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Hospital efficiency: how to spend less maintaining quality?

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Abstract
Introduction. The recent global economic crisis is pushing governments worldwide to obtain a more explicit and urgent rationing of resources. The purpose of this study is to provide, through Data Envelopment Analysis (DEA), a methodological framework useful for investigating technical efficiency of hospital care.
Methods. To validate such framework, we compared 50 Italian public hospital trusts (AOs) to identify relative efficient using inputs and outputs from national databases. We also evaluated if, and how, efficiency is affected by various exogenous factors.
Results. On average, Italian AOs had an efficiency score of 77% (SD 0.12). Tobit regression model identified a positive association between efficiency and a lower case-mix index, being in the north of Italy, in a region with fiscal autonomy, with a higher public and a lower private expenditure on health as percentage of GDP.
Conclusions. DEA may provide useful and especially objective information regarding the technical efficiency of hospital care and support hospital management and policy makers' decisions.

Key words
- hospital care
- technical efficiency
- Data Envelopment Analysis
- Italy

INTRODUCTION

The recent global economic crisis has negatively affected the availability of budget for health care systems and, along with population ageing, rising prices in medical technology and health care, is pushing governments worldwide to obtain a more explicit and urgent rationalization of resources.

Health care spending needs therefore to become more effective. In this context, efficiency analyses play a crucial role to make hospitals managers and policy makers aware of who, and why, perform better in transforming spending into health outcomes and how to get significant efficiency gains.

Efficiency is a fundamental dimension in performance assessment frameworks and an intervention can be considered as technically efficient whether it is not possible to reach the same level (or greater levels) of output reducing the inputs [1, 2].

Literature defines different methods to evaluate the efficiency in the secondary care. Hollingsworth *et al.* classified this approaches using two characteristics, whether they are parametric or non-parametric, deterministic or stochastic [2]. Parametric approaches diverge from non-parametric ones for the use of specific assumptions on the form of the production frontier and are therefore more susceptible to model construction bias. Deterministic methodologies diverge from stochastic ones for the absence of random error evaluations and are therefore more susceptible to the outliers [2, 3].

Data Envelopment Analysis (DEA) has been recognized as an important tool in efficiency analysis. Golany and Roll [4] defined especially that DEA can be useful for identifying inefficiencies, supporting management evaluation, classifying the different Decision Making Units (DMUs) and evaluating different policies. Charnes, Cooper and Rhodes [5] in 1978 introduced the DEA for assessing the efficiency of not-for-profit organizations. Emrouznejad *et al.* [6] underline the high increase of published articles dealing with DEA applications since their first work, and a recent literature survey conducted by Liu *et al.* [7] pointed out the widespread use of DEA in the health care sector efficiency evaluation in the recent years. Bhat *et al.* [8], Hofmarcher *et al.* [9], Matranga *et al.* [10], Chowdhury *et al.* [11], Popescu *et al.* [12], Herwartz and Strumann [13] are some recent examples of DEA application for efficiency measurement in secondary care. Al-Refaie *et al.* [14] also used DEA for the Emergency Department efficiency evaluation in Jordanian Hospitals.

Hussey *et al.* [15] and Hollingsworth [16], deal with the hospital delivery of care. Regarding choices on input and output variables, both reviews found that physical characteristics are commonly used as inputs

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and outputs, while only a few studies used health outcomes variables as outputs. O'Neill *et al.* [3] also reviewed 79 published articles on DEA applications for hospital efficiency evaluation, concluding that almost half of them assume Costant Return Scale (CRS) while the other half use Variable Return Scale (VRS) or both techniques. However authors identified different works that investigate the relation between scale economies and hospital efficiency.

Given these previous examples of DEA applications, our study wants to define and validate a particular DEA model to evaluate hospital efficiency based on the linkage between physical characteristics and outcomes of care. In addition, we tried to investigate how other external factors could influence this relationship.

The Italian health care system provides promotion, maintenance and recovery of health for the whole population and it is mainly funded by national and regional taxation [17].

Hospital care is delivered mainly by 669 public structures, which provide both outpatient and inpatient services. Nevertheless, local health units (LHUs) also contract out services to 553 private hospitals, especially not-for-profit institutions [18].

Public structures include hospitals directly managed by LHUs (PHs), public hospital trusts (PHTs) which provide highly specialized care and fall under the direct responsibility of Regions, teaching hospitals (THs) managed under agreements between Regions and Universities and hospital relevant in terms of national scientific research (IRCCS) which activities are coordinated by the Ministry of Health.

When resources are constrained there is an inevitable quantity-quality trade-off. The purpose of this study is therefore to provide, through DEA technique, a methodological framework useful for investigating technical efficiency (TE) of hospital care.

To validate such a methodological framework, in this study we compare Italian PHTs to identify relative efficient and inefficient structures, benchmarks and targets for improvement. We also attempt to evaluate if, and how, efficiency is affected by various exogenous factors.

METHODS

The conceptual framework we used to model the provision of hospital care in Italy is summarized in *Figure 1*. The decision making units (DMUs) in the provision of secondary care are the Italian PHTs. Each PHT provides services to its patients by means of a combination of resources (from here on referred to as "inputs"). To compare TE, the final outcome of the PHT care provided should be considered as the additional health conferred to the patient. Since this outcome is not easy to be measured, we have to rely on proxy measures, such as quality indicators which are known to be directly related to health improvements. The health outcome (from here on referred to as "outputs") can differ among PHTs [19]. Finally, the relative efficiency of one hospital may differ due to elements that are outside the control of the PHT managers (e.g. demographic features of the served patients, economic conditions and organization of the regional health care delivery system in which hospitals are placed, severity and heterogeneity of the hospitalized patients). Since such contextual factors act as inputs in the hospital production process, they are called non-discretionary or exogenous inputs [19, 20].

We analysed TE in two stages. First, we calculated the relative TE by means of DEA. In the second stage, we carried out a regression analysis to relate efficiency scores to contextual factors for investigating their influence on the relative efficiency in the provision of hospital services.

DEA defines TE of a PHT as ratio of the weighted sum of its outputs over a weighted sum of its inputs and it uses linear programming techniques to compute efficiency scores for each PHT, in relative terms. TE is processed by solving the mathematical problem reported here under (equation 1):

[Equation 1]

$$\text{Maximise } TE_{PHTo} = \frac{\sum_{s=1}^{s} u_s \times y_s o}{\sum_{m=1}^{m} v_m \times x_m o}$$

Subject to:

$$\frac{\sum_{s=1}^{s} u_s \times y_s i}{\sum_{m=1}^{m} v_m \times x_m i} < 1 \qquad i = 1, \dots, 20$$

Where:

E_{PHTo}= efficiency of PHT zero
i = number of PHTs
$y_s o$ = quantity of outcomes s of PHTo
$x_m o$ = quantity of processes m of PHTo
u_s = weight attached to the outcomes s - generated from the model- , $u_s > 0$, $s = 1, \dots, S$
v_m= weight attached to the processes m - generated from the model- $v_m > 0$, $m = 1, \dots, M$

This mathematical problem aims at maximising the efficiency of the PHT zero by generating a set of weights (i.e. u_s and v_m) to be attached to its inputs and its outputs, subject to the constraint that when applied to the other PHTs under scrutiny, no one can assume efficiency scores greater than the unity. The aforementioned set of weights can assume any non negative value.

Such a mathematical formulation has an infinite number of solutions: [21] since u_s and v_m are solutions of this maximization problem, u_s and v_m are also solutions. This can be avoided by reformulating the mathematical programme into a linear programme by constraining the numerator or denominator of the efficiency ratio to be equal to unity. The problem, then, becomes one of either maximizing weighted output subject to weighted

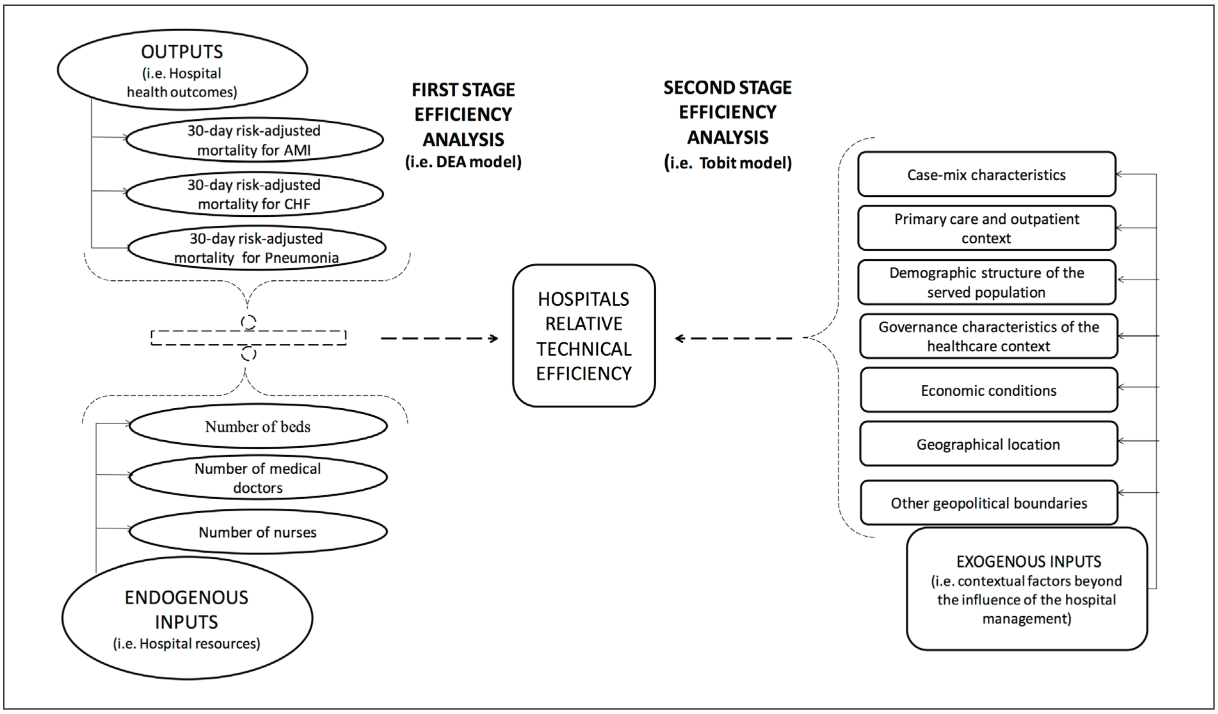

Figure 1
Conceptual framework used to model the provision of hospital care in Italy.

input equal to 1 or of minimizing weighted input subject to weighted output being equal to 1 [2]. This recognizes that in maximizing a ratio the relative values of the numerator and denominator are important and not their absolute values [22].

Since this efficiency analysis was carried out from the hospital manager perspective, we chose to run our DEA model under a Constant Return on Scale assumption, aiming to analyse TE in the provision of secondary care in each one of the 50 PHTs under scrutiny, by focusing on their productivity without regarding the scale of operations. Furthermore, the use of input/output measures in terms of ratios automatically implies an assumption of constant returns to scale, because the creation of the ratio removes any information about the size of the organisation. As for the efficiency orientation of our DEA model, we opted for an input-oriented TE analysis, because we were interested in exploring how each hospital under scrutiny could proportionally reduce its inputs, given the amount of output it provides, and could move to a technically efficient production point (in relation to the frontier determined by the other PHTs). Further, assuming that all hospitals were homogeneous in their production technology of secondary care, and assigning the same importance to the inputs and the outputs for the efficiency analysis, we decided not to apply any weight restriction to the data run in the model.

The software "DEA excel solver" developed by Joe Zhu [23] was used to compute efficiency scores and to identify best practice RGPs.

Hospitals are very complex entities, delivering numerous activities and as a result multiple output. Regarding input, there are three main input categories: labour, capital, and consumable resources (e.g. consumed drugs). These variables can be measured either in physical units or in monetary terms, as an overall aggregate measure or a set of disaggregated measures. Thus, from the input side we took into account several points for selecting an adequate set of inputs. Firstly, since our analysis takes a short term perspective, to understand the resources currently at the disposal of hospital management we opted for considering a set of disaggregated inputs (e.g. labour vs. capital). Secondly, a DEA model using measures of labour inputs disaggregated by skill type is likely to be effective to investigate the relationship between efficiency and the mix of inputs employed (MDs, nurses). Thus, to model our efficiency analysis we used the following variables as input:

X1 - Number of beds per patient admitted
X2 - Number of medical doctors per patient admitted
X3 - Number of nurses per patient admitted.

In healthcare, especially in secondary care, demand for health services derives from the belief that health care will make a positive contribution to health status. Thereby health care outputs should be defined in terms of health care outcomes delivered (e.g. in terms of QALY gained following a surgical intervention). PHTs rarely collect data on health outcomes routinely, thus, this information is not available and we have to rely on in-hospital quality indicators when there is evidence that such measures are a proxy close to health improvements. Assuming that all healthcare services provided by each PHT are of similar appropriateness, a total of three intermediate output proxies closely related to the final outcome were included in the DEA model. We defined the overall outputs in terms of three hospital quality measures [24]:

Y1 - 30-day risk-adjusted mortality for acute myocardial infarction

Y2 - 30-day risk-adjusted mortality for congestive heart failure

Y3 - 30-day risk-adjusted mortality for pneumonia.

Data were collected from the Italian Ministry of Health database (X1-X3) and from the National Program for the Evaluation of Health Outcomes, carried out by the Italian Ministry of Health and the National Agency for Regional Health Services, (Y1-Y3) covering the year 2010.

To take into account the uncertainty related to the assumptions made for the application of the DEA model, a sensitivity analysis with the bootstrap method based on 2000 replications has been performed using the FEAR package in the R-Gui software interface.

In a second stage, we modelled the efficiency scores obtained by DEA against some variables potentially affecting the production process of the PHTs and non controllable – at least in a short-term period – by the hospitals managers, in order to analyse their influence on efficiency. We used the DEA efficiency scores as a dependent variable in a Tobit regression analysis, where we used as independent variables a set of contextual factors. Specifically (see Additional File 1 available online as Supplementary material), in order to analyse if and how hospital performance is related to how care is organized in the outpatient setting, we considered (E1) *admission volume*, (E2) *entropy index* (the level of specialization of the medical centers) and (E3) *case mix index* (the complexity of the medical treatments supplied by each observation) to account of the diversity and clinical complexity of disease of all patients cared for, (E4) *old-age dependency ratio* to account for the regional demographic differences, (E5) *area of the country -north, centre or south-*, (E6) *presence of regional fiscal autonomy*, (E7) *public* and (E8) *private expenditure on health as percentage of gross domestic product (GDP)*, (E9) *average reimbursement for DRG* (average of the level of funding attributed to a specific DRG by the different Regions) and (E10) *presence of a financial repayment plan* to look at the regional health care systems' differences in economic conditions and (E11) *potentially avoidable hospital discharge* (any hospital admission that was either a potentially preventable readmission or an avoidable admission as identified by the Italian Institute of Statistics) *for heart failure*, (E12) *chronic obstructive pulmonary disease* and (E13) *long-term complication of diabetes* as indicators of regional quality in primary care.

Data were collected using several sources covering the year 2010. Information about hospitals have been extracted from the Ministry of Health database (E1-E3), while variables regarding regions (E4-E13) have been extracted from administrative databases of the Italian Institute of Statistics.

Each contextual factor was computed in a univariate analysis and, if resulted significantly affecting the effect estimated with a p-value lower than 0.20, was included in a multivariate analysis. Factors associated with a p-value lower than 0.05 at multivariate analysis were considered to significantly modify the hospital TE.

Statistical analyses were performed with the software STATA version 12.0 (Statacorp, College Station TX, USA).

Since DEA measures efficiency relative to an estimate of the frontier, we used the bootstrap approach proposed by Simar and Wilson, [25] to estimate the bias-corrected measure of TE as well as confidence intervals for efficiency scores, by running 2000 bootstrap replications using "FEAR" software [26].

RESULTS

We calculated the relative TE of 50 PHTs. Efficiency score, input and output current values, input target values, output slacks values for each of 50 PHTs are summarized in *Table 1*.

Efficient and inefficient structures resulted spread all over the country, with an average efficiency score of 77% and a standard deviation of 0.10.

Input target values listed in *Table 1* indicate what should be the percentage reduction of input current values (X1, X2, X3) for each health facility to achieve maximum efficiency score. For example, if "AO dei Colli di Napoli" decreases the number of beds per patient admitted by 31.1%, the number of medical doctors per patient admitted by 31.1% and the number of nurses per patient admitted by 47.7%, compared to their current values, it could become efficient.

Output slacks values show what should be the percentage increase of output current values (Y1, Y2, Y3) to become efficient even if each health facility reaches its input target value. For example, "AO Santa Maria di Terni" to become 100% efficient should not only decrease the number of beds per patient admitted by 8.4%, the number of medical doctors per patient admitted by 8.4% and the number of nurses per patient admitted by 19.9%, but also reduce the 30-days mortality rate for myocardial infarction by 5.3% and the 30-days mortality rate for congestive heart failure by 2.7%.

Additional file 2, available online as Supplementary material, summarizes the results of the sensitivity analysis and reports the corrected efficiency scores for each DMU, the upper and the lower bound of the 95% confidence interval, the Bias error and the variance estimate. Corrected efficiency scores highlight the differences between the structures, especially for those with better levels of TE, and in some cases (i.e. between DMU n.5 and n.6 or n.33 and n.34) turn over the results of the original DEA model. Nevertheless, these scores fit the confidence intervals and the low estimate variance attests the strength of the model applied. These considerations suggest that the results of a DEA model application should be read quite cautiously always taking into account the differences between the structures.

Results from the regression analysis *(Table 2)* indicate that neither (E1) admission volume, (E2) entropy index, (E4) old-age dependency ratio, (E9) average reimbursement for DRG, (E10) presence of a financial repayment plan or (E11) potentially avoidable hospital discharge for heart failure, (E12) chronic obstructive pulmonary disease and (E13) long-term complication of diabetes affect the efficiency level of hospitals.

On the other hand, (E6) the presence of regional fiscal autonomy and (E7) a higher public expenditure on

Table 1
Efficiency Scores with current and target values of Input and Output variables included in the DEA model

Decision Making Unit	Efficiency Score (%)	INPUT						OUTPUT					
		Current values (x100 admissions)			Target values (Δ%)			Current values			Slacks (Δ%)		
		X_1	X_2	X_3	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_1	Y_2	Y_3
(1) A.O. U****** I ** S*******	100	0.02	0.01	0.03	0.0	0.0	0.0	89.45	88.06	93.68	0.0	0.0	0.0
(1) A.O. U****** I ** S*******	100	0.02	0.01	0.03	0.0	0.0	0.0	89.45	88.06	93.68	0.0	0.0	0.0
(2) A.O. S***'A****** A**** ** T******	100	0.02	0.01	0.02	0.0	0.0	0.0	87.8	88.6	91.32	0.0	0.0	0.0
(3) A.O. O******* R****** V**** S**** - C******* ** P******	100	0.02	0.02	0.03	0.0	0.0	0.0	90.22	95.55	94.64	0.0	0.0	0.0
(4) A.O. ** D******** *** G****	97.4	0.02	0.01	0.04	-2.6	-2.6	-23.3	90.41	91.43	96.57	2.7	0.0	0.7
(5) A.O. C********* ** C******	93.5	0.02	0.02	0.03	-15.7	-34.2	-6.5	91.61	91.83	89.87	0.0	0.7	6.0
(6) A.O. ** P******	92.2	0.02	0.02	0.03	-7.8	-7.8	-12.1	94.32	90.46	94.09	0.0	7.3	4.6
(7) A.O. S**** M**** ** T****	91.6	0.02	0.01	0.03	-8.4	-8.4	-19.9	85.21	89.61	93.57	5.3	2.7	0.0
(8) A.O. P******* - C****** ** C********	90.8	0.02	0.02	0.04	-9.2	-9.2	-22.9	91.95	87.3	98.18	2.2	11.7	0.0
(9) A.O. ** D**** * V********	88.6	0.02	0.01	0.03	-11.4	-11.4	-17.8	92.94	93.53	93.01	2.1	0.0	6.8
(10) A.O. G******** ** C******	87.6	0.02	0.02	0.03	-12.4	-37.5	-12.4	94.01	89.19	91.4	0.0	6.9	7.1
(11) A.O. S** G******* M****** ** A*******	82.7	0.02	0.02	0.03	-17.3	-17.3	-20.4	93.52	92.38	96.83	0.0	3.9	0.8
(12) A.O. G******* B***** ** C*******	81.7	0.02	0.02	0.03	-18.3	-18.3	-21.0	92.34	91.15	94.69	0.0	4.8	1.9
(13) A.O. S** S******** ** P*****	81.6	0.02	0.01	0.03	-18.4	-18.4	-27.0	90.47	87.05	91.72	0.0	5.5	2.7
(14) A.O. S****** C***** ** B******	80.2	0.02	0.01	0.04	-19.8	-19.8	-26.5	95.49	89.33	97.19	0.0	8.0	2.2
(15) A.O. ** B**** A*******	80.1	0.02	0.01	0.04	-19.9	-19.9	-31.6	89.47	90.98	95.34	2.5	0.0	0.5
(16) A.O. ** L******	80.0	0.03	0.01	0.04	-21.5	-20.0	-28.9	90.27	96.09	92.56	8.1	0.0	10.4
(17) A.O. A****** C********* ** N*****	79.2	0.02	0.02	0.04	-20.8	-20.8	-35.8	82.47	86.73	84.29	1.8	0.0	4.0
(18) A.O. S** G****** ** M****	78.9	0.02	0.02	0.05	-21.1	-21.1	-44.7	92.75	89.95	97.2	0.3	7.0	0.0
(19) A.O. S***'A****** A**** ** G********	78.5	0.03	0.01	0.03	-29.6	-21.5	-23.1	88.28	88.87	94.22	2.3	0.0	0.3
(20) A.O. G****** R**** ** B********	78.4	0.02	0.02	0.04	-21.6	-21.6	-35.9	94.08	93.17	95.92	0.0	4.8	2.5
(21) A.O. F*************** * O******** ** M*****	77.8	0.02	0.02	0.04	-22.2	-22.2	-29.1	92.19	89.16	92.64	0.0	5.9	3.8
(22) A.O. ** C******	77.6	0.03	0.01	0.04	-33.1	-22.4	-27.4	89.93	91.98	94.91	3.9	0.0	3.1
(23) A.O. ** R***** E*****	76.8	0.02	0.01	0.03	-23.7	-23.2	-23.2	90.08	84.84	94.73	0.7	6.4	0.0
(24) A.O. S**** M**** ***** A***** ** P********	75.8	0.02	0.01	0.04	-24.2	-24.2	-33.8	91.48	91.07	89.23	0.0	1.2	6.7
(25) A.O. ** C******	75.6	0.03	0.02	0.03	-24.9	-42.0	-24.4	93.4	91.95	92.61	0.0	2.5	4.9
(26) A.O. ** M********	75.0	0.03	0.01	0.04	-25.0	-25.0	-39.1	87.72	92.72	95.45	5.7	0.0	1.3
(27) A.O. S**** C**** * C**** ** C****	74.9	0.03	0.02	0.04	-25.1	-25.1	-40.8	95.34	91.83	94.64	0.0	4.8	4.8
(28) A.O ***** P******** ** L****	74.9	0.03	0.01	0.04	-25.1	-25.1	-37.4	94.84	90.51	93.92	0.0	3.5	5.7
(29) A.O. ** V*****	74.7	0.02	0.02	0.04	-25.3	-25.3	-34.3	91.91	87.75	89.06	0.0	6.2	7.4
(30) A.O. S** P**** ** M*****	74.7	0.03	0.02	0.04	-25.3	-25.3	-28.2	93.23	91.51	91.14	0.0	4.8	6.7
(31) A.O. O***** M********* ** T*****	74.3	0.02	0.02	0.04	-25.7	-25.7	-31.9	93.69	96.24	94.26	0.0	1.7	4.0
(32) A.O. S****** R****** ** S****	73.8	0.02	0.02	0.04	-26.2	-31.9	-26.2	90.02	88.27	94.16	0.2	5.3	0.0
(33) A.O. O******* M******* ** C****	73.6	0.03	0.01	0.04	-26.4	-26.4	-29.2	90.81	89.49	92.13	0.0	1.1	2.9
(34) A.O. C***** - D* C******* - B********** ** P******	73.5	0.03	0.03	0.05	-26.5	-31.1	-44.3	95.73	89.23	92.41	0.0	13.6	8.7
(35) A.O. C**** P*** ** M******	73.1	0.03	0.01	0.05	-26.9	-26.9	-50.9	91.66	89.83	95.74	0.3	2.6	0.0
(36) A.O. B****** M******** M****** ** R***** C*******	72.5	0.02	0.02	0.04	-27.5	-27.5	-35.6	89.81	87.93	93.16	0.0	5.4	0.7
(37) A.O.R. S** C**** ** P******	72.1	0.03	0.01	0.04	-27.9	-27.9	-28.4	92.09	79.93	97.24	0.8	14.4	0.0
(38) A.O. L**** S**** ** M*****	72.1	0.03	0.02	0.04	-27.9	-30.2	-27.9	95.68	91.59	93.29	0.0	7.6	7.1
(39) A.O. S***'A*** ** C***	71.3	0.03	0.02	0.05	-28.7	-28.7	-47.4	93.68	93.4	94.9	0.0	2.1	2.8
(40) A.O. S**** A****** * B***** * C***** A***** ** A********	69.8	0.03	0.02	0.04	-30.2	-30.2	-32.1	95.93	92.21	95.17	0.0	5.8	5.0
(41) A.O. *** C**** ** N*****	68.9	0.03	0.02	0.05	-31.1	-31.1	-47.7	96.14	92.35	97.86	0.0	5.5	2.2
(42) A.O. O******* R****** ** B******	67.4	0.03	0.02	0.05	-32.6	-32.6	-51.4	92.31	87.88	93.1	0.0	5.6	3.2
(43) A.O. ***** P******** ** L***	66.1	0.03	0.02	0.05	-33.9	-33.9	-43.4	91.12	92.46	90.97	3.0	0.0	8.0
(44) A.O. S** F****** N*** ** R***	65.9	0.03	0.02	0.05	-34.1	-34.1	-42.3	91.16	92.14	94.32	0.0	3.0	1.1
(45) A.O. S** C**** B******* ** M*****	65.1	0.03	0.02	0.05	-34.9	-34.9	-46.7	93.66	85.21	95.74	0.0	10.8	1.8
(46) A.O. S** G******* - A********* ** R***	64.4	0.03	0.02	0.05	-35.6	-35.6	-45.5	93.17	90.26	88.7	0.0	7.6	9.9
(47) A.O. S** C****** - F******** ** R***	63.6	0.03	0.03	0.07	-36.4	-42.5	-59.4	87.6	86.39	90.16	0.0	7.4	1.9
(48) A.O. S***'A*** * S** S********* ** C******	62.9	0.03	0.03	0.06	-37.1	-37.1	-47.1	87.24	87.55	97.09	6.1	11.9	0.0
(49) A.O. G**** S****** ** G********* M*******	59.2	0.03	0.02	0.05	-40.8	-40.8	-51.3	87.64	86.5	93.74	2.6	6.3	0.0
(50) A.O. O******* N******* C*' G***** ** M*****	58.6	0.03	0.02	0.05	-41.4	-41.4	-42.9	94.12	89.44	95.17	0.0	6.9	3.0

Table 2

Tobit regression results. In multivariate analysis where included only contextual factor that resulted significantly affecting the effect estimated at univariate analysis with a p-value lower than 0.20

Contextual factors	Univariate analysis p-value	Multivariate analysis p-value	Multivariate analysis regression coefficient and 95% CI
E_1	0.378		
E_2	0.975		
E_3	0.002	0.008	-0.265 (-0.458 – -0.072)
E_4	0.647		
E_5			
center vs north	0.718	0.199	
south vs north	0.013	0.005	-0.568 (-0.951 – -0.184)
E_6	< 0.001	< 0.001	0.153 (0.075 – 0.231)
E_7	0.013	0.005	0.361 (0.117 – 0.605)
E_8	0.015	0.008	-0.253 (-0.434 – -0.071)
E_9	0.229		
E_{10}	0.384		
E_{11}	0.059	0.846	
E_{12}	0.007	0.424	
E_{13}	0.069	0.291	

health as percentage of GDP have a significant positive relationship with efficiency. A higher case-mix index (E3), being in the south of the country (E5) and a higher private expenditure on health as percentage of GDP (E8), have a significant negative relationship with efficiency.

DISCUSSION

DEA can be a powerful tool to measure performance, when used wisely. A well demonstration is the greater and greater number of its applications in various fields. The main advantages of DEA are its objectivity with the possibility to provide efficiency ratings based on numerical data. DEA can readily incorporate multiple input and multiple output, which can be measured in very different units (not only money units) to calculate TE. It does not require relating inputs to outputs. In addition DEA only requires information on output and input quantities (not prices), thus it is particularly suitable for analyzing the efficiency of government service providers, especially those providing human services where it is difficult or impossible to assign prices to many of the outputs.

We included in the DEA model three intermediate output proxies closely related to the final outcome such as: 30-day risk-adjusted mortality for acute myocardial infarction 30-days mortality rate; 30-day risk-adjusted mortality for congestive heart failure 30-days mortality rate; 30-day risk-adjusted mortality for pneumonia 30-days mortality rate.

These outputs are in fact closely related to hospitals' efficiency and to quality of care. Higher condition-specific performance on these output is associated with lower risk-adjusted mortality for each of the three conditions [27].

Improving outcomes is the ultimate target of quality improvement, therefore the inclusion of outcomes measures assists in attaining improvement goals.

Acute myocardial infarction, congestive heart failure and pneumonia are three common hospital discharge diagnoses associated with high mortality and morbidity. Moreover, they represent an important economic burden on the health care system, therefore are the focus of several national efforts to improve quality of care.

30-day risk-adjusted mortality for these conditions 30-days mortality rate can be different between hospitals because hospitals that perform well have lower risk-adjusted mortality rates [27, 28].

To compare TE between different hospitals we used as inputs: number of beds per patient admitted, number of medical doctors per patient admitted and number of nurses per patient admitted. These measures are quality indicators directly related to health improvements. The selection of these inputs allowed to get a short term perspective and a prompt evaluation of the current resources management.

On the other hand, since DEA is a non stochastic approach, stochastic events such as measurement errors in the data may affect the result. For example, if one hospital's inputs are understated or its outputs overstated, it can become an outlier and significantly reduce the efficiency of other hospitals.

The selection of certain inputs and outputs, even if representative of hospital's global performance [27], results in the exclusion of others and may also bias results and underestimate or overestimate efficiency.

Moreover, hospital efficiency is likely affected by a various number of exogenous variables out of the control of hospital manager and a widely collection of those (E1-E13) has been included in the regression analysis.

However, other exogenous variables not considered may have affected the results of the study.

In this study in order to compare efficiency between different hospitals, we investigated the percentage reduction of input current values for each health facility to achieve maximum efficiency score and the percentage increase of output current values to become efficient even if each health facility reaches its input target value. Indeed, to improve its efficiency, a hospital should improve outcomes with the same or lower inputs used by another hospital. Attempting to measure performance provides a heightened awareness of inappropriateness and shortcomings for managers and policy makers. These results could provide them with useful clues to allocate their current inputs to the best of their capability: without further increases of number of beds per patient admitted, number of medical doctors per patient admitted or number of nurses per patient admitted, they could achieve a more efficient hospital. Therefore, DEA estimates the amount of additional service an inefficient hospital can provide without the need to use additional resources.

Moreover, through Tobit regression multiple supply factors were considered to compare hospital efficiency. These factors, as for example the presence of regional fiscal autonomy and a public or private expenditure on health, should be considered in such a context of unavoidable reorganization of health care system.

In Italy DEA methodology have been already adopted to analyse the efficiency of primary care, health reforms and of hospital care at a regional or local level [10, 29-31]. Our study is one of the first to provide, through DEA technique, a methodological framework useful for investigating TE of hospital care across the country. The methods we proposed for benchmarking efficiency in the secondary care context could be also used in other countries and at European Union level. In fact, this model can produce information about hospital performance using data available also for other countries and it is a potentially important tool to monitor quality of health care systems and compare efficiency of European Union hospitals – this has particular value in relation to new Directive 2011/24/EU on the application of patients' rights in cross-border healthcare.

CONCLUSIONS

This study, analyzing data from Italian PHTs through DEA technique, provides a methodological framework for investigating TE of hospital care that may be also applied in other contexts and countries.

Such technique could be of considerable value for hospitals managers and policy makers that need an explicit and reproducible method to support their decision for resources allocation.

Author's contribution statement

CP, IA e PF designed and performed the analysis with the support of AE, DMC and LMD. CP and AE wrote the paper under supervision of SML and RW. All authors reviewed and approved the final version.

Conflict of interest

There is no conflict of interest that could compromise the impartiality of the research reported. This research did not receive any specific grants or fellowships from any funding agency in the public, commercial or non-profit sectors.

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