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MEASUREMENT OF HEALTHCARE SYSTEM EFFICIENCY IN OECD COUNTRIES

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Abstract: Increased spending on healthcare systems in many countries tends to attract attention to their efficiency. The aim of this paper is to evaluate the efficiency of healthcare systems in the OECD countries and indicate causes of inefficiency by applying Data Envelopment Analysis (DEA) and using additive and super-efficiency models. The homogeneity of the sample is assessed and outliers are excluded. A ranking is established on the basis of efficiency scores. By means of DEA, fully efficient units are identified, forming a reference set (of best practice) for inefficient countries to follow.

Keywords: healthcare system efficiency, Data Envelopment Analysis

INTRODUCTION

An efficiently operating healthcare system makes an important contribution to increasing the general quality of life. Regularly conducted surveys point out the shortcomings of healthcare services. The most commonly identified problems are: overly expensive healthcare services, excessively long waiting times, and distance to healthcare facilities [OECD 2011]. The data which are most often used for comparisons of different national healthcare systems include total healthcare expenditure as a fraction of gross domestic product (GDP) or GDP per capita [Anell, Willis 2000]. The average healthcare expenditure for all OECD countries amounted to 6,8% of GDP in 1990, 7,8% in 2000 and 9,5% in 2010. In the same years, the corresponding figures for Poland were 4,8%; 5,5% and 7,0% respectively, and for the United States 12,4%; 13,7% and 17,6% [OECD 2012]. Another important factor which affects the performance of healthcare systems is the ageing of populations, which boosts the demand for healthcare services. Life expectancy in the OECD countries has been growing systematically: women's life expectancy (in years) increased from 78 in 1990 to 82,5 in 2010, while men's life expectancy increased from 71 in 1990 to 77 in 2010 [OECD 2012]. Because an average of 72% of healthcare is financed from public funds in the OECD countries, the aforementioned factors justify a need to evaluate the efficiency of these services [OECD 2012]. The aim of this paper is to propose a model for measuring healthcare system efficiency by means of DEA.

DATA ENVELOPMENT ANALYSIS AND THE EFFICIENCY OF HEALTHCARE SYSTEMS

DEA is a nonparametric method for measuring relative efficiency. This method has been undergoing dynamic development since 1978, when Charnes, Cooper and Rhodes published their seminal article entitled "Measuring the efficiency of decision making units" [Charnes et al. 1978]. The growth in the use of DEA is reflected in the statistics of publications registered in the Web of Science database. In the years 1978-1990, 225 such articles were published, but by 2009 this number had reached 4,597. It is foreseen that by 2020 the number of articles on the subject may reach 13,000 [Liu et al. 2013a]. DEA is a data-oriented approach for evaluating the performance of a set of homogeneous entities called decision making units (DMUs), which convert multiple inputs into multiple outputs [Cooper et al. 2011]. This method may be applied to a wide range of sectors (such as banking or healthcare) to identify sources of inefficiencies [Liu et al. 2013b].

Basic DEA models only measure radial efficiency but fail to evaluate the input excesses or output shortfalls (slacks), and hence only detect radial inefficiency. The DEA definition of efficiency is that the performance of a DMU is fully (100%) efficient only when the efficiency score equals one and the input and output slacks equal zero. When the efficiency score is one while one or more of the slacks differ from zero, the DMU is said to be weakly efficient [Cooper et al. 2000, Zhu, Cook 2007]. Unfortunately, the radial efficiency measure does not take into account non-zero slacks. The additive model is free from this flaw because it takes slacks into consideration directly in the computation of the efficiency measure. This was used as the basis for the development of the Slack Based Measure (SBM) model for evaluating efficiency [Cooper et al. 2000].

After choosing the structure of the model, it is important to define its orientation, according to whether the aim is to reduce the inputs and keep the outputs at the same level (input-oriented), or alternatively to maximise the outputs and keep the inputs at the same level (output-oriented) [Ozcan 2008].

Measurement of the efficiency of healthcare systems is not an easy task. The main difficulty is in correctly measuring the outcomes of the system. The most popular approach applies measurable intermediate indicators of services which are assumed to have a fundamental impact on the health status of the population. The outcomes of a healthcare system may be defined as changes in the health of the population attributable to healthcare expenditure, e.g. changes in life expectancy, infant mortality, inequity in access to healthcare, frequency of occurrence of certain diseases, etc. [González et al. 2010]. In spite of controversy over whether some of these variables are appropriate as relevant outcomes of healthcare systems, most analyses at the system level have relied on the use of life expectancy and infant mortality rates to evaluate the outcomes of health systems [e.g. Retzlaff-Roberts et al. 2004, Afonso, Aubyn 2005, Anell, Willis 2000, Hadad et al. 2013]. Nevertheless, some researchers argue that infant mortality in the OECD countries has ceased to be a dramatic problem. Undoubtedly, it does not concern most developed countries, but Mexico, Chile, Turkey and countries of the former eastern bloc still record infant mortality rates above the average. One of the most often quoted studies [Retzlaff-Roberts et al. 2004] adopts the infant mortality rate and life expectancy at birth as outputs. The inputs characterising the resources of the system include the number of physicians and the number of beds per 1,000 residents, the number of magnetic resonance imaging (MRI) devices per million residents and healthcare expenditure as a fraction of GDP.

Sometimes, international comparisons cannot be made due to insufficient data, and consequently some countries must be excluded from the analysis. The use of DEA requires much caution in the selection of the sample because of the rule that the set of objects compared must be homogeneous or almost homogeneous. This may be interpreted as a recommendation not to compare objects which are different in nature (outliers) [Guzik 2009, Haas, Murphy 2003]. An outlier is defined as an observation that deviates so much from other observations as to arouse suspicion that it was generated by a different mechanism [Ben-Gal 2010]. For example, Afonso and Aubyn exclude Mexico and Turkey from their study, because their outputs are outliers, in particular their infant mortality rates (25,9 and 40,3 respectively, while the mean value for all OECD countries is 7,1) [Afonso, Aubyn 2005]. Similarly, in the course of another evaluation [Hadad et al. 2013] Chile, Mexico and Turkey are excluded from the analysis because their purchasing power parity-adjusted GDP per capita is below 50% of the OECD average.

PROPOSED MODEL

An output-oriented SBM model with constant returns to scale is adopted here. This is appropriate in this context since healthcare systems desire to maximize health gains, rather than hold health gains constant and minimize inputs, as assumed in an input-oriented model [Hadad et al. 2013]. Let the DMU set consist of *n* objects, each having *m* inputs and *s* outputs. Following Cooper et al. [2011], the output-oriented SBM efficiency ρ_o^* for DMU_o is defined as:

$$\frac{1}{\rho_o^*} = \max_{\lambda, s^-, s^+} \left(1 + \frac{1}{s} \sum_{r=1}^{s} \frac{s_r^+}{y_{ro}} \right) , \tag{1}$$

subject to:

$$x_{io} = \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- \quad (i = 1,\dots,m)$$
$$y_{ro} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ \quad (r = 1,\dots,s) \tag{2}$$
$$\lambda_j \geq 0(\forall j)\ s_j^- \geq 0(\forall i)\ s_r^+ \geq 0(\forall r)$$

where: $\lambda = [\lambda_1,\dots,\lambda_n]$ are intensity variables,

$s_i^- = [s_1^-,\dots,s_n^-]$, $s_r^+ = [s_1^+,\dots,s_s^+]$ are vectors of input and output slacks respectively, and

$x_j = [x_{1j},\dots,x_{mj}]$, $y_j = [y_{1j},\dots,y_{sj}]$ are vectors of the inputs and outputs of DMU_j respectively.

In order to rank the SBM-efficient DMUs, the Super-SBM model can be used. An output-oriented super-SBM is defined in Cooper et al. [2011] as:

$$\rho_o^* = \min_{\bar{\mathbf{x}},\bar{\mathbf{y}},\boldsymbol{\lambda}} \frac{1}{(1/s)\sum_{r=1}^{s}(\bar{y}_r / y_{ro})} \tag{3}$$

subject to:

$$\bar{x}_i \geq \sum_{j=1, j\neq o}^{n} x_{ij}\lambda_j \quad (i = 1,\dots,m)$$
$$\bar{y}_r \leq \sum_{j=1, j\neq o}^{n} y_{rj}\lambda_j \quad (r = 1,\dots,s) \tag{4}$$
$$\bar{x}_i \geq x_{io}(\forall i)\ \bar{y}_r \leq y_{ro}(\forall r)\ \bar{y}_r \geq 0(\forall r)\ \lambda_j \geq 0(\forall j)\ j \neq o$$

Using an optimal solution of the above equations $(\lambda^*, \boldsymbol{s}^{-*}, \boldsymbol{s}^{+*})$ a projection of DMU$_o$= $(\boldsymbol{x}_o, \boldsymbol{y}_o)$ on the efficient frontier is defined as [Cooper et al. 2011]:

$$(\bar{\boldsymbol{x}}_o, \bar{\boldsymbol{y}}_o) = (\boldsymbol{x}_o - \boldsymbol{s}^{-*}, \boldsymbol{y}_o + \boldsymbol{s}^{+*}) \tag{5}$$

This approach determine the robustness of the efficiency scores by changing the reference set of the inefficient DMUs; rank the efficient DMUs; and estimates the super efficiency of the DMUs. The super efficiency model excludes each observation from its own reference set so that it is possible to obtain efficiency scores that exceed unity [Mogha et al. 2014, Cooper et al. 2011, Zanboori et al. 2014, Hadad et al. 2013].

In this article, the three variables regarded as inputs characterising the financial means invested in a healthcare system and its basic resources are: I1 – total healthcare expenditure expressed as % of GDP; I2 – number of physicians per 1 000 residents; I3 – number of hospital beds per 1 000 residents. Four variables are used to characterise the outputs of healthcare systems: O1 – Infant Mortality Rate (IMR), measured as the number of deaths of children less than one year old per 1,000 live births; Potential Years of Life Lost (PYLL), O2 for men and O3 for women – these indicators are expressed per 100,000 males and females; O4 – Life Expectancy at birth (LE). The efficiency measurement techniques used in this paper imply that the outputs are measured in such a way that "more is better" [Afonso, Aubyn 2005]. In order to maintain this assumption, IMR is converted into ISR (Infant Survival Rate), calculated as the quotient 1,000/IMR, and PYLL is converted into the quotient 100,000/PYLL. The analysis covers 33 OECD countries, data for which are taken from the OECD Health Database for the three years: 2000, 2005 and 2010 [OECD 2012] (Turkey was excluded because PYLL data is missing). Calculations are made using DEA-Solver LV 3.0 by Saitech.

INTERPRETATION OF RESULTS

One of the main advantages of DEA is that it allows the DMUs to have the full freedom to select linear programming weights. However, the efficient frontier can be influenced by outliers. Therefore, it is crucial to check for the presence of atypical DMUs [Bellini 2012]. To ensure the homogeneity of the sample evaluated, the outliers are identified on the basis of the method described earlier [Hadad et al. 2013]. Chile and Mexico are excluded from the sample because the efficient frontier may be influenced by them (when these two countries are considered in the calculations, Chile ranks first and Mexico eighth). Calculations are performed using the SBM model and SBM-efficient countries are ranked using the Super-SBM model (in which the efficiency score may be greater than unity).

Table 1. Efficiency scores

Country	2000	2005	2010	Country	2000	2005	2010
Australia	0.90	1.01	0.91	Japan	1.06	1.02	1.10
Austria	0.55	0.61	0.62	Korea	1.29	1.21	1.09
Belgium	0.66	0.69	0.72	Luxembourg	0.74	1.04	1.01
Canada	1.05	1.09	1.08	Netherlands	0.82	0.83	1.01
Czech Republic	0.73	0.85	1.00	New Zealand	0.68	0.93	1.02
Denmark	0.72	0.72	0.75	Norway	0.85	0.87	0.89
Estonia	0.52	1.01	1.04	Poland	0.66	0.67	1.00
Finland	0.72	0.76	1.00	Portugal	0.66	0.73	0.80
France	0.55	0.63	0.67	Slovak Republic	0.62	0.58	0.53
Germany	0.53	0.61	0.65	Slovenia	0.73	0.83	1.12
Greece	0.74	0.72	0.68	Spain	1.03	1.03	1.01
Hungary	0.40	0.45	0.55	Sweden	1.19	1.35	1.26
Iceland	0.72	1.03	1.06	Switzerland	0.64	0.68	0.70
Ireland	0.74	0.84	0.95	United Kingdom	1.01	1.01	1.01
Israel	0.83	1.00	1.11	United States	1.01	0.71	0.75
Italy	0.85	0.87	0.89				

Source: own calculations

Table 1 shows changes in the efficiency score over the period surveyed. On the basis of the analysis of efficiency scores, several characteristic groups of countries can be distinguished, and on the basis of the analysis of changes in the values of the individual model variables it is possible to determine the potential factors which explain the calculated efficiency level. In all the years considered, the following countries had full efficiency: Canada, Japan, Korea, Spain, Sweden and the United Kingdom. The most dynamic growth in efficiency can be seen for Estonia, Iceland, New Zealand, Poland and Slovenia, while for the Czech Republic, Finland, Israel, Luxemburg and the Netherlands there was growth but to a lesser extent. All these countries were inefficient in 2000 but were fully efficient in 2010. The least changes can be seen for Greece, the Slovak Republic and the United States. In the Australian healthcare system, there is efficiency growth for 2005 and an efficiency drop for 2010. Ireland and Portugal have a significant growth in efficiency, but are inefficient in 2010. The rest of the countries keep the same low efficiency level in all the years surveyed, with small growth trends.

Table 2. Data concerning selected countries which improved their efficiency

Country	I1	I2	I3	O1	O2	O3	O4	Rank	Year
Estonia	5.3	3.3	7.2	119.0	6.9	19.0	70.6	30	2000
	5.0	3.2	5.5	185.2	8.2	23.6	72.7	8	2005
	6.3	3.2	5.3	303.0	11.5	34.7	75.6	8	2010
Iceland	9.5	3.4	7.5	333.3	21.9	43.4	80.1	20	2000
	9.4	3.6	6.0	434.8	32.6	54.0	81.2	5	2005
	9.3	3.6	5.8	454.5	31.5	61.9	81.5	7	2010
New Zealand	7.6	2.2	6.2	158.7	19.2	31.6	78.3	21	2000
	8.4	2.1	4.5	200.0	21.9	35.6	79.8	12	2005
	10.1	2.6	2.7	192.3	22.9	36.4	81	9	2010
Poland	5.5	2.2	4.9	123.5	10.5	25.7	73.8	24	2000
	6.2	2.1	6.5	156.3	11.5	29.0	75.1	26	2005
	7.0	2.2	6.6	200.0	12.9	33.5	76.3	16	2010
Slovenia	8.3	2.2	5.4	204.1	14.1	31.9	75.5	17	2000
	8.3	2.4	4.8	243.9	16.9	36.4	77.7	18	2005
	9.0	2.4	4.6	400.0	21.8	45.7	79.5	2	2010

Source: own calculations

Table 2 presents a juxtaposition of data which explain the increase in efficiency for selected countries. The successive columns contain the inputs and outputs according to the previous description, as well as their ranking for the year shown in the right-hand column. Estonia, New Zealand, Poland and Slovenia considerably improved the efficiency of their healthcare systems, mainly through increased spending. In 2010, growth in spending relative to 2000 amounted to 19% for Estonia, 33% for New Zealand, 27% for Poland and 8,5% for Slovenia. The PYLL ratio improved in the range 15-83% for women and 19-66% for men.

The infant mortality rate improved in the range from 21.1% (New Zealand) to 154.5% (Estonia).

Table 3 describes selected countries whose healthcare systems exhibited full efficiency. In Japan, Korea and Sweden, expenditure on healthcare increased by 25%, 58% and 17%. The number of hospital beds per 1,000 residents decreased in Japan (7%) and Sweden (24%) and increased significantly in Korea (88%). The PYLL ratio improved by 21-57% for men and by 19-46% for women. The IMR improved by 39.1-65.6%.

Table 3. Data concerning selected countries with full efficiency in the period examined

Country	I1	I2	I3	O1	O2	O3	O4	Rank	Year
Japan	7.6	1.9	14.7	312.5	24.0	46.9	81.2	2	2000
	8.2	2.4	14.1	357.1	26.0	50.6	82.0	7	2005
	9.5	2.2	13.6	434.8	29.1	55.7	83.0	4	2010
Korea	4.5	1.3	4.7	188.7	14.4	33.3	76.0	1	2000
	5.7	1.6	5.9	212.8	19.1	40.9	78.5	2	2005
	7.1	2.0	8.8	312.5	22.6	48.6	80.7	5	2010
Sweden	8.2	3.1	3.6	294.1	26.0	42.9	79.7	3	2000
	9.1	3.5	2.9	416.7	29.4	47.1	80.6	1	2005
	9.6	3.8	2.7	400	32.5	53.1	81.5	1	2010

Source: own calculations

Table 4. Data concerning selected countries where efficiency deteriorated

Country	I1	I2	I3	O1	O2	O3	O4	Rank	Year
Greece	8.0	4.3	4.7	169.5	19.0	42.7	78	13	2000
	9.7	5.0	4.7	263.2	20.9	45.7	79.2	21	2005
	10.2	6.1	4.9	263.2	21.9	50.4	80.6	26	2010
Slovak Republic	5.5	3.4	7.9	116.3	10.6	26.9	73.3	26	2000
	7.0	3.0	6.8	138.9	11.9	28.6	74	30	2005
	9.0	3.3	6.4	175.4	13.8	32.5	75.2	31	2010
United States	13.7	2.3	3.5	144.9	15.0	25.7	76.7	7	2000
	15.8	2.4	3.2	144.9	15.4	26.6	77.4	23	2005
	17.6	2.4	3.1	163.9	16.3	27.8	78.7	22	2010

Source: own calculations

The next group, shown in Table 4, consists of countries whose efficiency deteriorated to various extents. The United States is an interesting case. Healthcare expenditure rose by 28% but only led to an improvement in the PYLL ratio of 8.5% for women and men and in the IMR of 13.1%. The Slovak Republic radically increased expenditure – by 64% – which translated into an improvement in the PYLL ratio for women of 21% and for men of 30%, and in the IMR of 51%. Greece increased expenditure by 28% but the changes in outputs are similar to those in the Slovak Republic. For fifteen countries which were inefficient in 2010, a projection is calculated which describes the output levels that need to be achieved in order to attain full efficiency with the current level of inputs. The suggested values of outputs for a given country are calculated using the restrictive conditions (2) when the optimal values of the decision variables (i.e. the optimal slacks and intensity variables) are inserted. Table 5 shows the direction and magnitude of the required change in outputs, according to equation (5).

Table 5. Suggested percentage changes in outputs for countries inefficient in 2010

Country	Score	O1	O2	O3	O4
Australia	0.906	38.7	0.0	2.7	0.0
Austria	0.618	107.3	57.5	59.1	23.5
Belgium	0.718	64.1	26.7	46.5	20
Denmark	0.749	42.4	41.1	43.7	6.7
France	0.670	87.3	40.6	41.7	27.7
Germany	0.651	82.3	39.8	57.5	34.6
Greece	0.675	41.2	79.8	33.2	38.2
Hungary	0.546	66.4	143.1	106.7	17
Ireland	0.948	17.9	3.3	0.7	0.0
Italy	0.894	34.8	9.2	3.6	0.0
Norway	0.893	3.4	15.6	18.8	10.1
Portugal	0.799	4.6	58.5	25.3	12.2
Slovak Republic	0.526	147.0	118.9	84.7	9.5
Switzerland	0.703	92.2	22.3	34.7	19.5
United States	0.753	30.4	56.1	44.4	0.0

Source: own calculations

Australia, Ireland, Italy and Norway are the best performers in this group, with some outputs at the level of the fully efficient countries and with significantly lower suggested changes in outputs compared to the other countries. The least efficient countries, such as Austria, Hungary and the Slovak Republic should improve their outputs to a significantly greater extent. For example the greatest changes required regard the PYLL ratio in Hungary – 143.1% for men and 106.7% for women - and in the Slovak Republic – 118.9% for men and 84.7% for women. These output changes are attainable through the proper management of healthcare systems by following the examples of the reference group of efficient countries. In several countries, surpluses of inputs are observed, e.g. GDP per capita could be reduced in Denmark (11.4%) and the United States (38.2%). The United States is the country which of all the OECD members spends the largest proportion of GDP on healthcare. In 2010, it spent 17.6% of its GDP on healthcare while the average was 9.5%. In these cases the outputs could be achieved with reduced inputs.

CONCLUSIONS

The model which has been proposed for assessing the efficiency of healthcare systems in OECD countries has allowed the goal of this study to be achieved. Changes have been traced over an 11-year period at 5-year intervals. In a large majority of countries a constant upward trend in efficiency can be observed or it is maintained at a constant good level. Of course, there are exceptions, such as Greece, the Slovak Republic and the United States.

In addition to ranking, which as such is valuable information, the DEA method also makes it possible to identify fully efficient units which constitute a reference set (of best practice) for the inefficient countries to follow. Because DEA determines relative efficiency, in subsequent periods it undergoes changes. Moreover, the number of efficient DMUs increases. Hence, application of the super-efficiency model provides additional information about the ranking of fully efficient countries. The use of the SBM model enables all slacks in inputs and outputs to be taken into account, which increases the discriminatory power and let to obtain more accurate measurements of the model applied [Hsu 2014].

Certain general conclusions can be drawn from the analysis in this article. In the group of countries with full efficiency throughout the entire period analysed, there are mainly countries with good established economic conditions. The greatest growths in efficiency are recorded for three countries of the former eastern bloc: Estonia, Poland and Slovenia, the healthcare systems of which are still undergoing transformation. As mentioned by other authors [e.g. González et al. 2010], achieving additional increases in the health status of the population in rich countries is much more expensive because of decreasing returns (flat-of-the-curve hypothesis). This is exemplified by the US healthcare system, where a significant increase in inputs does not translate into a proportional increase in outputs. In poorer countries, a more decisive increase in outputs is attained with relatively lower inputs. By contrast, in rich countries increasingly costly innovations and services can barely lead to modest improvements in the general health level of the population. Hence, it has been suggested that redirecting resources to other programmes promoting healthy lifestyles and habits could perhaps better improve general health in rich countries. On the other hand, in less developed countries, even modest investments in healthcare can be dramatically effective in terms of lives saved, increases in life expectancy and general improvements in living conditions. However, the magnitude of these effects also critically depends on the way in which resources are employed.

Projections which show the directions of desired changes are an important part of DEA efficiency evaluation.

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