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Assessing Hospital Efficiency: Non-parametric Evidence for Portugal

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Assessing Hospital Efficiency: Non-parametric Evidence for Portugal *

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Abstract

We compute DEA efficiency scores and Malmquist indexes for a panel data set comprising 68 Portuguese public hospitals belonging to the National Health System (NHS) in the period 2000-2005, when several units started being run in an entrepreneurial framework. With data on hospital services' and resource quantities we construct an output distance function, we assess by how much can output quantities be proportionally expanded without changing input quantities Our results show that, on average, the NHS hospital sector revealed positive but small productivity growth between 2000 and 2004. The mean TFP indices vary between 0.917 and 1.109, implying some differences in the Malmquist indices across specifications. Furthermore, there are significant fluctuations among NHS hospitals in terms of individual efficiency scores from one year to the other.

JEL classification: C14, C61, D24, H51, I12

Keywords: Public hospitals, Data Envelopment Analysis, Malmquist indices, Portugal

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* The opinions expressed herein are those of the authors and do not necessarily reflect those of the author's employers.

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Contents

1 – INTRODUCTION

During the period 1992-2003 Portuguese health care expenditure has rapidly increased with the share of public spending in total health spending also increasing from 60% in 1992 to around 70% in 2003. On the other hand, under a new legal framework, the enterprising model for the health sector was the option gradually preferred by the Government. For instance, in the end of 2002 the legal status of 31 hospitals (40 per cent) changed, from public institutions of the Administrative Public Sector (*SPA*) into hospital enterprises (*SA*) with limited liabilities. Whether such changes can spur increases in performance and efficiency regarding the services provided to the public is then a paramount issue in a context of limited public resources.

Data Envelopment Analysis (DEA) has been widely used to calculate changes in Total Factor Productivity within the public hospitals sector, where price data is difficult to find and multi-output production is relevant, since it does not require the imposition of any behavioural assumptions such as revenue maximization or cost minimization (Lovell, 2000). DEA analysis has also been used recently to assess the efficiency of the public sector in cross-country analysis for overall public sector efficiency analysis (Afonso et al., 2005), and to asses local government spending efficiency (for instance for Portugal, Afonso and Fernandes, 2006).

The aim of this paper is to estimate in a non-parametrical framework, measures of hospital technical efficiency across 68 Portuguese hospitals belonging to the National Health System (NHS) during the period 2000-2005. For that purpose we will use both DEA analysis and compute Malmquist indexes. Additionally, the paper also examines heterogeneity and efficiency resulting from the recent "privatisation" of some Portuguese hospitals.

The paper is organised as follows. Section two gives an overview of the Portuguese public hospital sector. Section three reviews the literature on the non-parametric measurement of hospital efficiency and explains the analytical framework used in the paper. Section four conducts our empirical efficiency analysis and discusses the results. Section five concludes.

2 – Overview of the Portuguese public hospital sector

Regarding the institutional framework the Portuguese National Health Care System (NHS) was created in 1979, following the approval of the Constitution in 1976. The health service model then put in place[1] was characterized by universal coverage, equity concerns, and financed via tax revenues. In fact, the Constitution guaranteed to all citizens 'the right to health', to be provided by a universal National Health Service, comprehensive and free of charge.

New principles were introduced in 1990 for the organization and functioning of the health system and assigned an explicit role to the private for-profit and non-for-profit sectors through contracting with the NHS.[2] The objectives of the NHS in promoting efficiency, quality, accountability and devolution of power were also emphasised (see Oliveira and Pinto, 2005; Bentes et al., 2004).

In what concerns hospital care, traditionally it was a much centralised sector dominated by public provision, and according to several authors it was characterized by inefficiency and performed poorly in terms of cost containment.[3] Recently, and following health reform trends in other European countries, a new hospital management law was passed through Portuguese Parliament in 2002.[4] The purpose of this Law was to "enable the changeover of some institutions into public enterprises as well as the set up of a series of entrepreneurial principles such as freedom of choice by the patient, budget contracting, and activity based payment of professionals" (Bentes et al., 2004, pp. 16)).

[1] According to the definition of Docteur and Oxley (2003), the Portuguese health system was put in place as a "public-integrated" model. Nowadays, this model also exists in the Nordic countries, Australia, Italy and Greece.

[2] Law nº 48/90 (see Base XXIV). The reforms introduced in the 1990s have been pushing the Portuguese health system put in place in the late 1970s towards a "public-contract model", characterized by an increased role and participation of the private sector (see Docteur and Oxley, 2003).

[3] See, for example, Dixon and Mossialos (2000) and Oliveira and Pinto (2005). Oliveira (2002) argues that inefficiency arises among Portuguese public hospitals for several reasons such as: (1) the payment system to doctors, traditionally based on collective contracts, gives little incentives for productivity and results mainly in a lack of doctors in the public system; (2) hospital administrations are not encouraged to keep within budgets limits because traditionally they are not penalised for overruns; (3) hospital administrations have little autonomy in what concerns management decisions about investments and human resources.

[4] Law nº 27/2002 that introduced amendments to the 1990 NHS Law.

There are several implications of the new hospital management law (see Lima and Whynes, 2003). First, collective contracts were replaced by individual labour contracts, with hospitals being now free to hire personnel and use different payment systems.[5] Second, it introduced more flexibility in the NHS hospitals management structures and allowed the coexistence of public entities with private entities acting in a cooperative way and sharing the same objective of satisfying patient needs. Third, the traditional concept of the "NHS hospital" was replaced by the new concept of "Network of health care providers", which according to article 2, nº 1 of Law nº 27/2002, includes four types of hospitals: [6]

i. Public providers with financial and administrative autonomy, under public management rules;[7]
ii. Public providers with administrative, financial and asset management autonomy, under private management;
iii. Providers under corporate law, with equity shares and the State as the exclusive shareholder;[8]
iv. Strictly private providers contracted by the State.

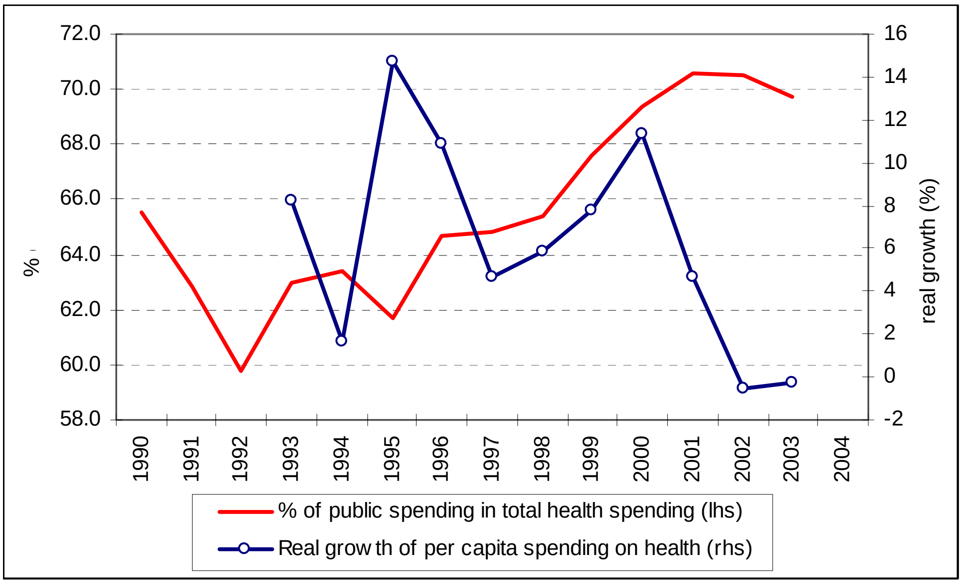
Among the four possible types of hospitals presented under the new legal framework, the enterprising model was the option preferred by the Government. In the end of 2002 the legal status of 31 hospitals (40 per cent) changed, from public institutions of the Administrative Public Sector (*SPA*) into hospital enterprises (*SA*) with limited liabilities.

In 2005, all hospital enterprises (*SA*) along with 2 hospitals that traditionally belonged to *SPA* were transformed into corporate public entities (*EPE*).[9] The purpose of this restructuring strategy was to increase hospital efficiency in terms of output production and financing. At the end of 2006, the NHS comprised the total number of public hospitals (*SPA* and *EPE*) but with different financing and accountability rules.

[5] As mentioned by Oliveira and Pinto (2005, pp. 213), this change "(…) is expected to increase the mobility of human resources, improve performance incentives and reduce inefficiencies in hospitals where the lack of doctors has acted as a constraint on the use of resources."
[6] See article 1, nº 1, Law nº 27/2002.
[7] See Decree-Law nº 188/2003.
[8] See Decree-Law nº 558/1999.
[9] See Decree-Law nº 233/2005.

From a financing perspective, over the last two decades, Portuguese health care expenditure has rapidly increased as a percentage of GDP. Figure 1 reports the annual growth rate of public per capita expenditure on health, in real terms, for the period 1992-2003. The annual growth rate of public per capita expenditure averaged 9.2 percent between 1995 and 2000, and then decreased thereafter. Additionally, the share of public spending in total health spending also increased form 60% in 1992 to around 70% in 2003.

Figure 1 – Public expenditure on health 1990-2004 (Portugal)



Source: OECD.

Although the 1990-2004 period was characterized by increases in public hospitals' provision, namely in the number of outpatient consultations, public health expenditure however grew at a faster rate than production (see Table 1). What is more, for most of the period, length of stay decreased and occupancy rates did not significantly improve. According to Oliveira (2005:215), these contradictory trends "(…) may be interpreted as an indicator for the lack of any efficiency gains."

Table 1 – Hospital utilisation and supply indicators, Portugal (1990-2004)

(Variation in relation to previous year is shown below)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Outpatient consultations (patients observed , by destination) /1	454	466,7	497,2	520	541	590,1	578,5	609	627	633	677	721,3	753,4	800	846
		0,03	0,07	0,05	0,04	0,09	-0,02	0,05	0,03	0,01	0,07	0,07	0,04	0,06	0,06
Average length of stay /1	9,6	9,3	8,8	8,4	8,3	8,2	8	7,8	8	7,9	8,5	8,2	7,9	7,8	7,8
		-0,03	-0,05	-0,05	-0,01	-0,01	-0,02	-0,03	0,03	-0,01	0,08	-0,04	-0,04	-0,01	0,00
Occupancy rate (%) /1	74,2	75,3	69,3	75,9	75,9	75,2	74,6	73,7	74,4	74,9	75,8	75,5	75,9	76,2	76,2
Total expenditure on health per capita, USD PPP /2	670	731	806	875	941	1134	1195	1341	1365	1469	1594	1693	1758	1797	n.a
		0,09	0,10	0,09	0,08	0,21	0,05	0,12	0,02	0,08	0,09	0,06	0,04	0,02	-
Share of **public** expenditure on Total expenditure on health per capita (%) /3	65,5	62,8	59,6	63	63,4	61,7	64,7	64,8	65,4	67,6	69,4	70,6	70,5	69,7	n.a
Annual growth rate of **public** per capita expenditure on health, in real terms /4			-	8,2	1,7	14,7	10,9	4,7	5,9	7,8	11,3	4,7	-0,5	-0,3	n.a
Per capita expenditure on **hospital** care, USD PPP /5	198	241	282	319	346	379	388	n.a.	-	-	-	-	-	-	-

Notes:

n.a. - not available.

/1 Institute of Health Financial Management and Informatics - IGIF (1995-1996) and IGIF Contas Globais do SNS, 1999, 2000; Direcção-Geral da Saúde, Centros de Saúde e Hospitais - Recursos e Produção do SNS, 2000-2004; OECD Health Data, 2003, 2nd edition; OECD Health Data, 2005.

/2 Data for 1991-1994: OECD Health Data, 1998; WHO Health for All Database 1999, IHS-HealthEcon calculations 1999.
Data for 1990 and 1995-1999: WHO Health for All Database, June 2003, IHS HealthEcon calculations 2004; OECD Health Data, 2003, 2nd edition;

/3 Data for 1991-1994: OECD Health Data, 1998; WHO Health for All database 1999, IHS-HealthEcon calculations 1999.
Data for 1990 and 1995-1999: WHO Health for All Database, June 2003, IHS HealthEcon calculations 2004; OECD Health Data, 2003, 2nd edition;
Data for 2000-2003: OECD Health Data, 2003, 2nd edition; OECD Health Data, 2005.

/4 Data for 1992-2003: OECD Health Data, 2005.

/5 WHO Health for All Database, June 2003, IHS-HealthEcon calculations 2004.

3 – Productivity measurement

In this section we briefly review the literature on non-parametric measurement of efficiency, notably regarding the hospital sector, and we also explain the analytical framework used in the paper.

3.1 – Literature review

Following Farrell (1957), economic efficiency, also referred to as X-efficiency, has two distinct components: "allocative efficiency" (AE) and "technical efficiency" (TE). Both components are put together in the overall efficiency (OE) relation as follows:

$$OE = TE \times AE \,. \tag{1}$$

Technical efficiency (TE) refers to producing the maximum output from a set of given inputs (output-oriented) or, alternatively, the capacity to minimise inputs to produce the same level of output (input-oriented). Thus, a decision-making unit (DMU), e.g. a public hospital, is technically efficient when it operates on its production frontier. On the other hand, allocative efficiency (AE) reflects the DMU ability to use the inputs in optimal proportions, in other words, it refers to the use of an input mix that maximizes revenue given output prices. A firm is overall efficient (OE) when it operates on its cost or revenue frontier.

Farrell's efficiency analysis (1957) was proposed in a cross-sectional context. However, dynamic approximations with the objective of quantifying efficiency changes over a period of time are also possible. These are commonly done within the framework of productivity measurement.[10] In this context, productivity is defined as "the ratio of an index of output to an index of input use" and productivity change as "the change of productivity over time".[11]

Index numbers are used to measure the changes in the levels of output produced and input used, between a base period and the current period. There are several index

[10] See, for example, Coelli, Rao and Battese (1998) and Balk (1998).
[11] Hollingsworth, Dawson and Maniadakis (1999, pp. 162).

number formulas. The most popular indices are the Laspeyres and Paasche indices (the former uses the base-period data on quantities or prices as weights, whereas the latter uses current-period's as weights), the Fisher index (a geometric average of Laspeyres and Paasche indices) and the Törnqvist index (which is often presented in a log-change form and is the weighted average change in the log of the price or quantity of a particular good). [12]

All those indices mentioned above rely on two important assumptions about the DMUs' behaviour and technology: (a) DMUs are economically efficient; (b) and technologies exhibit global constant returns to scale.

To allow for inefficiencies one should replace production functions[13] by distance functions (OECD, 2001). Distance functions are representations of multi-output and multi-input technologies which assume neither decision-making units' efficient behaviour nor constant returns to scale. Furthermore, they require only data on input and output quantities (Färe et al., 1994) and can be computed in either the input or output orientations.

The Malmquist (1953) productivity index (MPI), first proposed and later introduced in the productivity measurement literature by Caves, Christensen and Diewert (1982), is defined in terms of distance functions and it is based on Malmquist's proposal to construct quantity indices as ratios of distance functions in the context of consumer theory .

The MPI measures the total factor productivity (TFP) change between two data points in terms of ratios of distance functions. Färe et al. (1994) extended further the MPI to measure hospital productivity. These authors took the Malmquist index defined in Caves, Christensen and Diewert (1982), and illustrated how the component distance

[12] For the measurement of the rates of change of outputs, inputs and productivity, these indices are usually linked together to make annual comparisons of consecutive years over a given period. This means that for every index for period t+1, period t provides the base. There is a strong preference in the literature in favour of chained indices because they involve only comparisons with consecutive periods, measuring smaller changes. Therefore, and according to Coelli, Rao and Battese (1998), some of the approximations involved in the derivation of theoretically meaningful productivity indices are more likely to hold.

[13] Production functions are representations of technologies which assume that firms operate technically in a efficient way.

functions could be estimated using Data Envelopment Analysis (DEA), a non-parametric technique. Moreover, they were the first to show how the resulting TFP indices could be decomposed into an efficiency change part and a technical change part (see Balk (1998)).

The advantage of the Malmquist index is that, when panel data are used, it allows the description of multi-output and multi-input production technologies requiring neither a priori behavioural assumptions about the production technology nor input or output price data (Coelli, Rao and Battese, 1998). Instead, it replaces them "with information on the structure of best practice service delivery technology" (Lovell, 2006, pp. 151). Furthermore, once the production technology is estimated, this measurement technique is capable of decomposing TFP into its two component parts: efficiency change and frontier change.

The properties mentioned above make the Malmquist index approach more appealing for measuring technical efficiency and productivity change in the public sector.[14] Indeed, price data are not in general available in the public sector or, if they exist, they do not reflect the marginal costs. This is particularly true in the case of public hospitals producing multiple outputs.

There are two main frontier estimation methods that are based either directly or indirectly upon a Malmquist index of the change in TFP: (i) stochastic frontier analysis (SFA) and (ii) data envelopment analysis (DEA). Although both SFA and DEA are efficiency measurement techniques capable of dealing with panel data, they do differ remarkably between each other. On one hand, stochastic production functions measure deviations from the ideal production frontier with an additional error term which denotes the inefficiency in the production. Despite of attempting to distinguish the effect of noise from the effect of inefficiency, SFA distance functions are parametric and deterministic and as such they may confound "the effect of omitted variables and measurement errors, as well as possible misspecification of the functional form" (Jacobs, Smith and Street, 2006).[15]

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[14] See Jacobs, Smith and Street (2006).

[15] The parametric approach in efficiency measurement was introduced by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). According to several authors (Coelli, 2002;

On the other hand, DEA is a non-parametric[16] local index, which means that it needs fewer assumptions about the form of the production technology than SFA, allowing productivity change and its components to be "producer-specific" (Jacobs, Smith and Street, 2006). By contrast, it cannot distinguish between statistical noise and inefficiency.

However, DEA became widely used to calculate changes in TFP within the public hospitals sector, where price data is difficult to find and multi-output production is relevant, because it needs fewer assumptions about the form of the production technology than SFA, thus not requiring the imposition of any behavioural assumptions such as revenue maximization or cost minimization. DEA analysis has also been used recently to assess the efficiency of the public sector in cross-country analysis in such areas as education, health (Afonso and St. Aubyn, 2005, 2006), for overall public sector efficiency analysis (Afonso et al., 2005), and to asses local government spending efficiency (Afonso and Fernandes, 2006).

Among dynamic approximations with the objective of quantifying the evolution of productivity over a period of time, the most widely used in DEA environment is the Malmquist productivity index.[17] In Table 2 we review some non-parametric applications measuring hospital efficiency with panel data.

Hollingsworth, Dawson and Maniadakis, 1999; 162), the main reference in this field is Nishimizu and Page (1982), because it was only afterwards that productivity changes started to be attributed to an efficiency component besides the technological one. Nishimizu and Page (1982) applied the linear programming methods proposed by Aigner and Chu (1968) to social sector panel data of Yugoslavia to construct parametric production frontiers and measured productivity growth as the sum of two components: efficiency change and technical change.

[16] Nonparametric frontier methods measure the efficiency of a DMU by the distance between the DMU's observed level of inputs and outputs and the best practice production frontier. This distance measure was introduced by Shepard (1970) and first made operational by Farrell (1957). Charnes, Cooper and Rhodes (1978) formulated it into a linear programming model (DEA). For a survey of DEA methodologies, see for example, Seiford and Thrall (1990).

[17] See Grosskopf (1993), Färe, Grosskopf and Roos (1997), Coelli, Rao and Battese (1998), Hollingsworth, Dawson and Maniadakis (1999) and Hollingsworth (2003).

Table 2 – Non-Parametric Hospital Efficiency with Panel Data

Reference	Data sample	Method (a)	Variables	
			Input	Output
Färe, Grosskopf, Lindgren and Roos (1994)	Small and middle-sized non-teaching hospitals in Sweden (1970-1985)	DEA	Real labour input; real non-labour input. (b)	Inpatient discharges; long-term patient bed days (representative cost drivers of long-term chronic care); doctors' visits (proxy of ambulatory care). (c)
Burgess and Wilson (1995)	U.S. hospitals (1985-1988)	DEA	Acute care inpatient days; case-mix weighted acute care inpatient discharges; long-term care inpatient days; number of outpatient visits; ambulatory surgical procedures; inpatient surgical procedures.	**Direct outputs:** number of acute-care hospital beds, weighted by a scope-of-services index; number of long-term hospital beds; registered nurses measured in FTE; licensed practical nurses measured in FTE; other clinical labour measured in FTE; non-clinical labour measured in FTE; long-term care labour measured in FTE. (d)
Linna (1998)	Acute care hospitals in Finland (1988-1994)	DEA; SFA	**Cost variable**: net operating costs; **Fixed factor variable**: total number (TN) of beds; **Price variables**: average hourly wage rate of labour; annual price index for local government health care expenditure.	**Outputs**: Total number (TN) of emergency visits; total sum of schedule and follow-up visits; DRG-weighted number of total admissions; TN of bed-days exceeding the cut-off point defined in the outlier analysis; Number of residents receiving 1 year of training; TN of on-the-job training weeks of nurses; TN of impact-weighted scientific publications; **Exogenous variables**: teaching dummy indicating the teaching status of the hospital; readmission rate for the admissions; year of the observation.
Maniadakis, Hollingsworth and Thanassoulis (1999)	Hospitals in Scotland (1991-1996)	DEA	Doctors; nurses; other personnel; beds; 100 cubic meters of building; admissions for stroke; admissions for fractured neck of femur; admissions for myocardial infraction.	**Intermediate outputs**: accident and emergency attendances; adjusted outpatient attendances; adjusted day cases; adjusted inpatient discharges. (e) **Output (final)**: Standardised survivals after admission for stroke; standardised survivals after admission for fractured neck of femur; standardised survivals after admission for myocardial infraction. (f)
McCallion, Glass, Jackson, Kerr and McKillop (2000)	Northern Ireland hospitals in UK (1986-1992)	DEA	Nursing staff; administrative staff; ancillary staff; specialists; bed complement.	Total number of inpatients (using discharges rather than length of stay) and outpatients registered in the following four output categories: general surgery; general medical; maternity; accident and emergency.
Sommersguter-Reichmann (2000)	Hospitals in Austria (1994-1998)	DEA	Full-time-equivalent of labour; total number of beds; total expenses for external medical services.	Number of patients treated in the outpatient care unit; total number of credit points according to the crucial sector multiplied with a steering factor.
Maniadakis, and Thanassoulis (2000)	Acute hospitals in Scotland (1991-1996)	DEA	Doctors (WTE); nurses (WTE); other personnel (WTE); beds (annual staffed); cubic meters (per 100); price variables.	Accident and emergency attendances; adjusted outpatients; adjusted day cases; adjusted inpatients.
Zere (2000); Zere, McIntyre and Addison (2001)	Non-academic Western Cape (South Africa) hospitals (1992-1998)	DEA	Hospitals Level I and II: total recurrent expenditure (including salaries of personnel, expenditure on drugs and other supplies); bed-size. Hospitals Level III: recurrent expenditure.	Inpatient days; outpatient visits.

Table 2 (cont.)

Reference	Data sample	Method	Variables	
			Input	Output
Chirikos and Sear (2000)	Florida (USA) acute care hospitals (1982-1993)	DEA; SFA	Cost or annual expenses are broken down by six categories: (1) wage and salary payments to personnel engaged in patient care activities; (2) wage and salary payments to personnel engaged in all non-patient care centres; (3) other expenses in patient care cost centres; (4) capital costs - adjusted depreciation charges - for plant assets; (5) adjusted depreciation charges for fixed and movable equipment; (6) other non-patient (administrative) costs attributable to capital use. (g)	**Intermediate products**: total admissions scaled by mean DRG weights; inpatient days net of the day of admission divided by three categories - Medicare; Medicaid; Blue Cross, other private payers, and self-pay patients; two composite indexes of outpatient service activity - one reflects the provision of special tests and procedures and it is cast in admission-equivalent terms, and the other measures the level of activity in ambulatory centres generating outpatient revenue in emergency room-equivalent terms.
Linna (2000)	Finnish hospitals (1988-1994)	DEA	**Personnel**: number of doctors in full time equivalents; number of other staff in full time equivalents; **Cost variables**: total cost of material and equipment; **Beds**: total number.	**Outpatient treatment**: total number of emergency visits; total sum of scheduled and follow-up visits; **Inpatient treatment**: DRG-weighted number of total admissions; DRG-weighted number of total episodes; total number of bed-days exceeding the cut-off point defined in the outlier analysis; **Teaching variables**: number of residents receiving one year of training at the hospital; total number of on-the-job training weeks of nurses; **Research variable**: total number of impact-weighted scientific publications.
Solà and Prior (2001)	Spanish (Catalan) hospitals (1990-1993)	DEA	**Health staff**: full-time medical and nursing personnel; **Other staff**: other non-health care staff, also full-time; **Beds**: number of beds assigned to continuous care of patients admitted; **Materials**: total value of current purchases in Spanish pesetas.	**Outputs** Acute: in-patient days spent in medical care, surgery, obstetrics, gynaecology and paediatrics; Long-stay: in-patient days spent in long-stay care and psychiatry; Intensive: in-patient days spent in intensive care; Visits: medical care on an outpatient basis, for the diagnosis, treating and monitoring of illness. (h) **'Undesirable outputs'** (i) Prevalence of nosocomial infections: number of clinically active infections divided by the number of patients studied.

Notes:
(a) DEA - Data Envelopment Analysis; SFA - Stochastic Frontier Analysis.
(b) Real labour input was estimated in two steps: first, average labour expenditure per hour is estimated for four types of labour in the hospital sector; then, a labour expenditure index is estimated for each hospital, which is used to deflate annual total labour expenditure. The consumer price index was used to deflate non-labour hospital expenditures.
(c) See Breyer (1987).
(d) FTE - Full Time Equivalents.
(e) Three intermediate outputs were adjusted for case-mix.
(f) This input-output set tries to capture the quality of services produced.
(g) These six categories are used directly in the DEA model; the sum of the six items is used to construct the dependent variable in the SFA model. Annual cost is scaled by a cross-sectional, state hospital price index that adjusts for nominal differences in input prices across local hospital markets.
(h) The authors understand "in-patient days" as the combination of night stay and the time corresponding to the serving of a main meal (lunch or supper).
(i) The authors understand "undesirable outputs" as lack of quality.

3.2 – Malmquist Productivity Index

In this sub-section we briefly explain the Malmquist productivity index (MPI), which we will use ahead in the empirical analysis. We begin by specifying the production technology using the output set as follows:

$$P(x) = \{y: x \text{ can produce } y\}, \tag{2}$$

where $P(x)$ represents the set of all outputs vector, y, which can be produced using the input vector, x. Assuming that technology satisfies several axioms,[18] the distance function (output oriented) is defined by

$$d_0(x, y) = \min\{\delta : (y/\delta) \in P(x)\}. \tag{3}$$

If y is an element of $P(x)$, the scalar δ will assume a value equal or inferior to one if y is on or above the production possibilities frontier, respectively. The values given by (3) are then used to calculate the MPI.

Following Färe et al. (1994), the output-oriented Malmquist TFP[19] change between period t and period $t+1$ is given by:

$$m_o(y_t, x_t, y_{t+1}, x_{t+1}) = \left[\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)} \times \frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_t, x_t)}\right]^{1/2}, \tag{4}$$

where $d_o^t(y_{t+1}, x_{t+1})$ represents the distance from the period $t+1$ observation and the period t technology. A value of m_o >1 indicates growth in productivity from period t to period $t+1$ whereas a value of m_o <1 indicates a decline.

This approach differs from the formulation of the Malmquist productivity index proposed by Caves, Christensen and Diewert (1982) because equation (4) is the

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[18] See Coelli, Rao and Battese (1998).

[19] In an output distance function, the objective is to maximize the proportional expansion of the output vector for a given input vector.

geometric mean of the shift in technology between the two periods, t and $t+1$. The first uses reference technology corresponding to period t, whereas the second does the same for period $t+1$. This procedure is used to avoid the necessity to arbitrarily choose one or other period as the reference base.

Färe et al. (1994) further decomposed the Malmquist index into two components: one measuring efficiency change and another measuring frontier change as follows:

$$m_o(y_t, x_t, y_{t+1}, x_{t+1}) = \frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)} \times \left[\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_{t+1}, x_{t+1})} \times \frac{d_o^t(y_t, x_t)}{d_o^{t+1}(y_t, x_t)} \right]^{1/2}, \qquad (5)$$

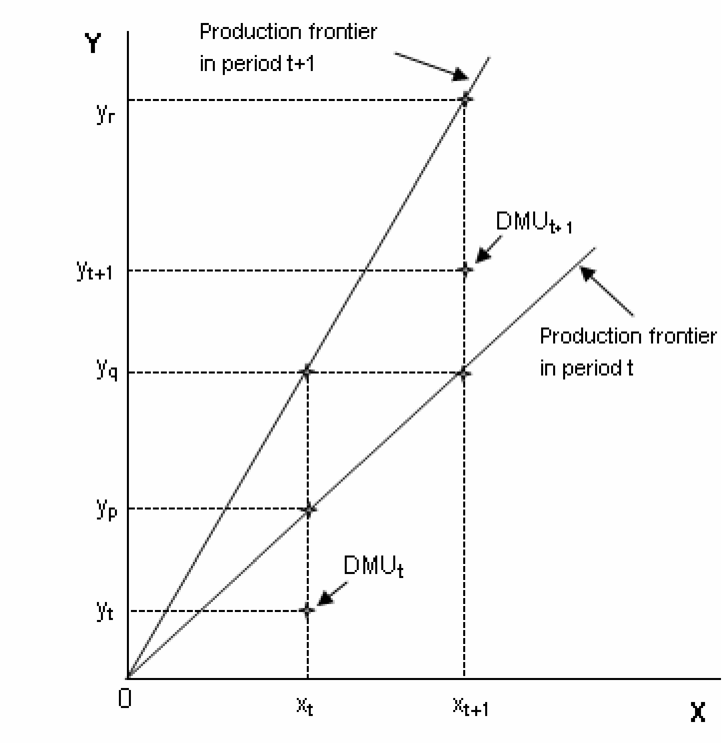
or equivalently $M = E \times T$.

The ratio outside the square brackets in the right-hand side of (5), denoted as E, indicates the levels of efficiency relative to the boundaries for years t and $t+1$ and whether or not a movement towards or away from the best-practice frontier has occurred between these two periods, t and $t+1$. The expression inside the square brackets in the right-hand side of (5), denoted by T, reflects technical change measured by the geometric mean of the movements experienced by the best-practice technology between period t and $t+1$. The interpretation of the results is similar for both coefficients: a value greater than one indicates improvement from period t to period $t+1$, whereas a value of less than one indicates a decline.

Figure 2 illustrates the definition and measurement of the output-oriented Malmquist index for the simple case where a DMU (e.g. a public hospital) uses only a single type of input, x, to produce a single type of output, y.

In the example depicted in Figure 2, the DMU is producing at a level of productivity less than what is feasible under each period's production frontier. The MPI indicates under constant returns to scale technology the potential rise in productivity as the frontier shifts from period t to $t+1$. For example, the DMU at time t could produce output y_p for input x_t; with the same input x_t it could produce output y_q at period $t+1$.

Figure 2 – Output-oriented Malmquist Productivity Index (MPI) Using Constant Returns to Scale



The decomposition of the Malmquist index according to equation (5) is given by the distance functions in equations (6) and (7):

$$E = \frac{y_{t+1} / y_r}{y_t / y_p} \tag{6}$$

$$T = \left[\frac{y_{t+1} / y_q}{y_{t+1} / y_r} \times \frac{y_t / y_p}{y_t / y_q} \right]^{1/2} . \tag{7}$$

According to equations (6) and (7), efficiency change (*E*) is the ratio of the output-oriented measure of Farrell technical efficiency in period *t+1* to that in period *t* and technical change (*T*) is the geometric mean of the shift in technology between period *t+1* and *t*.

If we calculate the Malmquist index in a DEA environment assuming constant returns to scale technology (CRS), then four linear programming problems should be solved for each hospital to compute the four distance functions which appear in equation (4) in each pair of adjacent time periods. The four output-oriented DEA linear programs are given in equations (8) to (11):

$$\begin{aligned} &\left\{d^{t+1}(y_{t+1}, x_{t+1})\right\}^{-1} = \max_{\phi,\lambda} \Phi \\ &s.t. \\ &-\Phi y_{i,t+1} + Y_{t+1}\lambda \geq 0 \qquad ; \\ &x_{i,t+1} - X_{t+1}\lambda \geq 0 \\ &\lambda \geq 0 \end{aligned} \tag{8}$$

where Φ is the technical efficiency, Y is the output matrix, $\lambda(N \times 1)$ is a vector of constants, and X is the input matrix,

$$\begin{aligned} &\left\{d^{t}(y_{t}, x_{t})\right\}^{-1} = \max_{\phi,\lambda} \Phi \\ &s.t. \\ &-\Phi y_{i,t} + Y_{t}\lambda \geq 0 \qquad ; \\ &x_{i,t} - X_{t}\lambda \geq 0 \\ &\lambda \geq 0 \end{aligned} \tag{9}$$

$$\begin{aligned} &\left\{d^{t+1}(y_{t}, x_{t})\right\}^{-1} = \max_{\phi,\lambda} \Phi \\ &s.t. \\ &-\Phi y_{i,t} + Y_{t+1}\lambda \geq 0 \qquad ; \\ &x_{i,t} - X_{t+1}\lambda \geq 0 \\ &\lambda \geq 0 \end{aligned} \tag{10}$$

$$\begin{aligned} &\left\{d^{t}(y_{t+1}, x_{t+1})\right\}^{-1} = \max_{\phi,\lambda} \Phi \\ &s.t. \\ &-\Phi y_{i,t+1} + Y_{t}\lambda \geq 0 \qquad . \\ &x_{i,t+1} - X_{1}\lambda \geq 0 \\ &\lambda \geq 0 \end{aligned} \tag{11}$$

Equations (8) and (9) represent the case where a data point observed in a period is compared to the frontier of that period. Similarly, in equations (10) and (11), data points are compared to the frontier of the previous period. Equations (8) to (10) should be solved once for each DMU.

To construct a chain index, it is necessary to solve for $N*(3T-2)$ linear programs, where N is the number of DMUs and T is the number of time periods (Coelli, Rao and Battese, 1998). For example, in the case of 68 hospitals across five years, our maximum data set, it is necessary to solve 884 linear programs, i.e. [68*(3*5-2)].

4 – EMPIRICAL ANALYSIS

4.1 – Data

In our analysis we envisage individual or merged NHS hospital as organizations that annually transform health services (y) from the consumption of several factors of production or inputs (x). Data on hospital production were sourced mainly from the Portuguese Health General Directorate's annual statistics, *Centros de Saúde e Hospitais - Recursos e Produção do SNS*. These annual statistics measure consistently since 2000 the same aspects of hospital activity, which allows overcoming some of the problems that may occur when dealing with longitudinal data.[20]

Our data set consists of 68 annual observations regarding hospital production during the period 2000-2005. The number of our observations does not change over the period, in order to construct a balanced panel.[21]

In Portugal, hospitals are classified within three categories: central, district and district level one. This classification indicates the number of specialities which a given hospital is equipped to treat, reflecting the type of services it may offer. For example, district hospitals level one (DH1) only provide internal medicine, surgery and a few basic specialities whereas district hospitals (DH) provide a considerable range of specialized

[20] As pointed by Jacobs, Smith and Street (2006), longitudinal data on hospital production can be affected by changes over time in data collection methods, technology, and by hospitals' merger activity.

[21] We excluded from our data set Psychiatric Hospitals, Regional Centers of Alcohology (*Centros Regionais de Alcoologia*), Recovering Psychiatric Centers (*Centros Psiquiátricos de Recuperação*), and Oncology Institutes (*IPO*). Indeed, the aforementioned NHS entities are defined by the Portuguese Health General Directorate as specialized health institutions.

services.[22] By contrast, central hospitals (CH) provide specialized services with advanced technology and highly qualified human resources. In this context, hospitals with the fewest number of specialities treat simpler cases, and if we compare them with DH and CH they are less equipped with advanced medical technology such as the computerised axial tomography scanners (CAT).

In Table 3 the 68 hospitals are distributed among the abovementioned three categories within each region. Accordingly, 46 per cent of the hospitals observed are district hospitals (DH), of which 41 per cent are in the *Centro* region. On the other hand, 29 per cent of the hospitals are central hospitals (CH),[23] of which 55 per cent belong to the *LVT* region. District hospitals level one (DH1) represent 25 per cent of our sample, of which almost 60 per cent belong to *Centro* region. It should be noted that there are no CH or DH1 in either *Alentejo* or in *Algarve* regions.

Table 3 – Distribution of observations by hospital category and by region (2005)

Region	Type of Hospital/Merger			Total
	CH	DH (a)	DH1	
Alentejo	-	3	-	3
Algarve	-	1	-	1
Centro	2	13	10	25
LVT (b)	11	6	2	19
Norte	7	8	5	20
Total	20	31	17	68

Notes: (a) The hospital Amadora-Sintra was included in this category.
(b) Lisboa e Vale do Tejo.

In 2005, only 57 per cent of the hospitals observed belonged to the general government sector (SPA).[24] The remaining 41 per cent had been transformed, in 2002, into hospital companies (SA).[25]

As mentioned by Quintela, Carvalho and Tranquada (2006:5), changes in hospital output may occur due to "(…) merging, splitting, creation and disappearance of units". In contrast, "(…) the [hospital] output trend should not be affected by changes in the

[22] See OECD (2004, pp. 57).
[23] Of which 3 are teaching hospitals: S. João (in Porto), Santa Maria (in Lisbon) and Universidade de Coimbra (in Coimbra).
[24] The hospital Amadora-Sintra was included in distinct category named "others".
[25] In 2005, all hospitals SA were transformed into entrepreneurial public entities (*EPE*) along with 2 more SPA hospitals (see article 1 of Decree-Law nº 233/2005). Tables I and II in the Appendix list all SPA and SA/EPE hospitals in function by 2006.

legal status especially when the unit continues to be engaged in the same activity the same way." Having this in mind, we only consider in the analysis those mergers[26] that were created before or during 2000. As for the identification of the hospitals' legal status, the distinction between SA (henceforth, EPE) and SPA hospitals that came into force only in 2003, was applied to our sample from 2000 onwards.

In what concerns the input variables, we use the number of active doctors (DOCTORS), nurses (NURSES) and other staff (OTHERSTAFF) to measure labour input, and the number of available beds for inpatient treatment (BEDS) to proxy capital input. Moreover, a range of outputs are considered in our analysis (see Table 4).[27] These variables consist of *volume* measures that according to the literature reflect the quantity of hospital service provision (intermediate output) and not hospital outcomes (improved health status).

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[26] Hospitals' merger activity refers to the congregation of two or more hospitals of different nature but with resource centralization.

[27] Since no information is available on the relative importance of certain outputs, we do not apply weight restrictions in the analysis.

Table 4 – Variables used in the empirical analysis (a)

Variable	Description	Observations
		Intermediate outputs
INPAT-ICM	ICM-weighted number of patients who leave hospital after inpatient admission.	Number of patients who leave hospital after inpatient admission in that period, weighted by the respective index of case-mix (ICM). The ICM is defined as the ratio between the total number of equivalent patients weighted by the relative share of the corresponding *Diagnosis Related Group* (*GDH*) and the total number of equivalent patients.[28]
INPAT-DAYS	Hospitalisation days	Total days used by all inpatients, measured for a given time period, and excluding the exit day.
OUTPAT	Number of outpatient visits	
EMERG	Number of emergency episodes	
SURGERY	Number of surgeries produced	
CAT	Categorical variable indicating the possession of CAT equipment: 2 if it exists; 1 otherwise	Only NHS hospitals that had CAT in 2000 were considered. This variable tries to capture an increasingly important branch of hospital activity: *diagnosis*.
		Inputs
DOCTORS	Number of active doctors	Health professionals that in the final day of the reference period worked in a given hospital.
NURSES	Number of active nurses	Health professionals that in the final day of the reference period worked in a given hospital.
OTHERSTAFF	Number of active workers other than doctors and nurses	Health professionals that in the final day of the reference period worked in a given hospital.
BEDS	Number of available beds	Number of available beds for inpatient treatment.

(a) Source: Directorate-General of Health (DGS).

Although there are claims in the literature that the final hospital output or outcome is improved health status of the population, which in turn is affected by various factors other than health care, such as mother's health, housing, education or food (see Färe et al., 1997), there is nonetheless a general agreement that measuring improvements in health status is very difficult mainly due to the multi-dimensional nature of health itself, the extreme subjectivity of measuring realities such as patient's improved health status and quality of life and the lack of proper information.

Thus, it is common to approach hospitals outputs by volume measures that do not intend to reflect the quality of the service rendered but are assumed to somehow positively

[28] Data on the case-mix index was provided by *Administração Central do Sistema de Saúde* (ACSS) upon our request. ACSS is a public institute responsible for the management of the financing system of the NHS.

influence the health status of the population (Breyer, 1987).[29] In this context, we measure the number of hospitalised treated patients weighted by the respective index of case-mix (INPAT-ICM),[30] the total number of inpatient days (INPAT-DAYS), of outpatient visits (OUTPAT), of emergency episodes (EMERG-TOT) and of surgeries produced (SURGERY). We also consider a *categorical variable* indicating if a given hospital has or has not CAT equipment since 2000 (CAT).

Table 5 summarises the descriptive statistics of our data set, where we observe the significant positive relative change of both the number of outpatient visits and of surgeries between 2000 and 2005. By contrast, there was a slight decrease in the average number of available beds and in hospitalisation days for the same period.

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29 See also Grosskopf and Valdmanis (1987).

30 To take into account the hospital case-mix, we weighted the number of treated patients by the corresponding index of case-mix (ICM) that is annually estimated by *Instituto de Gestão Informática e Financeira da Saúde* (IGIF) – variable INPAT-ICM.

Table 5 – Descriptive statistics of input and output variables

	Indicators	2000	2001	2002	2003	2004	2005
Inputs	Beds						
	Mean	296	313	283	282	281	283
	Min.	28	13	17	8	22	18
	Max.	1628	1628	1525	1530	1548	1505
	Doctors						
	Mean	189	204	192	185	185	189
	Min.	8	7	7	8	8	8
	Max.	1401	1401	1146	1090	1081	1148
	Nurses						
	Mean	313	333	319	323	332	342
	Min.	24	25	25	27	27	32
	Max.	1535	1542	1616	1559	1692	1727
	Other Health Staff						
	Mean	481	506	484	508	495	504
	Min.	56	56	58	54	73	74
	Max.	2143	2293	2165	4185	2401	2481
Outputs	Inpatient Days						
	Mean	81745	85531	78293	78174	78176	79552
	Min.	2912	2722	3804	1405	3145	2818
	Max.	456801	456801	433207	441944	443051	437080
	Outpatient Visits						
	Mean	77350	85719	84206	90913	97424	102819
	Min.	5554	8544	5259	8271	9146	9941
	Max.	370046	394482	414475	444505	467734	495145
	Emergencies						
	Mean	81272	86148	81540	86243	79953	81802
	Min.	4196	4346	707	3991	2462	781
	Max.	225597	230609	225727	249420	233600	235111
	Emergencies: treatment in the same hospital						
	Mean	6757	7823	7078	7247	7221	7152
	Min.	24	276	174	143	215	195
	Max.	28369	28517	28524	27374	25214	25161
	Emergencies: transfer to another hospital						
	Mean	2358	2557	2670	2608	2530	2475
	Min.	8	14	9	8	10	12
	Max.	11419	11419	11277	9154	7586	6739
	Inpatients weighted by ICM						
	Mean	10887	11955	11395	11629	11848	12128
	Min.	1325	1089	1202	492	544	1118
	Max.	61722	62697	66404	66267	72745	69785
	Surgeries						
	Mean	4948	5681	5302	5727	5885	6045
	Min.	314	382	233	233	15	426
	Max.	35457	37428	33132	32444	28970	34199

4.2 – Model specifications

We use data on hospital services' and resource quantities to construct an output distance function, thus addressing the question: by how much can the (intermediate) output quantities increase proportionally without changing input quantities? This approach is consistent with the assumption that hospital managers behave as "resource-constrained service maximisers" (see Lovell, 2002).

Valdmanis (1992), based on Nunamaker (1985), recommends that researchers should specify within a DEA analysis different models from the dataset to evaluate whether the ranking and efficiency of an individual DMU is variable-specific (or model-specific) or whether the results are robust to changes in dataset specifications.[31] Consequently, first we defined a basic model and then we introduce changes that took the form of alternative input/output definitions and/or the definition and selection of different populations within our dataset.

In Table 6 we characterise the alternative models used in our analysis. In our basic model (Model I) we only consider input and output variables for which we have information for all the 68 hospitals for the 2000-2005 period (4 input and 5 output variables), thus guaranteeing a balanced panel.

In order to test the effect of decreasing the number of input and output variables, we specify Model II (2 input and 3 output variables).

As noted before, the classification of the hospitals may to some degree take account of hospital's case-mix and factors likely to affect the service rendered such as staffing qualifications and medical technology used. To also take into account these differences in our analysis, we specified Models III and IV where we selected within our dataset only district hospitals and district level one hospitals. However, we added to the analysis two more output variables because there is more information for this subgroup in terms of outputs compared to the basic model (Model I). The cross-section sample

[31] Another option is to compare the results of a DEA study with results from other efficiency evaluation methods (e.g. SFA) applied to the same dataset.

belonging to this group consists of 48 hospitals, 31 of which are district hospitals, and 17 are district hospitals level one.

The instability of the environmental context and of the regulatory regime of the NHS hospitals spurred by the 2002 reform motivated the specification of Models V and VII, where we individualize two sub-groups, SPA hospitals and SA/EPE hospitals, respectively. In Model V and VII we use the same input and output variables specified for Model I. Model VI and VIII only differ from the previous models in what concerns the output measures used.

In order to test the homogeneity of our observations, we define two sub-groups of hospitals based on the following criteria: those with CAT equipment since 2000 (34 hospitals), and those without CAT equipment since 2000 (34 hospitals), thus dividing our initial sample into two equal parts.

Table 6 – Model Specifications

Models	**Indicators**				**Nº of DMUs**	**Description**
	Inputs	#	Outputs	#		
I	BEDS; DOCTORS; NURSES; OTHERSTAFF	4	INPAT-DAYS; OUTPAT; EMERG-TOT; INPAT-ICM; SURGERY.	5	68	These models include all observations.
II	BEDS; HEALTHSTAFF	2	OUTPAT; EMERG-TOT; INPAT-ICM.	3		
III	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT; EMERG-TOT; INPAT-ICM; SURGERY.	5	48	These models only consider district (DH) and district level-one (DH1) hospitals.
IV	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT; EMERG-TOT; EMERG-NONTRANSF; EMERG-TRANSF; INPAT-ICM; SURGERY.	7		
V	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT; EMERG-TOT; INPAT-ICM; SURGERY.	5	34	These models only consider SPA hospitals.
VI	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT; EMERG-TOT; EMERG-NONTRANSF; EMERG-TRANSF; INPAT-ICM; SURGERY.	7		
VII	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT; EMERG-TOT; INPAT-ICM; SURGERY.	5	28	These models only consider SA/EPE hospitals.
VIII	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT; EMERG-TOT; EMERG-NONTRANSF; EMERG-TRANSF; INPAT-ICM; SURGERY.	7		
IX	BEDS; DOCTORS; NURSES; OTHERSTAFF	4	INPAT-DAYS; OUTPAT; EMERG-TOT; INPAT-ICM; SURGERY.	5	34	These models only consider hospitals with CAT equipment in 2000.
X	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT; EMERG-TOT; EMERG-NONTRANSF; EMERG-TRANSF; INPAT-ICM; SURGERY.	7		
XI	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT; EMERG-TOT; INPAT-ICM; SURGERY.	5	34	These models only consider hospitals *without* CAT equipment in 2000, regardless of having bought it afterwards.
XII	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT; INPAT-ICM; SURGERY.	4		
XIII	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT EMERG-TOT; INPAT-ICM; SURGERY.	5	62	These models only consider hospitals with emergency service information
XIV	BEDS; DOCTORS; NURSES; OTHERSTAFF.	4	INPAT-DAYS; OUTPAT EMERG-TOT; EMERG-NONTRANSF; EMERG-TRANSF; INPAT-ICM; SURGERY.	7		

Finally, we test two models (Models XIII and XIV) where only the NHS hospitals with emergency service information were considered.[32]

4.3 – Results and discussion

We now turn to evaluate the productivity growth in the service provision of hospitals by subjecting the data to a Malmquist index analysis.[33] Additionally, in order to test if there is any potential for efficiency and productivity improvements by the Portuguese NHS hospitals and, if so, to quantify the corresponding magnitudes, the data was further subjected to a yearly DEA analysis. Here, it is assumed that hospital managers attempt to maximise the services that they provide and that such services can be approximated by the indicators discussed in the preceding section. The DEA formulation that we use in this study corresponds to the Charnes, Cooper and Rhodes (1978) formulation.[34]

Table 8 shows the evolution (annual means) of the Malmquist TFP index and of its technological (*T*) and efficiency (*E*) components between 2000 and 2005 for Model I.

Table 8 – Mean Productivity Indices for Model I (2000-2005)

	Efficiency Change (E)	Technical Change (T)	TFP /1
00/01	0.973	1.058	1.029
01/02	1.030	0.974	1.003
02/03	1.016	0.994	1.010
03/04	0.991	1.019	1.010
04/05	1.051	0.924	0.971
Mean	1.012	0.993	1.004

/1 TFP - Total Factor Productivity.

Preliminary estimates for our basic model (Model I) show that, on average, the NHS hospital sector revealed positive but small productivity growth (TFP) levels between 2000 and 2004, whereas in 2005 there was a slight decrease in TFP. It is also possible to

[32] Hospitals without emergency service information are the following ones: H. Santa Marta, H. Pulido Valente, H. Santa Cruz, H. Ortopédico de Outão, H. Joaquim Urbano and Instituto Oftalmológico Gama Pinto.

[33] Measures of DEA distance functions and of Malmquist TFP index and its components (EC and TC) were estimated using the DEAP programme. The estimated DEA model imposes constant returns to scale, an option in line with the literature reviewed in Table 3.

[34] For a detailed description of the DEA linear programming problem imposing constant returns to scale, see Grifell-Tatjé and Lovell (1995) and Coelli, Rao and Battese (1998).

conclude from Table 8 that the "efficiency change" component of TFP plays, on average, a major role in productivity growth than the "technical change" component.

Furthermore, the TPF summary estimates for individual hospitals (annual means) indicate that more than half of the NHS hospitals observed (42 out of 68) show either positive or no relative change in TFP between 2000 and 2005, whereas the remaining hospitals (26) show TFP decline (see Table A4 in the Appendix).

Table 8 summarises changes in total factor productivity (TFP) for our basic model (Model I) and for the several alternative specifications using the variables listed in Table 6. Additionally, we report in Tables A5a-A5c in the Appendix the variation of TFP indices and its components over time for all models (see Table 8).

Table 8 – Malmquist TFP summary results, hospitals' means (2000-2005)

Models	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Mean	1.004	1.012	1.006	1.002	1.013	1.017	1.015	1.009	1.006	1.006	1.000	0.999	1.011	1.006
Min.	0.917	0.882	0.920	0.918	0.901	0.896	0.975	0.921	0.955	0.901	0.917	0.919	0.921	0.918
Max.	1.109	1.070	1.100	1.098	1.410	1.416	1.094	1.089	1.054	1.060	1.100	1.110	1.109	1.107
Stdev.	0.029	0.032	0.035	0.034	0.086	0.093	0.025	0.030	0.024	0.029	0.037	0.037	0.032	0.031
≥ 1.00	42	47	29	25	24	18	21	19	23	23	21	16	42	35
% of total	61.8	69.1	60.4	52.1	70.6	52.9	75.0	67.9	67.7	67.7	61.8	47.1	67.7	56.5
< 1.00	26	21	19	23	15	16	7	9	11	11	13	18	20	27
% of total	38.2	30.9	39.6	47.9	44.1	47.1	25.0	32.1	32.4	32.4	38.2	52.9	32.3	43.6
DMU	68	68	48	48	34	34	28	28	34	34	34	34	62	62

Note that models III, V, VII, IX, XI and XIII differ from our basic model in terms of the units (hospitals) analysed, testing for homogeneity, whereas models IV, VI, VIII, X and XIV go a step further, testing also for different output specifications (the number of output indicators utilized across all these models is now 7 rather than 5).

Still according to Table 8, TFP indices vary on average between 0.999 (Model XII) and 1.017 (Models VI). Moreover, and across all models, there are more NHS hospitals that show either positive or no change in productivity across the eleven tested models, whereas between 7 and 27 reveal productivity decline.

The results of our sensitivity analysis highlight the specificity of Models XI and XII, both with the lowest TFP averages observed (1.000 and 0.990, respectively), and differing from each other only in terms of output specification.

The sub-group of 34 NHS hospitals analysed under these two models – hospitals *not having* CAT equipment in the year 2000, regardless of having bought it afterwards – registers the highest percentage of hospitals without emergency service information (62 percent). By contrast, only 24 percent (8 out of 34) of hospitals *with* CAT equipment in the year 2000 didn't have emergency service information.

If we compare Model I with those representing changes to it in terms of the units included - Models III, V, VII, IX, XI and XIII –, from Table 8 it is possible to conclude that:

- TFP behaves constantly through time across all these models until the period 2003-2004; from then on, both models V and IX depart from their previous trend in what concerns TFP growth through time, but in opposite directions: as for the first (second) model, TFP indices (average) decrease (increase) between 2003 and 2004, but then significantly increase (decrease) between 2004 and 2005;
- Model VII - which only considers SA/EPE hospitals - has the highest mean TFP (1.015), but also the smallest number of DMU's (28) within this context;
- Model V - which only considers SPA hospitals - has the second highest mean TFP (1.013), but also the highest standard deviation, revealing more heterogeneity within this sub-group of hospitals than, for instance, Models VII and IX which consider SA/EPE hospitals and NHS hospitals with CAT equipment in 2000, respectively;
- Model XIII - where only the NHS hospitals with emergency service information were considered (62 hospitals) – registers a mean TFP slightly higher than that reported for model I (1.011 and 1.004, respectively). It is interesting to note that in this model the number of units with TFP mean values equal or greater than unity equalizes that observed for model I (42 units). Therefore, the reduction in the number of DMU's from 68 to 62 improves TFP mean values because the six

DMU's that are now missing were, in model I, within the group of those DMU's with TFP mean values inferior to unity (worse performers).

In general, the specification of models differing from the baseline specification only differ in terms of the units considered, i.e., using the same set of input and output variables but applying it to different sub-groups of hospitals, had by effect a general increase of the TFP mean, with the exception of model XI.

The specification of a model (model II) to test the reduction of both input and output indicators previously included in model I had by effect the increase of both the number of units with TFP mean values equal or greater than unity (from 42 to 47 units) and of the TPF mean (1.012, a value slightly higher than the reported for model I, 1.004).

Comparing TFP indices observed in our basic model with the several variations both in terms of the units included and of the number of output indicators defined [35] - e.g. Models IV, VI, VIII, X and XIV- it is possible to conclude from Table 8 that the mean TFP does not significantly change, the exception being model VI - which refers to SPA hospitals -, with a mean TFP slightly higher than that reported for model I (1,017 and 1,004, respectively). However, this increase was achieved at the expense of a wider dispersion of the TFP mean values and of a reduction in the number of DMU's observed (from 68 to 34).

In general, increasing the number of (output) indicators translated into a reduction in the number of hospitals with mean values of TFP equal or greater than unity.

It is possible to conclude that there are some differences in the computed Malmquist indices across specifications. That circumstance motivated the examination of whether the NHS hospitals change their efficiency scores within a particular model specification across time.[36]

[35] Increasing the number of output indicators from 5 to 7.
[36] See Odeck (2005).

Table 9 shows the DEA estimated annual average efficiency scores using Model I (68 hospitals), imposing constant returns to scale.

Table 9 – Summary of DEA efficiency estimates for model I (2000-2005)

	2000	2001	2002	2003	2004	2005
Mean	0.892	0.869	0.893	0.907	0.899	0.943
Minimum	0.672	0.578	0.700	0.670	0.707	0.836
Maximum	1.000	1.000	1.000	1.000	1.000	1.000
Standard deviation	0.089	0.103	0.086	0.086	0.075	0.055
Nº of efficient observations	19	17	21	22	11	32
Frequency distribution:						
≤ 70	1	3	2	1	2	0
71-80	11	19	12	13	8	4
81-90	28	22	24	17	27	15
91-100	28	24	30	37	31	49

From Table 10 it is possible to conclude that, on average, hospital technical efficiency slightly increased during the six years between 2000 (0.892) and 2005 (0.943). Note that the standard deviation decreased from 0.089 in 2000 to 0.055 in 2005. The opposite tendency is observed both for the least efficient unit - whose efficiency score increased from 0.672 in 2000 to 0.836 in 2005 - and for the number of units in the frontier – from 19 in 2000 to 32 in 2005.

In what concerns efficiency scores’ frequency distribution, Table 10 also shows that the interval 0.91-1.00 has only 28 units in 2000 but it significantly rises to 49 units in 2005. Additionally, the total number of units with efficiency scores below 0.81 falls from 12 in 2000 to 4 in 2005. Therefore, and for the overall sample of 68 hospitals analysed in Model I, it seems fair to say that efficiency increased in the period 2000-2005.

According to Table 10, there are significant fluctuations among individual hospitals in terms of individual efficiency scores from one year to the other. From Table 11 it is possible to conclude that 28 hospitals (41 percent) are never on the frontier, whereas 20 hospitals (29 per cent) are in the frontier during 3 or more years.

Table 10 – DEA-CRS estimates per hospital for model I (2000-2005)

Hospitals	2000	2001	2002	2003	2004	2005	n. times on frontier
H. Águeda	1,000	1,000	1,000	1,000	0,863	1,000	5
H. Infante D. Pedro / Aveiro	0,881	0,825	0,835	0,913	0,857	0,966	0
H. São Miguel / Oliveira de Azeméis	0,975	1,000	1,000	1,000	0,895	1,000	4
H. São João da Madeira	0,875	0,882	1,000	0,971	0,808	1,000	2
H. São Sebastião da Feira	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**6**
H. José Luciano de Castro / Anadia	0,820	0,851	0,700	1,000	0,841	0,962	1
H. Dr. Francisco Zagalo / Ovar	0,855	0,920	0,918	0,915	0,872	1,000	1
H. Nossa Senhora da Ajuda / Espinho	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**6**
H. Visconde de Salreu / Estarreja	0,847	0,804	1,000	0,942	0,903	1,000	2
H. São Marcos / Braga	0,872	0,884	0,943	0,948	0,886	0,935	0
H. Santa Maria Maior / Barcelos	0,795	0,833	0,886	0,875	0,811	1,000	1
H. São João de Deus / Famalicão	0,809	0,770	0,700	0,761	0,747	0,814	0
H. Senhora da Oliveira / Guimarães	1,000	1,000	1,000	1,000	0,970	1,000	5
H. São José / Fafe	1,000	0,852	0,833	0,882	0,842	0,972	1
H. Bragança	1,000	0,922	0,870	1,000	0,902	1,000	3
H. Mirandela	0,848	0,941	1,000	0,862	0,744	0,896	1
H. Macedo de Cavaleiros	1,000	0,968	1,000	1,000	1,000	1,000	5
H.C. Cova da Beira (H. Covilhã; H. Fundão)	0,921	0,797	0,820	0,780	0,886	0,861	0
H. Amato Lusitano / Castelo Branco	0,797	0,785	0,770	0,768	0,756	0,832	0
H. Universidade de Coimbra	0,868	0,874	0,900	0,880	0,903	0,940	0
H. Figueira da Foz	0,742	0,762	0,755	0,795	0,823	0,923	0
H. Arcebispo João Crisóstomo / Cantanhede	0,900	0,999	0,899	0,999	0,903	0,794	0
H. Espírito Santo / Évora	0,846	0,743	0,796	0,820	0,831	0,756	0
H. Faro	0,849	0,837	0,854	0,883	0,948	0,925	0
H. Sousa Martins / Guarda	0,903	0,879	0,874	0,971	0,836	1,000	1
H. Nossa Senhora da Assunção / Seia	0,907	1,000	1,000	1,000	1,000	1,000	5
H.C. Caldas da Rainha 1/	0,886	0,578	0,813	0,808	0,894	0,844	0
H. Santo André / Leiria	0,977	0,893	0,942	1,000	0,906	1,000	2
H. Bernardino Lopes de Oliveira / Alcobaça	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**6**
H. Pombal	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**6**
H. São Pedro Gonçalves Telmo / Peniche	1,000	1,000	1,000	1,000	0,995	1,000	5
H. Prof. Dr. Fernando Fonseca	1,000	0,973	0,855	0,873	0,996	1,000	2
H. Curry Cabral	1,000	1,000	0,906	1,000	0,964	0,993	3
H. Egas Moniz	0,834	0,816	0,801	0,808	0,836	0,921	0
H. Pulido Valente	0,816	0,780	0,750	0,798	0,910	0,862	0
H. Santa Cruz	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**6**
H. Santa Maria	0,985	0,934	0,886	0,844	0,940	0,842	0
H. Santa Marta	0,847	0,878	1,000	1,000	0,983	1,000	3
H. São Francisco Xavier	0,916	0,879	0,889	0,902	0,959	0,936	0
Oftalmologic Institute Gama Pinto	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**6**
Maternity D.Estefânia	0,815	0,723	0,836	0,812	0,991	0,939	0
Maternity Alfredo da Costa	0,855	0,712	0,788	0,823	0,948	1,000	1
H. Reinaldo dos Santos / V. F. Xira	1,000	0,858	0,933	0,918	1,000	1,000	3
H. Dr. José Maria Grande / Portalegre	0,878	0,807	0,906	0,957	0,821	1,000	1
H. Santa Luzia / Elvas	0,774	0,797	0,790	0,854	0,824	0,869	0
H.C. Vila Nova de Gaia 1/	0,833	0,828	0,828	0,769	0,924	0,873	0
H. Joaquim Urbano	1,000	1,000	1,000	1,000	0,766	1,000	5
H. Maria Pia	0,706	0,640	0,769	0,670	0,796	0,910	0
H. Santo António	0,889	0,875	1,000	0,857	0,979	0,988	1

Table 10 (cont.)

Hospitals	2000	2001	2002	2003	2004	2005	n. times on frontier
H. São João	0,850	0,792	0,849	0,855	0,887	0,867	0
Maternity Júlio Dinis	0,672	0,857	0,916	0,749	0,763	0,907	0
H.C. Padre Américo / Vale de Sousa	0,913	0,768	0,830	0,887	0,943	1,000	1
H. Nossa Senhora da Conceição / Valongo	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**6**
H. Pedro Hispano [37]	0,956	0,907	1,000	0,976	0,973	1,000	2
H. Conde de São Bento / Santo Tirso	0,847	0,835	0,946	0,953	0,928	1,000	1
H. São Gonçalo / Amarante	0,744	0,714	0,958	1,000	0,893	1,000	2
H. Santarém	0,806	0,773	0,839	0,875	0,937	0,935	0
H. Ortopédico Santiago do Outão	0,855	0,899	0,954	0,914	0,938	0,954	0
H de S. Bernardo / Setúbal	0,838	0,842	0,846	0,785	0,975	0,851	0
H. Garcia de Orta / Almada	0,866	0,804	0,857	0,824	0,934	1,000	1
H. Nossa Senhora do Rosário / Barreiro	0,735	0,703	0,754	0,755	0,860	0,836	0
H. Litoral Alentejano / Santiago do Cacém[38]	1,000	1,000	1,000	1,000	0,868	0,926	4
H. Montijo	0,720	0,768	0,716	0,779	0,706	0,767	0
H. Chaves	0,770	0,728	0,762	0,807	0,784	0,781	0
H. Lamego	0,917	0,777	0,897	0,948	0,707	1,000	1
H. São Teotónio / Viseu	0,842	0,830	0,849	0,946	0,890	0,987	0
H. Cândido de Figueiredo / Tondela	1,000	1,000	0,774	1,000	0,875	0,863	3
H.C. Coimbra	0,983	1,000	0,947	0,980	1,000	0,899	2
Summary statistics							
Mean	0,892	0,869	0,893	0,907	0,899	0,943	
Minimum	0,672	0,578	0,700	0,670	0,706	0,756	
Maximum	1,000	1,000	1,000	1,000	1,000	1,000	
Standard deviation	0,091	0,105	0,092	0,090	0,082	0,071	

Notes: H.- Hospital; H.C.- Hospital Center.

Looking at the number of hospitals in the production possibility frontier maintaining their relative positions, only 7 hospitals (10 per cent) stay on the frontier during all the period of observation (6 years), of which 5 are SPA hospitals 2 are EPE hospitals. Of these 7 efficient hospitals, only 2 are Central (H. Santa Cruz, I.O. Gama Pinto), and the remaining 5 are District (H. São Sebastião da Feira, H. Nossa Senhora da Ajuda / Espinho, H. Bernardino Lopes de Oliveira / Alcobaça, H. Pombal, H. Nossa Senhora da Conceição / Valongo). Additionally, the mean efficiency scores of 15 per cent of the hospitals have fallen between 2000 and 2005, eventually indicating some difficulties in terms of productive efficiency over time, and signalling a theoretical corresponding margin of manoeuvre for improvements.

[37] Matosinhos' Local Health Unit (*Unidade Local de Saúde*).

[38] Previously, Hospital Conde do Bracial.

Table 10 also shows that the efficiency four hospitals (H. Águeda, H. Senhora da Oliveira / Guimarães, H. São Pedro Gonçalves Telmo / Peniche, H. Joaquim Urbano) are consistently on the frontier over time. Finally, it is also possible to conclude that mean efficiency scores have been improving since 2000, for the entire set of 68 hospitals (Model I) of the NHS.

5 – CONCLUSION

In this study we used a data set of contiguous panel data comprising a sample of 68 Portuguese public hospitals in the years 2000-2005. Estimates for our baseline model show that, on average, the NHS hospital sector revealed positive but small productivity growth (Total Factor Productivity – TFP) levels between 2000 and 2004, whereas in 2005 there was a slight decrease in TFP.

Taking into account our basic model and several alternative specifications it is possible to see that the mean TFP indices vary between 0.917 and 1.109, implying that there are some differences in the computed Malmquist indices across specifications. That circumstance motivated the estimation of annual DEA efficiency scores for each model specification. In fact, there are significant fluctuations among NHS hospitals in terms of individual efficiency scores from one year to the other. Looking at the number of hospitals located in the production possibility frontier that maintain their relative positions, 27 out of 68 units appear on the frontier more than once and only 7 hospitals (10 percent) stay on the frontier in all years of the analysis.

Additionally, the mean efficiency scores of 15 per cent of the hospitals have fallen between 2000 and 2005, eventually indicating some difficulties in terms of productive efficiency over time, and signalling a theoretical corresponding margin of manoeuvre for improvements. Indeed, the analyses suggests that there is scope for developing performance indicators at hospital level, and also using panel data, in order to assess how hospitals can move towards the efficiency frontier. Finally, and in terms of future work, a two-step approach could also be used to study the possible determinants of inefficiencies observed in our sample of NHS hospitals.

REFERENCES

Afonso, A. and St. Aubyn, M. (2005). "Non-parametric Approaches to Education and Health Efficiency in OECD Countries", *Journal of Applied Economics*, 8 (2), 227-246.

Afonso, A. and St. Aubyn, M. (2006). "Cross-country Efficiency of Secondary Education Provision: a Semi-parametric Analysis with Non-discretionary Inputs", *Economic Modelling*, 23 (3), 476-491.

Afonso, A. and Fernandes, S. (2006). "Measuring local government spending efficiency: Evidence for the Lisbon Region", *Regional Studies*, 40 (1), 39-53.

Afonso, A.; Schuknecht, L. and Tanzi, V. (2005). "Public Sector Efficiency: an International Comparison," *Public Choice*, 123 (3-4), 321-347.

Aigner, D. and Chu, S. (1968). "On estimating the Industry Production Frontiers", *American Economic Review*, 58, 826-839.

Aigner, D; Lovell, C. and Schmidt, P. (1977). "Formulation and estimation of Stochastic Frontier Production Function Models", *Journal of Econometric*, 6, 21-37.

Balk, B. (1998), *Industrial Price, Quantity and Productivity Indices, The Micro-economic Theory and an Application*, Kluwer Academic Publishers.

Bentes, M; Dias, C.; Sakellarides, C. (2004). *Health care systems in transition: Portugal*, Copenhagen, WHO Regional Office for Europe on behalf of the European Observatory on Health Systems and Policies.

Breyer, F. (1987). "The Specification of a Hospital Cost Function – A Comment on the Recent Literature", *Journal of Health Economics*, 6, 147-157.

Burgess, J. and Wilson, P. (1995), "Decomposing hospital productivity changes, 1985-1988: A non-parametric Malmquist approach, *Journal of Productivity Analysis*, 6, 342-363.

Caves, D. , Christensen, L. and Diewert, W. (1982)."The Economic Theory of Index Numbers and the Measurment of Input, Output and Productivity", *Econometrica*, 50, 1393-1414.

Charnes, A.; Cooper, W. and Rhodes, E. (1978). "Measuring the Efficiency of Decision Making Units", *European Journal of Operational Research*, 2 (6), 429-444.

Chirikos, T. and Sear, A. (2000) "Measuring hospital efficiency: A comparison of two approaches", *Health Services Research*, 34 (6), 1389-408.

Coelli, T.; Rao, D. and Battese, G. (1998). *An Introduction to Efficiency and Productivity Analysis*, Sixth Printing (2002), Massachusetts, Kluwer Academic Publishers.

Coelli, T. (2002). “A Comparison of Alternative Productivity Growth Measures: With Application to Electricity Generation”, in: Fox, Kevin J. (ed.), *Efficiency in the Public Sector*, Kluwer, 169-200.

Dixon, A. and Mossialos, E. (2000). “Has the Portuguese NHS achieved its objectives of equity and efficiency?”, *International Social Security Review*, 53(4), 49-78.

Docteur, E. and H. Oxley (2003). *Health-Care Systems: Lessons from the Reform Experience*, OECD Health Working Papers, No. 9, OECD Publishing.

Färe, R.; Grosskopf, S., Lindgren, B. and Poullier, J. P. (1997). “Productivity growth in health cared delivery”, *Medical Care*, 35, 354-366.

Färe, R.; Grosskopf, S., Lindgren, B. and Roos, P. (1994). “Productivity developments in Swedish hospitals: A Malmquist output index approach”, in: Charnes, A.; Cooper, W., Lewin, A. and Seiford L. (eds.), *Data Envelopment Analysis: Theory, Methodology and Applications*, Boston, Kluwer, 253-272.

Farrell, M. (1957). “The Measurement of Productive Efficiency”, *Journal of the Royal Statistical Society Series A (General)*, 120 (3), 253-281.

Grifell-Tatjé, E. and Lovell, C. (1995). “A Note on the Malmquist Productivity Index”, *Economics Letters,* 47, 169-75.

Grosskopf, S. (1993). “Efficiency and Productivity”, in Fried H. O., Lovell, C. A. K. and Schmidt, S. S. (eds.), *The Measurement of Productive Efficiency: Techniques and Applications*, New York, Oxford University Press, 160-194.

Hollingsworth, B. (2003), “Non-parametric and Parametric Applications Measuring Efficiency in Health Care”, *Health Care Management Science*, 6, 203-218.

Hollingsworth, B.; Dawson, P. and Maniadakis, N. (1999). “Efficiency measurement of health care: A review of non-parametric methods and applications”, *Health Care Management Science*, 2, 161–172.

Jacobs, R.; Smith, P. and Street, A. (2006). *Measuring Efficiency in Health Care*, Cambridge, Cambridge University Press.

Lima, E. and Whynes, D. K. (2003). *Finance and Performance of Portuguese Hospitals*, Working Paper nº 20, Núcleo de Investigação em Microeconomia Aplicada, Braga, Universidade do Minho.

Linna, M. (1998). “Measuring hospital cost efficiency with panel data models”, *Health Economics*, 7, 415-427.

Linna, M. (2000). “Health Care Financing Reform and the Productivity Change in Finnish Hospitals”, *Jpurnal of Health Care Financing*, 26(3), 83-100.

Lovell C. (2000). “Measuring Efficiency in the Public Sector”, in: Blank, Jos L. T. (ed.), *Public Provision and Performance*, Amsterdam, North-Holland, 23-53.

Lovell, C. (2002). “Performance Assessment in the Public Sector”, in: Fox, Kevin J. (ed.), *Efficiency in the Public Sector,* Kluwer Academic Publishers, 11-35.

Lovell, C. (2006). “Malmquist Productivity Index – Government Funded Education Services”, in: Avkiran, Necmi K. (ed.), *Productivity Analysis in the Service Sector with Data Envelopment Analysis*, third edition, publisher Necmi K. Avkiran, University of Queensland, Brisbane-Australia, 149-161.

Malmquist, S. (1953). “Index numbers and indifference surfaces”, *Trabajos de Estatistica*, 4, 209-242.

Maniadakis N.; Hollingsworth, B. and Thanassoulis, E. (1999). “The Impact of the Internal Market on Hospital Efficiency, Productivity and Service Quality”, *Journal of Health Care Management Science* , 2(2), 75-85.

Maniadakis, N and Thanassoulis, E. (2000). “Changes in Productivity of a Sample of Scottish Hospitals: A Cost Index Approach”, *Applied Economics*, 32, 1575-1589.

McCallion, G.; Glass, J. , Jackson, R., Kerr, C. and McKillop, D. (2000). “Investigating productivity change and hospital size: A non-parametric approach”, *Applied Economics*, 32, 161–174.

McKee, M. and Healy, J. (eds.) (2002). *Hospitals in a changing Europe*, European Observatory on Health Care Systems Series, Buckingham, Open University Press.

Meeusen, W. and van den Broeck, J. (1977). “Efficiency estimation from Cobb-Douglas Production Functions with Composed Error”, *International Economic Review*, 18, 435-444.

Nishimizu, M. and Page, J. (1982). “Total Factor Productivity Growth, Technical Progress and Technical Efficiency Change: Dimensions of Productivity Change in Yugoslavia, 1965-78”, *Economic Journal*, 92, 920-936.

Nunamaker, T. (1985). “Using Data Envelopment Analysis to Measure the Efficiency of Non-Profit Organizations: A Critical Evaluation”, *Managerial and Decision Economics*, 6(1), 50-58.

Odeck, J. (2005). “Evaluating Target Achievements in the Public Sector: An Application of a Rare Non-Parametric DEA and Malmquist Indices” *Journal of Applied Economics*, 8(1), 171-190.

OECD (2001). *Measuring Productivity: Measurement of Aggregate and Industry Level Productivity Growth*, OECD, Paris. Available in 26.11.2006 in the following URL: http://www.oecd.org/dataoecd/59/29/2352458.pdf

OECD (2004). *OECD Health Data 2004*. OECD, Paris.

OECD (2005). *OECD Health Data 2005*. OECD, Paris.

Oliveira, M. (2002). "Will hospital Management Reform in Portugal Work?", *Euro Observer. Newsletter of the European Observatory on Health Care Systems*, 4, 3-4.

Oliveira, M. and Pinto, C. (2005). "Health care reform in Portugal: an evaluation of the NHS experience", *Health Economics*, 14, 203-220.

Portuguese Observatory on Health Care Systems (2001). *Conhecer os Caminhos da Saúde*, Spring Report, ENSP: Lisbon.

Quintela, I.; Carvalho, A. and Tranquada, S. (2006). "The Portuguese Experience: Estimation of the output of hospitals according to different methodologies", Paper presented for the joint OECD/ONS/Government of Norway workshop, *Measurement of non-market output in education and health*, London, October 3-5.

Seiford, L. and Thrall, R. (1990). "Recent Developments in DEA: The Mathematical Programming Approach to Frontier Analysis", *Journal of Econometrics*, 46, 7-38.

Shepard, R. W. (1970). *Theory of Cost and Production Functions*, Princeton, Princeton University Press.

Solà, M. and Prior, D. (2001), "Measuring productivity and Quality Changes using Data Envelopment Analysis: An Application to Catalan Hospitals", *Financial Accountability and Management*, 17(3), 219-245.

Sommersguter-Reichmann, M. (2000). "The impact of the Austrian hospital financing reform on hospital productivity: empirical evidence on efficiency and technology changes using a non-parametric input-based Malmquist approach", *Health Care Management Science*, 3, 309-321.

Valdmanis, V. (1992). "Sensitivity analysis for DEA models: An empirical example using public vs. NFP hospitals", *Journal of Public Economics*, 48, 185–205.

Zere, E. (2000), Hospital Efficiency in Sub-Saharan Africa Evidence from South Africa, Working Paper 187 (June), World Institute for Development Economics Research: The United Nations University.

Zere E.; McIntyre D. and Addison T. (2001). "Technical efficiency and productivity of public sector hospitals in three South African provinces", *South African Journal of Economics*, 69(2), 336-358.