EVALUATION OF CROATIA'S REGIONAL HOSPITAL EFFICIENCY: AN APPLICATION OF DATA ENVELOPMENT ANALYSIS

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Abstract

Due to expenditure increases that can be attributed to several reasons, healthcare systems throughout the world strive towards cost containment. In order to conduct it in a satisfactory manner, it is necessary first to determine the sources of inefficiency in the process of providing healthcare services.

In this paper regional healthcare efficiency of Croatian counties is measured based on hospital performance in three-year period (2007-2009) using Data Envelopment Analysis (DEA). The set of inputs and outputs consists of six indicators. Four of them are directly related to the healthcare efficiency, while two are external/uncontrollable factors included in order to take into account great regional socio-economic disparities. Analysis is carried out using models with assumption of variable returns-to-scale (BCC). Since the hospitals have little control over their outputs and more opportunities to reduce inputs used to produce them, input-oriented models are used.

In terms of providing hospital healthcare services, DEA identifies efficient counties as examples of good operating practices (benchmark members) and inefficient counties that are analyzed in detail to determine not only the sources but also the amounts of their inefficiency in each source. To enable proper monitoring of efficiency dynamics and make conclusions on behaviour of the county (whether its efficiency has improved, deteriorated or stagnated), window analysis is applied. Based on the results, guidelines for implementing necessary improvements to achieve efficiency are given. Analysis reveals great disparities among counties.

JEL Classification:I11, I14, I15

Keywords: regional hospital efficiency, county, data envelopment analysis, window analysis

INTRODUCTION

Healthcare systems worldwide are increasingly the subject of analysis aimed at defining, measuring and improving their efficiency. However, despite the importance of efficiency measurement in healthcare services, the more frequent use of advanced econometric and mathematical frontier techniques in this field started only in 1990's (Worthington, 2004).

This paper is the outcome of a research related to multicriterial evaluation of the achieved regional levels of the Croatian healthcare system. The purpose is to present the results of the analysis of regional hospital efficiency in Croatia using Data Envelopment Analysis (DEA) and its extension in the treatment of the same problem.

DEA is a non-parametric productive efficiency measurement method for operations with multiple inputs and multiple outputs. This approach first establishes an efficient frontier formed by a set of decision making units (DMUs) that exhibit best practices and then assigns the efficiency level to other non-frontier units according to their distances to the efficient frontier. In this way the method combines and transforms multiple inputs and outputs into a single efficiency index.

The study of Liu et al. (2013) surveys the DEA literature by applying a citation-based approach and testifies to numerous DEA applications in a variety of contexts and countries. An interesting and cited example in the international literature is evaluation of the efficiency of regional public healthcare delivery in Greece, in which the efficiency levels of the Greek prefectures were compared and analyzed by using DEA and FDH (free disposal hull) models for the year 2005 (Halkos & Tzeremes, 2011).

According to author's knowledge, DEA has not yet been used in the measurement of regional hospital efficiency in Croatia, which is one of the aspects that make this research original.

DATA AND METHODOLOGY

Croatian counties represent 21 entities whose relative hospital efficiency is evaluated in this paper. The choice of indicators for the purpose of this study was guided by the following principles: covering key natural indicators of hospital performance; exact measurability of indicators; availability and accessibility of data on indicators. In addition, in any DEA application, it is suggested as rule of thumb that the number of entities should be at least three times the number of indicators (Banker et al., 1989).

Accordingly, four indicators are included into analysis. The inputs are represented by the number of hospital beds and the number of hospital doctors, while the outputs are the number of inpatient care days and the number of medical examinations in specialist offices. Great disparities among the counties, regarding all here selected indicators, may be explained by different population sizes that also lead to different economic potential. For that reason, two external variables have been also used in this analysis. These are population as non-controllable input and gross domestic product (GDP) as non-controllable output.[1] Again, it can be realized that Croatian counties are characterized by great dissimilarities, both in terms of population size and GDP. All these inequalities are expected to have a major impact on the health provision.

Data for selected six indicators are relating to the period 2007-2009 and were taken from Croatian National Institute of Public Health and Croatian Bureau of Statistics[2].

Basic DEA models commonly used in applications are CCR (Charnes et al., 1978) and BCC (Banker et al., 1984). CCR model is built on the assumption of constant and BCC model on the assumption of variable (either increasing or decreasing) returns to scale activities. In addition, the DEA model can be adjusted to the strategy chosen by management and therefore oriented on input reduction (*input-oriented model*) or on output augmentation (*output-oriented model*).

Let us consider the set of n DMUs. Each of them (DMU$_j$, j = 1, 2, ..., n) produces s outputs and for their production uses m inputs. Let us denote $x_j = \{x_{ij}, i = 1,2,...,m\}$ the vector of inputs and $y_j = \{y_{rj}, r = 1,2,...,s\}$ the vector of outputs for the DMU$_j$. Then the data set is given by two matrices – the matrix of inputs: $X = (x_{ij}, i = 1,2,...,m, j = 1,2,...,n)$ and the matrix of outputs: $Y = (y_{rj}, r = 1,2,...,s, j = 1,2,...,n)$.

The basic principle of DEA models in evaluation of efficiency of the DMU$_o$, $o \in \{1, 2, ..., n\}$[3] consists in looking for a virtual DMU with inputs and outputs defined as the linear combination of inputs and outputs of the other DMUs in the decision set, i.e. $X\lambda$ and $Y\lambda$, where $\lambda = (\lambda_1, \lambda_2, ..., \lambda_n)$, $\lambda > 0$ is the vector of weights (coefficients of

[1] Unlike controllable variables that management can control and change, non-controllable variables are given and cannot be influenced by management.

[2] GDP was taken at constant prices of the year 2007.

[3] The following procedure is based on Cooper et al. (2006, pp. 87-89).

linear combination) of the DMUs. The virtual DMU should be better (or at least not worse) than the analysed DMU$_o$. The problem of looking for a virtual DMU can generally be formulated as standard linear programming problem:

$$\begin{array}{lll} (BCC-I_o) & \min \theta_B & \\ \text{subject to} & \theta_B x_o - X\lambda \geq 0 & (1) \\ & Y\lambda \geq y_o & (2) \\ & e\lambda = 1 & (3) \\ & \lambda \geq 0 & (4) \end{array}$$

where e is a row vector with all elements equal to 1. Condition (1) consists of m, condition (2) of s, and condition (4) of n constraints. In our case, n = 21, m = 3, s = 3.[4] Vector λ shows the proportions contributed by efficient DMUs to the projection of DMU$_o$ onto efficient frontier. The optimal objective value θ_B^* ($0 < \theta_B^* \leq 1$) is the efficiency result, and for inefficient DMU$_o$ also the input reduction rate.

It is obvious from constraints (1) and (2) that $(X\lambda, Y\lambda)$ outperforms $(\theta_B^* x_o, y_o)$ when $\theta_B^* < 1$. With regard to this property, the input *excesses* $s^- \in \mathbf{R}^m$ and the output *shortfalls* $s^+ \in \mathbf{R}^s$ are defined and identified as „slack" vectors by

$$s^- = \theta_B x_o - X\lambda, \qquad s^+ = Y\lambda - y_o,$$

with $s^- \geq 0$, $s^+ \geq 0$ for any feasible solution (θ_B, λ) of $(BCC-I_o)$.

To discover the possible input excesses and output shortfalls, a two-phase procedure is used. In the first phase, θ_B is minimized and, in the second phase, the sum of the input excesses and output shortfalls is maximized keeping $\theta_B = \theta_B^*$ (the optimal objective value obtained in the first phase).

Definition 1 (BCC-Efficiency): *If an optimal solution* $(\theta_B^*, \lambda^*, s^{-*}, s^{+*})$ *obtained in this two-phase process satisfies* $\theta_B^* = 1$ *and has no slack* ($s^{-*} = 0$, $s^{+*} = 0$)*, then the DMU$_o$ is called* BCC-efficient*, otherwise it is* BCC-inefficient.

Definition 2 (Reference Set): *For a BCC-inefficient DMU$_o$, its* reference set E_o *is defined based on an optimal solution* λ^* *by* $E_o = \{ j \mid \lambda_j^* > 0 \}$ $(j \in \{1, 2, ..., n\})$.

An optimal solution can be expressed as

$$\theta_B^* x_o = \sum_{j \in E_o} x_j \lambda_j^* + s^{-*}, \qquad y_o = \sum_{j \in E_o} y_j \lambda_j^* - s^{+*}.$$

These relations suggest that the efficiency of (x_o, y_o) for DMU$_o$ can be improved if the input values are reduced radially by the ratio θ_B^* (thus removing technical inefficiency) and the input excesses recorded in s^{-*} are eliminated, and if the output values are augmented by the output shortfalls in s^{+*} (thus removing mix inefficiency). Described improvement can be expressed by the following formula known as *the BCC-projection:*

$$x_o = \theta_B^* x_o - s^{-*}, \qquad y_o = y_o + s^{+*}.$$

[4] The constraint in conditions (1) or (2) relating to non-controllable input or output becomes equality while all remaining constraints and conditions do not change.

The need for the monitoring of regional healthcare development dynamics, which is extremely important for healthcare policy makers, leads to the use of window analysis as one of the extensions to DEA models. In that case, data for several periods for each DMU are included into analysis, and each DMU is regarded as if it were a different DMU in each of the reporting periods.

EMPIRICAL RESULTS

Knowledge of the production frontier characteristics for the process to be analyzed is crucial for model type selection. Since that could not be determined with certainty in the case of regional healthcare performance, the analysis was carried out under both (constant and variable returns-to-scale) assumptions. It appeared that differences between the results obtained by CCR and BCC model were significant. They may be attributed to the return effect with respect to the range of activities thus making the BCC model more suitable for describing the analyzed hospital activity.

Since input quantities appear to be the primary decision variables and therefore the management has greater control over the inputs compared to the outputs used, input-orientation is utilized (Coelli et al., 2005).

The assessment of Croatian counties' relative hospital efficiency is based on empirical data on six healthcare indicators and computed by program package DEA-Solver-Pro 7.0F (Saitech, Inc.). Due to the nature of selected indicators, comparisons of the counties were made on a yearly basis.

At first, we shall observe the middle year of the period studied. According to the analysis of obtained results, average relative efficiency in 2008 is 0.9582. This means that an average county should only use 95.82% of the currently used quantity of inputs to produce the same quantity of the currently produced outputs, if it wishes to reach the efficiency frontier. In other words, if it wishes to do business efficiently, it should produce (1–0.9582)/0.9582 = 4.36% more output with the same input level.

Table 1: The reference set frequency (2008)

Efficient county (Frequency)		
City of Zagreb (2)	Koprivnica-Križevci (6)	Lika-Senj (2)
Zagreb (5)	Primorje-Gorski kotar (0)	Osijek-Baranja (0)
Krapina-Zagorje (5)	Virovitica-Podravina (3)	Vukovar-Sirmium (0)
Sisak-Moslavina (0)	Požega-Slavonia (0)	Split-Dalmatia (0)
Varaždin (0)	Slavonski Brod-Posavina (3)	Istria (1)

Source: Author's calculations

All six inefficient counties showed efficiency below average: Šibenik-Knin (0.6786), Dubrovnik-Neretva (0.8587), Zadar (0.8677), Međimurje (0.8873), Karlovac (0.8988) and Bjelovar-Bilogora (0.9311). Fifteen counties proved to be relatively efficient which makes 71% of the total number. County that was rated efficient usually appears in the reference sets of inefficient counties. The frequency of its occurrence in those sets can be considered an indication of whether it is a role model to other counties. Table 1 displays these frequencies for every efficient county.

County of Koprivnica-Križevci can be considered the most efficient, because it serves as a reference for all six inefficient counties.

Among the obtained results are the projections of all counties against the efficiency frontier, i.e. the values of inputs and outputs that they should come up with to achieve relative efficiency. When it comes to efficient county, empirical data and their projections do not differ. The differences between empirical and projected values of every input and output and their averages for all counties are displayed in Table 2.

Table 2: Sources and amounts of inefficiency (2008)

Inefficient county	Proposed improvements (%)			
	Inputs		Outputs	
	Hospital beds	Hospital doctors	Inpatient care days	Medical examinations
Karlovac	-10.12	-25.81	0.00	7.42
Bjelovar-Bilogora	-6.89	-6.89	0.00	36.34
Zadar	-13.23	-24.33	0.00	8.24
Šibenik-Knin	-32.14	-32.14	0.00	7.89
Dubrovnik-Neretva	-14.13	-14.13	0.00	11.99
Međimurje	-11.27	-29.96	0.00	41.58
Average per county	-14.63	-22.21	0.00	18.91

Source: Author's calculations

Significantly greater average influence of inputs rather than outputs is predetermined by selection of model orientation.

On average, hospital doctors have the strongest influence on inefficiency. At the same time, the major needed modifications are concerning medical examinations in the case of Bjelovar-Bilogora and Međimurje. It is also evident that the number of inpatient care days is not a source of inefficiency. Although the number of inpatient care days is controllable, it is evidently not a source of inefficiency. Some of these facts indicate the need for deeper consideration of the causes of such results and introduction of measures for their improvement.[5]

Sources and amounts of relative inefficiency and proposed improvements are extremely valuable information on which authorities can set goals and make decisions leading to them. The importance of reference set should also be emphasized because it provides information on the role models for each inefficient county.

The next step of this research was carried out using window analysis. Since a three-year period 2007-2009 is chosen, the window (i.e. the period within which the comparisons are performed) ranges from one to three years. For the purposes of this study, one window that includes all three years is used. The relative efficiency results are listed in Table 3. Among 63 observed entities, 33 turned out to be efficient. The highest efficiency results were achieved in 2007. Five counties were efficient during the entire period. The worst efficiency results, according to both

[5] As non-controllable variables, population and GDP do not change.

number of efficient counties and lowest average efficiency, were achieved in 2008. Although the average efficiency is quite high, the differences between the average and worst efficiency results, especially prominent in 2008, suggest large regional disparities in Croatia concerning healthcare.

Table 3: Window analysis results

County	Relative efficiency results			
	2007	2008	2009	Average per county
Grad Zagreb	1	1	1	1
Zagrebačka	1	1	1	1
Krapinsko-zagorska	1	1	1	1
Sisačko-moslavačka	1	1	1	1
Karlovačka	0.97656	0.89568	0.87984	0.91736
Varaždinska	1	1	0.91475	0.97158
Koprivničko-križevačka	0.95386	1	0.91917	0.95768
Bjelovarsko-bilogorska	0.96544	0.91679	0.84796	0.91006
Primorsko-goranska	0.97955	1	1	0.99318
Ličko-senjska	1	1	1	1
Virovitičko-podravska	1	0.97443	1	0.99148
Požeško-slavonska	0.99998	1	1	0.99999
Brodsko-posavska	1	0.97900	1	0.99300
Zadarska	0.91304	0.86446	0.86884	0.88211
Osječko-baranjska	1	0.97828	1	0.99276
Šibensko-kninska	0.89895	0.65902	0.80925	0.78907
Vukovarsko-srijemska	1	0.80432	1	0.93477
Splitsko-dalmatinska	1	0.99875	1	0.99958
Istarska	1	0.98279	0.93818	0.97366
Dubrovačko-neretvanska	0.83447	0.85234	0.76574	0.81752
Međimurska	0.86488	0.87773	0.85887	0.86716
Average per year	0.97080	0.94208	0.94298	0.95195
Minimum efficiency result	0.83447	0.65902	0.76574	0.78907
Number (%) of efficient counties	12 (57%)	9 (43%)	12 (57%)	
Number (%) of inefficient counties	9 (43%)	12 (57%)	9 (43%)	

Source: Author's calculations

In window analysis model, each county is represented by three entities – one for each of the observed years. Due to the need of their mutual distinguishing, the name of each entity should consist of the county name and the corresponding year. Table 4 displays the reference set frequencies for every efficient entity. Although inefficient in 2007 and 2009, Koprivnica-Križevci in 2008 sets an exemplar by serving as reference for the largest number of inefficient counties in each of the observed years.

The average differences per inefficient county between empirical and projected values in every input and output are displayed in Table 5.

Table 4: The reference set frequency according to window analysis

Efficient county	Reference set frequency			
	2007	2008	2009	Σ
Grad Zagreb-2007	0	0	0	0
Zagrebačka-2007	0	0	0	0
Krapinsko-zagorska-2007	0	0	1	1
Sisačko-moslavačka-2007	0	0	0	0
Varaždinska-2007	1	0	1	2
Ličko-senjska-2007	0	0	0	0
Virovitičko-podravska-2007	3	5	4	12
Brodsko-posavska-2007	0	0	0	0
Osječko-baranjska-2007	0	0	0	0
Vukovarsko-srijemska-2007	0	0	1	1
Splitsko-dalmatinska-2007	1	1	0	2
Istarska-2007	1	2	2	5
Grad Zagreb-2008	2	3	1	6
Zagrebačka-2008	6	8	6	20
Krapinsko-zagorska-2008	5	5	6	16
Sisačko-moslavačka-2008	0	0	0	0
Varaždinska-2008	0	0	1	1
Koprivničko-križevačka-2008	8	10	8	26
Primorsko-goranska-2008	1	1	0	2
Ličko-senjska-2008	2	1	1	4
Požeško-slavonska-2008	1	0	1	2
Grad Zagreb-2009	2	2	1	5
Zagrebačka-2009	0	2	2	4
Krapinsko-zagorska-2009	0	1	0	1
Sisačko-moslavačka-2009	1	0	0	1
Primorsko-goranska-2009	0	0	0	0

Ličko-senjska-2009	2	2	2	6
Virovitičko-podravska-2009	0	2	2	4
Požeško-slavonska-2009	0	0	0	0
Brodsko-posavska-2009	3	5	3	11
Osječko-baranjska-2009	1	3	1	5
Vukovarsko-srijemska-2009	0	0	0	0
Splitsko-dalmatinska-2009	0	2	0	2

Source: Author's calculations

On average, the number of medical examinations has by far the strongest influence on inefficiency. On the other hand, the number of inpatient care days does not affect the efficiency, with the exception of 2008 where its improvement is required but quite negligible. That is particularly interesting because it was not at all the source of inefficiency when the year 2008 was observed separately. The reason lies in the fact that the overall performance of counties is better in the other two years. Specifically, best average values of all indicators at the state level are recorded in 2007 and 2009 (naturally, smaller amounts for inputs and larger amounts for outputs are preferable).

Table 5: Sources and average amounts of inefficiency according to window analysis

Inputs/Outputs		Proposed input and output improvements (%)		
		2007	2008	2009
Inputs	Hospital beds	-6.81	-10.37	-13.31
	Hospital doctors	-12.81	-14.22	-17.63
Outputs	Inpatient care days	0.00	0.09	0.00
	Medical examinations	12.10	95.45	12.20

Source: Author's calculations

CONCLUSION

The analysis in this paper, conducted using the DEA method, shows quite high average regional hospital efficiency scores of Croatian counties. However, some counties are lagging far behind, particularly Šibensko-kninska with the worst overall average score and Dubrovačko-neretvanska with the worst scores in 2007 and 2009. The analysis identified inpatient care days as the minor source and medical examinations in specialist offices as by far the largest source of inefficiency. This result is consistent with the disproportions of these indicators among counties.

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