

The analysis of convergence process of voivodships' efficiency in Poland using the DEA method

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Abstract

Since 1999 – when the new administrative division in Poland was introduced – it has been possible to measure and compare standard of living between Polish and other European regions (NUTS II). In 2004 Poland has joined the European Union. Since that year voivodships have become main beneficiaries of the EU funds. The essential part of the EU aid is related to the EU cohesion policy (convergence objective).

According to the fifth cohesion report “cohesion policy has made a significant contribution to spreading growth and prosperity across the Union, while reducing economic, social and territorial disparities”. However, the differences in standard of living still remains significant between countries as well as between regions within one country.

In many researches the level of welfare is measured using “classic” indicators (GDP per capita, GNI per capita, unemployment rate, etc.). In this paper the authors focus on the regional economies' efficiency. The efficiency will be measured using the Data Envelopment Analysis (DEA). Due to the method used, the efficiency will be measured as relative in nature, i.e. will be compared between voivodships within the period of research.

The goal of the paper is to analyze variety of relative voivodships' efficiency in order to answer the question whether the dispersion in efficiency is increasing or decreasing over time.

Key words: cohesion, convergence, efficiency, data envelopment analysis,

Introduction

Economic, social and territorial cohesion is a subject of investigation of many scholars and practitioners (i.e. politicians). The term of convergence (economic) refers to the situation in which poorer economies will tend to grow at faster rates than richer economies. In consequence, such economies will become more coherent, in terms of the welfare distribution. In theory, we can find a distinction between two types of convergence:

- β -convergence when the partial correlation between growth in income over time and its initial level is negative and
- σ -convergence when the dispersion of real per capita income (henceforth, simply "income") across a group of economies falls over time.

Breakthrough papers in "convergence literature" were written by Barro and Sala-i-Martin (1992) and Mankiw et al. (1992). Their findings suggest that convergence process could be found in all analysed examples (US states, EU regions, Japan prefectures). And the speed of the β -convergence process is around 2-3 percent per year (see also Young et al. 2008). Despite the literature's stress on β -convergence, economists have acknowledged that it is not a sufficient condition for σ -convergence. Quah (1993) and Friedman (1992) both suggest that σ -convergence is of greater interest since it speaks directly as to whether the distribution of income across economies is becoming more equitable. In our paper we follow that suggestion made by Quah and Friedman.

On the European Union level this issue is a special topic of interests. The main goal of current cohesion policy is to reduce disparities that still exist between Europe's regions. It is assumed that reducing such disparities is one of the cornerstones of the EU.

According to the EU authorities, cohesion policy has made a significant contribution to spreading growth and prosperity across the Union. The authors of *The fifth report on economic, social and territorial cohesion* claim, that the policy has created new jobs, increased human capital, built critical infrastructure and improved environmental protection, especially in the less developed regions (European Commission 2010). Such statement rises a question whether without cohesion policy disparities would be greater. As indicated in the latest EU strategic documents Europe 2020 cohesion policy will remain one of the priorities.

In Figure 1 the tendency in convergence process in European Union (NUTS II dimension) was demonstrated. The coefficient of variation, a common measure of disparities (described below), fell from 42.7 in 1996 to 39.1 in 2007 in the EU. Other dispersion measures, such as the Gini index or the S80/20 ratio (the ratio of the top 20% of regions to the bottom 20%), show much the same reduction.

The authors of the report indicate, that the growth in EU-12 regions has led to a marked narrowing of regional disparities in GDP per head in PPS terms across the Union. Nevertheless, disparities remain pronounced with GDP per inhabitant levels less than a third of the EU average in 7 Romanian and Bulgarian regions and levels over 50% higher than the EU average in 19 regions, of which 11 are capital city regions (European Commission 2010).

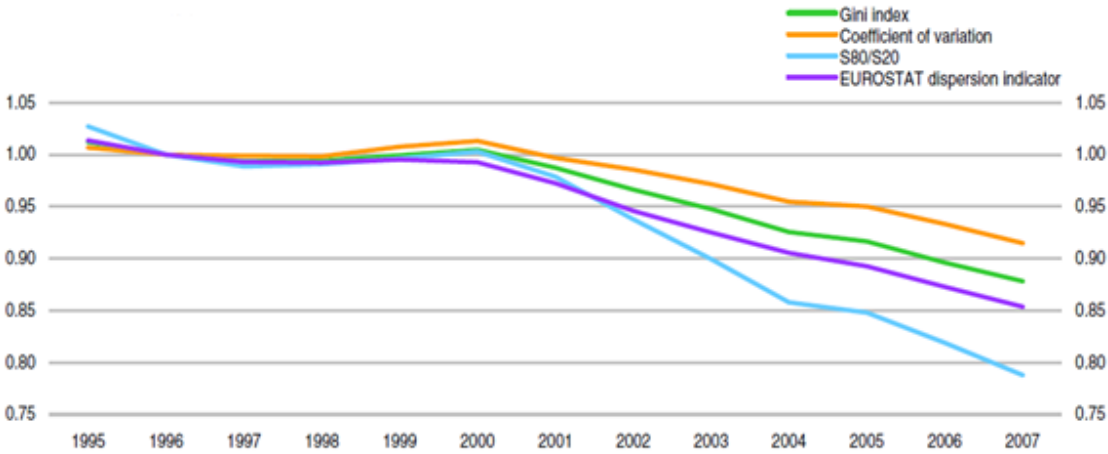


Figure 1: Measures of dispersion in GDP per head in the EU 1996-2007
 Source: European Commission (2010), p 11.

The main goal of the paper is to analyze variety of relative voivodships' efficiency in order to answer the question whether the dispersion in efficiency is increasing or decreasing over time. In the empirical part of the article the authors will focus on the efficiency and its convergence in Polish voivodships from 1999 to 2008. It was the intent of the authors to verify the thesis that the variety in economic efficiency of regions has been rising thorough last years. The first step of our study will be descriptive statistical analysis of economic disparities with the use of coefficient of variation and Theil index. The second step of our study will be variety analysis of the results of the DEA analysis. Than the authors will try to compare obtained results and draw conclusions.

Convergence process in Poland

In figure 2 the dynamics of income level (gross domestic product per inhabitant) in each voivodship (region) is illustrated.

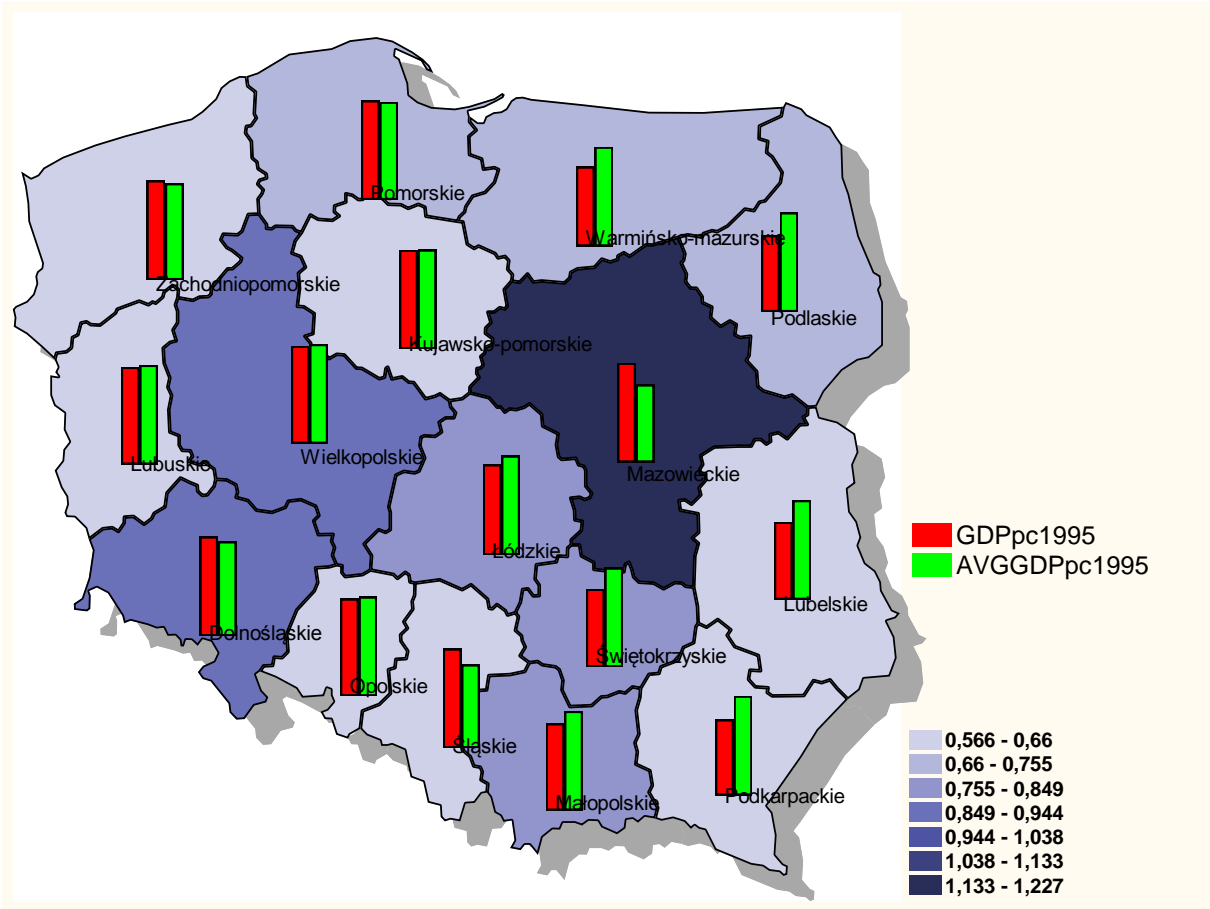


Figure 2: Change in GDP per capita in Polish voivodships from 1995 to 2008.

Source: Own calculations.

The colours in figure 2 represent change in gross domestic product per capita in each voivodship between 1995 and 2008 (the darker the colour, the faster the growth). The highest increase in GDP value was observed in Mazowieckie voivodship (over 120%). The red bars present GDP per capita in 1995 and the green bars represent the average GDP per capita in Poland for 1995. Generally, we may observe, that richer regions in 1995 growing faster than poorer ones.

This conclusion is verified using Theil index and weighted CV. The calculations are based on gross domestic product (GDP) per capita variable.

The formula for the Theil index is as follows:

$$I_T = \sum_{i=1}^n \frac{Y_i}{Y} \ln \frac{Y_i/P_i}{Y/P} \quad (1)$$

$\frac{Y_i}{Y}$ represents the share of each region in the total product of the regions ,

and $\frac{Y_i/P_i}{Y/P}$ represents the relation of the product per capita of each region to the product per inhabitant of regions taken as a whole. The Theil index can vary between 0 and $\ln P/P_i$. Maximum value $\ln P/P_i$ means that the whole of the product is concentrated in the region where the population is smallest and value equal zero means perfect equality in regional product per head.

A well known coefficient of variation is defined as : $CV = \frac{s}{\bar{x}} 100\%$, where s is the standard deviation and \bar{x} the average value. In our study we need weighted CV which is equal:

$$CV = \frac{\sqrt{\sum_i \left(\frac{Y_i}{P_i} - \frac{Y}{P}\right)^2 \frac{P_i}{P}}}{\frac{Y}{P}} \quad (2)$$

in which :

P_i share in population of region i

Y_i share in product of region i

CV value is usually positive, and the higher CV value the higher variation of a variable. The results of CV and the Theil index calculations for Poland are presented in figure 3. Please notice that in order to make it comparable the right vertical axes represents values of normalized Theil index.

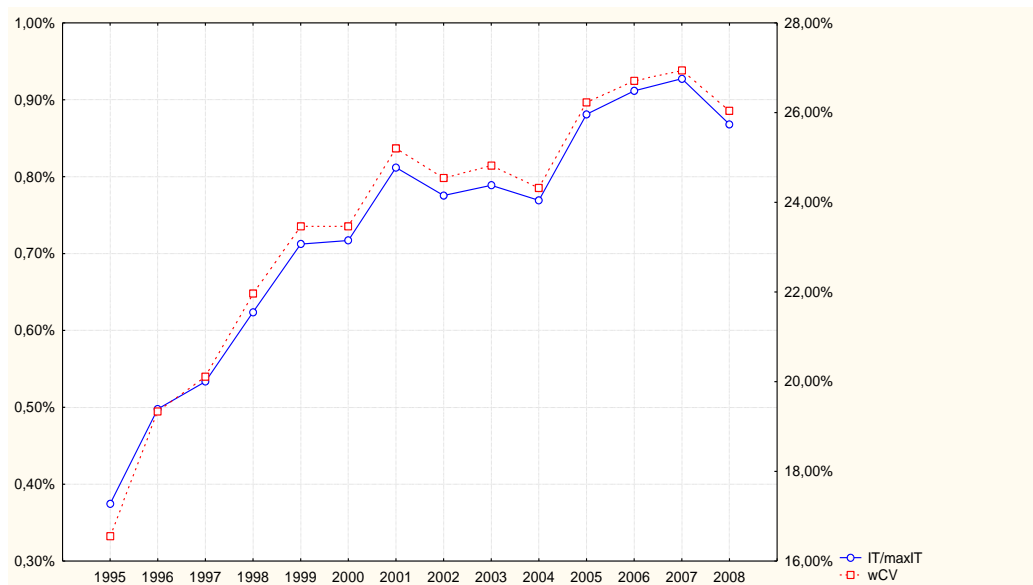


Figure 3: Dispersion of GDP per capita in years 1995-2008

Source: Own calculations.

As shown in figure 3 disparities in regional income in Poland were increasing from 1995 till 2008. Such a tendency was also found by other authors, for instance Próchniak (2004), Wójcik (2008) and was also noticed in the 5th Cohesion Report by European Commission (mentioned above), especially in new member countries: “for instance, in Romania the coefficient of variation rose from 15 in 1995 to 44 in 2007, reflecting the relative concentration of growth in one or two regions, especially the capital city region” (European Commission 2010). Moreover, based on HERMIN model forecasts, such a trend will be continued in Poland until 2020. (Kudłacz and Woźniak, 2010)

It is worth to be noticed that the results of using both methods (CV and I_T) are very similar. However, the Theil index gives us a better image of inequalities in Poland. The maximum value corresponds to maximum inequality in regional products per inhabitant, in which the whole of the product is concentrated in the region where the population is smallest (Lubuskie region). In Poland, we can notice below 1% of maximum possible inequality. As we can see in figure 3 the trend of growing disparities was interrupted in 1999, between 2001 and 2004, and in 2008. We would take a risk of formulating a statement that regional disparities are increasing during prosperity stage of economic cycle and are decreasing during economic slowdown. This would correspond to the Williamson curve hypothesis

(Williamson 1965), especially in the form tested by Petrakos, Rodriques-Pose, Rovolis (2003). According to them disparities are pro-cyclical in short run.

However, taking a look at the values in figure 1, allows us to notice that they are generally lower than the EU average (see above).

The DEA Method

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:

$$E_o = \frac{\sum_{r=1}^s u_r y_{ro}}{\sum_{i=1}^m v_i x_{io}} \quad (3)$$

where:

E_o – efficiency of the DMU_o (observed DMU)

x_{io} – amount of input i for the unit o , $i = 1; 2; \dots, m$ and $o = 1; 2; \dots, n$.

y_{ro} – amount of output r for the unit o , $r = 1; 2; \dots, s$ and $o = 1; 2; \dots, n$.

u_r – weight assigned to the output r , $r = 1; 2; \dots, s$.

v_i – weight assigned to the input i , $i = 1; 2; \dots, m$.

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:

$$\max \frac{\sum_{r=1}^s u_r y_{ro}}{\sum_{i=1}^m v_i x_{io}} \quad (4)$$

Subject to:

$$\frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} \leq 1, \quad j = 1, \dots, n \quad u_r \geq \varepsilon, \quad r = 1, \dots, s, \quad v_i \geq \varepsilon, \quad i = 1, \dots, m. \quad (5)$$

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:

$$\max \sum_{r=1}^s \mu_r y_{ro} \quad (6)$$

Subject to:

$$\begin{aligned} \sum_{i=1}^m v_i x_{io} = 1, \quad \sum_{r=1}^s \mu_r y_{rj} - \sum_{i=1}^m v_i x_{ij} \leq 0, \quad (7) \\ j = 1, \dots, n, \quad \mu_r \geq \varepsilon, \quad r = 1, \dots, s \quad v_i \geq \varepsilon, \quad i = 1, \dots, m. \end{aligned}$$

This model is known as the Charnes, Cooper, and Rhodes (CCR) model (Charnes et al., 1978)¹. 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:

$$\min \theta = \theta^* \quad (8)$$

Subject to:

$$\begin{aligned} \sum_{j=1}^n x_{ij} \lambda_j \leq \theta x_{io} \quad i = 1, 2, \dots, m \quad \sum_{j=1}^n y_{rj} \lambda_j \geq y_{ro} \quad r = 1, 2, \dots, s \\ \theta, \lambda_j \geq 0 \quad j = 1, 2, \dots, n \quad (9) \end{aligned}$$

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 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:

$$\max (\sum_{i=1}^m s_i^- + \sum_{r=1}^s s_r^+) \quad (10)$$

¹ 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.

Subject to:

$$\begin{aligned} \sum_{j=1}^n x_{ij}\lambda_j + s_i^- &= \theta^* x_{io} \quad i = 1, 2, \dots, m & \sum_{j=1}^n y_{rj}\lambda_j + s_r^+ &= y_{ro} \quad r = 1, 2, \dots, s \\ \lambda_j, s_i^-, s_r^+ &\geq 0 \end{aligned} \quad (11)$$

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 $s_i^-, s_r^+ = 0$. Such defined efficiency meets the Pareto-Koopmans understanding of efficiency which is in our model called CCR or DEA efficiency.

Choice of the variables

In order to use the DEA model it is necessary to divide variables affecting efficiency of the voivodship into two categories: inputs and outputs. It must be stated that in case of regional development such a division of variables is very difficult and ambiguous. Basically, it is one's personal decision to make such a division. Socio-economic processes are usually circle in nature. Process that is an effect of past action is immediately transformed into cause for future actions. Speaking in economic (or system dynamics) terms, inputs (fixed assets, land, human resource) is transformed into effects (income, production). But when these effects take place, they change the inputs as well.

Based on Kutvonen (2007) and Annoni and Kozovska (2010) the authors have made their own initial choice of factors that is as follows (with their indicators):

INPUTS:

- Public funding (self-government expenditures),
- Education (percentage of population with higher education),
- Competent workforce supply (participation of adults aged 25-64 in training and education),
- Research capacity (total R&D personnel),
- Political (European) support (% of public funding used for regional development),
- Macroeconomic stability (self-government gross debt),
- Infrastructure (motorway index, railway index),
- Health (life expectancy),
- Private capital (gross private capital),

- Technological readiness (percentage of households with access to Internet);

OUTPUTS:

- Socio-economic well being (regional GDP),
- Regional attractiveness (private investments),
- New knowledge (applied patents),
- Business growth (regional employment growth rate),
- Regional growth (annual growth of population),
- Market size (average compensation of employees),
- Labour market efficiency (long-term unemployment).

After the first choice of the variables listed above it was necessary to make the final selection. The authors decided to use two criteria for selecting the variables:

- availability of data for years 1999-2008,
- variety of variables.

Based on information provided by the Central Statistical Office of Poland (local data bank) some of the variables had to be discarded due to the lack of appropriate information for the selected period. For the variables remaining after the first step of selection, the variety was analysed . The results of that analysis is shown in Figure 4.

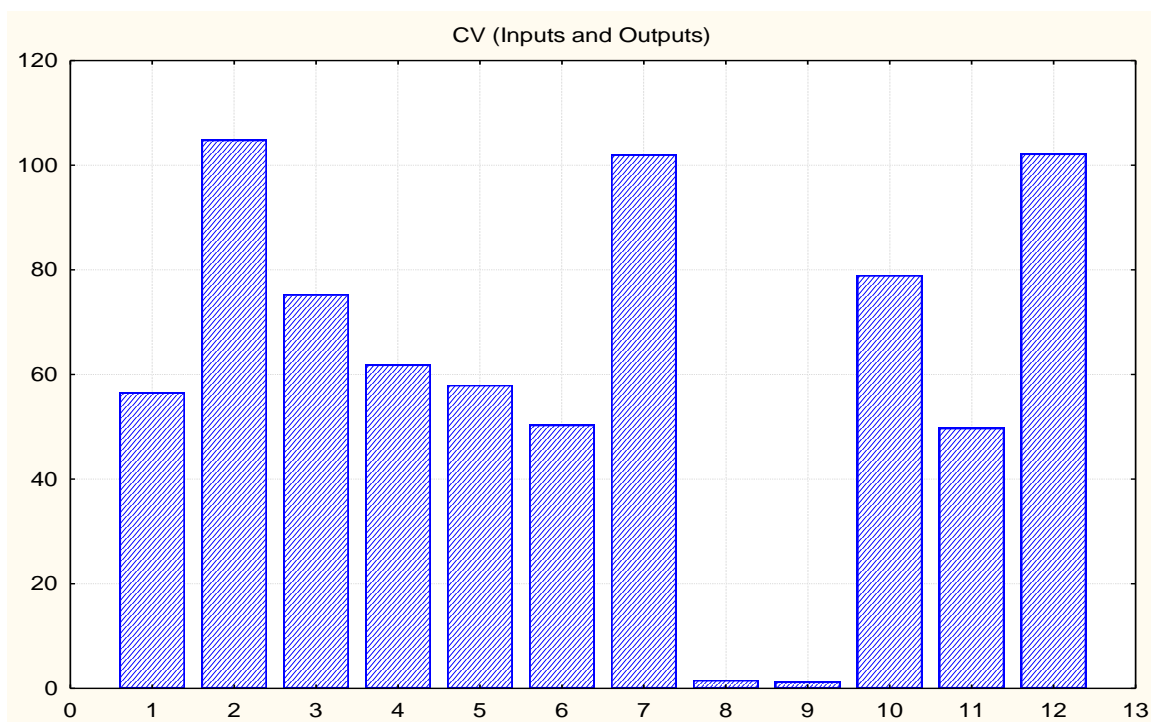


Figure 4: Variety of variables after the first step of selection.

Source: Own calculations.

Based on the volatility analysis the authors decided to discard two variables (No. 8 and 9), i.e. men and women life expectancy. The final list of variables for DEA analysis is as follows (I stands for input, O stands for outputs):

I1 – graduates of public higher schools (in persons)

I2 – graduates of non-public higher schools (in persons)

I3 – gross value of fixed assets (thous. of 2008 zł)

I4 – self-government expenditures (2008 zł)

I5 – standard-gauge electrified railways (in km)

O1- population (in persons)

O2 – private investment (in thous. of 2008 zł)

O3 – gross domestic product (in Mio. of 2008 zł)

O4 – population growth - live births(in persons)

O5 – long term unemployment (1/1000 people)

Results of the DEA Analysis

The above variables were analysed using DEA Solver Pro, ver.7.1. It is important to mention that in our study DMU represents voivodship in a single year. As a consequence, each voivodship's efficiency was compared to all other voivodships in all years. For instance, Mazowieckie voivodship in year 1999 was compared not only to all other voivodships in all years but to Mazowieckie in other years as well. The results of DEA analysis, i.e. scores for each DMU are shown in Figure 5. It must be added that all score values equal 1 are non-slack scores which refers to DEA efficient DMUs.

DMU	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
LODZKIE	1	1	0,97401	0,95585	0,9639	0,956377	0,953957	0,950958	0,982516	0,978505
MAZOWIECKIE	1	1	0,979748	0,953817	1	0,974715	0,983409	0,983557	1	1
MALOPOLSKIE	1	1	0,928178	0,920768	0,939193	0,926713	0,92537	0,952524	0,959712	0,951784
SLASKIE	1	0,976546	0,969659	0,951068	0,991668	1	0,979264	0,966535	0,999574	1
LUBELSKIE	1	0,98335	0,972142	0,935584	0,930579	0,962466	0,920444	0,922918	0,933108	0,952201
PODKARPACKIE	1	1	1	0,996915	1	0,981886	0,981083	0,97199	0,990379	0,989172
PODLASKIE	1	1	0,975223	0,965947	0,949994	0,937053	0,928933	0,942013	0,964352	1
SWIETOKRZYSKIE	1	0,96047	0,92498	0,917107	0,912983	0,902013	0,85826	0,888903	0,945078	1
LUBUSKIE	1	1	1	0,981925	0,967911	1	1	0,985847	0,983704	1
WIELKOPOLSKIE	1	1	0,989306	0,959958	0,962399	0,984291	0,961713	0,947715	0,98251	0,990347
ZACHODNIOPOMORSKIE	0,891719	0,898477	0,870847	0,874232	0,881271	0,865019	0,854169	0,857421	0,884886	0,926603
DOLNOSLASKIE	0,994051	0,964713	0,945356	0,902417	0,908091	0,907467	0,911085	0,956344	0,99601	0,937928
OPOLSKIE	1	0,984853	0,879346	0,913779	0,926699	0,894996	0,831834	0,807751	0,869764	1
KUJAWSKO-POMORSKIE	1	1	0,987356	0,968003	0,979513	0,990126	0,981099	0,99758	1	1
POMORSKIE	1	1	0,934547	0,933255	0,975809	0,99124	0,991542	0,994136	1	1
WARMINSKO-MAZURSKIE	1	0,976201	0,919933	0,903754	0,899914	0,902738	0,887709	0,912948	0,914081	0,943922

Figure 5: DEA scores for each DMU.

Source: Own calculations.

As shown in Figure 5, effectiveness of voivodships differ over time. It might be interesting to notice that efficiency of voivodships was generally higher in 1999. Accession of Poland to the European Union did not change the level of regional efficiency significantly. It is worth to be stressed that efficiency was a little bit better in the beginning of recent economic crisis, in 2008. Changes in average score on year by year basis are shown in Figure 6.

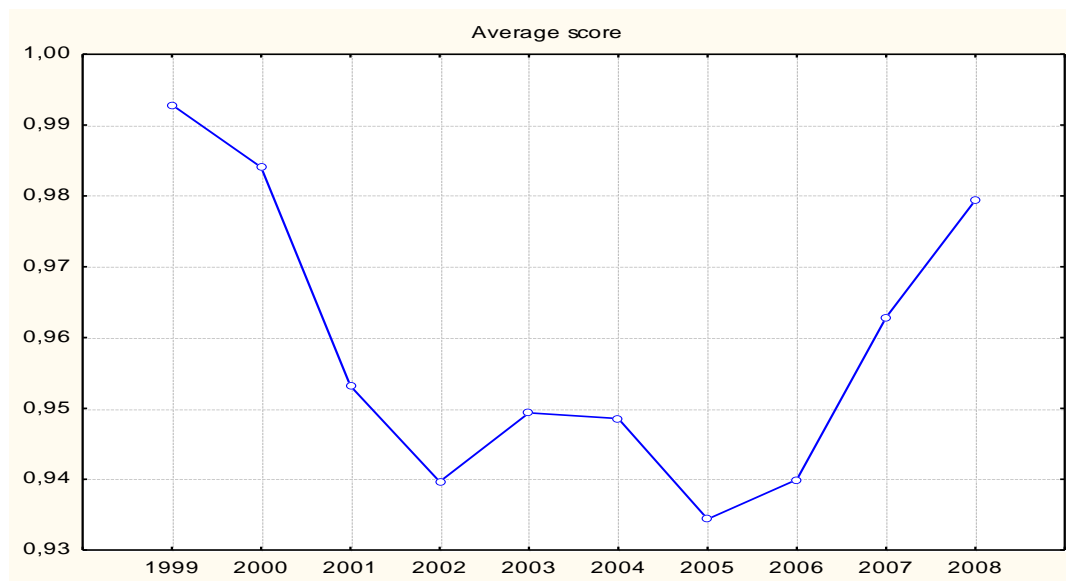


Figure 6: Changes in average DEA scores 1999-2008.

Source: Own calculations.

Comparing results illustrated in figure 6 and economic growth in the period of analysis, we can observe strong negative relation between these two variables. Changes in the DEA scores seem to be prior to changes in GDP growth. It may be supposed that efficiency scores level may be a leading indicator for economic growth. A shift between the two variables is about 2 years.

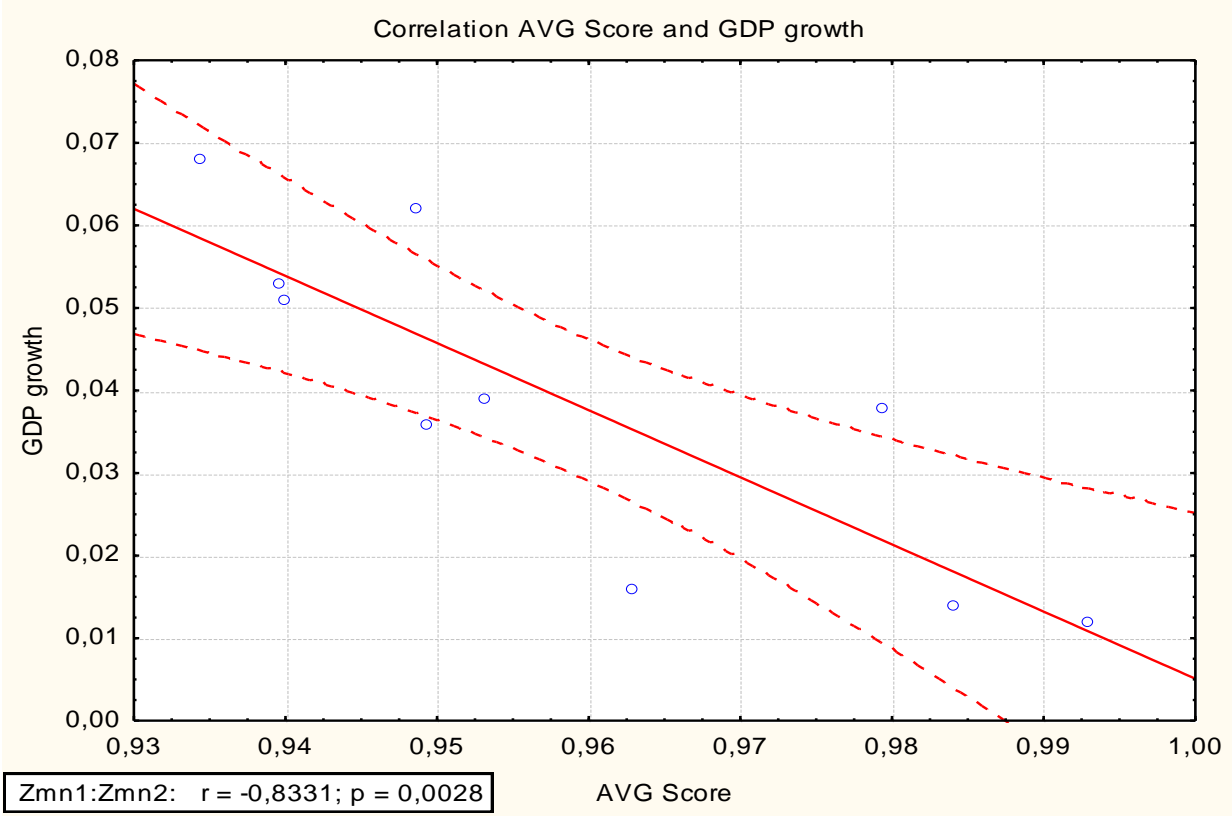


Figure 7: Correlation between GDP growth in Poland and average score.

Source: Own calculations.

Figure 7 presents the result of the authors’ simulation. A two year shift in GDP growth has been made and then the correlation for the variables was calculated. Of course such a relation should be examined by future empirical studies.

The coefficient of variation for the results obtained from the DEA analysis (1999-2008 period) was calculated and then, it was compared to variation of GDP per capita. It is shown in Figure 8. As we can see variation of GDP per capita and the DEA scores are pretty similar. Coefficient of correlation for the two variables equals to 0,638 which means that there exist positive relationship between the variables. The correlation is significant at the p-value level of 5%.

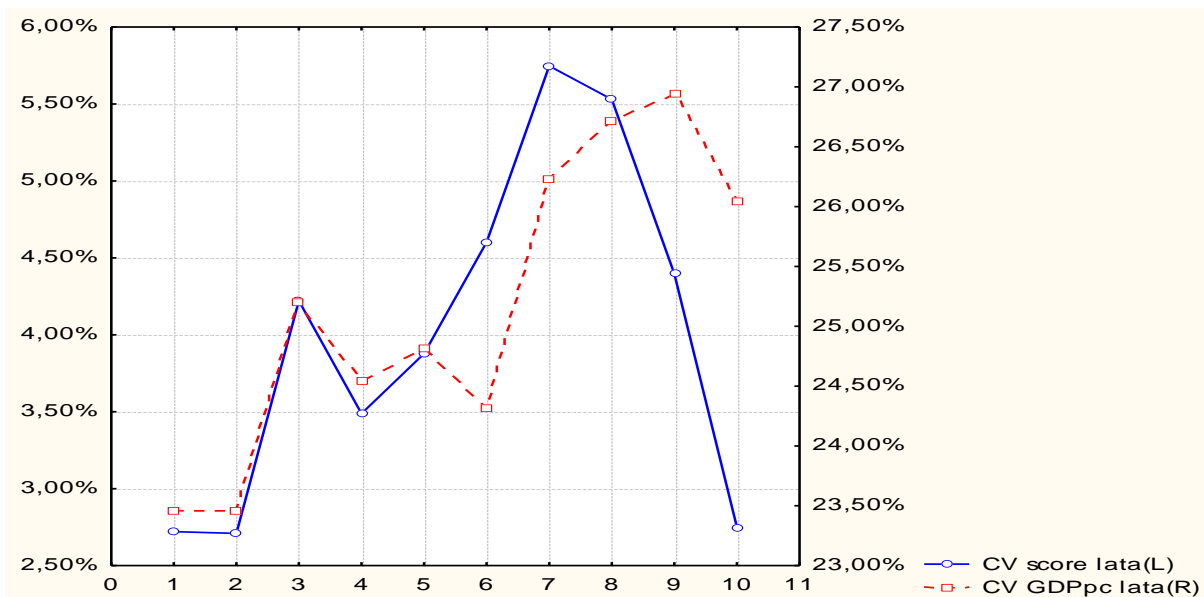


Figure 8: Comparison of GDP per capita and DEA scores variation.

Source: Own calculations.

Corollary, dispersion in economic efficiency of Polish voivodships reveals tendency similar to divergence in voivodships' income level during the period of analysis. However, we cannot say there is any relation between scores (in average) and the level of GDP per capita (for each voivodship; see figure 9). So, the reasons for increasing variation of the two variables may be possibly different. Furthermore, variation of efficiency is clearly lesser than variation of income level.

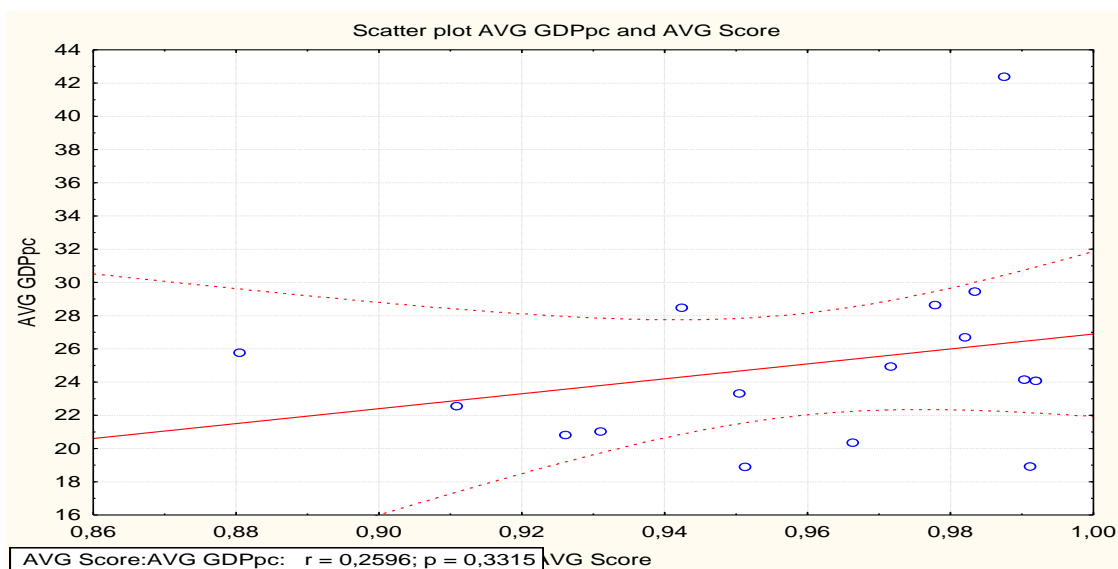


Figure 9: Correlation between average GDP per capita and average DEA scores.

Source: Own calculations.

Conclusions

1. In the article, it was proved that Polish voivodships experienced the divergence process in income per capita level since 1999 to 2008 (based on the Theil index and CV analysis).
2. The same process was observed for evaluation of economic efficiency of the regions over time of analysis. There is a significant correlation between income per capita variation and efficiency score variation.
3. The reasons for inequality increase in income level and economic efficiency seem to be different. No significant correlation between GDP per capita and average DEA score was found.
4. Business cycle in Poland seems to be related to economic efficiency of voivodships.

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