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Defining the Optimal Size of Medical Laboratories at the Primary Level of Health Care with Data Envelopment Analysis: Defining the Efficiency of Medical Laboratories

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ABSTRACT

Introduction: As an integral part of health care, biomedical laboratories are an important contributor to quality patient care. There are only few studies on technical and economic efficiency in the field of laboratory medicine. Nevertheless, such research is crucial to further optimize public resources. **Aim:** The aim of our research is to create and verify a model for defining the scale efficiency of medical laboratories at the primary level of health care. **Methods:** Twenty-one laboratories at the primary level of health care in Slovenia were included in the analysis. The efficiency of medical laboratories was determined using data envelopment analysis. We additionally used hierarchical cluster analysis to determine the homogeneous groups within the analyzed sample of units. **Results:** We determined the high technical and pure technical efficiency of the analyzed laboratories. The analysis results showed that changes in work processes represent only a minuscule improvement in efficiency, while more can be achieved through a proper scaling of laboratory services. The impact of the operating scale on the efficiency of laboratories is up to twice as high as the process inefficiency. If we take into account the operating modes of laboratories, the optimal scale of services starts at 237,570 automatic tests. **Conclusions:** We note that increased automation and consolidation of laboratory activities could contribute to a greater efficiency of medical laboratories and consequently reduce public spending. DEA is an appropriate tool for the efficiency analysis of public medical laboratories and of appropriate support for policy creation and evaluation in the field of laboratory medicine.

Keywords: Laboratories, Efficiency, Health care, Automation, Public sector.

1. INTRODUCTION

The trend of increasing health care expenditure is a reason why efficiency studies can become an important factor in the rationalization of public spending and tools for identifying successful health care practices (1). Research on the efficiency of health care providers has a long history. However, there is little research on the health care efficiency of medical laboratories. To determine the efficiency of public service providers, we can use several methods, for but data envelopment analysis (DEA) is one of most commonly used methods for evaluating efficiency in health care (2, 3, 4, 5).

A health care provider who uses the minimum amount of inputs to produce a given level of health care services is defined as technically efficient. If we also consider the input prices, we can additionally define allocative efficiency (2). The DEA method has been established particularly in the public sector; among its advantages, the efficiency frontier is determined based on empirical data without a pre-specified production function. The result is a mathematical evaluation of the analyzed unit efficiency with respect to reference sets and the choice of input and output variables (6). The input variables in DEA research are often defined with variables related to labour, the value of fixed assets and the cost of medicines. The output variables are defined as hospital days, the number of admissions, the number of beds, the number of medical tests performed and hospital revenue (7).

Laboratories at the primary level of medical care perform basic laboratory testing for diagnostic pur-

poses. With the development of technology and the increased need for high-quality laboratory test results, measures are needed to increase the efficiency of laboratory medicine with consequently greater cost-effectiveness (8, 9, 10). Financial rationalization in laboratory medicine can be achieved through the consolidation, centralization and regionalization of laboratory services; furthermore, the importance of laboratory automation is highlighted in connection with the cost-effectiveness of laboratories (10, 11, 12, 13).

To determine the optimal size of laboratories, we analyze scale efficiency (SE). SE is defined as the ability of the analyzed units to identify the optimal productive size within the inputs used. At the optimal size, laboratories can take advantage of economies of scale, i.e., produce the largest amount of laboratory tests per unit of input and reduce the average cost of production. The determination of the SE has never been used to determine the optimal size of laboratories; therefore, to provide the foundations of our research, we used DEA research that defines the optimal size of health care institutions at the primary and secondary levels of health care (14, 15, 16).

Quite a few health care DEA efficiency studies have been conducted in the field of primary medical care. The analyzed units of research at the primary level are institutions as a whole and as individual parts, e.g., general clinics, dentistry offices, diabetic clinics, and perinatal care centers (16, 17, 18). As part of health care institutions at the primary level, biomedical laboratories have not been the subject of efficiency research to date (5). Nevertheless, we found DEA-based efficiency research on ten laboratories affiliated with the Shiraz University of Medical Science (19), twelve laboratories grouped under the Croatian Institute of Public Health (20), and twenty laboratories affiliated with the Urmia University of Medical Science (21), reaching the common conclusion that these medical laboratories are mostly highly technically efficient.

2. AIM

The aim of our research is to create and verify a model for defining the scale efficiency of laboratories at the primary level of medical care as a tool for making recommendations on the optimal scale of laboratory units with adjustment of operating modes.

3. METHODS

3.1. Methods

DEA establishes a convex refracting surface of optimal efficiency on the basis of the highest ratios between outputs and inputs, i.e., the data envelope that includes efficient units, with inefficient units being located above or below the envelope. The assumption of the technology used is one of the essential elements when applying the DEA methodology. In this way, return to scale (RTS) describes the rate of output produced (increase or decrease) with connection to the amount of inputs used. If we assume a proportional change in the output produced in response to a pro-

portional change in the input consumed, then the constant return to scale (CRS) model is used. However, if the change in the variable is disproportionate and may increase or decrease, the variable return to scale (VRS) model is used. The score of the CRS DEA model represents technical efficiency, while the score of the VRS DEA model represents pure technical efficiency, i.e., process efficiency. The SE is a quotient between the CRS and VRS efficiency and enables us to define how close to the optimum size the observed unit is and whether the cause of the technically inefficient unit is its inadequate size (2, 22, 23).

In our research, the input variables are labour (number of working hours), capital (number of biomedical analysts) and consumable goods (costs of laboratory reagents and materials) (19, 20, 21). Primary-level laboratories mostly perform basic laboratory diagnostics; thus, we divided our output into the number of automatic and manual tests carried out.

DEA-based research on efficiency in health care is mostly input oriented, which is also supported by systematic reviews of DEA research (5, 24). This means that health care providers have more control over the inputs they consume than the outputs they produce. The abovementioned facts indicate the rationale of applying the input-oriented DEA method for our research.

For a more detailed analysis and increased discrimination between individual units, we determine the subgroups operating under similar conditions by conducting hierarchical cluster analysis of the cross-efficiency scores, i.e., weights assigned to the evaluated unit by its peers (25). Furthermore, cluster analysis using correlation coefficients helps us identify groups with similar operating modes, and together with the DEA method, it improves the sorting of similar units for purposes of comparative analysis (26).

In our research, the optimal size of laboratory units is determined by the number of automatic tests performed and the consequent adjustment of the inputs used. Stated represents the basis for identifying the optimal scale of services.

3.2. Materials

The data for our research were obtained through a questionnaire sent to all 57 primary health care centers in Slovenia. Twenty-one primary health care centers provided us with complete data sets for further comprehensive analysis. The lack of public data is the reason for the limited set of considered units. Our research included primary health care centers and, consequently, their laboratories for 687,221 citizens, representing 35% of all citizens with a selected personal physician at the primary level of health care in Slovenia. We analyze data for the year 2017.

The heterogeneity in the variables (Table 1) is a result of the regional distribution of health services and is expected because the purpose of our research is to determine the optimal laboratory unit size. This fact dictated the need for a methodological approach that focuses on analyzing groups of units with a similar operating mode. In principle, DEA assumes a homogeneous

	Min	Max	Average	Median	SD	25P-75P
Number of working hours	1,722	170,003	20,488.71	11228,00	35,760.61	6,605.50 to 16,096.00
Number of biomedical analysers	3	43	9	6	9	4 to 9
Cost of laboratory reagents and materials	31,986.00	1,711,241.00	254,801.43	116,454.00	383,035.15	70,661.50 to 228,002.25
Number of automatic tests	13,917	2,679,055	368,023.67	178,359.00	593,071.67	113,469.50 to 272,194.50
Number of manual tests	1,261	205,332	21,037.67	7,250.00	44,353.52	4,865.50 to 13,724.50

Table 1. Descriptive statistics of input-output variables

set of units; however, research has also confirmed the applicability of this method to assess heterogeneous populations of observed units in the field of primary health care (27).

In the analysis, we used Frontier Analyst (Banxia Software, Kendal, UK) and MedCalc (Panmun Education, Ostend, Belgium).

4. RESULTS

The average technical efficiency of laboratories calculated under the assumption of CRS was 82.05%, while the expected average pure technical efficiency was higher and amounted to 93.33% (Table 2).

Unit name	Number of automatic tests	Score CRS (%)	Score VRS (%)	SE (%)	RTS
L11	13,917	44.59	100.00	44.59	1
L13	21,177	48.75	100.00	48.75	1
L18	79,811	68.51	84.15	81.41	1
L3	83,062	90.00	100.00	90.00	1
L17	88,487	100.00	100.00	100.00	0
L9	121,797	86.21	100.00	86.21	1
L5	125,290	75.19	87.07	86.36	1
L16	125,497	72.38	96.27	75.18	1
L15	125,979	81.28	89.15	91.17	1
L12	149,138	50.37	82.08	61.37	1
L20	178,359	100.00	100.00	100.00	0
L1	196,593	83.97	84.22	99.70	-1
L7	198,742	72.14	73.06	98.74	1
L4	206,022	99.50	99.64	99.86	0
L21	237,570	100.00	100.00	100.00	0
L14	245,065	62.13	64.34	96.57	1
L19	353,583	100.00	100.00	100.00	0
L6	581,945	100.00	100.00	100.00	0
L2	847,640	100.00	100.00	100.00	0
L10	1,069,768	88.00	100.00	88.00	-1
L8	2,679,055	100.00	100.00	100.00	0
Mean	368,023.67	82.05	93.33	88.00	
SD	593,071.67	18.28	10.19	16.67	

Table 2. Efficiency results

As shown in Table 2, seven analyzed laboratories (L2, L6, L8, L17, L19, L20 and L21) are both technically and purely technically efficient; therefore, they are also scale efficient, which means that they have the optimal size. The rest of the laboratories are technically and scale inefficient. Five of them are purely technically efficient and overall inefficient due to their inadequate size (L3, L9, L10, L11 and L13). Four laboratories (L1, L4, L7 and L14) operate very close to the optimal size, with a scale efficiency close to 100 %. Laboratories with lower scale efficiency operate sub-optimally. There are seven completely inefficient laboratories with lower scale efficiency (L5, L9, L10, L12, L15, L16 and L18).
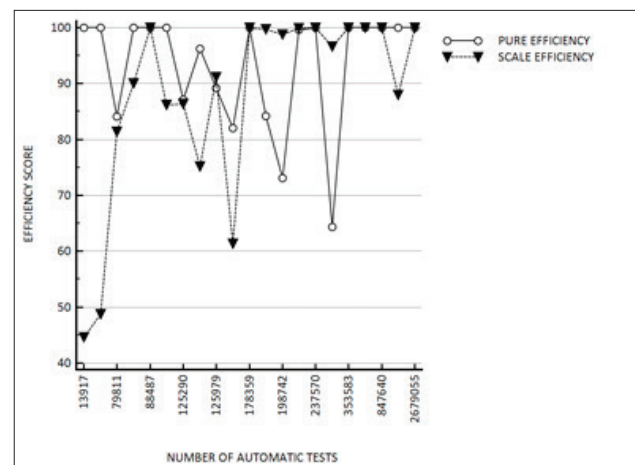

Figure 1. Chart of scale efficiency

Figure 1 shows the scale efficiency and pure technical efficiency in relation to the number of automatic tests carried out, which represent a significant proportion of laboratory services. The broken line of scale efficiency has several peaks, which means that we have several areas with an optimal range of operation.

	Group 1		Group 2		Group 3	
	N	Mean	N	Mean	N	Mean
Automatic tests / Recorded hours	12	18.45	6	17.70	3	10.26
Automatic tests / Number of analysers	12	28,197	6	43,674	3	51,113
Automatic tests / Material costs	12	1.58	6	1.10	3	1.09
Manual tests / Recorded hours	12	0.96	6	0.97	3	1.15
Manual tests / Material costs	12	0.07	6	0.06	3	0.12

Table 3. Output-input ratio by group

The hierarchical cluster analysis of cross-efficiency revealed three homogeneous groups of units. The char-

acteristics of the groups are shown in Table 3 with the output-to-input value ratios.

As shown in Table 3, the first group includes 12 laboratories with a service range of 79,811 to 1,069,796 automatic tests. The second group includes 6 laboratories with a range of 21,177 to 581,945, and the third group of 3 laboratories had a service range of 13,917 to 2,679,055. Like the second group, the first group also has a high ratio between the number of automatic tests and recorded hours and a low ratio between the number of automatic tests and the number of analyzers, which means that, on average, they have a larger number of analyzers. Considering the low value of the ratio between the number of manual tests and recorded hours, we note that the first group carries out more automatic and fewer manual tests than the other two groups. The second group uses a significantly smaller number of analyzers and consumes more materials than the first group. This group carries out more manual tests than the first group and fewer than the third group. The third group significantly deviates downward in terms of the number of automatic tests and performs more manual tests.

We also determine the optimal range of services for the three groups presented above. For the first group, the optimum operating range in terms of the increasing return to scale is 178,359 automatic tests; on the other hand, for the decreasing return to scale, we define the last value, which is 847,640 automatic tests. For the second group, the optimal range starts at 237,570 automatic tests. The third group is the smallest, but we conclude that the optimal scale of services occurs at 88,487 automatic tests. If the point of the optimal scale of the third group is attributed to a deviation from the operating mode of the remaining groups, we note that the optimal scale of services is greater than 178,000 tests. This fact is clearly apparent from Table 2, as 9 out of 10 units with a lower value than those indicated (L3, L5, L9, L11, L12, L3, L15, L16, and L18) have an SE lower than 91.2%.

5. DISCUSSION

In our research, we determined the high technical and pure technical efficiency of the analyzed laboratories. Previous studies of efficiency in the field of laboratory medicine also provide evidence of the high technical efficiency of medical laboratories (19, 21). We conclude that the impact of the operating scale on the efficiency of laboratories is up to twice as high as the process inefficiency. It is possible to assume that by changing the way of work, it is possible to achieve a laboratory efficiency improvement of 6.67%, while adjusting the size of the laboratories represents the remaining possible improvement. Laboratories with lower scale efficiency operate sub-optimally and demonstrate an opportunity to improve efficiency by adjusting their inputs and outputs and by adjusting their operating modes.

Based on the cluster analysis, we defined three operating modes of laboratories. The output-input group ratio analysis notes that the first group is the most oriented towards automatic tests. Group three places greater emphasis on manual tests than the other two groups. In our case, the second group represents the middle path, which we assume is also the most appropriate according to the nature of the work. A more detailed analysis of individual unit operations should be conducted to develop more detailed recommendations regarding the optimal operating mode.

The research results show that in the given example, if we take into consideration the operating modes, the optimal scale of services starts at 237,570 automatic tests. Based on the example of primary health care centers in Greece (16), we conclude that the same smaller laboratories suffer more from scale inefficiency and could become effective by increasing their size and, consequently, their range of services. DEA-based research on efficiency at the primary level of medical care also notes that productivity improvement over time occurs due to improved pure technical efficiency and a positive change in SE (28). By achieving economies of scale and greater automation, there will be a greater impact on larger laboratories due to the reduction in the costs of laboratory reagents and materials. Similar to the situation in France, primary-level laboratories could consolidate their main activity through the establishment of regional laboratory centers, which would achieve a greater degree of automation and, consequently, a higher degree of efficiency due to their appropriate size. Access to laboratory services as a fundamental right of all citizens could be ensured with several collection points and the high-quality and timely transport of samples. It is also emphasized that laboratories should cooperate, consolidate themselves and create strategic alliances to increase their efficiency and reduce their operating costs (29).

6. CONCLUSION

The findings hold both practical and theoretical significance. In practice, the presented method can help us draw up proposals for improvements in terms of defining the optimal size of laboratories and selecting the most appropriate operating modes. In methodological terms, we contribute to the scientific corpus of health care DEA models and expand the scope of method applicability with the aim of a comprehensive methodological coverage of health care.

The research limitation is the limited set of measure units considered.

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