 0 and 1. The linear program chooses the weights in such a way that only the most efficient units reach 1. From the mathematical point of view, to compute the DEA efficiency measure for n DMUs (for each one separately), we have to solve the following fractional linear programming model:

$$\max \frac{\sum_{r=1}^{s} u_r y_{ro}}{\sum_{i=1}^{m} v_i x_{io}} \tag{2}$$

Subject to:

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \quad j = 1, \dots, n \quad u_r \geq \varepsilon, \quad r = 1, \dots, s, \quad v_i \geq \varepsilon, \quad i = 1, \dots, m. \tag{3}$$

where ε is an infinitesimal constant.

By solving the above program, we can find the efficiency of each DMU. If the efficiency is one, then the entity is said to be efficient, and will lie on the efficiency frontier. The efficiency frontier is plotted by connecting points representing all efficient DMUs. and is said to "envelop" points representing all units. (Cooper, Seiford, Tone, 2006)

Due to the fact that the purpose function has non-linear form, we must convert the above fractional model into a linear program format. Then we can easily find the solution, using e.g. computer software.

As the weighted sum of inputs is constrained to be unity and the objective function is the weighted sum of outputs that has to be maximized, we get the converted output-maximization DEA model:

$$max \sum_{r=1}^{s} \mu_r y_{ro} \tag{4}$$

Subject to:

$$\sum_{i=1}^{m} v_i x_{io} = 1, \quad \sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \tag{5}$$
$$j = 1, \dots, n, \quad \mu_r \geq \varepsilon, \quad r = 1, \dots, s \quad v_i \geq \varepsilon, \quad i = 1, \dots, m.$$

This model is known as the Charnes, Cooper, and Rhodes (CCR) model (Charnes et al., 1978)[6]. Obviously, the fractional program formulated in (2) and (3) is equivalent to linear program presented in (4) and (5). A general input minimization CCR model can be derived in the same way.

Proceeding, we are able now to formulate the dual problem to (4) and (5). So we get:

$$min\theta = \theta^* \tag{6}$$

Subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j \leq \theta x_{io} \quad i = 1,2, \dots, m \quad \sum_{j=1}^{n} y_{rj}\lambda_j \geq y_{ro} \quad r = 1,2, \dots, s$$
$$\theta, \lambda_j \geq 0 \quad j = 1,2, \dots, n \tag{7}$$

By finding θ^* we are able to define the efficient DMU lying on the efficiency frontier. This DMU is efficient in terms of Farell's definition of efficiency (also called weak, radial or technical efficiency). In these terms a DMU is to be rated as fully (100%) efficient on the basis of available evidence if and only if the performances of other DMUs does not show that some of its inputs or outputs can be improved without worsening some of its other inputs or outputs. However, some DMUs lying on the efficiency frontier (θ^*) may be not fully efficient since they may have non-zero "slacks". Slack will represent excess in inputs (s^-) or shortfall in

[6] CCR model is one of two commonly used DEA models. The other one is called BCC (Banker, Charnes, Cooper) model. For evolution and other extensions of the DEA model see: Tavares, G., (2002). A Bibliography of Data Envelopment Analysis (1978-2001), RUTCOR, Rutgers University.

outputs (s^+). Taking optimal Θ* from (6) we will formulate the next linear problem which can be used to calculate the efficiency in terms of slacks:

$$max(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+) \quad (8)$$

Subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta^* x_{io} \quad i = 1,2,\dots,m \qquad \sum_{j=1}^{n} y_{rj}\lambda_j + s_r^+ = y_{ro} \quad r = 1,2,\dots,s$$

$$\lambda_j, s_i^-, s_r^+ \geq 0 \quad (9)$$

By using (8) and (9) we are able to find efficient DMUs in terms of DEA, which means a DMU(s) that fulfils the following requirements: $\theta^*=1$ and $is_i^-, s_r^+ = 0$. Such defined efficiency meets the Pareto-Koopmans understanding of efficiency which is in our model called CCR or DEA efficiency.

In the empirical part of the article the authors focus on the efficiency in construction sector, taking into account possible improvements in results. So we need to adopt the output oriented version of the model.

It is worth knowing that an optimal solution for that version can be derived directly from the input oriented model. In terms of input oriented version of the model (6), the optimal solution for the output oriented model is equal: $1/\theta^*; \lambda^*/\theta^*$ (10)

Data and the model application

The data for this study have been obtained from the Central Statistical Office of Poland (www.stat.gov.pl). The data cover period from 1999 to 2007. Five economic variables are used to evaluate the effectiveness of construction industry (according to Polish Classification of Activities 2004) between sixteen voivodships. In this article a Decision Making Unit (DMU) represents construction industry in a voivodship.

The variables have been defined by the Central Statistical Office as follows:

Inputs:
- gross value of fixed assets in sector F (private sector) – referred to as PRC,
- gross value of fixed assets in sector F (public sector) – referred to as PBC,
- employed persons in sector F (in the main workplace) – referred to as EMP;

Outputs:
- gross value added in sector F - referred to as GVA,
- new total usable floor space (m^2) – referred to as SPP.

Due to the nominal data were obtained for GVA, PRC and PBC the GVA deflator was used in order to convert the data to the real terms (2007 prices) as shown in figure 1.

Figure 1. GVA deflator (2007 as a base year)

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007
GVA deflator	77,9	83,5	86,4	88,4	88,7	92,4	94,8	96,2	100,0

Source: Own calculation based on www.stat.gov.pl (15.10.2010).

For the purpose of the article CSR (constant returns to scale) model of DEA was chosen. All calculations were conducted in DEA Solver. Figure 2 presents scores calculated for all 16 DMUs in the selected period.

Figure 2. The scores (1/score, see equation 10) for 16 units from 1999 to 2007.

DMU	999	000	001	002	003	004	005	006	007
Łódzkie (LD)	1,000	1,000	1,000	1,000	1,000	1,039	1,000	1,000	1,022
Mazowieckie (MZ)	1,000	1,000	1,000	1,072	1,103	1,119	1,055	1,000	1,000
Małopolskie (ML)	1,179	1,154	1,105	1,134	1,049	1,260	1,140	1,119	1,093
Śląskie (SL)	1,089	1,117	1,202	1,194	1,142	1,248	1,197	1,115	1,101
Lubelskie (LB)	1,053	1,064	1,007	1,000	1,083	1,109	1,036	1,066	1,035
Podkarpackie (PK)	1,122	1,053	1,000	1,000	1,000	1,000	1,000	1,080	1,108
Podlaskie (PD)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Świętokrzyskie (SW)	1,000	1,000	1,000	1,000	1,000	1,000	1,033	1,000	1,014
Lubuskie (LS)	1,000	1,003	1,034	1,000	1,000	1,000	1,035	1,000	1,017
Wielkopolskie (WP)	1,162	1,000	1,083	1,127	1,115	1,163	1,120	1,046	1,133
Zachodniopomorskie (ZP)	1,111	1,059	1,077	1,094	1,050	1,063	1,008	1,000	1,000
Dolnośląskie (DL)	1,120	1,073	1,015	1,002	1,023	1,137	1,017	1,000	1,000
Opolskie (OP)	1,000	1,002	1,086	1,097	1,009	1,000	1,000	1,000	1,000
Kujawsko-pomorskie (KP)	1,060	1,038	1,107	1,063	1,060	1,108	1,066	1,040	1,030
Pomorskie (PM)	1,001	1,000	1,000	1,000	1,017	1,064	1,000	1,000	1,034
Warmińsko-mazurskie (WM)	1,000	1,000	1,000	1,000	1,027	1,000	1,000	1,000	1,000

Source: Own calculations.

As shown in Figure 2 there is only one voivodship (Podlaskie) that has been 100% efficient for the selected period. And in Figure 3 a set of references for all voivodships was presented. During the time of the analysis Podlaskie voivodship was a benchmark for other DMUs 56 times.

Figure 3. A set of interactions between 16 DMUs

DMU	1999	2000	2001	2002	2003	2004	2005	2006	2007
Łódzkie (LD)	5	2	5	0	6		6	0	
Mazowieckie (MZ)	9	3	2					0	4
Małopolskie (ML)									
Śląskie (SL)									
Lubelskie (LB)				0					
Podkarpackie (PK)			0	0	3	0	0		
Podlaskie (PD)	7	4	9	8	8	3	10	2	5
Świętokrzyskie (SW)	8	8	6	7	2	10		0	
Lubuskie (LS)	0				6	7		5	
Wielkopolskie (WP)		6							
Zachodniopomorskie (ZP)								2	5
Dolnośląskie (DL)								2	5
Opolskie (OP)	2					0	1	0	0

Kujawsko-pomorskie (KP)									
Pomorskie (PM)		2	2	3			1	0	
Warmińsko-mazurskie (WM)	0	4	3	2		6	2	3	4

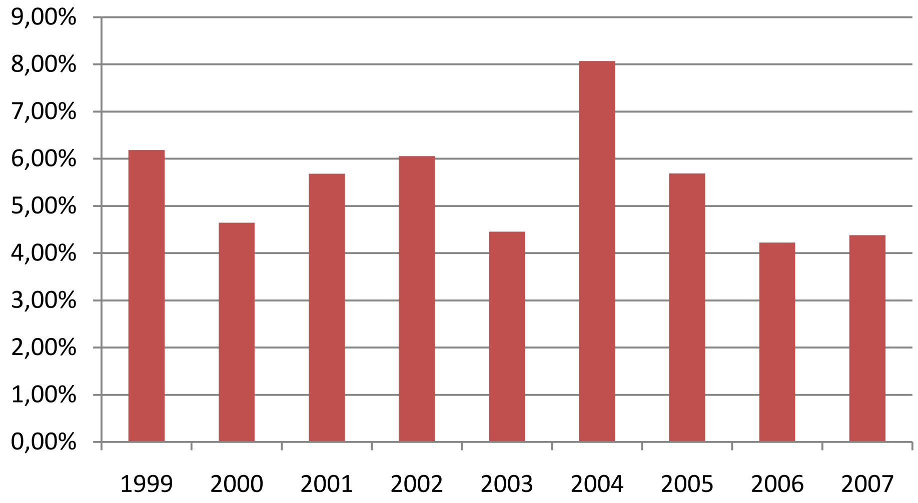
Source: Own calculations.

The Swietokrzyskie voivodship was a DMU with the second frequency of references. Some voivodships were permanenetly inefficient within the timeframe of the analysis. Among them we can find: Malopolskie, Slaskie and Kujawsko-Pomorskie. In Figure 3 we can see some voivodships with the number of references equal zero which means that such a DMU is efficient in the terms of the DEA analysis however, it never was a benchmark for other DMUs. Analysing reference sets for every year of the study we can also notice that the average number of benchmarks for each inefficient DMU was not greater than 3. The poorest efficiency during the period 1999-2007 was noticed for the Malopolskie voivodship in 2004. In order to be recognized as efficient, having a given set of inputs, that DMU ought to have outputs 1,26 times greater than it had.

It should be born in mind that one cannot compare the obtained results through the years, but there may be made such comparisons within one year.

In Figure 4 coefficient of variation for the DMU scores are presented.

Figure 4: Coefficient of variation for the DMU scores

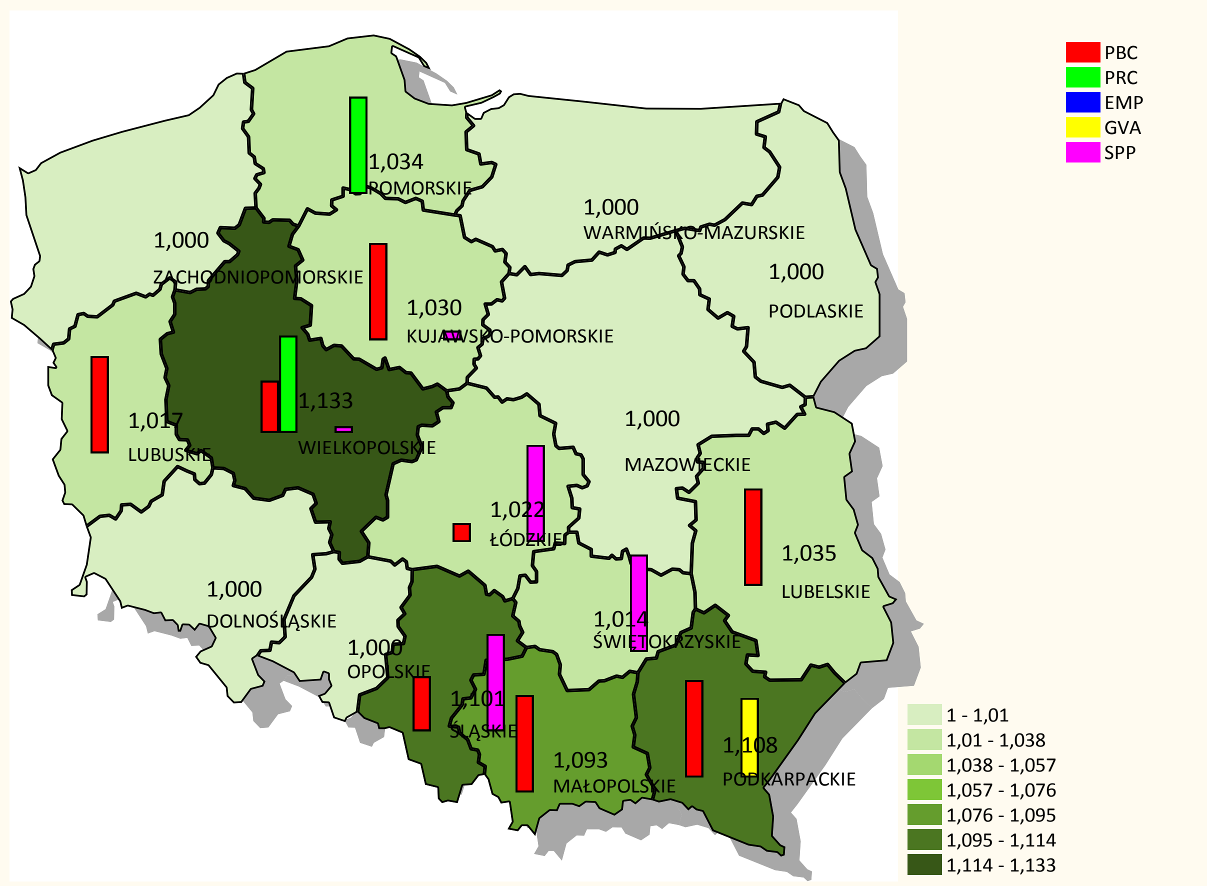


Source: Own calculations.

As shown in Figure 4 there have been slight volatility of scores during the period of 1999-2007. The maximum variation of scores can be observed in 2004 which was the year of Poland's accession to the European Union.

For the further analysis we will concentrate on data for the year 2007, and then will focus on specific results obtained for the Malopolskie voivodship.

Figure 5. A map illustrating voivodship ranking and slacks.



In Figure 5 we have presented the relative effectiveness of the construction industry in 16 voivodships. On the map above value 1 represents the most effective units in terms of technical efficiency. Bars shown on the map represent slacks for all five variables. As the voivodships with score 1 have zero slacks, we can consider them as CCR effective.

It is worth noticing to be noticed that only 6 voivodships have slacks in outputs which means that they can improve their effectiveness by increasing effects of their activities. For instance, the Slaskie voivodship should raise its SPP factor for 306 thousands of square meters. And 10 DMUs have slacks in inputs which means that they have to reduce inputs in order to be more effective. For instance, the Lubelskie voivodship should reduce its PBC for almost 3 billion zlotys. DMUs with input and output slacks can make a choice between reducing inputs and increasing outputs, i.e. Lodzkie, Slaskie, Podkarpackie, Swietokrzyskie, Wielkopolskie, Kujawsko-Pomorskie.

In Figure 6 weighted data for the year 2007 are presented.

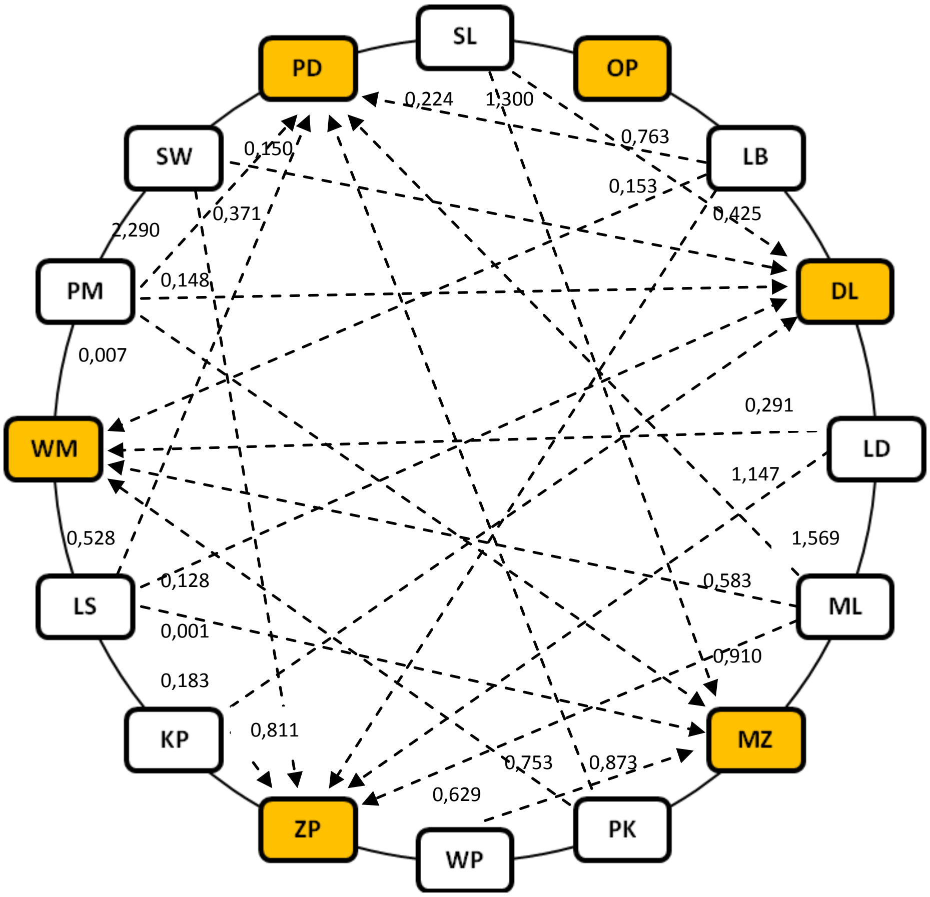
Figure 6. Weighted data for 2007.

DMU	Score	VX(1) PBC	VX(2) PRC	VX(3) EMP	UY(1) GVA	UY(2) SPP
Łódzkie (LD)	0,978647	0,0000	0,7229	0,2989	1,0000	0,0000
Mazowieckie (MZ)	1	0,0000	0,0239	0,9761	1,0000	0,0000
Małopolskie (ML)	0,9150704	0,0000	0,5125	0,5803	0,8315	0,1685
Śląskie (SL)	0,9079268	0,0000	0,0198	1,0816	1,0000	0,0000
Lubelskie (LB)	0,9660648	0,0000	0,4903	0,5448	0,8318	0,1682
Podkarpackie (PK)	0,9027812	0,0000	0,7672	0,3405	0,0000	1,0000
Podlaskie (PD)	1	0,0000	0,0000	1,0000	0,6338	0,3662
Świętokrzyskie (SW)	0,9862498	0,0000	0,4915	0,5225	1,0000	0,0000
Lubuskie (LS)	0,9833531	0,0000	0,0823	0,9347	0,9226	0,0774
Wielkopolskie (WP)	0,8825015	0,0000	0,0000	1,1331	1,0000	0,0000
Zachodniopomorskie (ZP)	1	0,0000	0,7120	0,2880	1,0000	0,0000
Dolnośląskie (DL)	1	0,0500	0,5538	0,3962	1,0000	0,0000
Opolskie (OP)	1	1,0000	0,0000	0,0000	1,0000	0,0000
Kujawsko-pomorskie (KP)	0,9712278	0,0000	0,4939	0,5358	1,0000	0,0000
Pomorskie (PM)	0,9672082	0,0084	0,0000	1,0255	0,9113	0,0887
Warmińsko-mazurskie (WM)	1	0,3743	0,6257	0,0000	1,0000	0,0000

Source: Own calculations.

As shown in Figure 6 in 2007 there were 6 leader voivodships, i.e. Mazowieckie, Podlaskie, Zachodniopomorskie, Dolnoslaskie, Opolskie, and Warminsko-Mazurskie. By solving the output oriented model of DEA we obtained optimal weights for each variable in our analysis. According to (1) we can calculate the efficiency score for each DMU. Using these data one can compile a ranking of all voivodships. As we can see in Figure 6 some of the variables must have weights equal to zero which does not mean that such a variable is not important. As a matter of fact it implies that in case of substituting such a weight by non-zero value given DMU would never get a higher score. And in the case of six leading voivodships, as they all have zero slacks, weights equal to zero as shown in Figure 6 have in fact infinitesimal Archimedean values.

Figure 7. A set of interactions for 2007.



Source: Own calculations.

In Figure 7 a set of benchmarks for each DMU is presented with values of lambdas. The lambda represents the benchmarking coefficient. For each inefficient DMU we can see a set of connections (dotted arrows) with reference DMUs (represented by rectangles painted grey). Adequate weights are presented along the arrows.

For further analysis of relative efficiency the Malopolskie voivodship was chosen. Basing on (6) and (7) , with given inputs and outputs for the Malopolskie Province, we can obtain score efficiency (1,093) and a set of lambdas. The score of 1.093 indicates that the Malopolskie Province compared to other 15 DMUs is not efficient. And non-zero lambdas suggest reference DMUs (benchmarks), i.e. Podlaskie, Zachodniopomorskie and Warminsko-Mazurskie Provinces. These results are presented in Figure 8.

As suggested by B. Guzik (2009) empirical data of all variables for each reference DMU may be called empirical technology vector t (coordinates in columns 2-4 in Figure 8) . For example, technology vector for the Podlaskie Province t_{PD} equal [56,37; 530,977; 16,818; 1499; 430,826]^T. Therefore, an optimal technology for the Malopolskie voivodship can be calculated according to the following formula:

$$t_{MP} = 1{,}569t_{PD} + 0{,}91t_{ZP} + 0{,}583t_{WM}$$

The results of these calculations are shown in column 8 in Figure 8 and are referred to as projection (weighted sum).

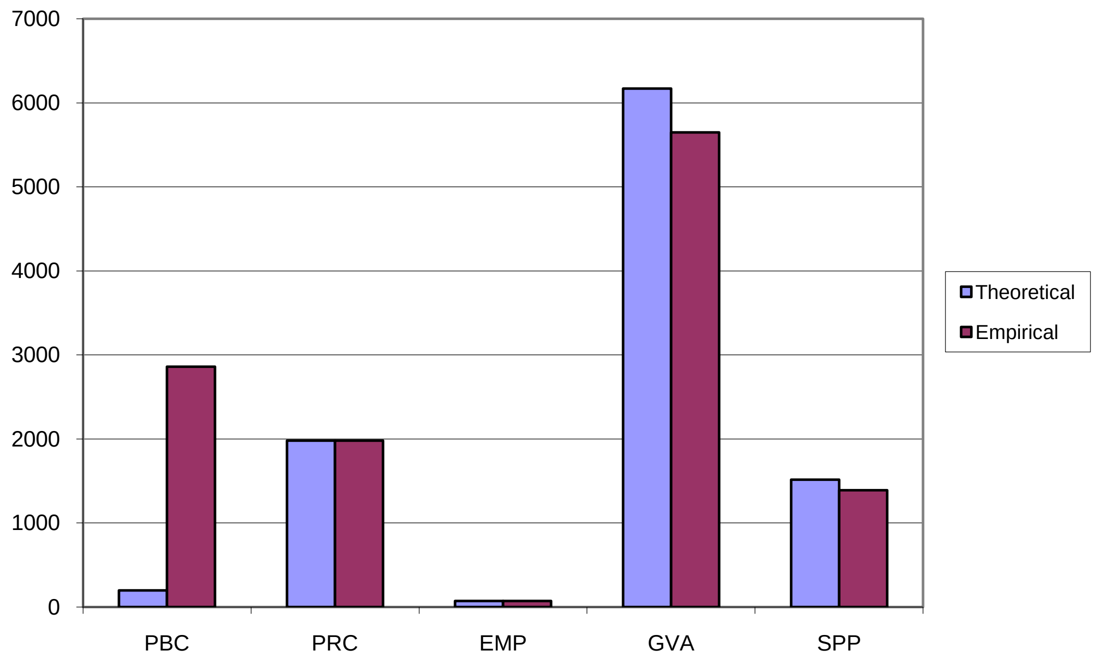
Figure 8. Optimal technology (projection) for the Malopolskie voivodship

Variables	Benchmarks			Lambdas					
	PD	ZP	WM	1,569	0,91	0,583	Weighted sum (Projection)	Empirical data	Ratio
(I)PBC	56,37	97,9	36,233	88	89,1	21,12	199	2862	0,069
(I)PRC	530,977	911,8	545,357	833	830	317,9	1 981	1982	1
(I)EMP	16,818	34,55	24,133	26	31,4	14,07	72	71,93	1
(O)GDP	1499	2992	1876	2 352	2723	1094	6 168	5647	1,093
(O)SPP	430,826	609,9	490,333	676	555	285,9	1 517	1389	1,093
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10

Source: Own calculations

By comparing empirical data for the Malopolskie Province with weighted sums we can clearly notice reasons for this DMU inefficiency (as shown in Figure 9).

Figure 9. DEA results for the Malopolskie voivodship



Source: Own calculations.

For example, empirical value of GVA for the Malopolskie Province equals 5 647 Mio. PLN whilst an optimal level of that variable is 6 168 Mio. PLN which represents 1.093 of empirical value, i.e. measure of DEA efficiency.

Conclusions

1. DEA method is still unappreciated in regional research and planning for evaluating efficiency in Poland. Such a non-parametric approach of study can be especially useful in

conditions of short time series of data which is the case of Polish voivodships. DEA model provides important policy implications. It is possible to evaluate the management of a DMU or performance of an input or output sector over time. Such applications provide information about objective values of inputs and outputs making it possible to utilise this information for limited projection purposes. This gives policy makers the opportunity to estimate future inputs and outputs needed to achieve efficiency.

2. Taking into account the results of the article it is worth to be noticed that during the period of years 1999 - 2007 there was only one permanently efficient voivodship (section F), i.e. Podlaskie. There were also some permanently inefficient voivodships, i.e. Malopolskie, Slaskie and Kujawsko-Pomorskie.

3. Taking a closer look at 2007 we can observe six DEA efficient provinces and ten DMUs having slacks in either inputs or outputs. In the Malopolska case a set of references comprises Podlaskie, Zachodniopomorskie, Warminsko-Mazurskie. In future actions Malopolska's decision makers in order to improve efficiency in construction sector should pay attention to inputs and outputs levels in the benchmarks.

4. In evaluating practice an approach used in this paper may and should be developed by DEA model extensions, such as BCC, CEM, SE-DEA, CEP, and so on.

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Abstrakt

Głównym celem opracowania jest zaprezentowanie modelu Data Envelopment Analysis (DEA) oraz jego potencjału jako metody oceny efektywności sektorów ekonomicznych gospodarki. Część empiryczna artykułu dotyczy oceny efektywności budownictwa (definiowanego według sekcji PKD) w latach 1999-2007.

W pierwszej sekcji artykułu zaprezentowano istotę modelu DEA (w ujęciu CCR). Następnie przedstawiono charakterystykę zmiennych wykorzystanych w analizie oraz wyniki badania. W analizie wsparto się programem DEA solver software.