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Measuring Intra-Hospital Clinic Efficiency and Productivity: An Application to a Greek University General Hospital

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Abstract:

In this paper we use Data Envelopment Analysis and the Malmquist Productivity Index and its decompositions to assess the productive efficiency and productivity of the in-patient clinics of a large Greek University General Hospital. Clinics are represented by means of a simple model whereby they use inputs (labor and capital) to produce outputs (in-patient days and patient discharges). The efficiency model is input oriented and assumes constant returns to scale. Model validation analyses showed that this model appears to be externally valid. The framework proposed here is a simple and useful tool for informing intra-hospital management decisions.

Keywords: Hospital efficiency, productivity, health.

JEL Classification: I11, I12, I18

1. Introduction

The measurement of efficiency and productivity is unambiguously of potential great value for every organisation employing inputs to produce outputs or services. Efficiency and productivity measurements can input in the stimulation of policy development and contribute to the resource allocation process. Also, from a managerial perspective they are a powerful tool that provides a platform for assessing diachronic performance and identifying best practices. Efficiency and productivity assessments can be effectively utilized for the evaluation of input-output producers that operate in imperfect markets. That is the case for health care institutions such as hospitals. Health care markets do not adhere to traditional neo-classical optimizing behavior. In short, the provision of health services entails market failures and non-

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profit maximizing behavior arising from institutional structures that differ from private ownership and individual property rights. For these reasons health care institutions are frequently suspect of inefficiency and compromised productivity.

Given the large size of the health care sector, marginal efficiency and productivity improvements can result in significant cost savings and therefore, efficiency and productivity measurements have reasonably attracted significant interest. An approach that has been increasingly utilized to assess productive performance, is the non-parametric mathematical programming approach, which goes by the name Data Envelopment Analysis or DEA. DEA encapsulates a very popular approach to productivity measurement, namely, the Malmquist Productivity Index (Malmquist, 1953). Both have been widely used in the assessment of hospital efficiency and productivity (Färe, Grosskopf, Lindgren and Roos, 1989; Maniadakis et al, 1999; Maniadakis and Thanassoulis, 2000; 2004; Sola and Prior, 2001). Most commonly they have been used at an aggregate level to evaluate policy changes and benchmark a hospital's activity according to its efficient counterparts (or peers) in a sample of hospitals. However, the measurement of efficiency and productivity can be of great value at the micro level as it can be employed to compare and benchmark different departments, clinics, specialities, consultants or procedures within a hospital. This paper applies DEA to benchmark the inpatient clinics of a Greek hospital. It aims at providing a simple and consistent platform for assessing intra-hospital clinic productive efficiency and productivity. A simple input-output model is constructed to represent the operations of hospital's in-patient clinics and the validity of the model is tested.

2. Technical Background

Efficiency is a relative concept. It is defined by comparing observed to optimal productive performance. There are five concepts of efficiency: pure technical efficiency and scale efficiency comprise technical efficiency, technical and allocative (or price) efficiency comprise, in turn, (or cost) efficiency. Following Farell's work (1953), technical efficiency is producing the maximum amount of output given inputs, or alternatively producing a given quantity of output with minimum quantities of inputs. Scale efficiency refers to optimal size and allocative efficiency occurs when the output mix is that which maximizes revenue given output price. When a producer is technically efficient it operates on its production frontier and when it is cost efficient it operates on its cost or revenue frontier. In this paper the focal point is technical efficiency (or productive efficiency) since the quantification of allocative efficiency requires input unit price information which was not available. Productivity on the other side is an absolute concept. It is defined as the ratio of an index of the output over an index of the input used to produce it. Productivity can be decomposed to technical efficiency change and technical change. The former can be decomposed further to pure technical efficiency change and scale efficiency change (Färe et al., 1989; 1994; 1995).

Assume that in any time period t, hospital clinics are using a vector of inputs $x^t \in \Re^n_+$, to produce a vector of outputs $y^t \in \Re^m_+$. The technology T of production can be represented by the (direct) input requirement set which contains all the input vectors x^t capable of securing the output vector y^t, or:

$$L^t(y^t) = \{x^t : (y^t,x^t) \in T^t\} \quad (1).$$

This input set is bounded from below from the input isoquant which contains the minimum input vectors capable of securing certain output, and its mathematical formulation is:

$$\text{Isoq}L^t(y^t) = \{x^t : x^t \in L^t(y^t), \lambda x^t \notin L^t(y^t) \text{ for } \lambda < 1\} \quad (2).$$

The isoquant defines a frontier or otherwise a boundary to the input set and those input vectors that lie on it are efficient in the sense that any radial reduction to them within $L^t(y^t)$ is not possible. Alternatively, the technology of production can be represented in terms of the input distance function, which with reference to the input set is defined as:

$$D_i^t(y^t,x^t) = \{\sup_{\theta} \{\theta > 0: (x^t/\theta) \in L^t(y^t), \theta > 0\} \quad (3).$$

This function measures the maximum factor by which a given input vector, x^t, can be deflated radially within $L^t(y^t)$. $D_i^t(y^t,x^t)$ provides a complete representation of the technology in the sense that $D_i^t(y^t,x^t) \geq 1$ is sufficient for $x^t \in L^t(y^t)$ and if $D_i^t(y^t,x^t) = 1$ then $x^t \in \text{Isoq}L^t(y^t)$ defined in (2). Let us define now the input oriented measure of technical efficiency as follows:

$$TE_i^t(y^t,x^t \mid c) = \{\min_{\lambda} \{\lambda > 0: \lambda x^t \in L^t(y^t|c)\} \quad (4).$$

where i denotes input orientation and c stands for constant returns to scale (CRS). $TE_i^t(y^t,x^t \mid c)$ indicates how much the observed input vector, x^t, could be radially contracted under CRS[5] and it is: homogeneous of degree - 1 in x^t, homogeneous of degree + 1 in y^t, homogeneous of degree 0 in (x^t,y^t), bounded in (0, 1], independent of

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[5] Assuming for example that $TE_i^t(y^t,x^t \mid c)$ = 0.75, this implies that observed output can be produced using only 75% of the inputs used to secure it.

units of measurement, $TE_i^t(y^t, x^t | c) = 1 \Leftrightarrow x^t \in IsoqL^t(y^t|c)$ and $TE_i^t(y^t, x^t | c) = 1/D_i^t(y^t, x^t | c)$. Similarly, define the input oriented measure of pure technical efficiency as:

$$PTE_i^t(y^t, x^t | v) = \{\min_{\lambda} \{\lambda > 0: \lambda x^t \in L^t(y^t|v)\} \quad (5).$$

where v here stands for variable returns to scale (VRS). This measure shows by how much the observed input vector, x^t, could be contracted under VRS, while being able to secure the observed output, y^t. It has the same properties with (4) and $PTE_i^t(y^t, x^t | v)$ is: $PTE_i^t(y^t, x^t | v) = 1 \Leftrightarrow x^t \in IsoqL^t(y^t|v)$ and $PTE_i^t(y^t, x^t | v) = 1/D_i^t(y^t, x^t | v)$. Finally, define the input oriented measure of scale efficiency as:

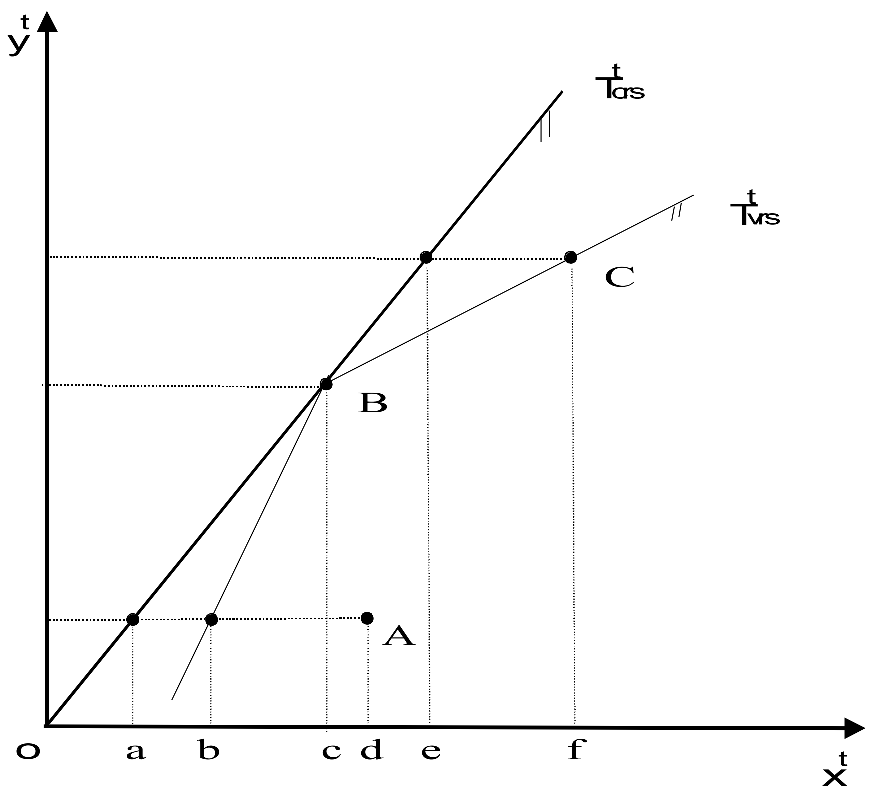
$$SE_i^t(y^t, x^t) = \frac{TE_i^t(y^t, x^t | c)}{PTE_i^t(y^t, x^t | v)} \quad (6).$$

that is, the ratio of the input technical to the input pure technical efficiency measure and it captures the amount of inefficiency attributed to the fact that production is not taking place at the most productive scale size point. Clearly, an input vector is scale efficient if $TE_i^t(y^t, x^t | c) = PTE_i^t(y^t, x^t | v)$, in other words if efficiency is the same relative to the CRS and VRS technologies. $SE_i^t(y^t, x^t)$ has similar properties to those of the measures defined in (4) and (5) and $SE_i^t(y^t, x^t) = 1 \Leftrightarrow PTE_i^t(y^t, x^t | v) = TE_i^t(y^t, x^t | c)$, and $SE_i^t(y^t, x^t) = D_i^t(y^t, x^t | c) / D_i^t(y^t, x^t | v)$.

Graphically these measures of efficiency are illustrated in figure 1 where the technology set (represented in equation 1) is used instead of the input set, because the former makes it easier to distinguish between the CRS and VRS technology. T_{crs}^t and T_{vrs}^t is the production boundary of the CRS and VRS technology, respectively. The figure depicts three producers, A, B and C. Hence, producer B is pure technically and scale efficient. Producer C is pure technically efficient because it is on the VRS technological boundary but it operates in an area of decreasing returns to scale and thus, it is scale inefficient. To be scale efficient C had to use input quantity e rather than f. In terms of the distances the scale efficiency of unit C will be: $SE_i^t(y^t, x^t) = TE_i^t(y^t, x^t | c) / PTE_i^t(y^t, x^t | v) = (oe/of)/(of/of) = oe/of$.

Finally, producer A is pure technically inefficient because it is in the interior of the VRS frontier and scale inefficient because it operates in an area of increasing returns to scale. Its technical efficiency is: $TE_i^t(y^t, x^t \mid c)$ = *oa/od,* its pure technical efficiency is: $PTE_i^t(y^t, x^t \mid v)$ = *ob/od,* and finally its scale efficiency is: $SE_i^t(y^t, x^t)$ = $TE_i^t(y^t, x^t \mid c) / PTE_i^t(y^t, x^t \mid v)$ = *(oa/od)/(ob/od)= oa/ob.*

Figure 1: Technology under CRS and VRS



Assume now that there is an adjacent time period *t+1* and define production similarly to period *t.* According to Färe *et al* (1989) the Malmquist Productivity Index (IM), defined in terms of distance functions and for constant returns to scale, is as follows:

$$IM(y^t, x^t, y^{t+1}, x^{t+1}) = \left[\frac{D_i^t(y^{t+1}, x^{t+1} \mid c)}{D_i^t(y^t, x^t \mid c)} \frac{D_i^{t+1}(y^{t+1}, x^{t+1} \mid c)}{D_i^{t+1}(y^t, x^t \mid c)} \right]^{1/2}$$

(7).

IM can be decomposed as follows (Färe et al. 1989) and (Färe et al. 1994): as follows:

$$IM(y^t, x^t, y^{t+1}, x^{t+1}) = \frac{D_i^{t+1}(y^{t+1}, x^{t+1}|v)}{D_i^t(y^t, x^t|v)} \frac{D_i^{t+1}(y^{t+1}, x^{t+1}|c)/D_i^{t+1}(y^{t+1}, x^{t+1}|v)}{D_i^t(y^t, x^t|c)/D_i^t(y^t, x^t|v)}$$

$$\times \left[\frac{D_i^t(y^{t+1}, x^{t+1}|c)}{D_i^{t+1}(y^{t+1}, x^{t+1}|c)} \frac{D_i^t(y^t, x^t|c)}{D_i^{t+1}(y^t, x^t|c)} \right]^{1/2}$$

(8).

The first term in (8) is an input oriented index of pure technical efficiency. The latter is decomposed to pure technical efficiency change and scale efficiency change, which equal the first and second components of (8), respectively. The second index in the brackets is an input measure of scale efficiency. Their product is an input measure of technical change. In terms of distances, in Figure 2, which represents the input set $L^t(y^t)$, the Malmquist index of period t is: IM^t = *(OB/OC)/(OG/OE).* Similarly, the index of period t+1 is: IM^{t+1} = *(OB/OA)/(OG/OF).* Finally, the geometric mean index (7) is: IM = $[(OB/OC)/(OG/OE)\ (OB/OA)/(OG/OF)]^{1/2}$. Hence, when the index (7) is 1 that indicates progress, whereas a value greater than 1 indicate regress and a value equal to 1 indicates that performance has remained constant.

In the context of DEA, The input oriented measure of technical efficiency defined in (4) and its reciprocal input distance function for every producer k can be computed as follows:

$$TE_i^t(y^t, x^t | c) = 1/D_i^t(y^t, x^t | c) = \min_{\lambda} \lambda$$

Subject to:

$$\sum_{j=1}^{J} z_j y_{jm}^t \geq y_{km}^t$$

$$\sum_{j=1}^{J} z_j x_{jn}^t \leq \lambda x_{kn}^t$$

$$z_j \geq 0$$

(9).

To compute the input oriented measure of pure technical efficiency defined in (5), and its reciprocal distance function, $PTE_i^t(y^t, x^t \mid v) = 1/D_i^t(y^t, x^t \mid v)$, one has to add in (9) the constraint: $\sum_1^J z_j = 1$, which makes the boundary of the technology to exhibit VRS. Then, the ratio of the two measures will give the scale efficiency measure, $SE_i^t(y^t, x^t)$. Similarly, for every producer k, the cross-period distance function is computed as follows:

$$1/D_i^t(y^{t+1}, x^{t+1} \mid c) = TE_i^t(y^{t+1}, x^{t+1} \mid c) = \min_{\lambda} \lambda$$

Subject to:

$$\sum_{j=1}^{J} z_j y_{jm}^t \geq y_{km}^{t+1}$$

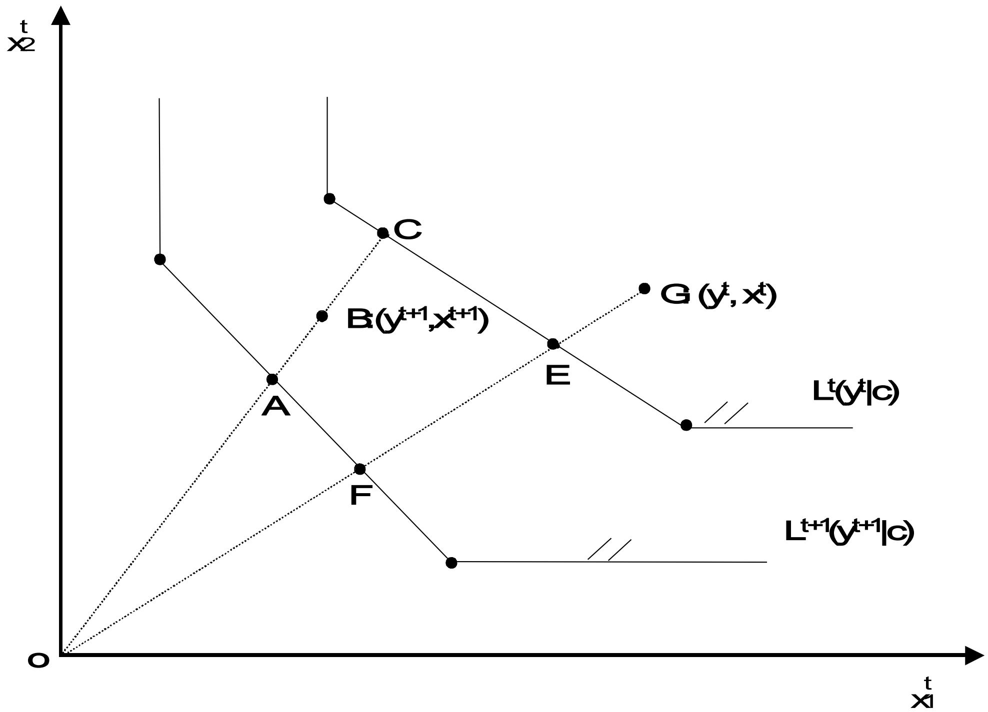
$$\sum_{j=1}^{J} z_j x_{jn}^t \leq \lambda x_{kn}^{t+1}$$

$$z_j \geq 0$$

(10).

The distance $1/D_i^{t+1}(y^t, x^t \mid c) = TE_i^{t+1}(y^t, x^t \mid)$ can be computed in a similar manner if we reverse the superscripts in (10).

Figure 2: The Input Malmqusit Productivity Index



3. A Framework for Assessing Efficiency and Productivity

The output of hospitals is multiple and heterogeneous, and hence, it is difficult to capture in discrete countable units. Consequently, proxy measures of output must be employed. We assume that clinic operations can be represented by means of input-output models whereby each clinic uses quantities of inputs to generate outputs in the form of services. Generally, hospitals and hence hospital clinics, are assumed to organise and expend in the production and delivery of health care and health, labour resources, such as doctors and nurses and capital resources, such as buildings and technologies, approximated in the number of beds. In this context and analogous to the variables used in similar studies we specified as labour inputs the number of physicians, the number of nurses and equivalents employed in each clinic and the number of beds, which is assumed to be a proxy measure of capital expenditure. On the part of outputs we used the number of patient discharges and the number of in-patient days. In order to increase the homogeneity of outputs we included in the analysis only in-patient clinics and excluded out-patient clinics, day care services, clinical examinations and laboratories.

This is by no means a complete representation of clinic operations since information about case-mix and case severity is not present, and also, information concerning quality of health care has not been accounted for. Ideally, in order to make comparisons it is reasonable to aggregate cases in a sensible way so as to reflect the fact that dissimilar cases have dissimilar resource implications. In this way, clinics which may use more resources because they treat more severe or complicated cases will not be penalized when measuring efficiency and productivity. However, this requires high levels of statistical information, which were not available and hence, we selected this model specification which is consistent with the literature in terms of the selection of inputs and proxy outputs (Hollingsworth *et al* 1999).

The model employed is input-oriented and we run it for constant returns to scale (CRS). Model orientation was dictated from the perspective of the analysis (managerial) and from the fact that hospital output, contrary to hospital inputs, is uncontrollable. The dataset was provided by Patras University General Hospital and refers to the period 1998-2005, inclusive. Results were obtained using "DEA.P Version 2.1 for Windows" by Coelli (1996). Statistical correlations were estimated using SPSS. In order to test whether the reforms of 2001 had any impact on efficiency and productivity we analyzed performance before and after than period.

4. Results

In this article we present productivity results for two periods, period 1998 to 2001 before the introduction of health care reforms in the National Health Service and period 2002 to 2005 after the reforms. We also present results on clinic efficiency for the years 2001 and 2005. The results for the constant returns to scale models for the years 2001 and 2005 are illustrated in Table 1. Efficiency scores calculate the extent to which the input of a clinic can be reduced to reach the efficient frontier formed by its peers. Thus, in 2005 two clinics achieved efficiency scores of 100% whereas in 2001 four clinics achieved efficiency. At the other end of the spectrum, with the lowest efficiency scores, the intensive care unit appears to be inefficient in both years. This result was expected due to the specific characteristics of this unit. The mean efficiency score was 78.4% in 2001 and 76.2 % in 2005, in other words technical efficiency experienced a small reduction.

Table 1: Efficiency scores under CRS

Clinics	Efficiency scores 2005	Efficiency scores 2001
General Ward	1.000	1.000
Paediatric	0.679	0.647
Neurological	0.590	0.780
Nephrology	0.616	0.643
Cardiology	1.000	1.000

Dermatological	0.742	0.874
Psychiatric	0.929	1.000
Surgical	0.759	0.663
Otolaryngology	0.731	0.875
Orthopaedic	0.753	0.705
Urology	0.711	0.764
Ophthalmologic	0.836	1.000
Neurosurgical	0.930	0.684
Intensive care unit	0.563	0.578
Gynaecological/Obstetrical	0.587	0.697
Mean	0.762	0.784

Table 2: Productivity changes 1998- 2005

	1998/99	1999/00	2000/01	2002/03	2003/04	2004/05
Geometric Mean	0.985	0.939	1.127	0.999	1.066	0.982
Standard Deviation	0.235	0.116	0.246	0,086	0,116	0,069
Max Progress	1.518	1.134	1.886	1.205	1.304	1.085
Max regress	0.698	0.724	0.941	0.865	0.877	0.868
Clinics regressed	6	5	11	9	4	6
Clinics progressed	9	10	4	6	11	9

The assessment of productivity change is presented in Table 2 for the years 1998-2001 and 2002-2005 respectively. The table displays geometric means derived from the entire sample of clinics, standard deviations, maximum progress and regress, and the number of clinics that either progressed, stayed constant or regressed. On average, there was a 2.5% progress in the year 1998/99 and 6.1% in 1999/2000. In the year 2000/01 the clinics of the hospital regressed, on average, 12.7%. This implies than in order to produce a certain amount of output, the clinics need on average 12.7% more inputs in 2000/01 compared to 1998/99. Overall there was a productivity regress. The overall productivity regress for the period 1998-2001 was 1.4%. Similarly, there was an overall productivity regress in the period 2002-2005 of 1.5%.

Table 3 illustrates the decomposition of productivity. Technical change shows the extent to which the efficient frontier swifts from one period to the next and it reflects the performance of the efficient clinics only. In 1998/99 there was a 2.6% progress followed by a larger progress of 4.3% in 1999/00. In 2000/01 there was a significant regress 20.2% and thus, overall the clinics of the hospital became 3.8% less efficient. In 2002/2003 there was a marginal progress, followed by a 6.6%

regress in the consecutive year which in turn was followed by a small progress of 1.8%.

Technical efficiency change shows the extent to which individual clinics are catching up the efficient frontier formed by their peers. Generally, technical efficiency is moving an opposite direction to that of technical change. In 1998/99 technical efficiency regressed 1.2% and there was a progress of 1.8% and 6.3% in the following years. Thus, the overall technical efficiency progressed 2.4%. A possible explanation for these scores is that whilst efficient clinics were becoming more efficient, inefficient clinics did not catch up. Analogously, technical efficiency progressed in 2002-2005 by 5.5%.

Finally, the decomposition of technical efficiency change shows that scale and pure technical efficiency contribute equivalently. Pure technical efficiency remained constant in 1998/99 and regressed 1.8% in the following period. In 2000/01 pure technical efficiency progressed approximately 5% and hence, the overall progress was 1.3%. Scale efficiency regressed 1.2% in 1998/99 and progressed 3.6% and 1.4% in the successive years. The overall effect of scale and pure technical efficiency change is 1.3% and 1.1%, respectively. In the period 2002-2005 overall pure technical efficiency remained almost constant (progress of 0.1%) whereas, scale efficiency progressed by 5.4%

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Table 3: The decomposition of productivity 1998-2005

	1998/99	1999/00	2000/01	'98-'01	2002/03	2003/04	2004/05	'02-'05
Productivity change	0.985	0.939	1.127	1,014	0.999	1.066	0.982	1,015
Technical change	0.974	0.957	1.202	1,039	1.215	0.933	1.029	1,053
Technical efficiency change	1.012	0.982	0.937	0,977	0.822	1.074	0.955	0,945
Scale	1.012	0.964	0.986	0,987	0.821	1.076	0.957	0,946
Pure technical	1.000	1.018	0.951	0,989	1.001	0.998	0.998	0,999

Model Validation

Nunamaker (1985) advocated that a model must be subjected to a variety of alternative variable sets and specifications. In other words he proposed a form of sensitivity analysis using different variables. A model that shows minor changes in the list of variables is considered robust. Ganley and Cubbin (1992) as reproduced in Parkin and Hollingsworth (1997) suggested that the internal and external validity[6] of a model can be tested by sensitivity analysis in the methods and data used. A test of internal validity is to compare the results obtained using different inputs and outputs,

6 *"Internal validity answers the question –do the methods used alter the results?*

whereas a test of external validity is consistency over time that is to use data from different time periods. Because DEA is a non-parametric method it is not possible to compare directly the efficiency scores produced by different models. However, one can use different model specifications and apply non-parametric correlation tests to compare the overall results. (Valdmanis, 1992), (Parkin and Hollingsworth, 1997).

Table 4: Model specifications

Models	In-patient days	Patient Discharges	Physicians	Nurses	Total Personnel	Beds
Model 1	X	X	X	X		X
Model 2	X	X			X	X
Model 3	X				X	X
Model 4		X			X	X

Table 4 indicates the various specifications of variables used in modelling efficiency and productivity. The first model is the basic model analysed in previous sections. The second model aggregates labour, the third model considers that the sole output of the hospital's clinics is in-patient days. Finally, the fourth model assumes that clinics produce a single output, patient discharges, using two inputs, labour (nurses and doctors) and capital (approximated by the number of beds). Tables 5 and 6 show the Spearman rank correlation coefficients for the results of different models and time periods. The external validity of the basic model, (model 1) is investigated using data from different time periods (1998, 1999, and 2000). Spearman rank correlation test show that there is a statistically significant correlation at 5% ($p<0.05$). It should be noted though that despite the statistically significant correlation between different model's specifications and models using different time data, the size of correlation is small. This may be due to the small sample size. However, small sample sizes facilitate the qualitative study of each individual clinic.

Table 5: Spearman rank correlation (Different models)

	Model 1	Model 2	Model 3
Model 2	0,891*		
Model 3	0,617*	0,440	
Model 4	0,566	0,675*	0,187

* p < .05

External validity answers the question-are the results applicabe more generally?" (Parkin and Hollingsworth, 1997)

Table 6: Spearman rank correlation (Different time periods)

	1998	1999	2000
1999	0,507*		
2000	0,508*	0,731*	
2001	0,207	0,675*	0,794*

* $p < .05$

5. Conclusions

The quantification of hospital efficiency and productivity has become a major concern for both health policy makers and health managers. The methods which have been increasingly used in the computation of efficiency and productivity are Data Envelopment Analysis (DEA) and the Malmquist Productivity Index. These methods have been primarily used at the aggregate level to assess hospital perfomance and inform policy decisions. In this study DEA was applied to a large Greek University General Hospital, operating within the framework of the public Greek National Health System. The scope of the analysis was to assess the efficiency and diachronic performance of its in-patient clinics during a period when reforms were introduced. Clinic operations were represented by means of an input-output model whereby each clinic uses quantities of inputs to generate outputs in the form of services. Specifically, clinics were considered to transform labour (physicians and nurses) and capital (approximated by the number of beds) into services, which were assumed to be approximated by the number of patient discharges and in-patient days. Despite the small sample size of this study validation showed that the input-ouput model proposed here has significant external validity. DEA works better when the product is homogeneous and uni-dimensional and not multiple and heterogeneous like health care. Recently, Health Outcomes measurement has demonstrated dramatic advances and thus, it can provide analysts with a plethora of methods for quantifying hospital output. A particularly interesting research extension is to quantify hospital output in terms of measures such as the number of successful treatments, the prevalence of nosocomial infections, and various mortality, morbidity and standardised survival measures, which account for quality of care.

Notwithstanding the difficulties in conceptualising hospital and clinics in terms of an input-output model, the methodology proposed here can be used to benchmark intra-hospital best practices by looking at the input-output quantities and the production scale of the efficient clinics as identified by the productive efficiency scores, the Input Malmquist Productivity scores and their components. The information derived can be used to improve the performance of inefficient clinics and eventually increase overall hospital efficiency. Furthermore, it is a tool for informing management decisions regarding resource allocation and thus, it is a step towards the benchmarking of clinic's operations, the correction of inefficiencies, and eventually the promotion of efficient intra-hospital performance. The results can be extended and integrated to a quantitative or qualitative study, investigating the various factors in the internal and external environment of clinics that affect their performance.

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