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An analysis of hospital efficiency and productivity growth using the Luenberger productivity indicator

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ABSTRACT

An Analysis of Hospital Efficiency and Productivity Growth Using the Luenberger Productivity Indicator

We analyze the efficiency and productivity growth of a representative sample of Portuguese hospitals from 1997 to 2004, using an innovative approach by employing the directional distance function and the Luenberger productivity indicator. The primary advantage of our approach is that both input contractions and output expansions are considered. Our model generates a productivity indicator that is decomposed into the usual constituents of productivity growth: technological change and efficiency change. The results show that, on average, Portuguese hospitals did not experience productivity growth during the period analyzed. In addition, the incidence of positive productivity growth across Portuguese hospitals was remarkably low.

JEL Classification: I11, I18, L5

Keywords: hospitals, Luenberger productivity indicator, efficiency, technological change, productivity

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1. Introduction

The aim of this paper is to analyze hospital efficiency and productivity growth. For that, we employ the Luenberger productivity indicator to study a representative sample of Portuguese hospitals in the period 1997-2004. Whereas productivity may be estimated by parametric techniques, the most popular approach employs non-parametric methods – data envelopment analysis (DEA) and the Malmquist productivity index. Yet, differences exist between productivity measures based on ratios (indices) and differences (indicators). Since Malmquist indices often overestimate productivity change, recently, difference-based productivity indicators, such as the Luenberger productivity indicator, have been introduced [1]. In this paper, we innovate in the field of hospital performance studies with an application of the directional distance function and of the Luenberger productivity indicator to the analysis of hospital efficiency and productivity growth. Quite interestingly, the Luenberger productivity indicator is decomposed into the familiar constituents of productivity growth: technological change and efficiency change, and, hence, our analysis sheds light on both of these interesting dimensions of productivity growth.

The hospital sector constitutes an important ground for productivity studies. Hospitals absorb a large share of public health expenditures. As the hospital sector is highly regulated, there is an obvious need for assessing its performance (see [2] for an illuminating discussion on the need to analyze the efficiency and productivity of health care organizations). In Portugal, the ratio of health expenditures to GDP has increased from 8.4% in 1998 to 9.6% in 2003, exceeding the average values in the EU, of 8.2% in 1998 and 8.8% in 2003. Confronted with an endemic public deficit, Portugal is being forced by the European Maastricht Treaty to shrink its public expenditures. As hospitals command about 50% of public health expenditures, there is much warranted discussion in Portugal on how to reform the hospital sector. However, scant research has been conducted on Portuguese hospitals [3-5]. More to the point, and to be short, these studies overlooked productivity growth issues, unlike this paper. Present reforms include the closing of small, regional health facilities as well as the construction of new hospitals. Reforms also include the implementation of restrictions on prescription drug subsidies, doctors' wages and hours worked, organizational changes, such as defining some public hospitals as publicly-owned companies. Hence, policymakers need to establish whether a given (de)regulation model achieves its intended effects on productivity. For that, some formal assessment of hospital productivity growth is in order. This paper contributes to fill this gap in the Portuguese case and innovates in the field of hospital performance studies with the introduction of the Luenberger productivity indicator.

The remainder of this paper is organized as follows. Section 2 reviews the literature. Section 3 details the methodology. Section 4 presents the data and the results. Section 5 concludes.

2. Literature Review

Hospital efficiency analysis is an important issue within the field of health economics. There are two contemporary approaches to measure hospital efficiency: the parametric approach and the non-parametric approach. Particularly important to the present paper are the studies that have focused on national markets. Among the studies that have employed non-parametric frontier techniques, several approaches are observed. First and foremost, we find the traditional DEA approach, which identifies technical efficiency. This approach was adopted by the early literature [6-11]. Second, we find the studies that focus on the decomposition of technical and allocative efficiency, such as Morey, Fine and Loree [12] and Byrnes and Valdmanis [13]. Third, and finally, we note the emergence of more innovative studies that deal with the disposal hull model [14], the congestion DEA model [15], and the output distance function [16].

Pilyavsky et al. [17] analyze Ukrainian hospitals, using a DEA model. Barbeta, Turati and Zago [16] analyze Italian hospitals, using an output distance function and adopting stochastic and DEA approaches. Siciliani [11] analyzes the technical efficiency of Italian hospitals, while Häkkinen [18] analyzes the technical efficiency of the Finnish health care system, using a DEA model. Dismuke and Sena [4] focus on Portuguese hospitals, using a DEA model; and, Hofmarcher, Paterson and Riedel [19] analyze Austrian hospitals, using a DEA model, as well.

Among the studies that employ parametric approaches, we mention Blank and Eggink [20] who analyze the efficiency of Dutch hospitals, using a stochastic frontier model to distinguish between technical and allocative efficiency. Greene [21] analyzes the technical efficiency of US hospitals, focusing on heterogeneity issues. Rosko [22] and Zuckerman et al. [23] adopt a stochastic cost frontier to analyze US hospitals.

3. Theoretical Background

Chambers, Chung, and Fare [24-25] propose flexible measures of firm performance, deriving from production theory. They introduced the directional distance function, which, in production theory, is the opposite of Luenberger's benefit function (see Luenberger [26] for a discussion of the benefit function in a consumer context). The directional distance function measures the smallest changes in inputs and outputs in a given direction, which are necessary for a producer to reach the production frontier. The directional distance function determines, thus, a shortcut in one direction, which permits an observed production unit to reach the production frontier. In economic terms, the directional distance function makes it possible to evaluate the scale of the economies that can be achieved and the possible improvements in production; it also provides a benchmark, by defining a reference point to be reached. The principal advantage of the directional distance function lies in its ability to take account, simultaneously, of (variations in) both inputs and outputs.

Let the technology be described by a set, $T \subseteq R_+^N \times R_+^M$, defined by:

$$T_t = \{(x_t, y_t) : x_t \text{ can produce } y_t\}, \quad (1)$$

where $x_t \in R_+^N$ is a vector of inputs and $y_t \in R_+^M$ is a vector of outputs at the time period t .

Throughout this paper, technology satisfies the following conventional assumptions:

A1: $(0,0) \in T_t, (0, y_t) \in T_t \Rightarrow y_t = 0$, i.e., no free lunch;

A2: the set $A(x_t) = \{(u_t, y_t) \in T_t; u_t \leq x_t\}$ of dominating observations is bounded $\forall x_t \in R_+^N$, i.e., infinite outputs are not allowed with a finite input vector;

A3: T_t is closed;

A4: $\forall (x_t, y_t) \in T_t, (x_t, -y_t) \leq (u_t, -v_t) \Rightarrow (u_t, v_t) \in T_t$, i.e., fewer outputs can always be produced with more inputs, and vice versa (strong disposal of inputs and outputs);

A5: T_t is convex.

The directional distance function generalizes the traditional Shephard distance function [27]. The directional distance function projects an input and/or output vector from itself to the technology frontier, in a pre-assigned direction. In the case of a radial direction, out of the origin, we retrieve the classical Shephard distance function. We are finally in position to formally define the directional distance function. The function $D_t : R^{n+p} \times R^{n+p} \rightarrow R \cup \{-\infty\} \cup \{+\infty\}$ defined by

$$D_t(x_t, y_t; g) = \begin{cases} \sup\{\delta : (x_t - \delta h; y_t + \delta k) \in T_t\} & \text{if } (x_t - \delta h; y_t + \delta k) \in T_t, \delta \in R \\ -\infty & \text{otherwise} \end{cases} \quad (2)$$

is called the directional distance function in the direction of $g = (h, k)$. To make this approach operational, it is necessary to take an appropriate direction. We do this by considering the direction $g = (x, y)$. In this case, the directional distance function is similar to the proportional distance function introduced by Briec [28]. This distance function is based on simultaneous proportional modifications of inputs and outputs; it generalizes Debreu's [29] and Farrell's [30] measures and is equally straightforward to interpret.

To estimate the proportional distance function, we use a non-parametric approach [31-32] and solve our program using linear programming techniques in Mathematica v. 5.0. The technology can be written as:

$$T_t = \left\{ (x_t, y_t), x_t \geq \sum_j \theta_j x_t^j, y_t \leq \sum_j \theta_j y_t^j, \sum_j \theta_j = 1, \theta_j \geq 0, j = 1, \dots, J \right\}. \quad (3)$$

The linear program that calculates the values of the directional distance function is given by:

$$\begin{aligned} D_t(x_t, y_t) &= \max \delta_t \\ \text{s.t. } x_t - \delta_t x_t &\geq \sum_j \theta_j x_t^j, \end{aligned} \quad (4)$$

$$y_t + \delta_t y_t \leq \sum_j \theta_j y_t^j ,$$

$$\sum_j \theta_j = 1, \quad j = 1 \dots J .$$

Suppose that an individual hospital is represented by a production vector, (x_t, y_t) , with corresponding technology T_t , and, then, the production vector is changed to (x_{t+1}, y_{t+1}) with corresponding technology T_{t+1} . In order to assign a cardinal measure to the productivity change, we can use the directional distance function in one of two ways, using either the initial technology at t or the final technology at $t+1$ as a reference. In this case, the Luenberger productivity indicator proposed by Chambers [29-30] can be employed to evaluate productivity change. The productivity indicator is constructed as the arithmetic mean of the productivity change measured by the technology at T_{t+1} and the productivity change measured by the technology at T_t .

The Luenberger productivity indicator is defined as:

$$L(z_t, z_{t+1}) = \frac{1}{2} [D_{t+1}(z_t; g) - D_{t+1}(z_{t+1}; g) + D_t(z_t; g) - D_t(z_{t+1}; g)] \quad (5)$$

where $z_t = (x_t, y_t)$. Positive productivity growth (decline) is indicated by a positive (negative) value of L . Unlike the Malmquist index, the Luenberger productivity indicator is additively decomposed:

$$L(z_t, z_{t+1}) = [D_t(z_t; g) - D_{t+1}(z_{t+1}; g)] + \frac{1}{2} [D_{t+1}(z_{t+1}; g) - D_t(z_{t+1}; g) + D_{t+1}(z_t; g) - D_t(z_t; g)] \quad (6)$$

where the term inside the first brackets measures efficiency change between time periods t and $t+1$, while the arithmetic mean of the difference between the two figures inside the second brackets expresses the technological change component, which represents the shift of technology between the two time periods. This decomposition was inspired by the breakdown of the Malmquist productivity index in Färe et al. [33].

4. Data and Results

We compiled our dataset on Portuguese hospitals from the Portuguese Ministry of Health and from the financial accounts of Portuguese hospitals. Our dataset covers the years from 1997 up to 2004 and 51 hospitals – the vast majority of hospitals in Portugal – and, hence, we are left with a balanced panel of 408 observations.

We assume that hospitals produce four outputs: (i) case flows (number of persons that leave the hospital), (ii) length of stay (average number of days a person stays in the hospital), (iii)

consultations and (iv) emergency cases. Hospitals employ, in turn, three inputs: (vi) number of beds, (vii) personnel and (viii) total variable costs. Table 1 presents descriptive statistics.

<Table 1 here>

The Luenberger productivity indicator is calculated using linear programming techniques. Table 2 reports the results. The Luenberger productivity indicator (L) is decomposed into its two constituents: technical-efficiency change (the diffusion or catch-up component - EFFCH), and technological change (the innovation or frontier-shift component - TECH). EFFCH represents the diffusion of best-practice technology in the management of hospitals and it is attributable to, among other factors, technical experience, management and organization. Improvements in technical efficiency denote upgraded organizational factors associated with the use of inputs and outputs, as well as the relationship between inputs and outputs. TECH, in its turn, and to be short, results from the adoption of new technologies by best-practice hospitals and is closely associated with investment.

<Table 2 here>

From Table 2 we observe that the productivity change score is mixed for Portuguese hospitals, in the period analyzed. The mean value of L (-5.1%) is negative, signifying that there was productivity decline during the period analyzed.

The mean value of EFFCH is close to 0 (+0.59%), implying that the average L score is explained by TECH. In this sense, Portuguese hospitals were very efficient during the period analyzed. Many hospitals represent the production frontier throughout the sample period, achieving, thus, nil EFFCH scores. In such a case, only technological change explains productivity variations. This is of primary interest, and naturally leads to the analysis of the nature of TECH, which can be neutral or biased. In terms of the directional distance function, the nature of TECH has been analyzed recently by Briec et al. [34].

The TECH component is negative on average. Moreover, for the hospitals where productivity increases, it is the technical efficiency component that drives productivity change. Taken at face value, this result suggests that there was low investment in new technologies.

For the sake of exposition, we consider six possible combinations of technical efficiency change and technological change. In particular, the combinations are as follows:

1. Improvements in technical efficiency co-exist with positive technological change. We find no hospitals that meet this criterion, the best possible combination.
2. Positive nil technical efficiency change co-exists with positive technological change. We find 5 hospitals – about 10% of the total number of hospitals in the sample – in this category.
3. Improvement in technical efficiency co-exists with negative technological change. We find 15 hospitals in this category, or about 30% of the sample.

4. Deterioration in technical efficiency co-exists with positive technological change. We find 3 hospitals in this category or about 5% of the sample.
5. Zero technical efficiency co-exists with negative technological change. There are 15 hospitals in this category, or about 30% of the sample.
6. Negative technological change co-exists with deterioration in technical efficiency, the worst combination possible. 13 hospitals – about 25% of the sample – experienced this combination of events.

5. Conclusion

This paper analyzed hospital efficiency and productivity growth employing the directional distance function and the Luenberger productivity indicator to study a representative sample of Portuguese hospitals. The results show that the average Portuguese hospital did not experience productivity growth between 1997 and 2004. In particular, no hospital experienced simultaneously improvements in technical efficiency and positive technological change. In addition, only those hospitals with nil technical efficiency change and positive technological change experienced a positive Luenberger productivity indicator, denoting productivity growth. Therefore, there is room to increase both technical efficiency and technological change. In a broad economic sense, technical change (innovation) – the main driver of productivity growth – is related to investment. Capital accumulation, which determines the adoption of technology by best-practice hospitals, thereby shifts the efficiency frontier. This is verified by the fact that there is a positive technological change for only 8 of the 51 hospitals analyzed.

This paper cannot be directly compared with other papers that analyze hospital efficiency and productivity growth, since it uses an innovative approach. However, it should be noted that, in contrast with Hofmarcher et al. [19], our results present higher levels of inefficiency, which may be attributable to the method adopted. Future research ought to consider different time periods and variables in order to allow comparisons across alternative methodologies and to identify investment episodes and policy reforms associated with a given dynamic path of productivity.

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Table 1. Descriptive Statistics 1997-2004

| Variables | Minimum | Maximum | Mean | Stand. Dev. |
|--------------------------|-----------|-------------|------------|-------------|
| Outputs: | | | | |
| Case flows | 2 310 | 24 547 | 10 841 | 5 561 |
| Length of stay | 4 | 13 | 7 | 1 |
| Consultations | 13 459 | 284 276 | 76 698 | 48 195 |
| Emergency cases | 0 | 217 603 | 88 340 | 42 668 |
| Inputs: | | | | |
| Beds | 66 | 661 | 294 | 148 |
| Personnel | 213 | 2 698 | 991 | 574 |
| Variable costs (real; €) | 6 678 855 | 123 812 767 | 39 444 716 | 26 034 611 |

Table 2. Productivity Changes in Hospitals ranked according to the Luenberger Indicator (1997-2004)

| N. Hospital | EFFCH | TECH | L | N. Hospital | EFFCH | TECH | L |
|----------------------------|--------|--------|--------|---------------------------|--------|--------|--------|
| 1 CH Vila Nova de Gaia | 0.000 | 0.160 | 0.160 | 27 H Viseu | 0.000 | -0.057 | -0.057 |
| 2 CH Coimbra | 0.000 | 0.102 | 0.102 | 28 H Angra do Heroísmo | 0.003 | -0.061 | -0.058 |
| 3 H Almada | -0.029 | 0.108 | 0.079 | 29 H Vale do Sousa | 0.000 | -0.065 | -0.065 |
| 4 H Portalegre | 0.102 | -0.048 | 0.054 | 30 H Chaves | 0.090 | -0.160 | -0.070 |
| 5 H Amarante | 0.086 | -0.039 | 0.047 | 31 H Horta | -0.033 | -0.037 | -0.070 |
| 6 H Egas Moniz | 0.000 | 0.042 | 0.042 | 32 CH Médio Tejo | 0.000 | -0.070 | -0.070 |
| 7 H Évora | 0.036 | -0.009 | 0.027 | 33 H Elvas | 0.107 | -0.179 | -0.072 |
| 8 H Faro | 0.022 | -0.001 | 0.021 | 34 H Aveiro | 0.018 | -0.092 | -0.074 |
| 9 CH Alto Minho | 0.022 | -0.009 | 0.013 | 35 H Leiria | 0.000 | -0.074 | -0.074 |
| 10 H Santa Maria da Feira | 0.000 | 0.011 | 0.011 | 36 H V. F. de Xira | -0.005 | -0.082 | -0.087 |
| 11 H Bragança | 0.105 | -0.099 | 0.006 | 37 H Famalicão | -0.019 | -0.073 | -0.092 |
| 12 H Braga | 0.000 | 0.006 | 0.006 | 38 CH Baixo Alentejo | 0.004 | -0.103 | -0.099 |
| 13 H Pulido Valente | 0.047 | -0.047 | 0.000 | 39 CH Barlavento Algarvio | -0.034 | -0.081 | -0.115 |
| 14 H Figueira da Foz | -0.028 | 0.023 | -0.005 | 40 H S. Francisco Xavier | -0.070 | -0.048 | -0.118 |
| 15 CH Caldas da Rainha | 0.080 | -0.086 | -0.006 | 41 H Oliveira de Azeméis | 0.000 | -0.136 | -0.136 |
| 16 H Divino Espírito Santo | 0.019 | -0.026 | -0.007 | 42 H Ovar | 0.000 | -0.136 | -0.136 |
| 17 H Mirandela | -0.035 | 0.022 | -0.013 | 43 CH Vila do Conde | 0.000 | -0.138 | -0.138 |
| 18 H Santo Tirso | 0.000 | -0.015 | -0.015 | 44 H Guarda | -0.013 | -0.126 | -0.139 |
| 19 H Guimarães | 0.000 | -0.016 | -0.016 | 45 CH Cova da Beira | -0.004 | -0.139 | -0.143 |
| 20 H Setúbal | -0.001 | -0.021 | -0.022 | 46 H Castelo Branco | -0.057 | -0.092 | -0.149 |
| 21 H Santarém | 0.048 | -0.073 | -0.025 | 47 H Barcelos | -0.014 | -0.137 | -0.151 |
| 22 CH Cascais | 0.000 | -0.027 | -0.027 | 48 H Lamego | 0.000 | -0.154 | -0.154 |
| 23 H Barreiro | -0.017 | -0.013 | -0.030 | 49 H Águeda | 0.000 | -0.164 | -0.164 |
| 24 H São João da Madeira | 0.000 | -0.035 | -0.035 | 50 H Montijo | 0.000 | -0.193 | -0.193 |
| 25 H Curry Cabral | 0.000 | -0.047 | -0.047 | 51 CH Torres Vedras | -0.092 | -0.127 | -0.219 |
| 26 Vila Real Peso da Régua | -0.037 | -0.018 | -0.055 | | | | |
| Summary statistics: | | | | | | | |
| Mean | 0.006 | -0.056 | -0.051 | | | | |
| Median | 0.000 | -0.057 | -0.055 | | | | |
| St. Dev. | 0.041 | 0.073 | 0.078 | | | | |