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COVID-19: Changes in the Ranking of Polish Regions According to the Criterion Taking into Account both the Reluctance to Vaccinate and the Number of Deaths

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Abstract:

Purpose: *The aim of the article is to present a real-time assessment of the effectiveness of pandemic management in a selected country, here - on the example of Poland.*
Design/Methodology/Approach: *It is hypothesized that the territorial distribution of deaths due to the pandemic should be similar to the population in voivodships. The Gini index is an established method of measuring this uniformity. A similar hypothesis applies to the uniform distribution of vaccines.*
Findings: *The knowledge about uneven distribution should be an incentive for decision-makers to take preventive measures to reduce disproportions between regions according to the indicator taking into account the number of deaths per million inhabitants and similarly the number of vaccinations. The result is a ranking of provinces from worst to best in terms of fighting the pandemic.*
Practical Implications: *Such a classification should change the attitudes of the central authorities towards local decision-makers.*
Originality/Value: *The bi-criterion proposed by the authors includes a component related to vaccinations (with a plus) and deaths (with a minus). The more vaccinations and fewer deaths per million inhabitants, the better for a given region.*

Keywords: *COVID-19, region management, vaccination, pandemic criterion.*

JEL codes: *C23, C38, H12, I14.*

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1. Introduction

One of the fairly obvious ways of reducing the victims of a pandemic seems to be to avoid outbreaks of high-intensity infections that are distinguished by this infectivity in relation to the environment (Bertsimas *et al.,* 2020; Oronce *et al.,* 2020). The number of confirmed cases is the most commonly used indicator of infection intensity (Dong *et al.,* 2019, *https://gisanddata.maps.arcgis.com/apps/dashboards/*, accessed 8 Nov 2021).

This is the most important and most frequently used data source in statistical research. The website of the CSSE institute of the Johns Hopkins University in Baltimore (https://coronavirus.jhu.edu/map.html) considers this variable to be the most important and according to it, it classifies countries in the world in the ranking of SARS-CoV-2 infections. An example of research attitudes that take advantage of the stability of this variable may be the work of Snider *et al.* (2021) and a very extensive review work by Garcia *et al.* (2021) considering a number of variables influencing the statistics of death and infection.

In this study, when assessing the local effects of a pandemic, it was decided to base on the number of deaths. Of course, in order to objectively assess the effects in individual regions, it is necessary to relate them to the number of people. Such relative indicators are also often used, for example, by one of the most important sources of data on COVID-19 statistics - (*www.worldometers.info, accessed 10 Oct 2021)*. For Poland, an important source used in this work is *www.pokazwirusa.pl* accessed 6 Nov, 2021).

The second important variable that indirectly indicates the effectiveness of epidemic management in a given region is the number of vaccinations performed. Today (beginning of July 2021), the number of vaccinated people is no longer the result of the central allocation of vaccines, but more and more the result of the thrift of local authorities, the ability to convince, and the general social potential of a given voivodship (demographic structure, knowledge, education, openness to development and changes). The latter factor should also be related to the population size. The research will be continued until the end of October in order to determine the changes that have occurred over time in individual voivodships.

Taking into account both (the number of deaths and the number of vaccinations), an indicator was developed at the same time to assess the degree of sustainable effort in fighting the pandemic on a national scale. It should be expected that the differences between regions (bearing in mind the conversion of indicators into the number of population) should be small.

A method of calculating this differentiation was developed using Gini's models and a specific proprietary criterion taking into account the number of deaths and vaccinations in a given region.

2. Method of Investigating the Degree of Balance between Deaths and Vaccinations in Voivodships in Poland

Research aimed at assessing the even territorial distribution of deaths and vaccinations in a given country indirectly allows for the assessment of the effectiveness of crisis. Of course, there should be as few deaths as possible and as many vaccinations as possible in each region. These are the challenges for both central and local authorities. To assess the uniformity of the distribution of each factor, the so-called Gini Index allows, after plotting the Lorentz curve, for a numerical assessment of the degree of non-uniformity in the distribution of the considered feature. The more even the distribution among voivodships, the higher the society of a given country should assess management efficiency.

Of course, a natural dilemma will arise, more importantly. Or rather, what is worse. Whether the high average level of cumulative deaths in the entire country or a high disproportion among the regions of a given country. In addition, in the period of fighting the pandemic by vaccinating society, an important factor in the form of the varying degree of vaccination of the region will occur, of course also related to the number of inhabitants.

Most of the scientific literature related to pandemic modelling is devoted to the spread of infection and to a lesser extent deaths. Others selected to consider the even distribution of various epidemic-related indicators using the Gini index (Barrera-Algarin *et al.*, 2021; Lindström, 2020). A little later, however, there are papers relating to the relationship between the number of deaths and vaccination (Mills and Salisbury, 2021; Mathieu *et al.*, 2021).

Let be the given target territory T, here, Poland be given, which can be conventionally divided into N separable smaller territories T_i making up the target territory T (for Poland N = 16 voivodeships). The research will be carried out twice with a fairly large four-month interval in order to determine the trend in individual regions. Subsequent voivodships will be marked with the index i = 1, 2, ..., 16, and subsequent research dates with the index h = 1.2.

Each i-th territory has three characteristics P_i , V_i and D_i:

P_i - the number of people living in this i - territory in million in 2021;
D_i^1 - cumulative number of deaths from SARS-CoV-2 until the designated date of 17 June 2021;
D_i^2 - cumulative number of deaths from SARS-CoV-2 until the date 22 Oct 2021;
V_i^1 - number of vaccinations with the last dose in the i-th voivodship until the same day of 17 June 2021.
V_i^2 - number of vaccinations with the last dose in the i-th voivodship until the same day 22 of Oct 2021.

Let us introduce the variable - the number of deaths per million inhabitants living in the i-th region of a given country T_i as:

$$D_i^h = \frac{D_i}{P_i}, \qquad i = 1,2,\dots,N \qquad h = 1,2; \tag{1}$$

P_i should be expressed in millions of inhabitants. Similarly for vaccinations:

$$V_i^h = \frac{V_i}{P_i}, \qquad i = 1,2,\dots,N \qquad h = 1,2; \tag{2}$$

where h - is the index of the relevant data - 1 for data from the beginning up to June 17 and 2 - for four months period from June 2021 to Oct 22, 2021.

In further considerations, the integer variable M_i of the number of one-million granules of the population in a given region of T_i will be useful, which can be determined after rounding:

$$M_i = round\left(\frac{P_i}{D_i}\right), \qquad i = 1,2,\dots,N \tag{3}$$

The idea of determining the uneven distribution of infections and deaths in a given country will be reduced to the Lorentz curve model known from economics as a function of income distribution in a given society. It allows to determine what percentage of the society earns income above or below a certain level.

The result of the considerations is the vector z_k, $k = 1,2,\dots,K$ of granules of various sizes, approximately as many as there are millions of people in a given region (P_i sum). Let us denote the length of the vector z_k as K.

$$K = sum\ (M_i) \tag{4}$$

Now let's arrange these one-millionth granules according to their value L_i, ascending

$$Z_s = sort\ (z_k), ascend \tag{5}$$

Then we calculate the integral of the above curve according to the formula

$$Z_c\,(k) = \sum(1{:}\,k)\ Z_s \quad for\ \ k = 1,2,\dots,K \tag{6}$$

To normalize this curve let's set the sum of all Z_s as $Z = \sum(1{:}\,K) Z_c$

$$Z_n(k) = \frac{Z_c(k)}{Z} \tag{7}$$

We also place the normalized variable $k_n = \frac{k}{K}$ on the abscissa axis. In this way, we move along the demographic resources of a given country, expressing them in the form of a number belonging to [0,1].

Lorentz curves (https://www.economicshelp.org/blog/glossary/lorenz-curve/ accessed 7 Oct, 2021) and the resulting Gini coefficients *(https://worldpopulationreview.com/country-rankings/gini-coefficient-by-country, accessed 8 Aug, 2021)* will be calculated to determine the uniformity of the number of deaths in Polish voivodships, and then according to the same principles to calculate the uniformity of vaccinations. These calculations will be performed twice - for both terms.

3. Results - Studies on the Distribution of Deaths and Vaccinations for Various Regions

The research was carried out for the following data (columns 3-7 in Table 1) obtained from: *https://pl.wikipedia.org/wiki/Podzia%C5%82_administracyjny_Polski, accessed 10 Jun, 2021; https://coronavirus.jhu.edu/map.html accessed 20 Jun, 2021;*

Table 1. *Data for individual regions in the fight against the pandemic (Index 1 - data as of June 17; index 2 - data for October 22)*

Number	***Voiv***	***Population***	***Deaths1***	***Deaths2***	***Vaccines1***	***Vaccines2***
1	*"maz"*	*5.403*	*9423*	*9599*	*1858*	*2777*
2	*"sla"*	*4.533*	*9377*	*9514*	*1458*	*2102*
3	*"wlk"*	*3.493*	*7333*	*7444*	*1052*	*1707*
4	*"mal"*	*4.301*	*5815*	*5925*	*971*	*1502*
5	*"dol"*	*2.901*	*4892*	*4971*	*989*	*1410*
6	*"pom"*	*2.333*	*4445*	*4531*	*814*	*1166*
7	*"kuj"*	*2.077*	*4762*	*4863*	*614*	*948*
8	*"lod"*	*2.466*	*5081*	*5231*	*804*	*1168*
9	*"zpo"*	*1.701*	*2910*	*2970*	*566*	*810*
10	*"pka"*	*2.129*	*4432*	*4535*	*589*	*758*
11	*"lub"*	*2.117*	*4435*	*4693*	*587*	*815*
12	*"wma"*	*1.428*	*2996*	*3067*	*397*	*607*
13	*"lbs"*	*1.014*	*2041*	*2058*	*342*	*481*
14	*"swi"*	*1.241*	*2548*	*2609*	*338*	*508*
15	*"pls"*	*1.181*	*2140*	*2236*	*394*	*506*
16	*"opo"*	*0.986*	*2042*	*2063*	*319*	*417*

Source: *Own study.*

Table 1 includes the Deaths1 and Deaths2 columns as well as Vaccines1 and Vaccines2 for the two measurement dates considered here, respectively. With index 1, the variables for the 17th Jun data are marked, and with index 2 the variables for the 22nd Oct. It was assumed that the population in individual provinces did not change.

Individual abbreviations in the first column of Table 1 denote Polish regions (voivodships) written in Polish. They mean, respectively:

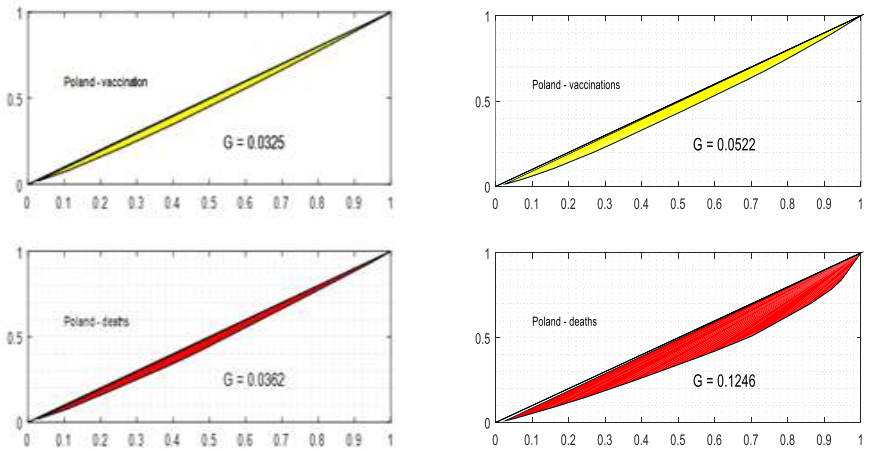
„maz" – mazowieckie; „sla" – slaskie; „wlk" – wielkopolskie; "mal" - malopolskie; "dol" - dolnoslaskie; "pom" - pomorskie; "kuj" - kujawsko-pomorskie; "lod" - lodzkie; "zpo" - zachodniopomorskie; "pka" - podkarpackie;"lub" - lubelskie; "wma" - warminsko-mazurskie; "lbs" - lubuskie; "swi" - swiętokrzyskie; "pls" - podlaskie; "opo" - opolskie;

Using data on deaths (col. 4 and 5, Table 1) and vaccinations (col. 6 and 7), taking into account the number of inhabitants in individual voivodships (col. 3), Gini coefficients for the two considered variables were calculated.

The Gini coefficients for these two distributions are shown in Figure 1a left for data from the beginning up to 17 June and in Figure 1b on the right for data from 17 June to 22 Oct. 2021 and is equal to:

- for the distribution of deaths in provinces according to the methodology described above, the following was obtained:
G_D = 0.0362 for 17 Jun 2021
G_D = 0.1246 for four months this year (2021)
- and for the vaccination schedule
G_V = 0.0325 for 17 Jun 2021
G_V = 0.0522 for four months to 22 Oct 2021

Figure 1a and 1b. *Illustration of Gini indicators for Polish voivodships for the distribution of vaccinations and postcovid deaths on 17 June 2021 (the left side) and for four months this year (the right side)*



Source: *Own study.*

Figure 1 (a and b) explains the interesting but also disturbing phenomenon of the growing variation in the degree of vaccination in individual provinces and the number of deaths per million inhabitants. While by June 2021 these disparities and deaths and vaccinations for Poland were impressively small, there has been a sharp deterioration in the last four months (www.pokazwirusa.pl). Of course, it is assumed that little variation in vaccination rates is socially good. The first measurement in June 2021 gave one of the best results in the world (Wiliński *et al.*, 2021), the latter completely destroyed this image of the country with surprisingly equal care of all regions.

For example, the whole world has a Gini index in terms of deaths at a level ten times higher than in the first study - about 0.38 (Wiliński *at al.*, 2021). The Gini index indicates that the situation in the country is deteriorating, which may result from the so-called fourth wave of the pandemic. However, how to determine which provinces are most at risk and how to admit to worse local management of the pandemic?

For this purpose, we introduce variables related to Table 1 and related values of deaths and vaccinations.

Let D_V [in thousand] be the sum of the differences between the measurement of the number of vaccinations in individual provinces on the second date and on the first date:

$$D_V = \sum_i (Vaccine2_i - Vaccine1_i), \quad for\ i = 1, 2, \dots, N \tag{8}$$

Similarly, let D_Z denote the sum of the differences between the measurement of the number of deaths in individual voivodeships on the second date and on the first date.

$$D_Z = \sum_i (Deaths2_i - Deaths1_i), \quad for\ i = 1, 2, \dots, N \tag{9}$$

Let us introduce the concept of the weight of the factor (deaths or vaccinations)

$$W_Z = \frac{D_V}{(D_V + D_Z)}\ ; \tag{10}$$

$$W_V = \frac{D_Z}{(D_V + D_Z)}\ ; \tag{11}$$

Then the relative increase in deaths in a given province will be as:

$$dZ_{w_i} = \frac{(Deaths2_i - Deaths1_i)}{Deaths1_i * W_Z}, \quad for\ i = 1, 2, \dots, N \tag{12}$$

$$dV_{w_i} = \frac{(Vaccines2_i - Vaccines1_i)}{Vaccines1_i * W_V}, \quad for\ i = 1, 2, \dots, N \tag{13}$$

The final criterion of the quality of changes in a given voivodship will be determined as the difference between the relative increase in vaccinations and the relative increase in deaths:

$$K_i = dV_{w_i} - dZ_{w_i}, \quad for\ i = 1, 2, \dots, N \tag{14}$$

This criterion can be explained as the difference of the relative increment of vaccinations (could be expressed as a percentage) but weighted by W_V and the relative increment of deaths, also weighted by Equation (14). A high K for the voivodeship is therefore beneficial (a lot of vaccinations, few deaths). The results of these calculations for individual voivodships are presented in Table 2.

Table 2. *Table illustrating the differences over approx. 4 months in the changes in the number of deaths and the increase in the number of vaccinations in individual provinces and the value of the K criterion, which determines these changes*

Num. (1)	*Voiv (2)*	*Population (3)*	*DelDea (4)*	*DelVac (5)*	*DelDeaW (6)*	*DelVacW (7)*	*Criterion K (8)*
1	*"maz"*	*5.403*	*0.019*	*0.495*	*0.014*	*0.112*	*0.098*
2	*"sla"*	*4.533*	*0.015*	*0.442*	*0.011*	*0.100*	*0.089*
3	*"wlk"*	*3.493*	*0.015*	*0.623*	*0.012*	*0.141*	*0.129*
4	*"mal"*	*4.301*	*0.019*	*0.547*	*0.015*	*0.124*	*0.109*
5	*"dol"*	*2.901*	*0.016*	*0.426*	*0.012*	*0.096*	*0.084*
6	*"pom"*	*2.333*	*0.019*	*0.432*	*0.015*	*0.098*	*0.083*
7	*"kuj"*	*2.077*	*0.021*	*0.544*	*0.016*	*0.123*	*0.107*
8	*"lod"*	*2.466*	*0.03*	*0.453*	*0.023*	*0.103*	*0.080*
9	*"zpo"*	*1.701*	*0.021*	*0.431*	*0.016*	*0.098*	*0.082*
10	*"pka"*	*2.129*	*0.023*	*0.287*	*0.018*	*0.065*	*0.047*
11	*"lub"*	*2.117*	*0.058*	*0.388*	*0.045*	*0.088*	*0.043*
12	*"wma"*	*1.428*	*0.024*	*0.529*	*0.018*	*0.12*	*0.102*
13	*"lbs"*	*1.014*	*0.008*	*0.406*	*0.006*	*0.092*	*0.086*
14	*"swi"*	*1.241*	*0.024*	*0.503*	*0.019*	*0.114*	*0.095*
15	*"pls"*	*1.181*	*0.045*	*0.284*	*0.035*	*0.064*	*0.029*
16	*"opo"*	*0.986*	*0.01*	*0.307*	*0.008*	*0.07*	*0.062*

Source: *Own study.*

Table 2 shows a large variation in the degree of pandemic risk in individual provinces. The worst results at the time of compiling these statistics (22 Oct 2021) are in Podlaskie, Lubelskie and Podkarpackie voivodships. The best voivodships are Wielkopolskie, Malopolskie and Kujawsko-Pomorskie.

In simplified terms, the criterion can be defined as a percentage of the increase in vaccination less the percentage of increase in deaths, both increments with appropriate weights. Looking at the last column, 2, it would be possible to define the improvement of the situation in Mazowieckie at 9.8%, in Slaskie at 8.9% and in Podlaskie only 2.9%.

4. Discussion and Conclusions

K indicator from col. 8 Table 2 significantly differentiates the involvement and results of individual voivodships. Of course, politicians at all levels can, and in particular will do so, justify the situation in the region. There are and will be delays in building health infrastructure, cultural differences, income, education, and many other factors named for example by Garcia *et al.* (2021). The aim of this paper is to present an objectively calculated ranking, without finding out the reasons and justifications.

The applied method of regional differentiation turned out to be extremely effective. It reveals several provinces with very large backlogs in fighting the pandemic. The ranking is prepared at the beginning of July 2021 and repeated in October, 2021. All the data included in it change daily, but with some inertia. In the authors' opinion, which they do not intend to justify too deeply due to many personal relationships and sentiments, the last places for Podlaskie, Lubelskie and Podkarpackie voivodships is not surprising.

This is mainly the result of strong anti-vaccination movements in these voivodships and also a relatively large number of deaths (e.g., in Lubelskie). The first place of the Wielkopolskie voivodship is rather a small surprise. The first few voivodships, maybe 5 or 7 out of Table 2 do not differ from the leaders, the rest are surprisingly far from the results of the best ones.

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