ORIGINAL ARTICLE

Severity of illness in the case-mix specification and performance: A study for Italian public hospitals

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Abstract

Background: Public hospitals' expenditures in Italy is approximately 45% of total public health financing. The reduction of public debt requires reducing total public health, as well as hospital expenditures in the public sector. Past health reforms introduced rules to improve the efficiency in controlling hospital costs with a better use of resources. The objective of this study is to derive technical efficiency as a performance measurement in the directly managed public hospitals in Italy under different case-mix specifications, as well as to discover the effect of it on technical efficiency.

Methods: Two different Data Envelopment Analysis (DEA) models are solved. To control for the influence of the case-mix complexity/severity of illness on technical efficiency, the distributions of DEA efficiency scores are compared applying statistical tests developed in the non-parametric efficiency analysis.

Results: On average, in the year 2007, the technical efficiency in the sample is lower (0.8071) in model B (output mix with weighted Case Mix Index) than in model A (0.8748). The bootstrap-corrected efficiency scores of models B and A are respectively 0.7185 and 0.8106. On average, the case mix index in the sample is 0.87859. Statistical tests confirm that the differences in the efficiency scores distribution are statistically significant, confirming that treatment complexity has influenced technical efficiency. At the individual hospital level, the effect is more evident, modifying the rank and the technical efficiency of the hospitals.

Conclusions: The different case-mix specifications adjusted with Case Mix Index, generate statistically significant differences in the distribution of the efficiency scores. This evidence permits us to conclude that the performance of the Local Health Trust's directly managed public Italian hospitals is influenced by the hospitals' case-mix severity/complexity. As a policy indication, we can observe that the need for policy makers and hospital managers to reduce hospital costs conflicts with the need to guarantee an optimum level of hospital resources with different case-mix complexities of the treated cases.

Key words

Hospital performance, Data envelopment analysis, Output specification, Public hospitals, Case-mix-index

1 Introduction

According to the "Rapporto annuale sull'attività di ricovero ospedaliero-Dati SDO 2007" [1], 687 out of the total of 1,303 hospitals in Italy are public hospitals, and approximately 64% of the 11.448 million total discharges in ordinary cases (acute) occur in hospital trusts and Local Health Trust's directly managed hospitals. The average weight of the treated cases increased from 1.09 in 2006 to 1.11 in 2007. Approximately 60% of the discharges are medical or unclassifiable Diagnosis Related Groups (DRG). On the spending side, public hospital expenditure is a major share of total public health spending (approximately 45%). The wave of healthcare reforms in Italy treated aspects of the health system, such as the system's financing, the financing of hospitals, the micro and macro efficiency of using resources, the quality of care and equity in financing. The motivation of the reforms was principally to reduce public health spending also by reducing public hospital expenditures. In Italy, a DRG system was introduced in 1995 [2, 3], moving from a global budgeting approach to DRG-based per-case hospital financing with the objective of controlling the growth of hospital costs. The DRG system is also a grouping system to define the case mix for hospitals [4-7], grouping homogeneous cases in the same categories according to diagnosis and consumption of resources. The case-mix measure may have an impact on the estimated efficiency score [8]; having several important applications, these scores can be used in managerial decision-making by administrators and health planners, are extremely useful in research on hospital performance and are essential to the successful implementation of reforms in hospital reimbursement that attempt to relate hospital payments to outputs produced, rather than to costs of inputs consumed [5]. However, the DRG's system di per se did not represent a measure of case-mix complexity. DRG weights must be assigned to each group and a weighted average taken to arrive at a single measure of case-mix complexity for a hospital. In the previous literature, differences in the case mix were captured by disaggregating outputs in different way by age of the patient or type of treatment in terms of impatient days [9]. In this study, following [9], the effect of differences in the case mix of patient specifications on hospital performance is pursuit using a Case Mix Index (CMI). CMI is a general measure of case-mix severity/complexity of treatment [6, 10-16], offering a method for constructing it. On the other hand many authors outline the importance of severity of illness on economic performance for hospitals [17-21]. For example, two hospitals can admit a similar number of surgical patients; however, one of the hospitals may treat more open-heart surgeries, whereas the other may perform more appendectomies, which is a much simpler operation that requires fewer inputs and less costs than open-heart surgeries. The assumption, here, is that the costs and inputs used for patient care are related to the severity/ complexity of the treated cases. The research questions posed in this study are 1) there are differences in the economic performance of the Local Health Trust's directly managed public hospitals in Italy when a CMI is used in the case-mix specification? and 2) it is possible to offer useful information for hospital managers and policy makers? To answer these questions, we solve two Data Envelopment Analysis (DEA) models using two different case-mix specifications as output, with and without CMI. Subsequently, to explore the influence of the CMI on the performance of the directly managed public hospitals, various statistical tests are conducted to compare the efficiency score distributions. The use of the CMI is not free of problems but assumes, for example, the existence of homogeneity of cost structures among hospitals [9]. However, the availability of public data on inputs and outputs of public hospitals permits us to use a CMI later having defined the output mix in terms of discharges (ordinary, day hospital and surgical), surgical interventions and days in hospitals. Several authors [22] assume that the average length of stay does not only depend on the case-mix complexity. In this study, we overcome this position assuming that the length of hospital stay can be increased and decreased in relation to the complexity/severity of illnesses of the case mix. The paper is structured as follows: in the next section, an overview of the material studied and the data used in the analysis is offered; in section 3, the method is described; in section 4, a DEA model and statistical tests used to compare DEA score efficiency distributions under different case-mix specifications are introduced; in section 5, the results are shown; finally, in sections 6 and 7, the conclusion and discussion are presented.

2 Material studied and data

The material viewed (as full paper and abstract on free PubMed database and Google Scholar search) covers non-parametric efficiency measurements in the hospital sector [23] and other useful arguments (for measurement of hospital case mix among other [24-29]; differences in the case mix complexity among other [30, 31]; the classification of hospitals on measured output [32, 33]; comparison between different to measure the severity of illness among other [16, 34]). It includes different studies on the hospital output specification [35], on the specification of inputs and outputs [36] and on the relation between hospital performance and case-mix measure [8, 37-39]. Researchers often encounter different problems, one of which is to resolve the problem of considering the complexity and severity of illness of the treated hospital cases [40]. Among others [5], using the Commission on Professional and Hospital Activities' Resource Need Index as a measure of case-mix complexity, examines the relative contributions of teaching commitment and other hospital characteristics, hospital service and insurer distributions, and area characteristics to variations in the case-mix complexity. The empirical estimates indicate that all three types of independent variables have a substantial influence [9], examine the effect of differences in the case mix of patients on measuring hospital performance. The authors compare the effect of differences in the case mix of patients on measuring hospital performance. The technique used in this study to assess hospital productivity is closely related to the Farrell measure of technical efficiency [9], indicate that their results can be due to a relatively homogeneous sample; more variation can occur with a more heterogeneous sample [41], employ the number of case-mix-adjusted discharges and of inpatient days to investigate the evolution of efficiency and productivity in the hospital sector of an Austrian province for the time period 1994-1996; in a second study, we use credit points, which are calculated in the course of the newly introduced diagnosis-related group-type financing system. These researchers calculate and compare individual efficiency scores for hospital wards as decision-making units (DMU) in specified medical fields. The authors utilize case-mix-adjusted discharges rather than primary discharges [8], found that the use of different case-mix measures, such as Adjusted Clinical Groups (ACGs) or Diagnostic Cost Groups (DCGs), had an effect on efficiency results [4], found that different definitions and case-mix measures for hospital output affect the results [22], to estimate the efficiency impact of the Greek National Health System reforms, apply a DEA model, specifying the output of hospitals in terms of the complexity and severity of illness of the case mix multiplying the hospitalized cases in each hospital with the case mix index and dividing by the respective mean in the sample. Other recent study for general practitioners [42].

To our knowledge, no empirical studies on Italian hospital efficiency and, in particular, on directly managed hospitals have explored the effect of different case-mix specification on hospital's technical efficiency. First, we should note that most Italian works adopt DEA [43, 44]. However, some applied studies consider the effect on technical efficiency of different hospital ownerships after the introduction of the DRG-based payment system in the Italian NHS during the second half of the 1990s [45]. Louis [46] examined potential changes in the quality of care associated with the DRG system implementation in Italy. Berta [47] analyzed the effects of some distortions (upcoding, cream skimming and readmissions) induced by the prospective payment system (DRG) on hospitals' technical efficiency. Their results show that cream skimming and upcoding have a negative impact on hospitals' technical efficiency. In his work [48], measures technical efficiency and analyzes the source of heterogeneity in public hospitals in Italy. He finds high heterogeneity inside and across regions. The source of heterogeneity is caused by inappropriate treatments, case complexities, day hospital admissions and the ratio between staff and beds. In his work, Schiavone [48] considers the complexity of treatments measured with the CMI as a determinant of efficiency in a two-stage analysis, while here, complexity is considered as a variable directly inserted in the DEA model as a multiplicative factor in the output specification. In the specification of his DEA model [48], considers the average-weight DRG rather than the CMI, as we do here. Here, CMI > 1 indicates that the hospital treats more cases than in the case of CMI = 1 and thus requires a higher level of inputs. Therefore, the optimal levels of resources are modified according to the influence of complexity of treatment on technical efficiency.

Summing up, the innovation of the present work stems from its joint adoption of a case mix index (to measure the complexity of the treated hospital cases or the case mix) in the directly managed public hospital in Italy and the use of managerial tools such as data envelopment analysis to discover and analyze the influence of different case-mix specifications on Italian public hospital performances. In particular, this study discovers the effect of case-mix complexity on hospital performance, assuming also that the complexity of the treated cases influences the days in hospitals and the number of surgical interventions.

Data

The data refer to inputs and outputs of Italian hospitals published by the Ministry of Health. The analyzed period is 2007. The data refer to doctors, nurses, medical-technical staff, rehabilitative staff, administrative staff, technical-professional staff, other non-medical staff, ordinary hospital beds, and day-hospital beds as inputs; and discharged, discharged one-day hospital, surgery discharge, surgical interventions, in-patient days, and pre-operative in-patient days as outputs; furthermore, data on the CMI are available.

Table 1. Descriptive statistics on the sample (Year 2007, N = 426)

Variables	Descriptive statistics	
	Mean	**Std.dev.**
Doctors	113.5986	112.0253
Nurses	278.6174	285.2114
Medical-technical staff	37.5493	44.04013
Rehabilitative staff	11.82864	19.82562
Administrative staff	.8028169	1.589256
Technical-professional staff	85.99296	109.1564
Other non-medical staff	35.85681	48.63062
Ordinary hospital beds	200.8169	196.6313
Day-hospital beds	18.29343	20.057
Discharged	7,621.202	7,265.272
Discharged one day hospital	887.6549	950.2204
Surgery discharge	2,854.615	3,248.302
Surgical interventions	7,902.765	9,404.051
In-patient days	56,223.44	58,999.96
Pre-operative in-patient days	10,525.2	13,394.63
Case Mix Index (of hospital)	.8785915	.1697081

On the sample, in the year 2007, on average hospitals treated case with a CMI < 1 (0.8785915) with volume of activities of 7,621.202 discharges, 887.6549 discharges one day hospital, 2,854.615 surgery discharges, 7,902.765 surgical interventions, 56,223.44 in-patient days, 10,525.2 pre-operative in-patient days. The resources used are, on average, 113.5986 doctors, 278.6174 nurses, 37.5493 medical-technical staff, 11.82864 rehabilitative staff, 0.8028169 administrative staff, 85.99296 technical-professional staff and 35.85681 other non-medical staff, as labour, while, 200.8169 ordinary hospital beds and 18.29343 day-hospital beds as capital inputs.

3 Method

3.1 Data envelopment analysis

DEA [49] is currently the main non-parametric method used to measure relative efficiency in most sectors, particularly in health organizations with multiple outputs, such as hospitals. In this study, hospitals are considered as DMU that have control on inputs and outputs. Each hospital has an input vector, $x \in R^p$, and an output vector, $y \in R^q$. Thus, the hospital activity plan is $(x, y) \in R^{p+q}$. The production possibility set is as follows:

$$P = \{(x, y) \mid x \text{ can produce y}\} \tag{1}$$

and the input-based Farrel efficiency [50] of the activity plan (x, y) is defined as follows:

$$\delta = \min\{\delta > 0 \mid (\delta \text{ x, y}) \text{ belongs to P}\} \tag{2}$$

δ is the maximal proportional contraction (or radial measure) of all inputs x that allows hospitals to produce y. $\delta = 0.8$ indicates that hospitals could have saved (or have potential gains) 20% off all inputs and still produce the same output, reducing their costs. The reasoning of an output-oriented measurement is similar but involves a maximal proportional expansion of all outputs using the same level of resources. In Figure 1, the maximal proportional contraction (or radial measure of efficiency) of all inputs is OC/OF.

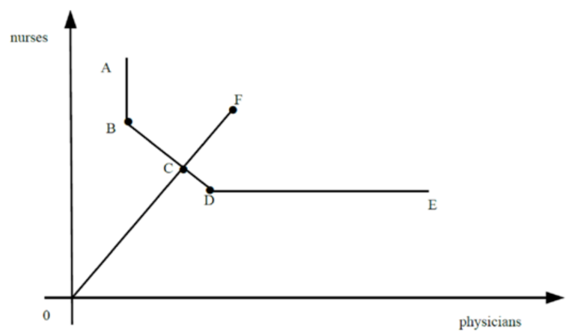

Figure 1. Best practice frontier and input radial measure of efficiency

Thus, hospital F could reduce its input combination (in Figure 1, physicians and nurses) by OC/OF, which is the ratio of the best practice input level (OC) to the actual input level (OF), referred to as technical efficiency. It is clear that technically efficiency is a component of cost minimization. In fact, if a hospital is technically inefficient because it uses more input to produce a given level of output than a similar hospital (on the efficient frontier), it cannot minimize costs.

3.2 DEA model and statistical tests

3.2.1 DEA input model

The DEA model estimates, Model A and Model B, are used in this study. Model A considers the following inputs: beds in ordinary in-patient regimen and a day-hospital regimen; medical staff; nursing staff; health-technical staff; and technical, administrative, and remaining staff. The following are considered as outputs: discharges, discharges within a day, surgical discharges, surgical interventions, days spent in the hospital, and pre-operative days in the hospital. Model B uses the same inputs but different specification outputs. Model B weighs its output mix using a case-mix index. The reason is that common proxies for intermediate hospital outputs such as patient days or the number of discharges reflect the complexity of the technology used to treat a specific illness. Thus, the same output between two hospitals differ in terms of severity of illness and resources consumed. Therefore, here, the number of case-mix-adjusted discharges, y_{icm}, is given by multiplication of the case mix index and the "original" number of discharges for each hospital:

$$y_{icm} = CMI * y \tag{3}$$

where CMI is the case mix index of the structure as reported in the data set published by the Ministry of Health, and y is the output vector as defined before. Finally, for each model, there are nine inputs and six outputs. For both the A and B model, a DEA-VRS (Variable Returns-of-Scale) input model is solved (envelopment form):

For Model A, the following program 1 is solved using the equation:

$$\begin{aligned} &\min \theta \\ &\text{s.t. } \theta x_o \geq X\lambda; \qquad \text{program 1} \\ &y_o \leq Y\lambda; \\ &e\lambda = 1;\ \lambda \geq 0 . \end{aligned}$$

For Model B, the following program 2 is used:

$$\begin{aligned} &\min \theta \\ &\text{s.t. } \theta x_o \geq X\lambda; \qquad \text{program 2} \\ &y_{oicm} \leq Y_{icm}\lambda; \\ &e\lambda = 1;\ \lambda \geq 0 \end{aligned}$$

where X is the input matrix that is the same for Model A and Model B, and Y reflects the situation in which Model A considers use as output (rather than weighing discharges, in Y_{icm}). Table 2 indicates both the inputs and outputs for each model.

Table 2. Inputs and outputs of the DEA model

	MODEL A	MODEL B
INPUTS		
Ordinary beds	x	x
Day-hospital beds	x	x
Medical staff	x	x
Nursing staff	x	x
Health-technical staff	x	x
Technical-professional staff	x	x
Administrative staff	x	x
Other staff	x	x
OUTPUTS		
Ordinary discharges	x	
One-day discharges	x	
Surgical discharges	x	
Surgical interventions	x	
Days in hospital	x	
Pre-operative days in hospital	x	
CMI-weighed ordinary discharges		x
CMI-weighed one-day discharges		x
CMI-weighed surgical discharges		x
CMI-weighed days in hospital		x
CMI-weighed surgical interventions		x
CMI-weighed pre-operative days in hospital		x

The selection of inputs and outputs for the DEA model [23, 36] derived by public data availability. In particular, here, for directly managed public Italian hospitals, to address the problem that cases can differ in terms of complexity and severity of illness, ordinary, one-day, and surgical discharges, days in hospital, surgical interventions and pre-operative days in hospital are adjusted for the CMI [22, 40]. This output-mix specification also assumes that days in hospital depend on the complexity and severity of illness.

3.2.2 Statistical tests

In the non-parametric literature, different statistical tests are conducted to compare score efficiency distributions across two groups. Here, following [51, 52] we apply the Mann-Whitney test and the Kolmogorov-Smirnov test to test inefficiency differences between Model A and Model B, respectively, with output mix not weighted with the case mix index and output mix weighted with the case mix index. The test is used to confirm whether the complexity of treatment influences, on average, technical efficiency. Following the Mann-Whitney test, the test statistic is given by the following:

$$T_{MW} = \frac{U_1 - (N_1 N_2 / 2)}{\sqrt{N_1 N_2 (N_1 + N_2 - 1/12}} \quad (4)$$

$$U_1 = N_1 N_2 + \frac{N_1(N_1+1)}{2} - W_1 \quad (5)$$

where W_1 is the sum rank for the first group of directly managed hospitals. The distribution of the Mann-Whitney test statistic is approximated well by the standard normal distribution for sufficiently large values of N_1 and N_2 (*e.g.*, N_1, N_2 >10). In the case of the Kolmogorov-Smirnov test, the test statistic is given by the maximum vertical distance between $F^{G1}\left(\ln\left(\hat{\theta}_j\right)\right)$ and $F^{G2}\left(\ln\left(\hat{\theta}_j\right)\right)$, the empirical distribution of the group G_1 and G_2. This statistic, by construction, takes values between 0 and 1, and a high value for this statistic is indicative of significant differences in inefficiency between the two groups.

4 Results

On average, in the year 2007, technical efficiency of the sample (in all 426 public hospitals directly managed by local health trusts) is lower (0.8071) in the model with CMI-weighted outputs (Model B) than in the other model (0.8748) (see Table 3). The bootstrap-corrected efficiency confirms this result, and the scores are 0.7185 in the model with weighted output (Model B) and 0.8106 in the other model (Model A) (see Table 4). On average on the sample, the case mix index in the year 2007 is 0.8785 (see Table 3), and the majority of the directly managed hospitals treated cases that are less complex than the standard case mix index (CMI = 1) (see Figure 3).

Table 3. Descriptive statistics of efficiency scores and the CMI (Year 2007, N = 426)

Model	Min (Max)	Mean	SD
Model A			
Efficiency score	0.3529	0.8748	0.1371
Model B			
Efficiency score	0.322	0.8071	0.1674
CMI	0.53 (2.95)	0.8785	0.1697

Table 4. Mean values of the bootstrapped confidence interval and the corrected efficiency score (Year 2007, N = 426)

Model	Efficiency score	Corrected efficiency score	Interval of confidence at 5%	
			low	high
Model A	0.8748	0.8106	0.7301	0.8715
Model B	0.8071	0.7185	0.6380	0.8015

Thus, for the year 2007, comparing both models, the efficiency results on average suggest significant differences in hospital efficiency. The statistical tests in Table 5 reveal, however, that the differences between the score efficiency distributions are statistically significant.

Table 5. Statistical tests

	p-value	Value of test statistic
Kolmogorov-Sminorv	8.046e-10	0.2254
Mann-Whitney	5.377e-09	111370.5

The value of the Kolmogorov-Smirnov test statistic (0.2254), with H0: distance is not statistically significant, indicates statistically significant differences in efficiency scores distribution between the two groups (p value < .05). This test is based on the evidence of the Shapiro-Wilk, Jarque-Bera normality test and the Barlett variance homogeneity test. These tests, however, does not permit us to accept the normality hypothesis (Shapiro-Wilk, Jarque-Bera normality test), while the Barlett test does not permit us to accept the homogeneity variance hypothesis between Model A and Model B. Mann-Whitney test confirm that differences in the two distributions are statistically significant (p-value < .05). The number of full efficient hospitals that modifying own rank are 33 (150 in the model without weighted outputs vs. 117 in the model with weighted outputs), and the difference in the hospital expenditure reduction is justified by the different technical efficiency performance in Model A and Model B. A complete analysis for each hospitals reveals that the number of hospitals with a level of efficiency ≤ 0.7 that change their rank are 78 (48 in the model without weighted outputs, Model A, vs. 126 in the model with weighted outputs, Model B), while the number of hospitals with a level of efficiency from 0.7 and < 1 that change their rank is 45 (228 in the model without weighted outputs, Model B vs. 183 in the model with weighted outputs).

5 Discussion

In this study, the effect of different case-mix specifications on the technical efficiency of Italian hospitals directly managed by Local Health Trusts has been tested. Following [9], the output-mix specification has "inflated" and "deflated" the value of each output giving a greater (or lesser) value of outputs to hospitals with a more severe (or less severe) case mix. In addition, we have directly measured the effect that the case mix has on production performance by comparing the efficiency scores of hospitals using these adjusted outputs with hospitals using the unadjusted outputs. To this end, we have estimated two DEA models, one of which weighs the output mix with the case mix index, assuming that the index, following part of the literature selected, is a possible measure to consider the complexity/severity of illness of the hospitals' treated cases. The limit of the use of the Data Envelopment Model is the assumption that the relation between input and output is deterministic [53]. However, we have overcome this limitation by applying a bootstrapped approach as the non-parametric efficiency analysis suggests [54]. The evidence provides very useful information for us, policy makers and hospital managers [55] to address the problem of reducing hospital expenditures trough better use of the resources considering the complexity/severity of illness of the case mix treated in hospitals. However, the analysis is severely limited by the production model drawn for the hospital. In this study, the economic production model for the hospital estimated with DEA is derived from the availability of public data on inputs/outputs. The DEA is, also, highly consolidated in international economic literature on efficiency analysis in the health sector [23]. A scatter plot (see Figure 2) between efficiency scores and the case mix index reveals a positive relation between them. This result indicates that, on average in our sample, the higher is the case mix index of the hospital, the more efficient is the hospital.

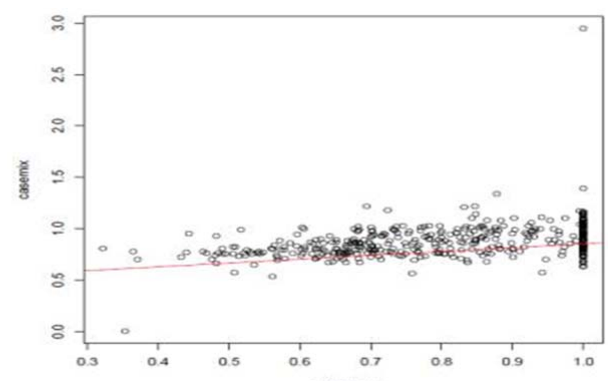

Figure 2. Scatter plot and regression line between the case mix index and the efficiency score for Model B in the year 2007

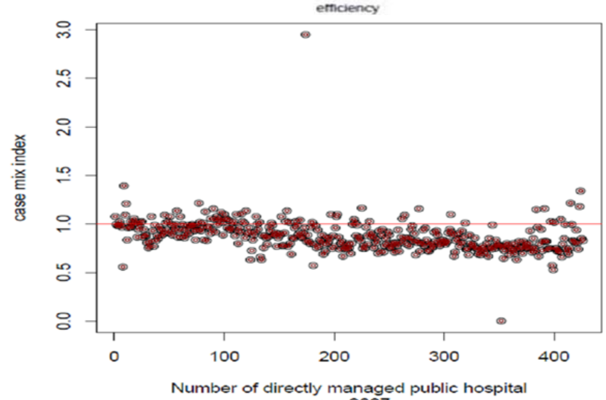

Figure 3. Distribution of the case mix index on the sample of Italian hospitals directly managed by local health trusts in 2007

The distribution of the case mix index (see Figure 3) confirms that the majority of the Italian hospitals directly managed by local health trusts has a case mix index under the standard value of 1.

6 Conclusions

Severity of illness measurement can be separated into two levels: individual and hospitals level. At hospital level severity of illness describe the aggregate difficulty in the treatment of the diseases presenting themselves at each hospital as compared to other hospitals and most of the information utilized for this purpose comes from administrative data. There are different perspectives in the definition of severity. Resources consumption has been applied as a proxy of severity, especially at hospitals level. The most used for hospital resource consumption measure is CMI [6]. In Italy the DRG system is a iso-resources system adopted for public hospitals, while CMI is the indicator adopted for complexity of treated cases. In this work we have used CMI to control for the complexity at hospital level and weigh our hospital output with it [56]. In the year 2007, on average, the Italian hospitals directly managed by local health trusts directly could use approximately 20% (1-0.8071) less resources to produce the same volume of activity, as weighted by their clinical complexity. Conversely, these hospitals could use approximately 13% (1-0.8748) less resources if the complexity of the hospitals' treated cases would not have been considered in the analysis. At the same time on average hospital in the sample treat cases less severe (CMI = 0.8785) that national standard (CMI = 1). The influence of severity of illness on technical efficiency has been of 0.0677 (0.8785-0.8071). This analysis provides an opportunity to better investigate to what extent and in what directions the economic performance of a hospital is influenced by clinical aspects. In this study, only the relationship between technical efficiency and clinical complexity has been investigated; however, it is known that the volume of activity is also related to the quality of resources and the complexity of the treatments. Reducing hospitals costs through efficiency improvement [57] without neglect severity of illness is the final policy indication in this paper. Differents aspects can be considered as limitations of the study: 1) the monotonicity of the measure in a DEA approach, 2) each hospital compare itself also with hospital outside own regions of activity, increasing the differences in the variability of the cost structure, 3) case mix specification is defined by the researcher and availability of data, in this case input-output files have also average case mix index for each hospitals, 4) variation in the number of sample observations influence the score. The case mix methods that account for the severity of patients constitute also a useful indicator of quality [58] for the management of different hospital services and of the hospital as a whole [59].

Acknowledgments

The Ministry of Health provided public data regarding hospital inputs and outputs.

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