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Determining the Adequacy of Operation of DMUs in Health Care

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The authors of the article deal with the quantitative analysis of results of the development of health care services. The aim of the article is to determine the key conditions for measuring the results of health system functioning and evaluation of its adequacy. The research question focuses on the method of measuring the operational efficiency of Slovenian hospitals. The introduction defines efficiency within the concept of adequacy and its dimensions of efficiency, accessibility and quality. The empirical part of the article presents the use of the DEA method for determining the adequacy of operation of hospitals on the basis of data on Slovenian hospitals. It is apparent that the model for the evaluation of adequacy of operation of hospitals is suitable within limitations. The interpretation of results is hampered by inadequately structured data and non-transparent prices of hospital services. Therefore, the results of the research indicate the direction in which the database should be developed to ensure greater comparability in a rather heterogeneous population of hospitals. Furthermore, the authors point out that new indicators, reflecting the condition of the dimensions of adequacy, should be included in the model for the purposes of the evaluation of adequacy. On the basis of the results of the research, the question of implementing suitable methods of planning and controlling the adequacy of the functioning of health care into practice arises.

Keywords: DEA, health care, adequacy, indicators, hospitals, efficiency.

1. Introduction

The efficiency of the functioning of the public sector must be observed within the concept of adequacy, which is defined within the framework of public expenditure management as a quantitative construct, composed of three dimensions - quality, accessibility and efficiency.

The assurance of effective functioning of the health system and individual business decision-making units in health care is a complex process (system), where the requirements, data and information are transferred from the policy makers through the implementation of policies to the providers of programmes and projects and back. In the light of planning and monitoring the achievement of effective operation, there are several data and information levels at which various types of variables can be observed. The achievement of the set results depends primarily on:

- clear and understandable definitions of the levels of quality and accessibility (standard), which may be achieved within the available resources and requirements in relation to the production volume;
- efficient functioning of the units implementing the programmes or projects.

The general challenge of adequacy is therefore the assurance of quality health care services that are equally accessible to all users and performed in an efficient manner. The decision makers in the area of care services must take into account all three dimensions of adequacy when considering the investments and costs of health care services. Their task is to:

- define the suitable measures of quality and accessibility or standards at the level of policy administrators, which are then implemented into the programmes and projects;
- plan and ensure the efficiency of functioning.

The article addresses the problem of determining the efficient functioning of the business decision-making units in the public sector by using the DEA method in the example of the Slovenian network of public hospitals. It tests the following statements:

- the accessible data on the functioning of the Slovenian health system are not suitable for a qualitative analysis of the efficiency of functioning of system units;
- the DEA method enables the construction of a model for examining the efficiency of the public health care units which provides applicable results in rather heterogeneous sets even with lower quality data;
- the results of the model enable the analysis of functioning of individual units in relation to the highest performing units and the analysis of opportunities to improve the functioning of the system as a whole.

The remaining content of the article is divided into four chapters. First, the concept and definition of adequacy of public expenditure are presented. Next the basic definitions of Data Envelopment Analysis are given. The empirical part presents an example of the use of the DEA method in measuring the efficiency of the Slovenian acute hospitals. The article ends with the interpretation of results and conclusions.

2. Efficiency of Functioning of Public Health Care

The discussion on the efficient functioning of public health care was set within the context of adequacy. The definition of adequacy of public health care can be developed over the definition of dimensions of performance in health care (Basu, Andrews, Kishore, Panjabi, & Stuckler, 2012), adopted as a standard by the World Health Organisation (Murray & Frenk, 2001):

- access and responsiveness (availability, timeliness, hospitality)
- impartiality and equality (financial barriers of access to health care services, distributive justice);
- quality (integrity of services, standards of management, diagnostic accuracy, retention of patients);
- results (treatment success rate, population coverage (when performing actions), morbidity, mortality rate);
- responsibility and transparency (accessibility and quality of data, public health functions, capacity for improvement);
- efficiency (costs, redundancy, fragmentation, delays).

The given six dimensions may be reclassified into the three dimensions above as follows:

- accessibility (access and responsiveness, impartiality and equality); and
- quality (quality, results and responsibility and transparency);
- efficiency.

The measure of operational adequacy is therefore composed of the measures of quality and accessibility (interval value with the optimal value in the middle of the interval) and measures of volume (interval value with the optimal value at the upper limit of the interval).

According to Farrell (Farrell, 1957), the measure of efficient functioning of the public sector may be defined as a ratio between the outputs and inputs. Public health care services are provided by public or private units for the provision of public services, hereinafter referred to as the business decision-making units EPO. A unit operates effectively if it makes an optimal contribution to the outputs of the public sector as a whole. The measure of adequacy of public expenditure at the level of individual business decision-making unit is defined in the same manner as the measure of adequate functioning of the entire health system, whereby the relevant variables used for evaluating the results and expenditure should be taken into account in the calculations.

Health care costs are common scientific and research, as well as practical topics of various studies, which use different approaches, while significant efforts were made to prove that investments have substantial effects on health care. Therefore, the analysis of time series of costs and results of health care is used at the macro level, and on the basis of a significant increase in health indicators, it is presumed that investment in health care is effective, which is also indicated by the future predictions (Luce, Mauskopf, Sloan, Ostermann, & Paramore, 2006; Murphy & Topel, 2006).

However, several authors reply to such a demonstration that while it is true that it may be presumed from the indicators used for proving the suitability of results of investments in health care that the results are suitable, these methods do not reveal whether the investments in health care are too low, adequate or too high. The fact that investments in health care on average produced positive results does not necessarily imply that the health system is efficient (Frakt, 2012). Thus, most of the persons involved agree that the funds in health care are not spent efficiently and that no link has been established between the increase in funds and the results. It is not known whether the allocation of resources between health care and other uses of public funds is efficient nor how much health we should be getting for the funds invested (Baicker & Chandra, 2011). The problem is that the benefits of various types of spending vary to a great extent. Certain treatments aimed at a wide population of patients bring considerable benefits with a relatively low spending. Certain other treatments have high values for individual specific patients and a low value for others. There is also a wide range of treatments which contribute to a rapid growth of spending of funds, while their health benefits are questionable. Therefore, a more efficient distribution of spending offers great opportunities (Baicker, Chandra, & Skinner, 2012).

The purpose of the discussion on adequacy and efficiency in health care was to establish the necessity of measuring and ensuring the adequacy of spending of health care funds. In view of the responsibility for the results (ordinary operations – management, investment – owners), it is necessary to observe efficiency in terms of the optimisation of ordinary operations (contribution of management) and the optimisation of investment (contribution of owners) separately.

The public health care system must operate effectively and efficiently within the challenge of adequacy. In this regard, the model for addressing efficiency analysis is crucial for addressing the complete adequacy. The model for addressing adequacy is an upgrade of the basic model of efficiency; however, the upgrade can be accomplished only on the basis of good, adequately structured data of the model of efficiency.

3. Data Envelopment Analysis (DEA) Method

The data envelopment analysis method is based on the concept presented by Farrell (Farrell, 1957) in his article on the problem of measurement of efficiency. His aim was to unify the methodology of measuring efficiency to make it more suitable for measuring efficiency of any production unit, from workshops to the economy as a whole. The measures of adequacy and efficiency of the public sector presented in the introduction represent such a model, adapted to the public sector. Farrell's approach is based on the analysis of activity, whereby the measure of efficiency is the ratio between outputs and inputs. Initially, the concept was not widely applicable, since it was presented by Farrell only on the example of an individual output and input. The method that put the Farrell's concept into operation was developed by Charnes, Cooper and Rhodes (Charnes, Cooper, & Rhodes, 1978), and the original example referred to the evaluation of public programmes, while the authors at the very start indicated the guidelines for using the method in the economic sector or engineering. The method is based on linear programming and measures the proportional efficiency of business decision-making units. The set of business decision-making units for treatment with the data envelopment analysis method can be defined rather freely. The business decision-making unit must offer the possibility of controlling the inputs and outputs, while units where the same variables can be used for evaluating the inputs and outputs can be compared with each other. The basic CCR (Charnes – Cooper – Rhodes) model was a starting point for the development of several different models that take into account various assumptions and limitations.

The CCR model is a constant return model and is for n business decision-making units (EPO), of which each EPO_j uses m inputs x_{ij} (i = 1, …, m) and s outputs y_{rj} (r = 1, …, s), written in the basic form as a ratio between outputs and inputs (Charnes et al., 1978) in the form of a fractional program:

$$max h_0 = \frac{\sum_r u_r y_{ro}}{\sum_i v_i x_{i0}}$$

$$\frac{\sum_r u_r y_{rj}}{\sum_i v_i x_{ij}} \leq 1; j = 1, \dots, n, \qquad (1)$$

$$u_r, v_i \geq 0, \qquad r = 1, \dots, s; i = 1, \dots, m.$$

Values y_{rj}, and x_{ij} are given values of outputs and inputs, indicating past operating results. Values u_r, v_i are variable weights, enabling each unit to be weighted for its optimal benefit function within the given limitations, determined by the values of variable y and x with all units. Efficient units are those that reach the ratio 1. The definition is written in the input form; therefore, the proportionally inefficient units reach the ratio < 1.

The transformation process, used for selecting the solution with the value of the denominator within the definition equalling 1 among all the solutions of the fractional program (14), enables us to write the problem (14) in the form of a linear program (Cook & Seiford, 2009):

$$\begin{gathered} e_o = max \sum_i \mu_i y_{io} \\ \sum_i \nu_i x_{io} = 1 \\ \sum_r \mu_r y_{rj} - \sum_i \nu_i x_{ij} \leq 0, \forall j \\ \mu_r, \upsilon_i \geq \varepsilon, za\ vse\ r, i. \end{gathered} \tag{2}$$

The consideration is the same as with (14), the measure of efficiency remains unchanged, whereas the weights are different; therefore, they are marked with Greek letters μ and v.

By using the dual linear program, reference sets of business decision-making units are formed, so the problem is written also in this form:

$$\begin{gathered} min\ \theta_o - \left(\sum_r s_r^+ + \sum_i s_i^-\right) \\ \sum_j \lambda_j x_{ij} + s_i^- = \theta_0 x_{io}, i = 1, \dots, m \\ \sum_j \lambda_j y_{rj} + s_r^- = y_{ro}, r = 1, \dots, s \\ \sum_j \lambda_j y_{rj} + s_r^- = y_{ro}, r = 1, \dots, s \\ \theta_o neomejen. \end{gathered} \tag{3}$$

The result of the dual linear program (16) is the measure of efficiency and values of coefficients λ_j of linear combination of values of variables of efficient units, which represents the manner of operation of the observed EPO_o unit. Thus, the manner of operation is expressed by the manners of operation of the group of reference units that determine the subspace of service possibility for the observed unit.

The model is used to establish a convex refracting surface of optimal efficiency, a data envelope that includes efficient units, while the inefficient units are located above (input model) or below (output model) the envelope.

The example of the output model was selected as the graphic representation of the method, since it is more easily understood than the graphic representation of the input model. The example of the network of Slovenian hospitals was selected to demonstrate the model, and is analysed in detail also in the empirical part. One input and two outputs are used in the example:

- input
  - scope of work of doctors (hours worked by doctors);
- output
  - scope of work of acute treatment of patients – number of weighted comparable examples – HRG-weight;
  - scope of specialist services – number of points of specialist treatment of patients – POINTS.

The scope of work of acute treatment of patients is measured using the methodology of diagnosis related group (DRG) and equals the sum of all performed procedures. The scope of specialist points is a similarly weighted sum of all performed specialist examinations.

In this manner, the graph of service capacity field may be presented with the calculation of relative outputs (Figure 1).

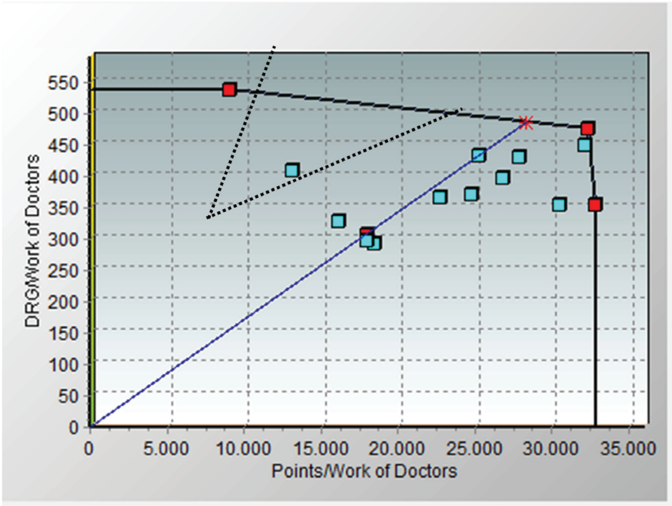

Figure 1: Service capacity field – output model

The data envelope is a convex broken line, linking the efficient units. It links the unit with the maximum value of the first variable with the units of maximum combinations of both values to the unit with the maximum value of the second variables.

The graph nicely illustrates the basic concept of the data envelope which is based on the assumption that units operate in an ideal ratio within the limitations, given by the operation of other units. The given example includes three efficient units, the unit with the maximum value of the variable on the x-axis (the rightmost unit), the unit with the maximum value of the variable on the y-axis (the uppermost unit) and the unit with the largest radial distance from the centre. Inefficient units are classified within the service capacity field. These units could become efficient if they moved to the envelope along the line passing through the centre and the given unit. The measure of efficiency is the ratio between the lengths of lines from the centre to the unit in question and from the centre to the intersection with the envelope. This can be a point on one of the lines between two efficient units or, in a specific case, exactly one of the efficient units. The points on the envelope present the manner for an efficient operation of an inefficient unit, which is determined as the weighted sum of manners of operation of efficient units that determine the section of the envelope, where the point of efficiency of a selected unit is located. The manner of operation of an inefficient unit, where the extended line from the centre to the unit falls exactly into one of the efficient units, is identical to this comparative unit.

The data envelopment analysis method brought the possibility of comparison and competition between the public sector units, which are generally limited in marketing (selling prices, target groups of customers, market share); therefore, their competitiveness must be expressed in the quality and efficient use of given resources.

4. Results of the Model

The model was designed using the data envelopment analysis (DEA) method. The Frontier Analyst (FA, 2011) software was used to process the data. The model includes five variables, two inputs (the work of doctors (WD) and the scope of care (C)) and three outputs (the number of points for specialist examinations

– POINTS, the sum of weights of groups of acute treatment (Diagnosis Related Group) cases – DRG and the number of inpatient hospital care days – ID (Table 1).

Table 1: Scope of health care services and used scope of health care professionals

Ei	POINTSi	DRGi	ICDi	WDi	WCi
E1	653.121	7.403	53.103	36,5	168,7
E2	120.723	4.613	14.269	9,2	24,6
E3	71.225	4.554	12.395	8,0	25,6
E4	654.668	5.975	35.066	19,8	60,4
E5	3.217.796	35.415	184.122	120,7	481,4
E6	1.508.237	14.324	65.394	49,7	184,0
E7	1.047.139	12.153	55.561	46,3	188,0
E8	1.586.540	18.285	103.810	48,4	264,0
E9	983.090	16.782	105.092	61,1	240,4
E10	1.902.860	20.942	111.308	54,4	314,7
E11	735.104	9.310	50.760	29,8	138,3
E12	1.145.828	14.746	69.686	45,7	205,5
E13	508.661	6.455	31.399	18,2	76,9
E14	9.886.054	102.949	590.422	543,2	2.197,6
E15	4.567.918	47.604	366.126	248,4	1.017,3

Since this is an environment where it is more difficult for the units to have an impact on outputs (the scope of services depends on the contract with the Health Insurance Institute of Slovenia, while the share of marketing activities is very small), we chose the input model. The efficiency of the units may be analysed under the assumption of constant or variable returns to scale. This example is limited to the constant returns to scale due to practical reasons; however, a comprehensive model for addressing efficiency should take into account also the analysis under the assumption of variable returns to scale.

Table 2: Results of comparison of units with the DEA model

	e_0	D1	D2	D3	D4	D5	R1	R2	R3	R4	R5	DEA (%)
E1	0,73	–26,9	–26,9	31,7	3,6	0,0	–9,8	–45,4	206.946	387	0,0	73,1
E2	1,00	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	100,0
E3	1,00	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	100,0
E4	1,00	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	100,0
E5	0,92	–8,2	–8,2	0,0	0,0	7,0	–9,9	–39,4	0,0	0,0	12.915	91,8
E6	0,93	–7,0	–12,0	0,0	0,0	25,9	–3,5	–22,1	0,0	0,0	16.928	93,0
E7	0,82	–17,9	–17,9	0,0	0,0	21,0	–8,3	–33,6	0,0	0,0	11.664	82,1
E8	1,00	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	100,0
E9	0,91	–9,2	–9,2	84,0	8,6	0,0	–5,7	–22,2	825.518	17.14	0,0	90,8
E10	1,00	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	100,0
E11	0,86	–14,0	–14,0	7,5	0,0	0,0	–4,2	–19,3	55.383	0,0	0,0	86,0
E12	0,92	–8,0	–8,0	0,0	0,0	8,0	–3,7	–16,5	0,0	0,0	5.541	92,0
E13	0,97	–3,3	–3,3	0,0	0,0	0,9	–0,6	–2,5	0,0	0,0	282	96,7
E14	0,68	–31,9	–31,9	0,0	0,0	11,9	–176,8	–701,3	0,0	0,0	70.376	68,1
E15	0,77	–22,9	–22,9	35,8	5,8	0,0	–57,0	–233,3	1.634.933	4.151	0,0	77,1

Key: e_o – efficiency, Dj – shares of required changes in the variable j, R_j – absolute values of required changes in the variable, Dj, j = 1, 2, 3, 4, 5 – variable codes: D1 - WD – work of doctors, D2 - WC – scope of care, work performed by medical personnel, D3 - POINTS – number of specialist points, D4 - DRG-weights – sum of weighted Healthcare Resource Group cases of acute treatment, D5 – ICD - number of hospital care days.

The analysis of the results of the selected data envelopment model will start with the review of the efficiency level which indicates the share of inputs that the units are allowed to spend to become efficient. This is followed by a short description of how this fact affects individual variables. From the perspective of the administrator of the entire system, the most important units are those with the greatest deviations in absolute value, regardless of the efficiency level demonstrated; therefore, the group of units with the greatest opportunities for improvement will be observed separately. The results for this part of the analysis were obtained with the Frontier Analyst software by using the "Data Export" function. With units, which offer the greatest opportunities for improvement, a set of equivalent efficient units determining the subspace of service capacities for the selected unit will be presented. The results for this part of the analysis are obtained with the "Report" function.

According to the efficiency level (e_0), the analysis highlighted five efficient units (E2, E3, E4, E8 and E10). Five units form a group with the efficiency level between 0.90 and 1.00 (E5, E6, E9, E12, E13). The inputs in these units are up to 10 percent higher than in the efficient units in relation to the outputs. {Citation}Units E7 to E11 include excessive inputs by 10 to 20 percent, while the surplus of inputs in three units (E1, E14 and E15) exceeds 20 percent.

When considering the required improvements, two manners of unit behaviour should be taken into account. The units within the service capacity field, determined by the efficient units, whereby the limitations for all variables in the dual linear program are fully used (no unused limitations are formed), can reach the Pareto-Koopmans efficiency (without any variables with unused limitations) (Cooper, Seiford, & Tone, 2007; Koopmans, 1973) with the unchanged ratio between the variable values (radial shift on the envelope). The units outside the service capacity field include unused limitations. These units can become technically efficient (e_o = 1) if they reduce the inputs for the share, determined by the efficiency level; however, they can achieve the Pareto-Koopman efficiency only if they change the ratio between the variable values, since they must reduce/increase the value of the variable that does not utilise the limitation.

When dealing with results, this means that the required proportional changes in the units which can fulfill the conditions for the Pareto-Koopman efficiency amount to e_0-1 for all the variables under consideration (for inputs in the input model and for outputs in the output model). In this manner, units with unused limitations can achieve only technical efficiency, whereas in order to achieve the Pareto-Koopman efficiency, they must also compensate for the unused limitations.

The review of the results shows that all inefficient units display at least one output variable with unused limitations, which is indicated in Table 2 as the share of improvement in columns D_3, D_4 or D_5, unequal to zero. The shares of improvement with input variables (D_1 and D_2) differ only with the unit E_6, where the share of required improvement with the care variable is larger than e_0-1 by the share, represented by the balancing of the unused limitation.

Therefore, the plan to achieve efficiency for the least efficient unit E14 could be written as:

1. reduce the scope of work of doctors by 31.9%;
2. reduce the scope of care by 31.9%;
3. increase the number of hospital care days by 11.9%.

From the perspective of the system operator, the data on absolute values of opportunities for improvement are in any case more important, since his aim is to improve the efficiency of the entire system. On the basis of data in columns R_1 to R_5 in Table 4, it may be concluded that the units with significant opportunities for improvement are E1 (deviation in the scope of care (R_2) and number of points (R_3)), E_{14} (deviation in both inputs (R_1 and R_2) and in the number of hospital care days (R_5)) and E_{15} (deviation in both inputs (R_1 and R_2), in points (R_3) and in HRG-weights (R_4)).

The final part of the discussion of the results of the data envelopment analysis method includes the presentation of the point of efficiency for the inefficient unit on the basis of linear combination. In this manner, the inefficient unit can consider its relation with efficient units with equivalent service models. The operation of the hypothetically efficient unit E_{14} can be defined with three equivalent units (the values of coefficients in linear combination are the result of the dual linear program (16)):

$$E_{14}^{*} = 12{,}6 \cdot E_3 + \ 65{,}4 \cdot E_4 + 24{,}7 \cdot E_{10}$$

Therefore, the target value for the variable WD (work of doctors) is:

$$12{,}6 \cdot 7{,}95 + 6{,}54 \cdot 20 + 2{,}47 \cdot 59{,}1 = 100{,}1 + 130{,}9 + 146{,}2 = 377{,}2$$

Thus, unit E_3 contributes 26.5%, E_4 34.7% and E_{10} 38.8% to efficient unit E_{14} in the input variable WD.

The presented manners of handling the phenomenon with the data envelopment analysis method are just part of the possible areas of observation. In any case, we usually do not have reliable data, suitable for a substantial discussion, in the first phase of the use of the model; therefore, the first step of such studies is the analysis of data relevance. In our example, the problem of inconsistent data on the scope of work and data on the scope of services is what stands out the most, since the scope of work also includes the time that was not allotted to services covered in the model.

The analysis of the efficiency level and opportunity for improvement allows us to determine both the position of individual unit compared to others and the manners and scope of required improvements. The analysis of unused limitations and groups of equivalent unit can be applied to present a detailed image of the service models used by the units within the system.

Similar to all methods of comparison, the data envelopment analysis method sets limits on the basis of given values and is therefore a tool for exerting constant pressure on increasing the efficiency of the system functioning. It is important that this method provides us with an insight into the service models used by the system units, so we can monitor and direct the achievement of efficiency within the various service models.

Conslusion

The article introduced the general definition of effective functioning of the public sector into the environment of health care. The review of literature showed that attempts are still being made to prove that the health care system in the present form is efficient; however, it is obvious that the assurance of adequacy of the health care system is a key task of both decision-makers and providers of programmes and projects. The presented example shows that the development of activities cannot be measured with absolute indicators, but only in a relative manner.

Quality decision-making can be achieved by subsystems only on the basis of information, the key to success being the accessibility of data and the use of suitable methods. Unfortunately, policy administrators are not aware of their responsibility for the functioning of the system and do not understand that for the purpose of development of policies and achievement of effective functioning it is necessary to ensure quality data at the micro level and, by comparing the implementing unit, determine which units are efficient and which are inefficient and why.

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