Professor Marinko ŠKARE, PhD (corresponding author)
E-mail : mskare@unipu.hr
Assistant Professor Danijela RABAR
E-mail: drabar@unipu.hr
Juraj Dobrila University of Pula
"Dr. Mijo Mirković" Faculty of Economics and Tourism
Croatia

REGIONAL EFFICIENCY ASSESSMENT USING DEA WINDOW ANALYSIS

Abstract. *A regional disparity is becoming increasingly important growth constraint. Policy makers need quantitative knowledge to design effective, targeted policies. In this paper, regional efficiency of Croatian counties is measured (2005-2007) using data envelopment analysis (DEA). Regional efficiency is driven by naturally, historically and politically conditioned unequal county positions over which counties do not have total control. Categorical approach is introduced as an extension to the basic DEA models. This approach, combined with window analysis, changes relations among efficiency scores in favour of continental counties. The results should assists policy makers in designing effective regional policies by identifying main regional disparity determinants using an improved DEA model.*

Keywords: *Regional efficiency, Data envelopment analysis, Window analysis, Categorical variables.*

JEL Classification: R58, R11, R0, C61

1. Introduction

Regional efficiency and possibilities of its improvement have become one of the leading imperatives of all world economies. Achieving balanced national development and reducing interregional socio-economic disparities is a comprehensive economic challenge. In the extensive literature researching strategy and policy of regional development, there is consensus that regions in which economic policy makers better understand the importance of evaluation and use of information and technology have better chance of establishing successful economies.

Regional efficiency is generally assessed based on partial comparisons of regional growth and development indicators. Those are mostly one-on-one comparisons in which GDP per capita as a key socio-economic indicator is put into relationship with some of the others – such as employment, investment, exports, education level, etc. Each of these comparisons results with a degree of correlation between two indicators, but does not give a complete picture of the achieved level of regional development.

Although the importance of partial comparisons is unquestionable, the introduction of composite indicators as weighted averages of the basic indicators is anticipated. Regions are classified according to the overall development, but the improvement amount of each indicator in order to reach more developed regions is still not specified. Traditional methods for measuring efficiency require knowledge of the explicit functional form linking inputs and outputs. In addition, parametric methods require a priori determination of input and output weights making assessment of their importance subjective.

The purpose of this paper is to present the results of the analysis of regional efficiency in Croatia extending traditionally used efficiency measuring methods overcoming conventional drawbacks by using Data Envelopment Analysis. This method is often used in combination with some multi-criteria decision-making approaches to circumvent their drawbacks relating to the preferences of the decision makers. Thus Grošelj et al. (2011) focus on the group AHP (Analytical Hierarchy Process) methods which are based on DEA.

Although the DEA method itself is present in the literature concerning the assessment of regional efficiency (Maudos et al. 2000; Afonso and Fernandes 2006; Enflo and Hjertstrand 2009), the combination of categorical approach and window analysis is original as well as the use of unique combination of inputs and outputs. The results of the study underline the importance of combining categorical approach and window analysis for future research (see Ke et al. in press; Munda and Saisana 2011).

The special emphasis is on determining sources and amounts of inefficiency for each region in relation to other regions based on empirical data. This type of information is of great importance for several reasons. First of all, it is the result of a procedure that compares all regions according to all relevant socio-economic indicators at the same time. This provides a comprehensive picture of regional efficiency in the entire country. Secondly, knowledge of the factors that cause inefficiency in a particular region is not sufficient without knowledge of the exact measure of their influence. This measure is provided through the amounts of inefficiency in each source.

The paper is organized as follows: section 2 discusses traditional regional efficiency measurement methods and inherited advantages and shortcomings. Section 3 introduces extension to standard DEA models setting up mathematical framework for the study. Empirical results of the model application for measuring regional efficiency in Croatia are presented in section 4. Section 5 presents the summary of our findings emphasizing most important policy implications.

2. Theoretical Framework and Related Literature

Filipić et al. (1998) analysed regional efficiency in Croatia through regional disparities at macro-region and county levels in the years 1971 and 1991. Using multicriterial *Promethee method*, the authors concluded that the units mostly retained their development rankings, while only a few of them substantially improved or worsened their position.

Cziraky et al. (2002) combined a *structural equation model with latent variables and cluster analysis* to categorize Croatia's local units into four clusters according to their specific socio-economic characteristics on the basis of 12 socio-economic variables.

Rašić Bakarić (2006) used *factor and cluster analysis* to group local units of three Croatian counties into clusters on the basis of 11 selected socio-economic indicators. The results pointed out that distance between spatial units, in this case cities and municipalities, did not necessarily imply their "distance" i.e. the difference according to criteria of socio-economic development. Local and regional economic development in emerging economies is a complex process as suggested by Ersoy and Taylor (2012). Regional disparity and convergence models and theories are continuously evolving, see Song et al. (2012). Divergences in the basic public services is a big issue in the regional development of some countries as China, Qichun and Xuebing (2013). Spatial commonality through market integration could play a significant role in alleviating regional disparities, Cojanu (2013). Regional differences in self-employment drive unemployment on the regional level, Botrić (2012).

Nestić and Vecchi (2006) analysed data on household expenditure for the period 2002-2004. Using *econometric analysis*, the authors found significant regional disparities in poverty rates which were more significant in rural than in urban Croatian regions.

The United Nations Development Programme (UNDP) and Croatia's National Competitiveness Council (NCC) introduced Regional Competitiveness Index of Croatia 2007. This comprehensive scientific study calculated the competitiveness of Croatia's regions according to *World Economic Forum methodology*, based on 176 statistical and perceptive indicators representing eight pillars of competitiveness.

Using five key socio-economic indicators, (Puljiz 2007) created the *development index* and applied it at county and local level aiming to categorize units according to the degree of development. Regulation on the development index, codified by Croatian government, stipulated that index as unique methodological framework for evaluating, classifying and monitoring the development of territorial units.

Despite the fact that each of the aforementioned methods makes unquestionable contribution to the measurement of regional disparities and development levels, all those approaches have several drawbacks. First of all, assigning weights to indicators is highly controversial[1]. In addition, although those methods determine development level, they neither rank indicators by their impact to obtained result nor specify guidelines for improvement.

In assessing the relative efficiency, two separate issues are often present. First is the request for appropriate dynamics monitoring of the obtained results. Second is the need to respect unequal positions of the observed entities, on which they have little or no influence. DEA treats these issues separately – the first using window analysis, and the second using categorical variables. The real problem arises with the need to reach their simultaneous solution since no DEA model deals with both of them at the same time. In order to bridge this problem, a design of a new model is advanced in this paper.

3. Data and Model Setup

Croatian counties represent 21 entities whose relative socio-economic efficiency is measured in this paper. Systematic analysis of regional development cannot be based on a single indicator because no single indicator concerns all relevant determinants. It is therefore necessary to choose proper indicator from a set of relevant indicators. Prior to model setup, a large number of socio-economic indicators relevant to the analysis of regional development were considered. Their choice for the purposes of this study followed the subsequent line of thought: capturing human and material components and living standards as three outstanding criteria for determining degree of socio-economic development; exact measurability of indicators; availability and accessibility of data on indicators.

Accordingly, ten socio-economic indicators[2] are included into analysis[3]. The inputs are represented by registered unemployment rate and number of support allowance users. The outputs are share of secondary sector in gross value added (GVA), gross fixed capital formation in fixed assets (by headquarter of investor), level of import coverage by export[4], number of graduated students (by residence), gross domestic product (GDP), level of emigrants coverage by immigrants[5], number of active legal entities and number of medical doctors.

[1] Weighting various inputs and outputs by pre-selected (fixed) weights simplifies matters for use but raises a host of other questions such as justifying ratios of assigned weights. Even more important are problems that can arise with the results since it is not clear how much of the efficiency ratings are due to the weights and how much inefficiency is associated with observations.

[2] Although there are no restrictions on the selection of inputs and outputs, the variables for which smaller amounts are preferable will be considered inputs, while those for which larger amounts are preferable will be considered outputs.

[3] When selecting inputs and outputs, it is crucial to avoid the unwanted emphasis that can be put on a particular variable (Cooper et al. 2006, pp. 19).

[4] level of import coverage by export = (total exports / total imports) *100

[5] level of emigrants coverage by immigrants = (number of immigrants / number of emigrants) *100

Data for these indicators are relating to the period 2005-2007 and were taken from the Croatian Employment Service, the Croatian Bureau of Statistics and the Ministry of Health and Social Welfare of the Republic of Croatia. However, they were not taken in their original form and reasons for that were as follows. Large differences in population between counties resulted in significant differences in all other listed indicators. To take that into account, numbers of support allowance users, graduated students and medical doctors were given per 100,000 inhabitants, number of active legal entities was given per 1,000 inhabitants, while capital formation and GDP were given per capita at constant prices of the year 2005. Aforementioned data adjustments make comparisons more reliable and results easier to interpret. The descriptive statistics of adjusted data for each variable are given in Table 1.

As a standard indicator of economic development level, which includes the contribution of the entire public sector, *per capita GDP* is traditionally considered the best measure of economic activity. The *unemployment rate*[6] is used as a key indicator of socio-economic differences, suitable for identification of so called „problem“ areas in regional development. Bearing in mind extreme importance of secondary sector's role in regional development level, it is measured by the *share of secondary sector in GVA*[7]. Investments are certainly one of the most important sources of economic growth and it was the leading reason for inclusion of *gross fixed capital formation in fixed assets*[8] into this study.

[6] For this study, the advantage of registered unemployment rate over Labour Force Survey is the possibility of using county-level rates. Shortcomings due to which registered unemployment rate is not used in international comparisons are irrelevant here because of the uniqueness of the legislative framework at the national level.

[7] In this case, the share of secondary sector in GVA is considered more relevant than commonly used indicators such as GVA or gross wages and salaries per employee in industrial enterprises. That is because ranking of counties by indicators per capita or per employee can lead to significantly different results between counties which can be a consequence for example of high unemployment rate in these counties.

[8] Available data on investments from the Croatian Bureau of Statistics were gross fixed capital formation in fixed assets by location of objects and by headquarter of investor. The reason for choosing the latter one was the fact that it should provide more realistic view on the development on counties’ economies.

Table 1: Descriptive statistics

	Periods	Inputs					Outputs				
		Registered unemployment rate	Support allowance users	Share of secondary sector in GVA	Gross fixed capital formation in fixed assets	Level of import coverage by export	Graduated students	GDP	Level of emigrants coverage by immigrants	Active legal entities	Medical doctors
mean	2005	20.9	3,256.2	21.0	7,903.3	86.9	356.6	51,643.1	119.5	17.9	213.8
	2006	19.8	3,077.4	21.9	8,856.0	85.7	383.4	53,894.4	112.6	20.4	217.0
	2007	17.1	2,823.5	22.0	9,344.0	87.1	410.5	56,729.3	109.1	21.9	225.2
	2005-2007	19.3	3,052.3	21.6	8,701.1	86.5	383.5	54,088.9	113.7	20.1	218.6
median	2005	20.9	2,741.0	20.2	5,666.8	88.4	333.0	46,853.0	93.9	15.6	217.1
	2006	20.4	2,550.0	19.8	6,080.1	88.1	348.7	48,742.3	90.0	16.9	219.7
	2007	18.5	2,345.3	22.5	6,823.7	90.5	373.5	53,013.9	94.6	18.4	220.3
	2005-2007	19.3	2,566.9	20.3	5,836.2	88.4	349.4	48,801.0	93.6	16.7	219.7
st.dev.	2005	7.2	2,198.0	7.1	9,298.4	37.3	98.1	16,129.3	56.5	8.7	71.9
	2006	7.2	2,053.4	7.1	11,069.7	35.3	105.3	16,597.2	55.5	10.1	71.8
	2007	6.5	1,890.9	7.0	11,561.7	34.6	108.5	17,186.3	44.6	10.8	78.2
	2005-2007	7.0	2,025.8	7.0	10,531.0	35.2	104.7	16,506.4	51.8	9.9	73.0
min	2005	7.8	610.5	9.4	2,069.4	16.7	194.3	33,205.0	65.2	9.0	82.6
	2006	7.0	586.4	11.0	2,300.6	16.7	272.5	35,001.9	58.1	10.2	82.7
	2007	5.7	550.5	8.1	2,465.4	16.8	272.0	36,211.0	61.5	10.9	86.5
max	2005	32.1	9,821.9	32.7	45,622.3	155.6	594.3	105,201.0	259.1	40.6	449.3
	2006	30.6	9,036.8	36.5	54,438.7	163.7	636.9	109,596.4	253.1	46.1	458.0
	2007	27.6	8,298.2	34.7	57,115.1	148.1	674.0	113,590.7	212.1	49.4	492.6

Source: Author's calculations

The *level of import coverage by export*[9] was chosen as one of the indicators of economic openness in which international exchange plays an important role as engine of economic growth. Since the results of numerous studies have confirmed the exceptional importance of higher education for regional development[10], it was advisable to include the *number of graduated students* as an indicator related to that part of education. The *number of support allowance users* was chosen as one of the possible indicators of poverty[11]. One of the non-economic indicators for measuring quality of life is the quality of health services[12], which is well presented by the *number of medical doctors*. The *level of emigrants' coverage by immigrants* should have been included into regional efficiency analysis as an indicator which covers both immigrants and emigrants, because large number of immigrants does not necessarily mean positive net migration of population[13]. The *number of active legal entities*[14] in a particular county illustrates its economic activity, and thus its economic development.

To circumvent the drawbacks of the traditional methods for measuring efficiency, which were mentioned in introduction, a non-parametric linear programming-based method Data Envelopment Analysis is used. With this methodology, degree of regional disparities can be accurately determined and development goals quantified.

In a relatively short period of time since its inception (Charnes et al. 1978), DEA has grown into a powerful quantitative, analytical tool for measuring and evaluating productivity and efficiency of performance. These evaluations can involve companies, organizations, countries and regions. Up through the year 2009, the field has accumulated approximately 4500 papers in ISI Web of Science database (Liu et al. 2013). A multitude of models that are distinguished by the assumption on returns to scale (constant or variable), by the purpose of the model

[9] There is a number of indicators based either on imports or exports (absolute value of imports and exports, shares of imports and exports in GDP, imports and exports per capita, etc.) which, when observed separately, do not reflect foreign trade balance appropriately. This was the reason to include an indicator which covered both imports and exports by putting them into a relative ratio.

[10] Concentration of various human profiles, arising from education and resulting in different skills, ideas and products, enables productivity growth thus generating general economic development.

[11] Larger number of support allowance users in relation to the total population means lower standard of living.

[12] The quality of health services, and thus indirectly the health itself, is a consequence of the situation in the health care system which plays an important role for a stable economic growth in the long run.

[13] As the difference between the number of immigrants and emigrants, net migration presents the attractiveness of a county which includes, among other natural advantages (climate, landscape, etc.), availability of jobs, recreational activities, etc.

[14] It is also one of the commonly used indicators of entrepreneurship development on which, among many others, is based Regional Competitiveness Index of Croatia 2007.

(minimizing inputs or maximizing outputs), by numerous extensions and relaxations, etc. have been developed.

DEA is a performance measurement technique generally used for evaluating the relative performance of a group of peer entities, called decision-making units (DMUs), which convert multiple inputs into multiple outputs. The whole procedure is based on empirical data[15] on inputs and outputs of all observed entities, which should be included into a linear program representing the chosen DEA model. It generates an empirical efficient production frontier enveloping data by the smallest set that satisfies the imposed production assumptions. By comparing all DMUs against efficient frontier, DEA model measures the relative efficiency of each DMU. Since spanned by the (best) existing DMUs, such frontier represents a practically attainable goal that inefficient DMUs should aspire to. The relative efficiency score can be any number which is within the interval $(0,1]$. DMUs classified as best performing (benchmarks) are rated '1', while the efficiency scores of other DMUs are calculated based on their distance from the efficient frontier instead according to a predetermined standard. The inefficiency is ascribed to input surpluses and/or output shortages and can be eliminated through projecting of the respective DMU to the efficient boundary. Basic models usually used in DEA applications are Charnes-Cooper-Rhodes and Banker-Charnes-Cooper, named by initials of their authors (CCR and BCC respectively). CCR model is characterized by constant and BCC model by variable returns to scale[16]. These models bring about wide range of useful results[17]. Among others, those are sources and amounts of inefficiency and proposed improvements in each input and each output for every entity, efficiency measure for each entity or activity of interest and reference set for each inefficient entity.

The management strategy could be aimed at either reducing the input amounts or at augmenting the output levels, while in both cases keeping the rest of the variables at their original levels. In order to meet such requirements, DEA models are moulded to reflect input or output-orientation, respectively. This distinction between differently oriented models results in different trajectories of projection on the efficient frontier and thus in different projection values of an inefficient entity. Therefore, the distances from inefficient county to its projections generally differ. Since smaller distance is easier to overcome, efficiency is not equally attainable by differently oriented models.

[15] One of the basic and very important features of DEA methodology is that measurement units of the different inputs and outputs do not need to be congruent.

[16] Since the CCR model was applicable only to processes with constant returns to scale, Banker et al. (1984) extended it in order to adapt it to processes with the assumption of variable returns to scale.

[17] The choice of returns to scale will usually depend not only on theoretical assumptions, but also "on the context and purpose of the analysis, or whether short-run or long-run efficiency is under scrutiny" (Jacobs et al. 2006, pp. 103).

Let the data set be given as $\mathbf{X} = (x_{ij}) \in \mathbf{R}^{m \times n}$ and $\mathbf{Y} = (y_{rj}) \in \mathbf{R}^{s \times n}$ where *n* is the number of DMUs, *m* is the number of inputs, *s* is the number of outputs. The input-oriented BCC model evaluates the efficiency of DMU_o, $o \in \{1, 2, ..., n\}$[18] by solving the following (multiplier form) linear program:

$$\max z = u_1 y_{1o} + ... + u_s y_{so} - u_0$$

subject to

$$v_1 x_{1o} + ... + v_m x_{mo} = 1$$

$$-v_1 x_{1j} - ... - v_m x_{mj} + u_1 y_{1j} + ... + u_s y_{sj} - u_0 e \le 0 \quad (j = 1, 2, ..., n)$$

$$v_1, v_2, ..., v_m \ge 0$$

$$u_1, u_2, ..., u_s \ge 0$$

u_0 free in sign

where variables v_i (*i* = 1, 2, ..., *m*) and u_r (*r* = 1, 2, ..., *s*) are input and output weights. The dual (envelopment) form of this linear program is expressed as:

(BCC_o) $\quad \min \theta_B$

subject to

$$\theta_B x_o - X\lambda \ge 0 \quad (1)$$

$$Y\lambda \ge y_o \quad (2)$$

$$e\lambda = 1 \quad (3)$$

$$\lambda \ge 0 \quad (4)$$

where $\lambda \in \mathbf{R}^n$ and *e* is a vector which has each element unity. Thus, conditions (1), (2) and (4) consist of *m*, *s* and *n* constraints, respectively. In the case we investigate, *n* = 21, *m* = 2, *s* = 8. Vector λ shows the proportions contributed by efficient DMUs to the projection of DMU_o onto efficient frontier. The optimal objective value θ_B^* ($0 < \theta_B^* \le 1$) is the efficiency score which for inefficient DMU_o also represents 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

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

with $s^- \ge 0$, $s^+ \ge 0$ for any feasible solution (θ_B, λ) of (BCC_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).

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

Definition 3.1. (BCC-Efficiency):

If an optimal solution $\left(\theta_B^*, \lambda^*, s^{-*}, s^{+*}\right)$ *obtained in this two-phase process for* (*BCC*$_o$) *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 3.2. (Reference Set):

For a BCC-inefficient DMU$_o$, *its* reference set E_o *is defined based on an optimal solution* λ^* *by*

$$E_o = \left\{ j \,\middle|\, \lambda_j^* > 0 \right\} \ \left(j \in \{1, 2, ..., n\} \right).$$

An optimal solution can be expressed as

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

$$y_o = \sum_{j \in E_o} y_j \lambda_j^* - s^{+*}.$$

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^* and the input excesses recorded in s^{-*} are eliminated, and if the output values are augmented by the output shortfalls in s^{+*}. Described improvement can be expressed by the following formula known as the BCC-projection:

$$\hat{x}_o = \theta_B^* x_o - s^{-*},$$

$$\hat{y}_o = y_o + s^{+*}.$$

On the other hand, the output-oriented BCC model evaluates the efficiency of the same DMU$_o$ by solving the following linear program:

$$\min z = v_1 x_{1o} + ... + v_m x_{mo} - v_0$$

subject to

$$u_1 y_{1o} + ... + u_s y_{so} = 1$$

$$v_1 x_{1j} + ... + v_m x_{mj} - u_1 y_{1j} - ... - u_s y_{sj} - v_0 e \geq 0 \quad \left(j = 1, 2, ..., n \right)$$

$$v_1, v_2, ..., v_m \geq 0$$

$$u_1, u_2, ..., u_s \geq 0$$

v_0 free in sign.

Its dual form is expressed as:

$$\max \eta_B$$

subject to

$$X\lambda \leq x_o$$

$$\eta_B y_o - Y\lambda \leq 0$$

$$e\lambda = 1$$

$$\lambda \geq 0$$

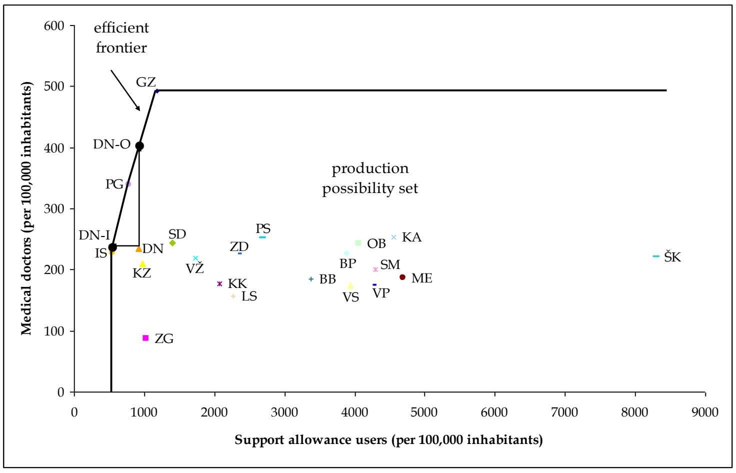
Unlike the input-oriented model, the optimal objective value η_B^* ($\eta_B^* \geq 1$) is the reciprocal of the efficiency result, and for inefficient DMU$_o$ also the output enlargement rate. This also makes the most important difference between input-oriented and output-oriented BCC models.

The slack $\left(t^-, t^+\right)$ of the output-oriented model is defined by $t^- = x_o - X\lambda$ and $t^+ = Y\lambda - \eta y_o$, while the projection is expressed by:

$$\hat{x}_o = x_o - t^{-*},$$
$$\hat{y}_o = \eta_B^* y_o + t^{+*}.$$

Efficient frontier of the BCC model is depicted on the example of one input (number of support allowance users per 100,000 inhabitants) and one output (number of medical doctors per 100,000 inhabitants) case that refers to the year 2007 (Figure 1). Efficient are the City of Zagreb (GZ) and the counties of Istria (IS) and Primorje-Gorski Kotar (PG). Projections of Dubrovnik-Neretva (DN) against the efficiency frontier are represented by points DN-I (for input-orientation) and DN-O (for output orientation). Positions of these projections show that its references in the input-oriented case are IS and PG while PG and GZ are its references in the output-oriented case.

Figure 1: Production frontier of the BCC model



Source: Author's calculations

In any DEA application, it is suggested as a rule of thumb that the number of DMUs should be at least three times the number of indicators (Banker et al. 1989). The reason for this requirement is in greater reliability of the efficiency results. Inclusion of data for several periods for each DMU can overcome this limitation in the way that each DMU is treated as a different DMU in each of the periods observed. This leads to the use of window analysis as one of the extensions to DEA models. Efficient frontier of the window analysis model is constructed in the same manner as in the basic model with the difference in the number of observed entities.

Another issue in evaluating the relative efficiency is dealing with situations when DMUs operate under different conditions over which they do not have total control. In such cases, the evaluation of all DMUs on equal footing would be unfair to those in worse position. It is therefore very important to provide appropriate comparisons that will take into account their "handicaps". The categorical approach, which is proposed as a solution to this problem, makes an important additional reason for using DEA in this study. As an extension to DEA models, hierarchical category is suitable for handling such situations. Specifically, in order to isolate the impact of unequal position on efficiency results, DMUs are divided into categories within which they can be compared. This way evaluating the efficiency by comparing DMUs in worst position with those in better position is avoided. The category number ranges 1, 2, ..., L, where DMUs in category 1 are in the most disadvantageous condition and will be compared only among themselves. DMUs in category 2 are in a better position than those in category 1, and will be compared with reference to DMUs in categories 1 and 2 and so on. In conclusion, DMUs in category L will be compared with reference to all DMUs.

The categorical BCC model results with L efficient frontiers. Each of them is constructed in the same manner as in the basic model, but on the basis of a different set of DMUs. The first set consists only of DMUs in category 1, the second set of DMUs in categories 1 and 2 and so on. The efficiency is therefore easier to achieve for all DMUs except for those in category L. This exception is due to the fact that they are still compared to all other DMUs.

4. Model Application and Empirical Results

Knowledge of the production frontier characteristics for the process under analysis is decisive when selecting model type. Since it could not be decidedly determined in the case of regional performance, the analysis was accomplished 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 analysed socio-economic activity.

Since economic growth is aimed at decreasing all here selected inputs and increasing all here selected outputs at the same time, both orientations are utilized and the obtained results are compared.

The evaluation of Croatian counties relative efficiency is performed in two steps, based on empirical data on ten socio-economic indicators, and calculated by the software tool DEA-Solver-Pro 7.0F (Saitech, Inc.). Due to the nature of selected indicators, comparisons of the counties were made on a yearly basis.

The first step of our research was carried out using window analysis. Since three-year period 2005-2007 is chosen, the length of the period within which the comparisons are performed (i.e. the window) can range from one to three years. If one intends to, for example, mutually compare all two-year periods, there will be two windows (2005-2006 and 2006-2007).

The main reason for the use of window analysis is in the number of indicators which, considering the number of counties, should not exceed seven. A second and complementary reason is its possibility to enable monitoring of relative efficiency dynamics.

For the aims of this study, a three-year window is used. Since each county is regarded as an individual entity for each year, this analysis includes the set of $21 \cdot 3 = 63$ entities. The relative efficiency results, enable the comparisons on two different levels: comparisons of counties/rows and comparisons of years/columns. While the number of efficient counties does not depend on model orientation, the differences between efficiency scores obtained by input and by output orientation are obvious. Out of 63 observed entities, 20 proved to be relatively efficient. The highest efficiency results were achieved in the year 2007 toward both orientations. It refers to the number of efficient entities (9) as well as to the average efficiency scores (0.716474 toward inputs and 0.947556 toward outputs). Solely the County of Istria proved to be continuously efficient. Four counties turned out to be efficient in two years, nine in one year, while seven counties were found to be inefficient during the entire period.

Average efficiency scores for all three periods are greater in output orientation than in input orientation. These differences related to orientation are extreme in certain aspects, for instance in minimum efficiency scores. The average efficiency of all 63 entities is 0.679485 for input orientation. It implies that, in order to achieve the efficiency frontier, an average entity (i.e. a county in a year) should combine only 67.95% of the actually used quantity of inputs and should generate at least the originally produced quantity of outputs. The average efficiency for output orientation is 0.930874. This means that, in order to operate efficiently, an average entity should generate 7.43%[19] more output using at most the original input levels. Such input reduction or output expansion without changing proportions eliminates one of the various types of inefficiency referred to as technical inefficiency. In the case of Croatian counties, technical efficiency in all periods is generally significantly “closer” according to output-orientation than in input-oriented case. It still does not mean that it is easier to achieve toward output-orientation because that depends on the specific situation in which particular county operates. Thus, in some cases, it is easier to achieve relatively higher reduction in input values than relatively smaller increase in output values.

[19] $1/0.930874 - 1 = 0.0743$

The worst efficiency results according to the number of efficient counties (5) were achieved in 2006. At the same time, the lowest average efficiency was achieved in 2005 both according to input (0.659067) and output (0.922527) orientation. Nevertheless, the worst of all 63 efficiency scores was achieved for input orientation in 2006 by the County of Vukovar-Sirmium (0.213164) and for output orientation in 2005 by the County of Bjelovar-Bilogora (0.645712). Large differences between the average and worst efficiency results give evidence of great disparities among Croatian counties. When it comes to an analysis and assessment of inefficiency, it is necessary to determine its sources and their amounts. Moreover, it is of extreme importance to identify proposed improvements. These valuable information serve as the initial point upon which authorities can set objectives and arrive at decisions that will enable their achievement. The importance of reference set should also be emphasized because it provides information on the role models for each inefficient county. Consequently, the county which appears most frequently in the reference sets of inefficient counties can be considered the most efficient. This represents one among various approaches proposed by researchers for ranking efficient DMUs in DEA models. Thus, Jablonsky (2012) presents two original models (goal programming and AHP), compares them with several super-efficiency models and other approaches, and illustrates the obtained results on a real data set (194 bank branches of one of the Czech commercial banks). Since window analysis, unlike basic DEA models, does not bring just mentioned valuable results, a new model will be constructed as follows. Three data sets on ten selected indicators, one for each of the observed years, are included into a basic BCC model for each county. In this way, each of 63 of them is treated as separate entity.

Such model construction is justified because it does not affect relative efficiency scores identified by window analysis using one three-year window and yet calculates additional crucial results.

County that was identified as efficient usually appears in the reference sets of inefficient counties. The frequency of its appearance in those sets can be considered as a criterion of being a role model for other inefficient counties. In addition, the magnitude of frequency in reference sets measures the extent of the robustness of an efficient county relative to other efficient counties. Istria-2007 sets a good example for the input-oriented case (28) and City of Zagreb-2007 leads in the output-oriented case (35). While the City of Zagreb stands out due to the performances in 2007, the County of Istria outperforms in all three years and that makes it relatively most successful county (Table 2).

Table 2: Window analysis results – one window (2005-2006-2007)

County	Relative efficiency results							
	Input-orientation				Output-orientation			
	2005	2006	2007	Average	2005	2006	2007	Average
City of Zagreb	0.877512	0.874066	1	0.917193	0.991634	0.973506	1	0.988380
Zagreb	1	0.734529	0.960625	0.898385	1	0.935554	0.993245	0.976266
Krapina-Zagorje	1	0.809305	1	0.936435	1	0.963562	1	0.987854
Varaždin	0.566089	0.722177	1	0.762755	0.880413	0.939757	1	0.940057
Koprivnica-Križevci	0.720125	0.754251	1	0.824792	0.949245	0.974335	1	0.974527
Međimurje	0.648251	0.689658	1	0.779303	0.931980	0.937599	1	0.956526
Bjelovar-Bilogora	0.244732	0.263649	0.288002	0.265461	0.645712	0.721783	0.753244	0.706913
Virovitica-Podravina	0.865101	1	0.759882	0.874994	0.981709	1	0.948611	0.976773
Požega-Slavonia	1	0.830988	1	0.943663	1	0.953607	1	0.984536
Brod-Posavina	0.259011	0.225224	0.280874	0.255036	0.803341	0.756383	0.857579	0.805768
Osijek-Baranja	0.494884	0.486874	0.419373	0.467044	0.891946	0.892712	0.857188	0.880615
Vukovar-Sirmium	0.245899	0.213164	0.250199	0.236421	0.703862	0.668801	0.787558	0.720074
Karlovac	0.319045	0.279911	0.369556	0.322837	0.928665	0.915770	0.974097	0.939510
Sisak-Moslavina	0.542716	1	0.600674	0.714463	0.982810	1	0.979661	0.987490
Primorje-Gorski Kotar	0.847935	1	1	0.949312	0.947909	1	1	0.982636
Lika-Senj	1	0.442852	0.437795	0.626882	1	0.855998	0.844598	0.900199
Zadar	1	1	0.376079	0.792026	1	1	0.943250	0.981083
Šibenik-Knin	0.245049	0.273372	0.523723	0.347382	0.895939	0.937925	0.980937	0.938267
Split-Dalmatia	0.376009	0.445663	0.779167	0.533613	0.935852	0.955162	0.978702	0.956572
Istria	1	1	1	1	1	1	1	1
Dubrovnik-Neretva	0.588052	0.875483	1	0.821179	0.902047	0.990883	1	0.964310

Average per year	0.659067	0.662913	0.716474	0.679485	0.922527	0.922540	0.947556	0.930874
Minimum efficiency result	0.244732	0.213164	0.250199	0.236421	0.645712	0.668801	0.753244	0.706913
Number (%) of efficient counties	6 (29%)	5 (24%)	9 (43%)		6 (29%)	5 (24%)	9 (43%)	
Number (%) of inefficient counties	15 (71%)	16 (76%)	12 (57%)		15 (71%)	16 (76%)	12 (57%)	

Source: Author's calculations

Table 3: Sources and average amounts of inefficiency according to window analysis – one window (2005-2006-2007)

Inputs/Outputs		**Input and output improvements**					
		Input-orientation			**Output-orientation**		
		2005	**2006**	**2007**	**2005**	**2006**	**2007**
Inputs	Registered unemployment rate	-50.58%	-46.19%	-51.64%	-25.69%	-27.35%	-18.51%
	Support allowance users	-52.75%	-48.84%	-59.29%	-23.83%	-18.62%	-19.52%
Outputs	Share of secondary sector in GVA	29.41%	19.69%	26.07%	18.95%	15.67%	12.27%
	Gross fixed capital formation in fixed assets	243.46%	209.18%	239.80%	178.58%	185.59%	221.73%
	Level of import coverage by export	15.08%	18.51%	22.24%	20.21%	32.54%	32.66%
	Graduated students	24.10%	18.04%	9.65%	21.01%	15.73%	11.29%

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	GDP	49.73%	47.94%	49.61%	30.67%	31.88%	29.98%
	Level of emigrants coverage by immigrants	55.15%	68.54%	77.18%	14.36%	19.07%	15.89%
	Active legal entities	109.20%	104.66%	110.68%	45.84%	45.51%	40.86%
	Medical doctors	15.39%	22.01%	27.77%	19.47%	29.36%	35.31%

Source: Author's calculations

Amongst a number of results, there are also input and output improvements that are proposed to the counties in order to project themselves onto the efficiency frontier and thus attain relative efficiency. In case of efficient counties, projected values coincide with the empirical values. The average differences per inefficient county between original and target values for every input and output are given in Table 3. During the entire period and according to both orientations, the inefficiency is by far mostly influenced by gross fixed capital formation in fixed assets. On the other hand, mostly the number of graduated students least affects relative efficiency. Another issue in evaluating the performance of Croatian counties is their great disparities caused by reasons over which economic policy makers do not have complete control. In that context, the evaluation carried out in the first step of our research seems unfair to continental counties and too indulgent to coastal counties and particularly to the City of Zagreb. Therefore, it appears most appropriate to classify Croatian counties into three categories. Hence, the City of Zagreb is placed in category 3 (good), all 7 counties of Adriatic Croatia in category 2 (average) and the rest of 13 counties in category 1 (poor).

The second step of our research was therefore carried out using categorical approach. The role of categorical models in measuring regional efficiency in Croatia is to alleviate the impact of naturally, historically and politically conditioned unequal position of its counties. At the same time, the primary role of window analysis models is to monitor the dynamics of achieving socio-economic efficiency of the counties. Those extensions to basic DEA models solve two independent problems but there is the question of model choice in the case of their simultaneous resolution. A satisfactory solution is provided by the combination of categorical model and window analysis.

Since no existing model meets these requirements, the new model is constructed on the basis of the previous window analysis model by assigning corresponding categories to all of 63 entities. This means that the category of a particular county is assigned to each of three entities that represent the county. Thus, out of 63 entities, 39 are in category 1 (poor), 21 in category 2 (average) and 3 in category 3 (good)[20]. So designed model will be hereafter referred to as the combined BCC model. Its results are identical to the results of window analysis using one three-year window with categorical approach. This opens the possibility of their comparison with the results of afore described window analysis model (with no categorical variables).

Application of the combined BCC model using both orientations led to the results shown in Table 4.

[20] Out of 21 counties, 13 are in category 1, 7 in category 2 and 1 in category 3. Since each of them is now represented by three entities, there are three times more entities in each category.

Table 4: Combined BCC model results – one window (2005-2006-2007) and three categories

County (category)	Relative efficiency results							
	Input-orientation				Output-orientation			
	2005	2006	2007	Average per county	2005	2006	2007	Average per county
City of Zagreb (3)	0.8775	0.8740	1	0.9171	0.9916	0.9735	1	0.9883
Zagreb (1)	1	0.9488	1	0.9829	1	0.9825	1	0.9941
Krapina-Zagorje (1)	1	1	1	1	1	1	1	1
Varaždin (1)	0.7138	0.7840	1	0.8326	0.9461	0.9592	1	0.9684
Koprivnica-Križevci (1)	0.7201	0.7606	1	0.8269	0.9503	0.9838	1	0.9780
Međimurje (1)	0.6620	0.7475	1	0.8032	0.9371	0.9617	1	0.9662
Bjelovar-Bilogora (1)	0.3979	0.4132	0.4439	0.4183	0.7746	0.8313	0.8373	0.8144
Virovitica-Podravina (1)	1	1	0.8025	0.9341	1	1	0.9661	0.9887
Požega-Slavonia (1)	1	0.8309	1	0.9436	1	0.9671	1	0.9890
Brod-Posavina (1)	0.3389	0.3741	0.5044	0.4058	0.9169	0.8985	0.9449	0.9201
Osijek-Baranja (1)	0.4948	0.5533	1	0.6827	0.9499	0.9861	1	0.9787
Vukovar-Sirmium (1)	0.3198	0.3349	0.3682	0.3410	0.7438	0.7235	0.8524	0.7733
Karlovac (1)	0.6397	0.6852	1	0.7750	0.9780	0.9531	1	0.9770
Sisak-Moslavina (1)	0.5427	1	0.6006	0.7144	0.9867	1	0.9862	0.9910

Primorje-Gorski Kotar (2)	1	1	1	1	1	1	1	1
Lika-Senj (2)	1	0.4428	0.4377	0.6268	1	0.8559	0.8578	0.9046
Zadar (2)	1	1	0.3760	0.7920	1	1	0.9572	0.9857
Šibenik-Knin (2)	0.2490	0.2934	0.6860	0.4094	0.9123	0.9478	0.9860	0.9487
Split-Dalmatia (2)	0.3760	0.4476	1	0.6078	0.9523	0.9749	1	0.9757
Istria (2)	1	1	1	1	1	1	1	1
Dubrovnik-Neretva (2)	0.5880	1	1	0.8626	0.9146	1	1	0.9715
Average per year	0.7105	0.7376	0.8199	0.7560	0.9502	0.9523	0.9708	0.9578
Minimum efficiency result	0.2490	0.2934	0.3682	0.3410	0.7438	0.7235	0.8373	0.7733
Number (%) of efficient counties	8 (38%)	7 (33%)	13 (62%)		8 (38%)	7 (33%)	13 (62%)	
Number (%) of inefficient counties	13 (62%)	14 (67%)	8 (38%)		13 (62%)	14 (67%)	8 (38%)	

Source: Author’s calculations

Comparisons of the results reveal the presence of their significant differences, with the exclusion of City of Zagreb and Istria[21]. With categorical approach, among 63 observed entities, 28 turned out to be efficient which were eight more than according to the previous model. Among those eight were Primorje-Gorski Kotar in 2005 and Krapina-Zagorje in 2006 that put those counties side by side with the County of Istria in terms of efficiency achieved in all three years. Five counties were efficient in two years, nine in one year, while four counties were not efficient even once.

Similar to the previous model, the highest results of average efficiency according to all criteria were achieved in the year 2007. This can be attributed to the favourable global economic trends and to Croatia's efforts in accelerating sustainable economic and social development of the counties in accordance with national and European strategies.

The worst of 63 efficiency scores were obtained by Šibenik-Knin in 2005 (0.249054) according to input-oriented model and by Vukovar-Sirmium in 2006 (0.723594) in output-oriented case. It is significant that these counties have been most affected by war during the 1990s.

Compared to the previous period, the highest efficiency growth was achieved by Split-Dalmatia (+0.552) according to input-oriented model and by Vukovar-Sirmium (+0.129) according to output-oriented model. Both results refer to the year 2007. At the same time, the highest efficiency decline was recorded by Zadar (–0.624) in 2007 according to input-oriented model and by Lika-Senj (–0.144) in 2006 according to output-oriented model.

Most of the frequencies generated by this model are significantly different compared to the previous model, mainly at the expense of Istria and City of Zagreb. That happened mostly because those two counties now cannot be members of reference sets of inefficient counties in category 1.

Average differences per inefficient county between empirical and projected values in every input and output are displayed in Table 5. Similar to the previous model, gross fixed capital formation in fixed assets has the strongest influence on inefficiency. On the other side, this influence is not nearly as strong as in the previous model. That is because capital formation in continental counties is generally considerably low compared with the rest of Croatia, thus raising the amount of average inefficiency in that output. Since the comparison of category 1 with the other two categories is here bypassed, the inefficiency related to capital formation is significantly reduced.

[21] The reasons of keeping the efficiency unchanged differ for these two counties. The City of Zagreb is in both models compared to the same set of counties and therefore nothing changes. Istria is relatively the best performing county, so the comparison with City of Zagreb does not threaten its efficiency score.

Table 5: Sources and average amounts of inefficiency according to the combined BCC model – one window (2005- 2006-2007) and three categories

Inputs/Outputs		Input and output improvements					
		Input-orientation			Output-orientation		
		2005	2006	2007	2005	2006	2007
Inputs	*Registered unemployment rate*	-47.23%	-41.13%	-47.26%	-25.68%	-27.40%	-26.04%
	Support allowance users	-50.44%	-41.70%	-57.15%	-24.16%	-21.02%	-25.03%
Outputs	Share of secondary sector in GVA	43.04%	32.78%	40.54%	28.67%	28.87%	29.48%
	Gross fixed capital formation in fixed assets	112.20%	84.71%	116.43%	67.04%	60.86%	90.39%
	Level of import coverage by export	24.29%	11.23%	9.67%	19.96%	11.58%	9.95%
	Graduated students	15.70%	10.09%	8.01%	18.12%	13.65%	11.43%
	GDP	30.66%	22.75%	26.36%	22.28%	18.03%	18.93%
	Level of emigrants coverage by immigrants	27.14%	33.89%	38.70%	11.68%	21.82%	27.33%
	Active legal entities	51.47%	37.44%	49.08%	31.37%	27.92%	33.31%
	Medical doctors	9.07%	10.33%	17.37%	11.03%	11.20%	15.65%

Source: Author’s calculations

Detailed differences in average efficiency amounts obtained by the combined model and window analysis with no categorical variables show interesting results. They are obviously more significant according to the input-orientation. Assessment of relative efficiency of Croatian counties according to two applied models was based on their two common features. Specifically, the counties were compared to one another at the level of one three-year period and based on the same set of indicators. In the window analysis model each county was compared to all other counties, while in the combined model a county was compared only to the counties from the same or lower categories. Therefore, relative efficiency scores according to the combined model were not lower than according to window analysis model. After classification of counties, a significant number of counties improved their efficiency. Some of them even became efficient. Therefore, the total average relative efficiency increased, advancing forward the categorical approach for most counties as preferred.

5. Conclusion

The analysis in this paper, conducted using the DEA method, shows that regional efficiency scores of Croatian counties differ significantly, which proves significant interregional socio-economic disparities. Categorical approach has somewhat mitigated those differences but they have still remained significant. Great socio-economic disparities among counties imply that economic policy makers should intensify their efforts for adjustment of the legal framework concerning regional development and for decentralization increase. The analysis of the scores of inefficient counties identified the number of graduated students as the minor source and gross fixed capital formation in fixed assets (by headquarter of investor) as by far the largest source of their inefficiency. This result is consistent with the disproportions of these indicators among counties. The City of Zagreb has achieved efficiency only in the year 2007. Since it dominates over the majority of counties by its development potential, such outcome does not coincide with the expected. These efficiency results could be mostly attributed to the low level of import coverage by export, which is almost three times lower than the average. Regardless of the model and its orientation, the results showed an increase in the average efficiency during the observed three-year period, which was most pronounced in the last year. The cause of such trend was in economic conditions at the time within Croatia and abroad.

The conclusions above are subject to some limitations. Unavailability or inaccessibility of data on particular socio-economic indicators narrowed down their choice. For the same reason, the selected period was shortened to the maximum number of consecutive years for which data were available on all selected indicators. Since the reduction in the number of indicators (in terms of the use of fewer excellent indicators) is in accordance with EU guidelines and practice of other referent European countries (Institute for International Relations 2006, pp. 7), the selection of indicators used in this paper is not questionable. On the other hand, the analysis of a longer period would be more useful because of allowing greater insight into the dynamics of regional development.

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