MEASURING HOSPITAL EFFICIENCY THROUGH DATA ENVELOPMENT ANALYSIS WHEN POLICY-MAKERS' PREFERENCES MATTER. AN APPLICATION TO A SAMPLE OF ITALIAN NHS HOSPITALS

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1. *Introduction*

In many countries, measuring the efficiency of health care services has become increasingly important since the early 1980s. In Italy, the devolution of the National Health Service (NHS) to regional governments, started in 2001 but not yet fully implemented, and the definition of national basic levels of public health care to be provided by each regional health care system has made it crucial to compare the relative performance of health care services both across different regions and across different Local Health Authorities (LHA) within each region.

In this paper, we focus on measuring the technical efficiency of acute hospitals operating within a NHS, which provide important services within the basic package of public health care. To this purpose, we develop four DEA models to measure the levels of technical efficiency of 85 acute hospitals in Veneto, a region in Northern Italy. The empirical analysis allows us to evaluate the role of demand and weight restrictions and will provide some useful insights into the levels of efficiency of hospitals.

The plan of the paper is the following. Section 2 briefly describes the main characteristics of DEA as a technique for measuring hospital technical efficiency. In section 3 we argue that precise value judgements are necessary in order to apply this method to the efficiency evaluation of hospitals operating within a National Health Service (NHS). These value judgements concern particularly the production technology and managers' or policy-makers' preferences for hospital output mix, and imply the adoption of constraints on input and/or on output weights. In section 4 we analyse the importance

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of distinguishing between different components of the technical inefficiency of hospitals operating within an NHS: *internal* inefficiency attributable to the responsibility of hospital management and *external* inefficiency that could be due to past health care policy decisions and to exogenous demand. In section 5, the DEA method is applied to measure the levels of technical efficiency of the hospitals in Veneto. Finally, section 6 reports some conclusions.

2. *Some issues on measuring hospital technical efficiency*

The technical efficiency of hospitals can be measured by parametric and non-parametric evaluation methods that permit simultaneous comparison of the inputs and outputs of a hospital's production process and produce concise indicators of efficiency. Both methods allow to consider the heterogeneous character of the output produced by different decision-making units (DMUs) and are particularly well-suited for developing indicators to compare the efficiency of different hospitals. Since each method is based on different hypotheses with differing degrees of stringency, they will lead to different (sometimes contrasting) results regarding the efficiency levels of the hospitals examined. Parametric analyses require a prior definition of a production function of hospital services, whereas the non-parametric analyses determine the relative efficiency scores of similar DMUs by means of linear programming techniques, without detailed descriptions of their production processes [1].

We will focus on a particular non-parametric method, *Data Envelopment Analysis* (DEA), which is encountering growing consensus as a powerful tool to measure hospital productivity. As it uses a particular type of linear programming, DEA makes it possible to determine the relative efficiency levels of similar hospitals without the need for a detailed description of the production process (i.e. without determining beforehand a certain number of parameters in order to explain the structure of the whole production process) [2]. Given the multiple input-output nature of hospital production proc-

[1] For a comparison between parametric and non-parametric methods, see: Banker, Conrad and Strauss (1986), Chirikos and Sear (2000), Jacobs (2001).

[2] Detailed descriptions of DEA can be found in several sources (Charnes, Cooper and Rhodes, 1978; Charnes *et al.*, 1994; Ganley and Cubbin, 1992; Cooper, Seiford and Tone, 2007). An extensive review of DEA applications in the area of health care is given by Hollingsworth, Dawson and Maniadakis (1999). For some recent interesting applications of DEA to hospital efficiency evaluation, see: O'Neill (1998), Puig-Junoy (2000), Steinmann and Zweifel (2003), Ventura, Gonzalez and Carcaba (2004). A complete survey of DEA studies on the efficiency of Italian hospitals is given by Canta, Piacenza and Turati (2006).

ess, the use of DEA is appropriate because it allows the heterogeneity of delivered outputs to be taken into account. Moreover, DEA is particularly useful when input prices are not available and therefore it is impossible to estimate a hospital cost function. This is the case of most Italian NHS hospitals, whose costs are generally embedded in the Local Health Authorities' costs and for which it would be unpracticable to assign a price to each used input. Finally, DEA does not require a single objective function to be defined for all DMUs. On the contrary, DEA defines efficiency as the ratio between a weighted sum of outputs and a weighted sum of inputs and it allows each DMU to choose the preferred weights to attach to inputs and outputs in order to maximise its efficiency ratio with respect to the other DMUs.

As Allen *et al.* (1997) pointed out, the flexibility of DEA may be brought into question when it is considered that the correct evaluation of the relative efficiency of hospitals may require the consideration of value judgements which can restrict the acceptable ranges of variation of the input and output weights. In fact, since the outputs provided by hospital services are usually included in the basic levels of public health care, the evaluation of the relative efficiency of hospitals should take into account the policy-maker's preferences. This implies imposing particular constraints on input and output weights.

Another issue that has often been neglected is the influence of variables outside the direct control of hospital management on hospital performance. In particular, we will show that the level of technical inefficiency observable using DEA can be broken down into *internal* inefficiency (attributable to hospital managers) and *external* inefficiency due both to an excess of supply with respect to demand and to scale inefficiencies. If these external inefficiency factors arise from past choices of health care planners, they should be considered exogenous with respect to the decisions of the hospital management.

In the following sections, we show how both the choice of specific constraints on input and output weights (in accordance with health care policy-makers' preferences) and the consideration of exogenous variables outside the control of hospital management (exogenous demand, past policy-makers' decisions) can affect the measurement of hospital technical efficiency with DEA.

3. *The need for value judgements and DEA weight restrictions*

The great flexibility in selecting optimal weights is a particular feature of DEA and is often wrongly confused with absolute lack of *a priori* hypotheses on the form of the production function of DMUs but we should not ignore the fact that the acceptable range of weights can vary according to the perspective of analysis that is adopted. At one extreme, a *hospital management perspective* can be adopted, that is, maximum freedom when choosing weights[3]. At the other extreme, a *complete centralised perspective* can be adopted in which input and output weights are determined univocally. In this case, however, the DEA loses its significance as it is reduced to the traditional type of analysis where each hospital's efficiency is measured as the ratio between weighted aggregations of selected outputs and inputs. At an intermediate level the relevant authority (e.g. a national or regional health care authority within an NHS) can set maximum and minimum boundaries for some or for all the weights, defining the acceptable range of variations of the weights that each DMU can choose. In this case, a *constrained DEA model* is applied according to the targets of the policy-maker[4].

Since many hospital services are considered of great social value, it is inevitable that to some extent the evaluations of relative efficiency of hospitals will be conditioned by value judgements.

Following Allen *et al.* (1997), value judgements concerning the relative importance of inputs and outputs can be incorporated in the DEA model, via weight restrictions, according to three broad approaches having different implications on the assessed relative efficiency of hospitals:

1) imposing direct restrictions on the weights of some or all inputs and outputs. This approach can be applied in two ways:

i) *absolute weight restrictions*, by imposing lower and upper bounds to weights;

ii) *assurance region methods*, which impose constraints on the marginal rates of substitution between inputs or outputs (defined by the ratio between input or output weights);

2) adjusting the observed input-output levels (cone-ratio approaches);

3) restricting the virtual weights of inputs and/or outputs[5]. For example, defining u_k the weight attached to the k-th output, the virtual weight for output y_k of hospital j – which defines the proportion of the total virtual output of DMU j devoted to output k, and is expressed as $(u_{kj} y_{kj})/(\sum_{k=1}^{K} u_{kj} y_{kj})$ – could be restricted within a given range[6].

[3] However, a value judgement is implicitly formulated as the implicit weights chosen by each hospital are considered acceptable. The issue of using acceptable weights for input or output is analysed by Jacobs, Smith and Street (2006), chapters 5 and 8.

[4] Allen *et al.* (1997) calls the single hospital perspective a «bottom up» approach and the policy-maker perspective a «top down» approach.

[5] Constraints on virtual weights are less binding than constraints on absolute weights. In fact, the latter determine a unique assurance region for all DMUs, while the former allow DMUs to choose the absolute weights that guarantee their best assurance region.

[6] See Pedraja-Chaparro, Salinas-Jimenez and Smith (1997), Charnes et al. (1994) and Cooper, Seiford and Tone (2007) for further reading on the role and implications of weight restrictions in DEA.

The bounds used in weight restrictions can be either exogenously set according to policy-maker (or top management) objectives, expert opinion and price/cost information (where available) or endogenously derived from the data. In the latter case, running an unbounded DEA at the first stage could provide useful information for definition of the weight restrictions to use in the constrained DEA at the second stage [7].

4. *The role of demand and of scale efficiency in the performance of NHS hospitals*

If the set of hospitals under examination includes units with excess supply with respect to demand, then the analysis of efficiency should capture this effect. In an NHS, an excess supply of hospital services could be due to past decisions of health care policy-makers, determining over-sizing of capacity with respect to actual demand with a negative influence on DEA efficiency scores. This particular source of inefficiency can be defined as *demand inefficiency*. Moreover, if we consider the hospitals operating within an NHS (which make their decisions according to national and regional health care authorities' guidelines), health care policy-makers could also be responsible, at least partly, for another source of inefficiency, i.e. *scale inefficiency*, arising from over- or under-sizing of hospitals with respect to their actual activity levels.

Both these sources of inefficiency can exist in the short term and can be considered, somehow, «external» to NHS hospitals' management responsibility, being determined in most cases by the decisions of health care planners [8].

In fact, within an NHS, a hospital could be kept active for reasons regarding broader health care policy, even if it exhibits a non-optimal bed capacity, high levels of potential production and insufficient demand. [9]

In this case, an NHS hospital could operate efficiently given the actual demand for its services (internal technical efficiency), but at the same time it could

[7] For example, Chilingerian and Sherman (1997) obtained optimal weights for inputs and outputs of primary care physicians with an unbounded DEA, at the first stage, and then used these weights to define a cone-ratio in a subsequent bounded DEA model based on HMO management's objectives.

[8] The problem of considering environmental constraints outside the management control is considered by Jacobs, Smith and Street (2006), chapter 8.

[9] For example, consider hospitals in poorly-served areas – such as islands, mountainous districts and other peripheral and low population density areas – which, if closed, would force people to travel long distances or face long waiting lists.

show external technical inefficiency (both scale and demand inefficiency), as its size is non-optimal and its input endowments are excessive in relation to actual demand. While the external inefficiency of public NHS hospitals can be due to decisions taken by national and regional policy-makers at a higher level than hospital management, private hospitals (for-profit and non-profit) operating within an NHS could be publicly subsidized in order to operate with a given (non-optimal) capacity and in a given (low demand) area. In both cases, scale inefficiency and demand inefficiency can be attributed to the responsibility of policy-makers and are therefore external to the hospital management.

The point can be further explained with the help of Figure 1, where we consider a very simple production process (one output y, acute care admissions, obtained via the utilization of one input x, the number of beds). In Figure 1 we show the *frontier production function* (FPF) for a given set of hospitals, describing the highest level of output y attainable via an efficient utilization of input x, and the *observed production function* (OPF^j) of a given hospital j[10]. In the example of Figure 1, we consider the existence of an expressed admissions demand y^L lower than the number of admissions that can be satisfied by the hospital, considering its OPF^j.

When the hospital capacity x^j is above the optimal size (x^*), *total inefficiency* can be split into three components:

1) *scale inefficiency* (the distance between the dotted line OM, linking the origin to point M that defines the optimal output with respect to actual capacity x^j, and the FPF, i.e. $y^M(x^j)$- $y^F(x^j)$);

2) *internal inefficiency* (the distance between FPF and OPF^j, i.e. $y^F(x^j) - y^j(x^j)$);

3) and *demand inefficiency* (the distance between OPF^j and the line y^L, i.e. $y^j(x^j) - y^L$).

If we consider hospitals operating within an NHS, the first and the third components of inefficiency can be considered as *external* source of inefficiency because they can be, at least in the short run, outside the control of hospital management.

Using DEA, it is possible to provide evidence of both sources of *external inefficiency*. *External scale inefficiency* (due to a non-optimal hospital size) can be measured by introducing the assumption of variable returns to scale (VRS), as in the BCC model (Banker, Charnes and Cooper 1984). On the other hand, measuring *external demand inefficiency* (due to a shortage of expressed demand with respect to supply) should take account of the exist-

[10] Figure 1 is used here just for explanatory purposes, while in the DEA the production frontier would be represented by a piecewise line.

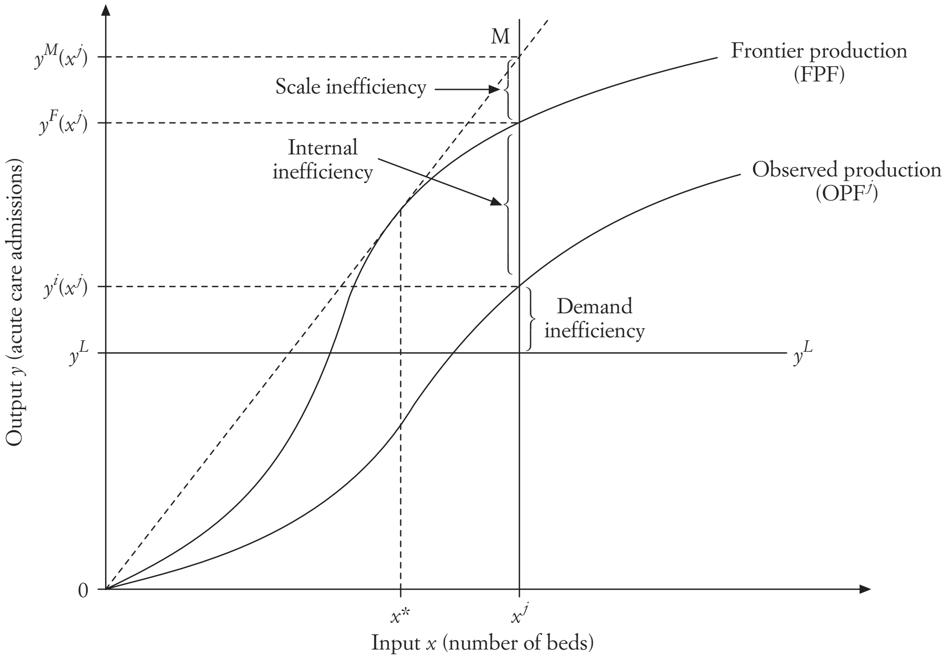

FIG. 1. Components of hospital total inefficiency.

ence of an additional constraint on the demand side. This can be done by adding to the BCC-DEA model a non-discretionary input variable representing the expressed demand level, such as y^L in Figure 1. The consideration of an additional exogenous demand input in BCC-DEA can be made following Cooper-Seiford-Tone's approach to the treatment of a non-controllable (NCN) variable (Cooper, Seiford and Tone, 2007, chapter 7) [11]. A possible choice (that we adopt in the next section) could be to approximate the non-discretionary level of expressed demand y^L by considering the actual number of hospital admissions. This is clearly an unsatisfactory choice, since the satisfied demand is undoubtedly influenced by the hospital's production process.

In any case, it is worth noting that the number of admissions (satisfied demand) cannot be larger than the expressed demand. Therefore, by using the satisfied demand as a NCN variable, two cases could arise:

– the hospital does not show demand inefficiency, so that we can surely state that it would not be demand inefficient even though the expressed de-

[11] Obviously, considering an additional input will tend to increase the number of efficient hospitals.

mand has been used; in this case, the only source of external inefficiency would be given by scale inefficiency;

– the hospital shows demand inefficiency: in this case we cannot surely state that this inefficiency is completely external, as the actual demand can be partially influenced by managers' behaviour.

Therefore, the use of the satisfied demand as an additional input can provide some useful information about the existence of environmental constraints influencing hospital efficiency.

Summing up, by using a Constant Return to Scale (CRS) model, a VRS model and then including an NCN demand variable, it is possible to compute:

– *total technical efficiency scores with CRS*: e_j;

– *total technical efficiency scores with VRS*: e_j^S;

– *internal technical efficiency scores with VRS-NCN*, e_j^I, which signals the ability of the hospital management to apply the most efficient production technique.

As the efficiency scores vary from 0 to 1, the total *inefficiency* of a hospital j, $(1-e_j)$, can be considered as the result of three components [12]:

– *internal inefficiency* due only to hospital management, computed as $(1-e_j^I)$;

– *external scale inefficiency*, computed as the difference between total efficiency with VRS and total efficiency with CRS: $(e_j^S-e_j)$;

– *external demand inefficiency*, computed as the difference between internal efficiency with VRS and total efficiency with VRS: $(e_j^I-e_j^S)$.

5. *A case study: the hospitals of the Veneto Region – Italy*

5.1. *The model*

Let's examine the effect of what we have discussed so far using data concerning the acute hospitals in Veneto, a region in Northern Italy.

The hospital technology is described by a simplified model with three outputs:

– an index of in-patient output calculated by weighting the number of acute care discharges with DRG weights (y_1);

– the number of days of treatment in day hospital (y_2);

[12] Three different components of inefficiency can be measured by comparing the scores obtained with three different DEA models: the CCR model (Charnes, Cooper and Rhodes, 1978); the BCC model; the Non-Controllable Variable BCC model. See Cooper, Seiford and Tone (2007). In section 5, we will adopt this methodology.

– the number of treatments provided by emergency services (y_3);

and five inputs:

– the number of physicians (x_1);

– the number of nurses (x_2);

– the number of other employees (x_3);

– the number of hospital beds (x_4);

– the total number of acute care admissions, additional input used as a proxy for hospital demand (x_5).

Output y_1 is built as a weighted sum of medical and surgical discharges differentiated by DRG (excluding day hospital cases). As aggregation weights, we use the relative standard costs (DRG tariffs) attached to each DRG, considered as proxies of the intensity of care embodied in each discharge classified in that DRG [13]. We choose weighted hospital discharges instead of patient days in order to avoid the incorporation of the length of stay in the measurement of in-patient activities, since this would penalize a possible substitution between length of stay and intensity of resource use [14]. Output y_2 is given by the number of days of treatment provided by medical and surgical day-hospital services. Output y_3 is the number of treatments provided by accident and emergency services.

We should argue that the chosen measures of hospital production represent only intermediate outputs, while the final output should be linked to the health improvement of patients and should be correlated to the quality of hospital care (Bloor and Maynard, 2006). Including measures of final outcome and of quality of care among the outputs (e.g. survival rates, readmission rates, or the incidence of hospital-acquired infections used as proxies for the quality of care) is often very problematic, either because of the lack of data or because of the difficulty in making a proper assessment of the available data [15].

[13] The DRG classification includes 492 categories, as in the 10th version of HCFA-DRG in the U.S.

[14] The theoretical inappropriatness of choosing in-patient days as output measure is argued by Feldstein (1967). In a recent work, Steinmann and Zweifel (2003), recognizing that the role of patient days in the hospital service production is rather ambiguous, consider two different DEA models: in the first, in-patient days are viewed as an input from a social point of view; in the second, adopting a hospital manager's viewpoint, in-patient days constitute an output as long as they form the basis of payment.

[15] A first attempt in this direction, with reference to Italian hospitals aggregated at regional level, has been made by Cellini *et al.* (2000) who included the total number of discharged patients among the inputs, and the number of patients discharged alive among the outputs. However, even Cellini *et al.* (2000) pointed out that this approach does not seem completely satisfactory since mortality rates depend not only on the quality of hospital care, but on many other factors totally out of control of hospitals.

TAB. 1. *The analysed DEA models*

Model	Orientation	Return to scale	Technical efficiency	Constraints	Responsibility for technical inefficiency
1 (CCR)	Input Output*	Constant (CRS)	Total	None	Hospital management and Policy-maker
2 (CCR)	Output	Constant (CRS)	Total	Virtual weight of output $y_1 \geq 70\%$	Hospital management and Policy-maker
3 (BCC)	Input	Variable (VRS)	Total	None	Hospital management and Policy-maker
4 (BCC-NCN)	Input	Variable (VRS)	Internal (addition of input x_5)	None	Hospital management

Notes: * Results obtained either with input-oriented or output-oriented CCR model are equivalent.
a) CCR model: Charnes, Cooper and Rhodes, 1978;
b) BCC model: Banker, Charnes and Cooper, 1984;
c) BCC-NCN model: BCC model modified with a non-controllable (NCN) variable (Cooper, Seiford and Tone, 2007, chapter 7).

Unfortunately, hospital records did not provide us any data about variables which could be related to quality of care. Therefore, our analysis provides only measures of technical efficiency of hospital production and should be considered just a first step within a complete evaluation process of the performances of Veneto hospitals, which would require a deeper analysis at DMU level.

The staff numbers (x_1, x_2, and x_3) are measured as the average number of full-time equivalent staff for the year, while the number of beds (x_4) is a proxy of the capital used in the hospital production process. Finally, the additional input x_5 represents a non-controllable demand variable introduced in order to separate total technical efficiency into its internal (managerial) and external components, according to the analysis in section 4.

We consider four different DEA models reported in Table 1.

In model 2, the following restriction on the virtual weights of output y_1 (acute care discharges adjusted with DRG) is imposed for each hospital j[16]:

$$(u_{1j} y_{1j}) / (\sum_{k=1}^{3} u_{kj} y_{kj}) \geq 0{,}7$$

i.e., each hospital cannot attribute a virtual weight lower than 70% to output y_1. This allows us to make efficiency evaluations that are more focused on output y_1, considered a priority, while it penalises the hospitals that specialise in other outputs. The particular choice of the lower bound of 70% can be justified by

[16] As explained in section 3, constraints on virtual weights are less binding than restrictions on absolute weights.

two different arguments. Firstly, the output virtual weights that can be chosen by each hospital should not be too far from the virtual weight chosen by a DMU built as the aggregate of the Veneto hospitals under evaluation («Veneto» DMU) that can be interpreted as an implicit expression of the Veneto Region's preferences concerning the relative importance of different outputs. The average virtual weight of output y_1, calculated for Veneto DMU in model 1 is 86%. This high value indicates that the virtual weight of acute care discharges should be sufficiently high in order to incorporate the relative importance attached to this output in the hospital production process. Secondly, it should be noted that the more recent health care policy of the Veneto Region gives incentives to shift hospital production from traditional forms of in-patient care (here represented by y_1) towards other types of outputs, such as day hospital services, that can increase the appropriateness and decrease the costs of the hospitals' production process. Consequently, the virtual weights of y_1 should be lower than 86% in order to guarantee that each hospital does not overlook other outputs. Summing up, the restriction we adopt on the virtual weights of output y_1 could be considered a reasonable compromise between these two arguments.

5.2. *The data*

The data used for the analysis refer to the year 1997 and come from the hospital discharge records of the Ministry of Health and the Veneto Region databases (Regione Veneto, 1999). Due to the lack of some information, the sample does not include all the Region's public and private hospitals. Only 85 structures are considered out of the 95 that actually existed. The sample consists of 59 LHA-public hospitals (i.e. hospitals directly run by Local Health Authorities), 2 public hospital trusts (the teaching hospitals of Padua and Verona) and 24 private hospitals affiliated to LHAs (seven of which are non-profit). As far as outputs y_1 and y_2 are concerned, the revenues of hospital trusts and private hospitals are based upon DRG tariffs, while LHA-public hospitals are financed partly on a capitation basis (considering the needs of the population residing within each Local Health Authority's territory) and partly by DRG tariffs (in order to compensate the services provided to patients residing outside the LHA). As regards emergency services y_3, they are compensated by special funds on a retrospective basis.

5.3. *Results and discussion*

Table 2 summarizes the main results from model 1 (CRS total efficiency without constraints) and model 2 (CRS total efficiency with a constraint on

TAB. 2. *The effect of a constraint on y_1 virtual weights (subset of hospitals affected by the constraint on virtual weights; scores in % ranked by total efficiency level)*

Hospital	Total efficiency with CRS (model 1)	Constrained total efficiency with CRS (model 2)	Reduction of efficiency due to restrictions on y_1 weight (mod. 2 – mod. 1)
U68	44.6	23.7	–21.0
U25	50.6	49.4	–1.3
U79	50.9	50.8	–0.02
U54	53.2	51.8	–1.4
U20	57.2	35.0	–22.2
U29	58.6	40.0	–18.6
U75	59.6	47.7	–11.9
U40	69.8	60.9	–8.8
U41	71.3	71.2	–0.2
U44	76.0	69.9	–6.1
U10	81.3	68.3	–13.0
U27	83.8	71.1	–12.7
U31	86.9	85.6	–1.3
U51	87.3	86.7	–0.5
U32	89.9	88.5	–1.4
U26	93.6	90.9	–2.6
U50	94.5	90.0	–4.5
U06	95.6	71.9	–23.7
U78	95.6	81.0	–14.7
U66	95.8	86.2	–9.6
U24	97.3	96.5	–0.8
U76	98.6	98.4	–0.3
U90	99.2	92.4	–6.8
U67	99.7	98.2	–1.5
U07	100.0	48.4	–51.6
U21	100.0	71.2	–28.8
Number of full efficient DMUs	13	11	–2
Average	74.5	71.3	–3.1
Minimum	15.6	15.6	–51.6
Maximum	100.0	100.0	–
Range	84.4	84.4	51.6
Standard deviation	22.8	23.1	8.0

y_1 virtual weights); the table shows only the data for the 26 hospitals that change (reduce) their efficiency score moving from model 1 to model 2. We observe a high variability in terms of total efficiency scores and a very low percentage of efficient DMUs both in model 1 (15.29%) and in model 2 (12,94%).

In model 1 (CRS total efficiency without constraints) most hospitals exhibit a very high virtual weight for output y_1 «discharges adjusted with DRG». In any case, as no constraints are imposed, it is possible to retrace some hospitals which exhibit a very low (or nil) virtual weight for y_1, while assigning a very high virtual weight to the number of days in day hospital y_2 or to emergency services y_3. This is plainly unsatisfactory, as discharges are an important component of total hospital output. Therefore, in model 2 (CRS total efficiency

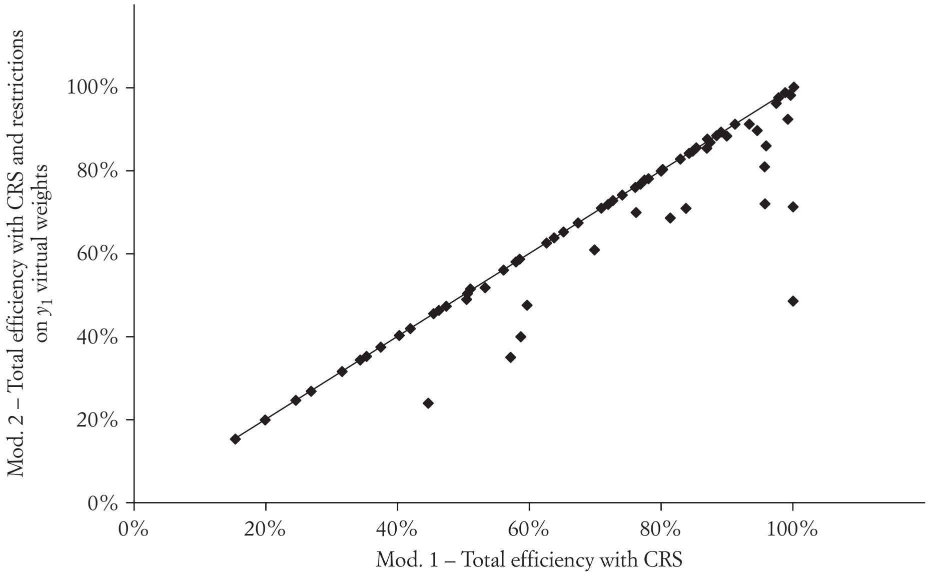

FIG. 2. Effect of a constraint on y_1 virtual weights on hospital efficiency scores.

with a constraint on y_1 virtual weights) we try to overcome this shortcoming by imposing a constraint on the virtual weights of hospital output y_1.

Table 2 shows that, after the introduction of the constraint on y_1 virtual weight, on average, total efficiency decreases from 74.5% (model 1) to 71.3% (model 2). The restriction penalises the DMUs that in model 1 assigned a virtual weight of less than 70% to acute care discharges. Table 2 and Figure 2 show this effect: hospitals that in the unbounded DEA (model 1) exhibited high performances have lower efficiency scores in model 2. Two cases that stand out are the LHA-public hospitals U07 and U21, which give absolute priority to day-hospital care (with weights close to 100% in model 1), and which drop from total efficiency scores of 100% to 48.4% and 71.2% respectively. These two hospitals are highly penalised with model 2, since with the unconstrained model 1 they assigned a weight higher than 95% to day hospital care and a nil weight to acute care discharges. On the other hand, all the 17 for-profit private hospitals do not change their efficiency scores, as they assign a very high weight to output y_1 (for 13 of them, the weight attached to y_1 is 100%) [17].

[17] This can be easily explained, since these private hospitals do not have emergency units and provide mostly long-stay in-patient services.

TAB. 3. *Scale and demand effects on hospital efficiency scores (a selection of hospitals changing their efficiency scores moving from model 1 to models 3 and 4, ranked by total efficiency level; efficiency scores in %)*

DMU	Total efficiency with CRS e_j (mod. 1)	Total efficiency with VRS e_j^S (mod. 3)	Internal efficiency with VRS e_j^I (mod. 4)	Scale inefficiency $(e_j^S - e_j)$ (I)	Demand inefficiency $(e_j^I - e_j^S)$ (II)	External inefficiency $(e_j^I - e_j)$ (III = I + II)	Internal inefficiency $(1 - e_j^I)$ (IV)	Total inefficiency $(1 - e_j)$ (V = III + IV)
U83	15.6	100.0	100.0	84.4	0.0	84.4	0.0	84.4
U70	19.9	54.9	55.1	35.0	0.1	35.2	44.9	80.1
U62	24.5	67.2	80.2	42.8	12.9	55.7	19.8	75.5
U13	26.8	80.3	84.6	53.5	4.2	57.7	15.4	73.2
U69	31.7	47.7	49.0	16.0	1.3	17.3	51.0	68.3
U61	34.6	37.5	37.8	2.9	0.3	3.2	62.2	65.4
U85	35.4	70.1	70.7	34.6	0.6	35.3	29.3	64.6
U38	37.3	75.0	100.0	37.7	25.0	62.7	0.0	62.7
U72	40.2	43.1	49.3	2.9	6.2	9.1	50.7	59.8
U42	41.9	100.0	100.0	58.1	0.0	58.1	0.0	58.1
U68	44.6	45.5	100.0	0.9	54.5	55.4	0.0	55.4
…	…	…	…	…	…	…	…	…
U06	95.6	100.0	100.0	4.4	0.0	4.4	0.0	4.4
U78	95.6	96.1	100.0	0.4	3.9	4.4	0.0	4.4
U66	95.8	100.0	100.0	4.2	0.0	4.2	0.0	4.2
U24	97.3	100.0	100.0	2.7	0.0	2.7	0.0	2.7
U56	98.1	100.0	100.0	1.9	0.0	1.9	0.0	1.9
U80	98.5	100.0	100.0	1.5	0.0	1.5	0.0	1.5
U76	98.6	100.0	100.0	1.4	0.0	1.4	0.0	1.4
U90	99.2	100.0	100.0	0.8	0.0	0.8	0.0	0.8
U74	99.6	100.0	100.0	0.4	0.0	0.4	0.0	0.4
U67	99.7	99.9	100.0	0.2	0.1	0.3	0.0	0.3
Number of efficient DMUs								
	13	33	47					
Average								
	74.5	86.3	90.8	11.8	4.5	16.3	9.2	25.5
Minimum								
	15.6	37.5	37.8	0.0	0.0	0.0	0.0	0.0
Maximum								
	100.0	100.0	100.0	84.4	54.5	84.4	62.2	84.4
Range								
	84.4	62.5	62.2	84.4	54.5	84.4	62.2	84.4
Standard deviation								
	22.8	16.6	14.8	16.6	9.0	18.7	14.8	22.8

Table 3 compares the main results from model 1, model 3 (VRS total efficiency without constraints) and model 4 (VRS internal efficiency without constraints). The table shows the data for a selection of the 72 hospitals that change (increase) their efficiency scores moving from model 1 to model 3 (among these DMUs, 51 increase their scores moving from model 3 to model

4). The total efficiency scores of model 3 are obtained running a BCC-DEA. Internal efficiency scores of model 4 are obtained by including among the inputs in the BCC-DEA a non-controllable demand variable, the total number of admissions x_5.

Assuming VRS and using an extra non-controllable variable obviously lead to efficiency scores that are higher than (or equal to) those obtained for total efficiency. In model 1, only 13 hospitals (15.29% of the total) are efficient, while 14 have an efficiency score lower than 50%. In model 3, 33 hospitals (38.82% of the total) are efficient and four exhibit a score below 50%. In model 4, 47 hospitals (55.29% of the total) are efficient and three exhibit a score below 50%.

Under the assumption of VRS (model 3), we find increasing returns to scale (IRS) for 42 hospitals and decreasing returns to scale (DRS) for 23, while 20 hospitals demonstrate constant returns to scale (CRS) (seven of these hospitals increase their efficiency). Generally, IRS are linked to lower (sometimes very low) total efficiency scores, while DRS are linked to higher total efficiency scores [18]. The existence of DRS is demonstrated only for public hospitals (21 LHA-hospitals and the two hospital trusts).

In general, we can conclude that most of the hospitals in Veneto are too small in relation to their output levels (i.e. IRS). This problem of scale inefficiency, which is the first cause of the low total efficiency scores, characterises mainly the private hospitals (about 80% of the total of private DMUs: fourteen for profit and five non-profit) [19], while only 39% of the LHA-public hospitals (23 DMUs) exhibit a sub-optimal size. This result indicates the particular role of private hospitals within the Veneto health care system: these hospitals are considered important within regional health care planning, as providers of supplementary services integrating public supply, even though they operate at a sub-optimal scale.

The previous conclusion is confirmed by Figure 3, which shows the relationships between the level of scale inefficiency, measured by comparing efficiency scores between model 3 and model 1 ($e_j^S - e_j$), and hospital size, measured in terms of number of beds: the higher scale inefficiency is linked to IRS and to a small capacity. Out of the 28 hospitals with scale inefficiency above the average (i.e. above 11.8%), 25 show IRS and 20 have less than

[18] Among the 33 hospitals with a total efficiency score under 70%, 29 exhibit IRS, three show CRS and only the LHA-public hospital U68 shows DRS. Moreover, almost all the inefficiency of U68 derives from a lack of demand. On the contrary, among the 39 hospitals with total efficiency above 70%, DRS are found for 28, IRS for 17 and CRS for four units.

[19] For one non-profit and six for-profit hospitals, inefficiency depends only on an inefficient scale.

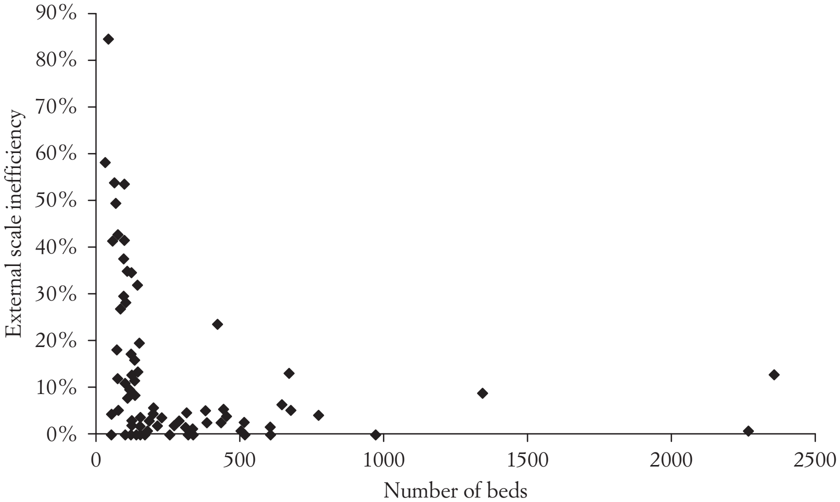

FIG. 3. Relationships between external scale inefficiency and hospital bed capacity.

200 beds. In contrast, only three units with scale inefficiency above the average have more than 200 beds and show DRS.

Table 3 also reports internal efficiency scores obtained with model 4 and demand inefficiency levels, that is, the second component of external inefficiency determined by an excess supply with respect to satisfied demand. Including an exogenous demand variable among the inputs has a noticeably positive impact on the efficiency scores, especially for many LHA-public hospitals (37 DMUs) and for some accredited private hospitals (nine for-profit and five non-profit) which can be considered as complementary to public services and which operate under the strict control of regional and local health authorities. Fourteen hospitals become fully efficient moving from model 3 (scale efficiency) to model 4 (internal efficiency). Among these hospitals, eight units exhibit a demand inefficiency index ($e_j^I - e_j^S$) higher than 10%: five LHA-public hospitals (U68, U75, U44, U53, U10)[20]; two non-profit private hospitals (U71 and U20); and one for-profit hospital (U38). As might be expected, all these DMUs are located in mountainous and/or low population density areas.

External inefficiency (measured by $e_j^I - e_j$), due to non-optimal scale and/or to exogenous demand, is the only component of total inefficiency for 34

[20] The effect of excess supply with respect to demand has a very strong impact on hospitals U68 (with 54.5% of demand inefficiency) and U20 (with 42.1% demand inefficiency).

hospitals (22 public). Twenty of these hospitals (13 public) exhibit only scale inefficiency and no demand inefficiency; therefore, we can conclude that, for these DMUs, low total efficiency scores can be better explained by past decisions made by policy-makers concerning the size of the hospital (this is mainly the case of LHA-public hospitals) or its role within the regional health care service (this is the case of some accredited private hospitals particularly involved in regional health care planning). Other 14 hospitals (9 public) exhibit both scale and demand inefficiency, but – owing to our particular choice of the non-controllable demand variable (the additional input x_5), as we explained in section 4 – in this case we cannot surely state that this inefficiency is completely external, as the actual demand could be partially influenced by managers' behaviour (e.g. a low demand determined by a low quality of provided services). Anyway, only for 7 out of 14 hospitals (5 public) demand inefficiency represents the most important component of external inefficiency while for the others it represents a negligible source of inefficiency.

In other words, for a large proportion of hospitals characterised by external inefficiency, it seems reasonable to attribute total technical inefficiency to external factors that are not (completely) within the control of the hospital management such as: a) regional health care policy decisions made in the past which determined both choices of non-optimal sizes and an excess of hospital bed capacity in relation to actual demand[21]; b) regional planning decisions deliberately aimed at guaranteeing the spread of hospitals across the territory, as it is considered unacceptable from a social viewpoint to deprive people living in peripheral and in sparsely populated areas (particularly in mountainous districts) of essential services.

Figure 4 represents the relationship between external scale inefficiency and external demand inefficiency. The dotted lines indicate the average level of the two components of inefficiency: respectively 11.8% and 4.5%. The figure shows that a large number of hospitals (31) exhibit both scale and demand inefficiency levels that are lower than average, while only three hospitals (one public: U62; two private: U38 and U71) show very high levels both of scale and demand inefficiency.

Table 4 shows the correlation coefficients between each pair of six different measures of hospital inefficiency: 1) increased inefficiency due to the introduction of a restriction on the virtual weights of y_1; 2) scale inefficiency; 3) demand inefficiency; 4) external inefficiency (given by the sum of scale

[21] Current regional health care policies tend to eliminate, or to limit, this excess supply even though they often face significant political obstacles.

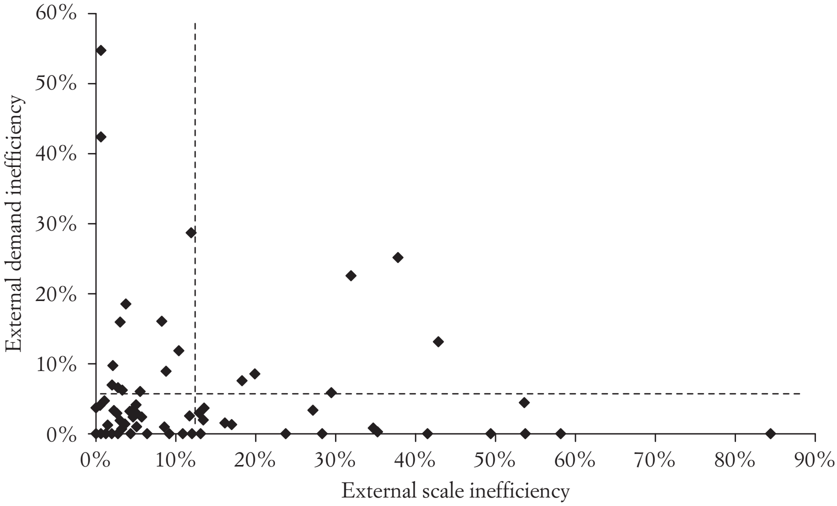

FIG. 4. Relationships between external scale inefficiency and external demand inefficiency.

TAB. 4. *Correlation coefficients between inefficiency levels*

	(1) Increased inefficiency	(2) Scale inefficiency	(3) Demand inefficiency	(4) External inefficiency	(5) Internal inefficiency	(6) Total inefficiency
(1) Increased inefficiency	1.0000					
(2) Scale inefficiency	–0.1424	1.0000				
(3) Demand inefficiency	0.2697	–0.0171	1.0000			
(4) External inefficiency	0.0030	0.8780	0.4636	1.0000		
(5) Internal inefficiency	–0.2138	–0.0485	–0.0946	–0.0883	1.0000	
(6) Total inefficiency	–0.1363	0.6888	0.3189	0.7631	0.5764	1.0000

and demand inefficiency); 5) internal inefficiency; 6) total inefficiency (given by the sum of internal and external inefficiency).

The first column of the table shows the correlation between the increased inefficiency due to the restriction on y_1 weight and the other types of inefficiency. The highest positive correlation (27%) is found with demand inefficiency since the effect of the constraint of y_1 weight is stronger (i.e.

very low weight on acute care discharges in model 1) for hospitals which also exhibit higher demand inefficiency. The fifth row shows that there is a very low negative correlation between internal and external inefficiency (less than –9%), so that we can say that the hospitals with internal inefficiency are generally different from those characterised by external inefficiency. Finally, the last row shows that total inefficiency is mostly correlated with external inefficiency (76%) and in particular with external scale inefficiency (69%).

It could be interesting to investigate whether the inefficiency scores are correlated with some characteristics of the analysed hospitals. To this purpose, many authors regress DEA scores on a set of potential explanatory variables. This approach is criticised by Simar and Wilson (2007) that argue that DEA scores are serially correlated and suggest a new statistical procedure based on specifying explicitly the data generating process and bootstrapping to obtain confidence intervals. In order to avoid this methodological issue, we do not attempt to develop a strict causality model, and we restrict ourselves to a simple analysis of the correlation between the six different measures of hospital inefficiency (described in Table 4) and the following hospital characteristics:

– the type of hospital;

– the number of beds;

– the case-mix index, to account for the complexity of discharges;

– the rotation index (number of patients that use one bed in a year, calculated as the ratio between the total number of discharges and the number of beds), to account for the rate of utilisation of hospital capacity.

Table 5 reports the average inefficiency measures for each type of hospital, showing that:

– for-profit hospitals do not increase their inefficiency when the weight restriction on y_1 is introduced: in fact, as explained before, all these hospitals attach a very high weight to the discharges adjusted with DRG;

– LHA-public hospitals exhibit a total inefficiency lower than the average; both internal and external inefficiency are important in worsening their performance;

– public hospital trusts are the less inefficient and their only source of inefficiency is given by decreasing returns to scale;

– private hospitals are more inefficient than public ones; for-profit hospitals are mostly characterised by scale inefficiency (27.05%), while non-profit hospitals are characterised by all the sources of inefficiency: scale (17.3%), demand (10.16%) and internal (12.06%) inefficiency.

Table 6 reports the partial correlation coefficients between inefficiency measures and the considered hospital characteristics, showing that:

TAB. 5. *Average inefficiency measures by type of hospital*

	(1) Increased inefficiency due to restrictions on y_1 weight	(2) Scale inefficiency	(3) Demand inefficiency	(4) External inefficiency (2+3)	(5) Internal inefficiency	(6) Total inefficiency (4+5)
LHA-Public Hospitals	4.01	6.94	4.36	11.31	9.84	21.14
Hospital Trusts	3.38	6.91	0.00	6.91	0.00	6.91
Non-profit Private hospitals	3.16	17.30	10.16	27.46	12.06	39.52
For-profit Private Hospitals	0.00	27.05	3.10	30.16	7.12	37.27
All Hospitals	3.12	11.82	4.48	16.30	9.24	25.55

– compared to LHA-public hospitals: only non-profit private hospitals are noticeably more likely to be totally inefficient; both hospital trusts and private hospitals (especially for-profit ones) are more likely to be scale inefficient; for-profit hospitals are considerably less likely to be demand inefficient; both hospital trusts and for profit hospitals are less likely to be internally inefficient;

– the growth of inefficiency due to the introduction of the weight restriction is lower when hospitals are private [22], with a large number of beds and a high rotation index;

– a higher case-mix index exhibits a high negative correlation with both scale inefficiency and total technical inefficiency;

– a high rotation index is associated with a strong reduction in all the types of inefficiency.

These results partially confirm the findings of many DEA models, showing that public provision of hospital services exhibits in general less inefficiency than private provision (for a survey of these empirical studies, see Hollingsworth, Dawson and Maniadakis, 1999) [23]. On the other hand, previous results of DEA models for Italy are sometimes different (a complete review of these studies is provided by Canta, Piacenza and Turati, 2006) [24],

[22] As we have shown before, y_1 represents the most important output for all for-profit hospitals.

[23] A recent work by Steinmann and Zweifel (2003) on the level of inefficiency of Swiss hospitals finds that private hospitals do not seem to be significantly less inefficient than public ones. The two authors remark that this result may be caused by the over-use of inputs (valued as amenities by patients) by private hospitals and they point out that this represents an important limitation in applying the purely quantitative criteria of DEA to hospitals.

[24] For example, Cellini, Pignataro and Rizzo (2000) find that private or public ownership does not play a significant role in explaining differences in Italian hospitals' efficiency. Likewise, Barbetta and Turati (2001) do not find a significant impact of the ownership structure on efficiency, considering a sample of hospitals located in Lombardia. On the other hand, Galizzi, Navarra and Vassallo (1999), considering a sample Italian hospitals for three years,

TAB. 6. *Partial correlation coefficients between inefficiency levels and hospital characteristics*

	(1) Increased inefficiency due to restrictions on y_1 weight	(2) Scale inefficiency	(3) Demand inefficiency	(4) External inefficiency	(5) Internal inefficiency	(6) Total inefficiency
Dummy-Hospital Trusts	0.1386	0.1344	0.0180	0.1340	–0.1161	0.0093
Dummy-Non-Profit Private hospitals	–0.1698	0.1772	0.0761	0.2080	0.0288	0.2124
Dummy-For-profit Private Hospitals	–0.3337	0.3052	–0.1512	0.1926	–0.1833	–0.0025
Number of beds	–0.1814	–0.0507	–0.0889	–0.1022	0.1169	0.0204
Case-mix index	0.1240	–0.3802	0.1205	–0.2864	–0.1936	–0.4141
Rotation index	–0.3583	–0.5405	–0.2952	–0.6159	–0.3542	–0.7271

even though, similarly to our analysis, several studies have found an average high degree of total technical inefficiency (Cellini, Rizzo and Pignataro, 2000; Fabbri, 2000; 2003) and a higher total efficiency of hospital trusts compared to LHA-public hospitals (Fabbri, 2000; 2003; Giuffrida, Lapecorella and Pignataro, 2000).

In the case of hospitals in Veneto, the relatively lower efficiency exhibited by accredited private hospitals depends on two main reasons. Firstly, a very high proportion of non-profit and (especially) for-profit hospitals are characterised by scale inefficiency. Secondly, many private hospitals (especially the non-profit ones) exhibit a relatively lower case-mix (accounted for by output y_1), since they deal especially with long-term and low complexity in-patient care which is characterised by DRG tariffs above actual costs. These results indicate that the role of accredited private hospitals in Veneto is often complementary to public services.

6. *Conclusions*

In this paper we have examined two possible directions of refinement of the DEA as a method for evaluating the relative technical efficiency of acute hospitals. First of all, since hospital services operating within an NHS are generally given high social value, hospital technical efficiency should be

find that private hospitals exhibit higher efficiency scores than public ones. Other works have investigated the effects of the reform of Italian NHS (in particular the introduction of the DRG-based payment system after 1995) on hospitals efficiency, finding evidence of an increase of public hospital efficiency (Fabbri, 2000) and a convergence in the mean level of efficiency between public and not-for-profit hospitals (Barbetta, Turati and Zago, 2007).

evaluated in relation to the preferences expressed by local and/or national communities through their elected representatives. For DEA, this means imposing constraints on input and output weights that are consistent with the preferences of the relevant policy-maker. Weight restrictions are based on modifications of the basic unbounded DEA model, in order to incorporate value judgements in the assessment of efficiency without eliminating a certain flexibility (freedom) vis-à-vis the value attached by hospitals to input and output variables. Secondly, we have shown how the assumption of VRS (variable returns to scale) and the inclusion of a demand variable among the inputs of the DEA model permit identification of how much inefficiency is due to factors outside the control of hospital management, such as past political decisions determining excess production capacity in relation to actual demand.

Based on these theoretical considerations, we have analysed the relative technical efficiency of hospitals in Veneto by using four models of DEA. Firstly, we find that the imposition of a lower bound of 70% on the virtual weight of acute care discharges weighted by case-mix (in order to encapsulate regional government objectives) reduces average efficiency from 74.5% to 71.3%; in fact, 26 hospitals worsen their efficiency levels because they attach too much importance to other outputs, such as day hospital care and emergency treatment.

Then, by assuming VRS and considering the impact of non-controllable demand on hospital efficiency, we show that, in many cases, low efficiency scores are attributable to external factors, which are not fully controlled by the hospital management. The problem of scale inefficiency characterises mainly the private hospitals (about 80% of the total of private hospitals exhibits increasing returns to scale), while only 39% of the LHA-public hospitals (23 DMUs) exhibits a sub-optimal size. The second source of external inefficiency (the shortage of demand) is important for many LHA-public hospitals (37 DMUs) and for some accredited private hospitals (nine for-profit and five non-profit). In general, for 34 hospitals (22 public) external inefficiency is the only component of total inefficiency. For these DMUs, low total efficiency scores can be mainly explained by past policy-makers' decisions on the size of the hospitals or their role within the regional health care service.

Finally, both non-profit and for-profit private hospitals exhibit a higher level of total inefficiency than public hospitals: for-profit hospitals are mostly characterised by scale inefficiency, while non-profit hospitals are affected by all different sources (both internal and external) of inefficiency.

Despite some limitations of the empirical analysis (due to the lack of information on out-patient services and on quality of hospital care), this paper represents a preliminary attempt to adapt the DEA method to the particular features of the hospital sector. It analyses the implications of modifying the basic DEA model in order to consider the impact on the measurement of hospital performance of both demand variables and policy-maker objectives to be pursued via specific restrictions on weights. Both these changes have noteworthy policy implications. Firstly, since measurement of hospital relative efficiency with DEA should be based on particular value judgements, the evaluation process of productive performance should be transparent, with an explicit definition of restrictions on input and output weights according to policy-makers' choices. These restrictions are crucial for specification of the DEA model in which the policy-makers should be involved, directly or indirectly. Secondly, the adoption of corrective actions aimed at increasing efficiency requires a distinction to be made between internal and external inefficiency. In fact, reducing the two types of inefficiency calls for different interventions: at hospital management level (for internal efficiency) or at health care planning authority level (for external efficiency).

Since there is no all-purpose method for considering the influence of demand and for translating policy-maker objectives into restrictions on weights, these could be fruitful areas of development for future research.

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Measuring Hospital Efficiency through Data Envelopment Analysis when Policy-makers' Preferences Matter. An Application to a Sample of Italian NHS Hospitals
by Vincenzo Rebba and Dino Rizzi

Summary: In this paper we show how both the choice of specific constraints on output weights (in accordance with health care policy-makers' preferences) and the consideration of exogenous variables outside the control of hospital management (and linked to past policy-makers' decisions) can affect the measurement of hospital technical efficiency using the *Data Envelopment Analysis* (DEA). Considering these issues, the DEA method is applied to measure the efficiency of 85 (public and private) hospitals in Veneto, a Northern region of Italy. The empirical analysis allows us to verify the role of weight restrictions and of demand in measuring the efficiency of hospitals operating within a National Health Service (NHS). We find that the imposition of a lower bound on the virtual weight of acute care discharges weighted by case-mix (in order to consider policy-maker objectives) reduces average hospital efficiency. Moreover, we show that, in many cases, low efficiency scores are attributable to external factors, which are not fully controlled by the hospital management. Finally, we show that accredited private hospitals exhibit a higher level of total inefficiency than public ones: for-profit hospitals are mostly characterised by scale inefficiency, while non-profit hospitals are affected by different sources of inefficiency. Most of the hospitals in Veneto are too small in relation to their output levels (i.e. are characterised by IRS) and this problem of scale inefficiency characterises mainly the accredited private hospitals. This result indicates that private hospitals are considered important within regional health care planning as providers of supplementary services integrating public supply, even though they operate at a sub-optimal scale.

Keywords: hospital performance, technical efficiency, data envelopment analysis, National Health Service.

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