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"THE OPTIMUM SIZE OF THE PORTUGUESE PUBLIC HOSPITAL"

ANDRÉ PACHECO FORTUNA
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This Work Project was carried out on the Applied Policy Analysis area, under the supervision of
PROFESSOR PEDRO PITA BARROS

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ABSTRACT

In a context of intensive structural reform, this paper estimates optimum bed-sizes for the Portuguese public hospitals. Considering costs and production data for the period 2003-2006, we estimate a production-theoretic quadratic cost-function, adjusted to better describe the underlying technology. Room for short-run scale-economies exploitation is found, but long-run scale-diseconomies are unambiguous. In light of these predictions and of an optimum around 233 fully-occupied beds, there is mixed evidence of potential gains from two hospital mergers and from one of the forthcoming constructions of public hospitals. The results are expected to contribute to shape the hospital network in a cost-efficient manner.

Keywords: optimum bed-sizes for hospitals, public hospitals, quadratic cost-function, scale-economies

1. INTRODUCTION

1.1 Motivation and overview

Public health expenditures tend to move towards non-sustainable paths in developed countries, and Portugal is no exception. Publicly-funded health expenditures reach 70.6% of total health expenditures, which represent 10.2% of GDP[1]. Given that the hospital system absorbs more than 50% of the total public health expenditures, roughly speaking, this study is concerned with productive efficiency of a non-negligible portion of about 3.6% of the Portuguese GDP.

In relatively small health systems like the Portuguese, efficiency gains such as hospital scale-economies are sometimes overlooked. The government´s intention to build 11 new public hospitals in the forthcoming years[2], as well as the numerous mergers recently pursued, both between hospitals (hospital centers, CH), and between hospitals and primary-care centers (local health units, ULS), support the timeliness of this study.

Moreira (2008) footnoted the need of a study focused on scale-efficiencies in Portuguese hospitals, while Gonçalves (2008) suggested it for future research. Hence, we also intend to fill an acknowledged gap in the empirical literature on the Portuguese hospital-sector.

In order to pursue the quantitative objectives, a database of 74 general acute-care public hospitals was constructed. The database comprises financial, technology, production, control and binary variables, for the period 2003-2006. The quadratic cost-function *a la* Preyra and Pink (2006) was selected among production-theoretic functional forms. It was adjusted ad-hoc, after early estimations, to improve its econometric properties. The main adjustments were conducted to account for the sample heterogeneity with respect to complexity/severity and quality of outputs, and to better reflect the structural and contextual specificities of the Portuguese public hospitals.

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[1] Source: OECD DSI Data Service & Information: statistical databases, 2006.

[2] *Lisboa (Todos-os-Santos)*, *Cascais*, *Vila Franca de Xira*, *Loures*, *Sintra* and *Braga* may come first, followed by *Guarda*, *Póvoa de Varzim/Vila do Conde*, *Évora*, *Vila Nova de Gaia* and *Algarve*.

The cost-function was able to provide a minimum-efficient-scale (MES) of 233 fully-occupied beds, as well as the extent of scale-economies in the short-run and in the long-run. Expanded by the mean occupancy-rate, the estimated optimum of 315 beds is surprisingly higher than the 214 bed-size found by Carreira (1999). As a complementary exercise, the application of the method is illustrated through the simulation of two hospital mergers and of a new hospital.

1.2 Context

The Portuguese public hospital is under intensive structural reform, started with the (gradual) implementation of a prospective financing scheme (1990). Compared with the competing schemes, such as direct reimbursement, prospective schemes are proved to better align the incentives for resource savings[3]. Another relevant innovation was the establishment of public-private partnerships (PPP) in the conception, construction and operation of new hospitals. However, the major reform experienced was the progressive but exceptionally quick transformation (since late 2002) of most publicly-managed public hospitals (SPA) into more firm-like management and legal entities (SA/EPE)[4]. This transformation was accompanied by numerous hospitals mergers, intended to stimulate a more global and effective view of health-care provision at the local/regional level, assure minimum standards of service quality and citizen accessibility and increase the hospital-sector efficiency. While the EPE transformation introduces flexibility in labor contracts and renewed incentives for budget rationalization, the mergers exploit synergies and strategic management centralization among closely located hospitals.

Most reforms had been tested through pioneer experiments undergone in governmentally selected hospitals[5]. The overall success of these innovative experiments, coupled with

[3] Hospital financing is beyond the scope of this study; see Lima and Whynes (2003) for insights on the issue.

[4] In 2005, all the 31 hospitals which were previously transformed into publicly-owned companies, SA *("Sociedades Anónimas")*, along with two other hospitals still in the SPA (*"Sector Público Administrativo"*) sphere, were transformed into corporate public entities, EPE ("*Entidades Públicas Empresariais"*). Since the main drive of the name change was political, rather than conceptual, we adopt the more recent denomination, "EPE", from this point on.

[5] *Fernando da Fonseca (Amadora-Sintra), São Sebastião (Feira), Barlavento Algarvio (Portimão), Unidade Local de Saúde de Matosinhos.*

international trends in the sector, gave important support to the reforms implemented. For detailed descriptions of these experiments see Barros (2009), or Harfouche (2008).

Legal and market spaces were opened recently to private initiatives[6], but most hospitals in Portugal are still within the public sphere. Idiosyncrasies of the public administration make public health-care provision particularly inefficient (though more equity-concerned). As implicitly suggested, the reforms were essentially designed to promote efficiency in hospitals' use of public resources. Despite the non-profit nature, the Portuguese public hospitals are now constrained by more credible budgets and have limited capacity to raise revenues, which makes efficiency an internal concern also. For snapshots of the Portuguese public health-sector and its most recent reforms see Moreira (2008), or Barros and Simões (2007).

In what follows: section 2 provides a brief literature review; section 3 describes the model, presents the empirical results, checks their robustness, and illustrates their application to three specific cases; section 4 concludes and provides hints for future research.[7]

2. LITERATURE REVIEW

The study of efficiency of hospitals as multi-product firms is recursive in Heath Economics' empirical and theoretical literature. First of all, it is fundamental to define the level of efficiency that is to be treated. From the literature, the most natural options are technical and allocative efficiencies. Since substitutability between inputs is not essential to understand scale effects, and reliable input prices would not be readily available (as discussed below), we explicitly disregard allocative efficiency considerations.

Two types of frontier methods became popular in (global) technical efficiency measurement: Data Envelopment Analysis (DEA) – non-parametric; and Stochastic Frontier Analysis (SFA) -

[6] The most remarkable in terms of service range and size are *Hospital da Luz* and *Hospital dos Lusíadas,* in Lisbon.

[7] A list of acronyms and abbreviations that appear across the text is provided in Appendix 1.

parametric. Resorting to linear-programming techniques, DEA has the advantage of not requiring *a priori* imposition of a functional form. The most attractive feature of SFA is that total inefficiency, measured by the distance of each observation to the production frontier, may be attributed to exogenous random disturbances and decomposed into technological change and technical efficiency. In Portugal, Afonso and Fernandes (2008) employ DEA after providing an extensive literature review of its international applications to the hospital-sector. Moreira (2008) and Harfouche (2008) use the same method to assess the consequences of the EPE transformation on technical efficiency. Franco (2001) and Menezes et al. (2006), in turn, study technical efficiency through SFA. Gonçalves (2008) employs both DEA and SFA concluding that the frontier improved in 2002-2004 due to the competition created, mainly by the SPA hospitals. C. Barros et al. (2008) innovate in the analysis of hospital efficiency (and productivity growth) by employing the Luenberger productivity indicator to Portuguese hospitals in 1997-2004. The low productivity growth found is consistent with principal-agent problems and X-inefficiency, targets of the hospital-sector reforms. The non-comparability of the results, together with poor quality of data, also recognized by Moreira (2008) and Harfouche (2008), implies cautious adoption of the results, but not of the methodology. All these authors discuss hospitals efficiency and illustrate that room for efficiency improvements exist. However, none of the methodologies used has proved suitable to estimate optimum sizes and scale-economies turning points.

The international literature is fertile in attempts to measure the optimum size of hospitals, especially in the US. Until early 1980s no consensus could be reached, with the optimum ranging from 150 to 900 beds. The 1980s were particularly intense in contributions for this literature branch but, given methodological divergences, convergence still sounded ambiguous. The 1990s were less active, but interesting contributions emerged, such as Dranove (1998). Relying on data about 14 non-revenue producing cost centers (e.g.: administration, medical records, housekeeping), Dranove concludes that substantial scale-economies exist up to 10.000 annual discharges (around 280 beds). Unfortunately, the methodology is hard to translate to Portuguese hospitals since data on cost centers are sparse, scarce, or simply unpublished. More recently, Preyra and Pink (2006), based on a sample of 210 acute and non-acute care Ontario (Canada) hospitals, came up with an optimum of 180 beds, well below commonly observed figures.

In Portugal, three authors estimated public hospital's optimum bed-sizes: Paiva (1993), 363; Carreira (1999), 214; and Lima (2003), 241. Paiva (1993) applied a transformed Cobb-Douglas to late 1980s data, while Lima, based on 1984-1994 data, used a *Transcendental Logarithmic* (*Translog*) cost-function to analyze district hospitals' efficiency[8]. In none of the cases the optimum size had a central role. Aletras (1999) alerts for the bias-risk of adopting second-best practices in estimating scale-efficiency. Therefore, it is worth to focus and redouble efforts on the issue, while trying to figure out whether the low optimum found by Preyra and Pink (2006) is due to the methodology adopted, country-specific factors, or, interestingly, to the decreasing trend of average lengths-of-stay (ALS) and bed usage in production of hospital care. In a broad sense, our hospital efficiency analysis has a strong background in the Portuguese literature, but is unique on its main goals and methodology.

3. METHODOLOGY AND EMPIRICAL RESULTS

3.1 Theoretical issues

Hospitals are firms that use multi-combinations of multi-inputs to produce multi-outputs. Despite complexity, if certain regularity conditions are met, the cost-function has the advantage of being represented as dual of the technically-efficient production-function[9]. This is true as long as hospitals minimize costs and the cost-function carries the economically relevant information for the production process. Grannemann et al. (1986) emphasizes the duality property, but casts doubts on the required pace of adjustment of some inputs, such as capital, in supporting the cost-

[8] Public hospitals are administratively divided into Central, District (D) and District Level 1 (D1), according to a set of criteria such as bed-size and amplitude of services provided (C is largest, D1 is smallest). Lima (2003) addresses D+D1 hospitals.

[9] The function regularity conditions are: non-negative; linearly homogeneous in factor prices (P); non-decreasing in P; concave in P; continuous in P; differentiable in P and non-decreasing in the output level (Carreira, 1999).

minimization assumption. The departure from automatic adjustment to long-run equilibrium justifies the inclusion of a separate category of inputs, the fixed-factors. Carreira (1999) rejects the profit-maximizing nature of Portuguese public hospitals, but admits that by maximizing the level of service with a prearranged budget, hospitals in fact minimize costs. Considering that budgets were fairly credible in the period analyzed, and that maximizing the level of service improves the utility of Portuguese hospitals managers, we keep cost-function duality[10].

One of the key choices the researcher must face when estimating cost-functions is between ad-hoc and production-theoretic forms. Among micro-founded forms, the so-called flexible functional-forms assumed a central role in the international literature (e.g. Aletras, 1999, Vita, 1990). Those forms are also abundant in the Portuguese literature, where the *Translog* takes the forefront: Paiva (1993), Carreira (1999), Franco (2001), Lima (2003), Menezes et al. (2006), Gonçalves (2008). The *Translog* is the second-order Taylor approximation to the true cost-function. Despite its desirable features, such as the goodness-of-fit, the possible existence of multiple local minimums complicates the determination of the global minimum in the numerical optimization process. In addition, Vita (1990) remarks the apparent performance deterioration of these functions in points distant from the approximation point, what limits the evaluation of large output expansions or contractions. We stick to the family of flexible forms, but differently from any form used with Portuguese data, a second-order polynomial is imposed. Convexity allows our functional-form's behavior to be consistent with a single MES of straightforward computation.

Vita (1990) closes a decade of intensive production in this branch of literature with a seminal contribution that insists on the superiority of the long-run functions compared to the short-run ones. Cowing and Holtmann (1983) had argued the opposite. Both authors and Preyra (1998) obtain the long-run cost-function by substituting the first-order conditions (FOC) in order to the

[10] The dual cost-function is represented as $C(Y,P) \equiv \min_X\{P^T X : F(Y,X) = 0\}$. Where Y is a vector of hospital outputs, X is a vector of production factors and P is a vector of the corresponding factor prices. F is the transformation function describing the hospitals´ technically-efficient production frontier.

fixed-factor in the short-run estimates. Intuitively, the optimum size of hospitals should be determined under long-run optimal capital levels. However, data available for empirical estimations is short-run, when capital levels do not adjust quickly. Thus, transforming short-run cost-functions into long-run require strongly sustained assumptions (e.g. Preyra and Pink, 2006). The rigidities of the public property regime in Portugal make it unlikely that public hospitals' capital is sold or transformed in the short-run. Even though, it is not unrealistic to imagine hospital facilities and equipment being rented for other purposes (e.g. research labs). In addition, the EPE transformation introduced the possibility of adjusting both quantity and prices of medical staff in a faster pace towards long-run levels. These arguments bring the input flexibility needed to support the long-run conjecture. Therefore, we estimate the short and derive long-run cost-functions.

3.2 The model

3.2.1 Functional form: structural part

The functional form used to describe the hospital production technology is quadratic, inspired by Preyra and Pink (1998). Accordingly, the total operating costs of a hospital are dependent on the vector of outputs it produces (Y)[11], and on fixed-factors it has to maintain to operate (K): C=C(Y,K). The components of both categories are allowed to interact with each other and themselves. In case it can be assumed further that fixed-factor prices (R) are constant, not capturing any cost variability between hospitals, the second-order polynomial is:

$$C(Y,K) = \alpha_0 + \sum_{i=1}^{m} \alpha_i Y_i + \sum_{i=1}^{m} \sum_{j=1}^{m} \alpha_{ij} Y_i Y_j + (\beta_1 + R)K + \beta_2 K^2 + \sum_{i=1}^{m} \gamma_i K Y_i$$

Clearly, hospitals in urban areas are not comparable in opportunity costs of land and infrastructures to hospitals in the suburbs, or in rural areas. It is common to include a rural/urban dummy variable to control for this predictable cost divergence, but not in Portuguese studies.

[11] Under the constitutional clause stating the right to "free" National Health Service (NHS) coverage, the exclusion mechanisms (up to the maximum capacity) are limited and, if public hospitals demand is exogenously determined, the output vectors are exogenous.

Since public hospitals administrations are exempted from renting the properties they occupy (government-owned), and accounting rather than economic information is required, opportunity costs should be disregarded and the constant fixed-factor prices assumption is adopted.

Cowing and Holtmann (1983) highlight the incorrectness of assuming no substitution possibilities between inputs through the omission of input prices. The omitted-variable bias would threat the validity of numerous studies focusing solely on technical efficiency were not two observations made: hospitals may sometimes be assumed to face equal prices (Preyra, 1998); data on input prices are often very difficult to get (the Portuguese case) and their proxies are unreliable. If price variation between units is unimportant in explaining cost variation, price information may be dropped. As long as purchases are centralized, wages are administratively determined, and the government owns the hospitals facilities, it seems reasonable to assume constant prices without further testing. Besides centralized purchases, the other two conditions fit very well to the Portuguese reality, at least in the pre-EPE period.

The EPE transformation consents wage flexibility and the hiring of labor as an external service. Two types of labor persist in the financial statements: hired permanently; bought as a subcontracted service. Labor costs are expected to become more volatile and, based on publicly available information, it is harder to disentangle labor costs from other contracted services. Searching for a proxy for labor prices, Carreira (1999) obtains the average cost of a "unit-of-labor" dividing total staff costs by total staff. However, the input combinations may differ substantially among hospitals due to internal policy issues, or to inconsistent input substitutability, magnified by different severity of cases treated[12]. In contrast with the preceding authors, Afonso and Fernandes (2008) are able to spit staff into three labor categories, but maintain high degree aggregation and, above all, true-price indetermination. Pharmaceuticals prices faced are also

[12] The ratio Nurses/Physicians is 1.5 for central hospitals as opposed to 2.7 for the remaining. Moreover, it is negatively correlated with the complexity indicator, the case-mix index (Corr=-0.2013), which signals that complexity induces departure from constant labor input substitution (central hospitals have higher case-mix indexes).

hard to determine. "Once the candidate for a factor price proxy is constructed, its behaviour should mimic the sort of behaviour which one expected from the true price variable", Preyra (1998). Input prices are omitted because, like Grannemann et al. (1986) and Preyra (1998), we think that the advantages of additional flexibility in this score do not outweigh scale-economies measurement problems associated with poor quality of the input prices data.

3.2.2 Functional form: ad-hoc part

Given that most hospital services might be provided by other types of health-care units, the economic definition of a hospital is not as trivial as it seems. By default, a hospital should be defined by its most distinguishing feature – the provision of inpatient acute-care services. Even if the health-care units analyzed satisfy this minimum requirement, huge technological heterogeneity may be present. Sample homogeneity becomes a particularly relevant issue when imposing a common theoretic cost-function to hospitals with wide ranging technologies. The sensitivity to outliers may be huge, and the regression residuals are large. Thus, an additional requirement that hospitals provide a minimum set of general services should be made. In order to maintain the general-care condition, in line with the literature (e.g. Preyra and Pink, 2006; Menezes et al., 2006), specialty hospitals such as maternities, addiction and rehabilitation centers, ophthalmologic and oncology institutes, were dropped from the original sample of public hospitals. In addition, none of the sample hospitals could provide no ambulatory surgeries, no chronic/long-term treatment sessions and no emergency episodes, at the same time.

Nonetheless, the Portuguese hospital network is small (around 100 hospitals), and only 70% of it is public (Barros, 2009), which prevents the law of large numbers to be entirely exploited. The use of all existing general-care hospitals and of panel-data attenuates the problem, but large heterogeneity affecting coefficients' explanatory power will persist. The sources of heterogeneity that are expected to remain include the average complexity/severity of patients, the quality of service, the teaching hospital condition, and factors such as the amplitude of the portfolio of services, the management-type (SPA/EPE) and the building discontinuity. This justifies the inclusion of an additional ad-hoc part in the functional form, but data availability constraints should be explored beforehand.

3.2.3 Model inputs

3.2.3.1 Sample

Five categories of variables should be distinguished at this stage: financial, or costs; technology, or inputs; production, or outputs; controls; and dummies. Financial data (including each hospital's inpatients case-mix index) were directly provided by ACSS[13]. Production and technology variables were taken from the annual reports published by DGS[14]. The number of in-hospital deaths, an input for quality indicators, was obtained directly from DGS. Dummy variables information was collected from several sources (e.g. hospital reports, hospital websites). The outcome was, therefore, a tailor-made database.

The sample is a cross-section of 74 general acute-care public hospitals, followed during four years. The lower limit is 2003, because the EPE transformation involved transition of accounting standards for 31 hospitals (28 in 2003 sample, 38.4%), which put important reservations on the reliability of financial data for 2002. The upper limit is 2006, since consolidated financial data beyond that was still unavailable at data collection time. The sample was enlarged from 73 to 74 hospitals in 2004 with the opening of a new hospital[15]. Five mergers occurred within the period of analysis[16], reducing the sample to 67 hospital reports in 2005[17]. All hospitals remained

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[13] *Administração Central do Sistema de Saúde* (ACSS), the Ministry of Health´s department responsible to intermediate public hospitals' funding, as well as to gather and publish most financial data. The entity responsible for hospitals' funding in *Açores* and *Funchal* hospital-center (*Madeira*) did not respond to data requests timely.

[14] *Direcção Geral de Saúde* (2003-2006). DGS is the general health directorate from the Ministry of Health.

[15] The new *Litoral Alentejano* hospital substitutes *Conde Bracial* hospital (Santiago do Cacém), excluded from 2003 sample for being near closure.

[16] *Centro Hospitalar de Lisboa Ocidental* and *Centro Hospitalar do Nordeste* amalgamated three hospitals each, and *Centro Hospitalar de Lisboa Central*, *Centro Hospitalar do Baixo Alentejo*, and *Centro Hospitalar do Baralavento Algarvio* amalgamated two different hospitals.

operational after merging but, since the resulting entities share a common administration board, with an integrated and refreshed view for the resources, merged hospitals are empirically treated as different from their original units. Consequently, the final result is an unbalanced panel of 280 observations. The balanced version comprises 240 observations (60 hospitals).

3.2.3.2 Variables: structural part

Total operating costs is described as the sum of all accounts in Portuguese cost statements (61 to 69), excluding amortizations and the noisiest accounts, i.e., financial and extraordinary costs and losses. On the one hand, Vitaliano (1987) points out that the "estimation of a total rather than an average cost function is preferred in econometric grounds because the latter introduces the size or output variable on both sides of the equation. This may cause bias in parameter estimates of as much as 10% and of unknown direction." On the other hand, Breyer (1987) reminds that when total costs are chosen, multi-co-linearity is expected to be present. However, ever since interactions in the functional form were introduced, it was predictable that multi-co-linearity in regression coefficients would be something to deal with.

Hospitals are multi-product firms, meaning that several outputs should be recognized in their cost-functions. Following the same logic of Preyra and Pink (2006), three types of outputs are considered: inpatient days (INP), emergencies and outpatient visits (EMO) and ambulatory surgeries (AMB)[18]. INP includes all existing types of inpatient days, multiplied by the hospital's inpatients case-mix index (CMI)[19]. Intuitively, what each hospital produces are treatment days with a certain complexity/severity, and the CMI should be able to control for this fact – more

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[17] And 66 in 2006, given that *Arcebispo João Crisóstomo* hospital (*Cantanhede*) has been closed for renewals.

[18] As in Harfouche (2008), the number of day-hospital sessions (CHR) is disregarded. It is a new practice, still absent in many hospitals, which aggregates treatments as heterogeneous as chemotherapy and psychotherapy. Non-significance of the coefficients of this variable was expected, since it is noisy and recorded in a deficient way. In fact, correlation of CHR with operating costs is only 0.58, compared with 0.69 for AMB, 0.95 for EMO and 0.96 for INP.

[19] CMI is calculated by ACSS for funding purposes and, by definition, averages 1 for all country´s public hospitals. Patients are sort by Diagnosis-Related Groups (DRG), more or less reliably. Hospitals treating above-average resource-consuming patients have an index above 1 and receive more funds per discharge. The opposite is also true. Ambulatory CMI is available from 2006, creating room for future improvements in AMB description.

complex cases are typically more resource-consuming. Higher average complexity/severity is equivalent to higher output for a certain number of inpatient days. In order to expurgate outputs from individual hospital policies concerning average lengths-of-stay (ALS) some authors prefer to use the number of inpatient discharges. Carreira (1999) notes that inpatient days increase either if the ALS increases or the number of discharges expands[20]. Average daily expenses for the same treatment tend to decay as ALS increases. Thus, caution should be put in coefficient interpretation as marginal costs of inpatient days. ALS may be independent from hospital policies (e.g. due to different patients' average age) and INP will explain better hospital operating costs in face of the large variability of ALS (mean=7.61, S.D.=3.13). However, it is important to be aware of the trade-off explanatory power versus theoretical appeal. The main reason for the EMO aggregation is empirical, but is also related with low bed-intensity requirements. AMB is costly and is becoming more important as medicine evolves and bed usage shrinks[21]. Regarding information limitations, what we call outputs are simply intermediate inputs of the ultimate output, which is better health status, or death delay. The effects of hospital intervention are usually hard to disentangle from other factors that improve health (e.g. behavior changes due to fear to be ill again). Thus, it was convenient to consider that "the output is that for which the firm receives revenue, inputs are factors used to provide these outputs", Preyra (1998).

In line with the literature, the number of operating beds is the fixed-factor[22]. The number of beds is representative of the capital stock and firm size. Since it may be unrealistic to assume that the hospital technology is independent from its size, interactions between the outputs and the beds indicator are allowed. Moreover, Vitaliano (1987) emphasizes the problem of vacant beds counting for final costs when available just for precautionary reasons. In order to solve this problem, we transformed the beds variable: BEDOR=(operating beds)*(occupancy-rates). Since

[20] $\Delta INP = \Delta discharges.\overline{ALS} + \overline{discharges}.\Delta ALS + \Delta discharges.\Delta ALS$

[21] Some hospitals are even creating separate facilities for this practice (e.g. *Santo António* hospital).

[22] Operating beds is statistically defined as the number of beds counted in a health-care unit, available and prepared for immediate inpatient treatment (cots for pediatrics and neonatology included).

vacant beds may not affect total operating costs much, potentially, the resulting variable has better explanatory power. However, the gain of explanatory power is traded-off against the loss of information about the short-run costs and opportunity costs of unused beds (e.g. cleaning; rooms they occupy). If the loss of information is negligible (low amounts, quick adjustment), the estimated optimum sizes are measured in (permanently) fully-occupied beds.

3.2.3.3 Variables: ad-hoc part

Recalling the above-mentioned persistent sample heterogeneity, an ad-hoc part is attached to the structural part of the functional form. One of the main difficulties of researchers in this field is to correctly capture the impact of quality standards on costs. “Outcome” quality indicators are more appealing than “process” indicators since they convey additional information related to the rationale for the existence of hospitals, i.e., improve health status. Menezes et al. (2006) prove that accredited hospitals have, on average, higher variable costs. Naturally, accreditation involves costly efforts which explain cost divergence. However, the ultimate objective of hospitals is to delay death, and Boto et al. (2008) found no relationship of accreditation (and benchmarking) with mortality rates. Our search and trial of outcome quality indicators selected the following:

$$Q_{it} = deaths_{it}/(inpatients_{it}.CMI) = deaths_{it}/INP_{it}, \qquad i = 1,\dots,79 \; and \; t = 1,\dots,4$$

Where *deaths* is the number of in-hospital deaths in a year. The CMI is relevant to control for the fact that hospitals treating more severe cases are expected, *ceteris paribus*, to have higher mortality rates. Q is interpreted as the lethality rate per adjusted inpatient day and there is no *a priori* expectation for the sign of its coefficient. More diligence in avoiding death involves typically more resource-consumption (e.g. test-machines use), but high-quality hospitals also attract more patients. Nevertheless, none of the outcome indicators tested is bias-free. Readmissions rates suffer from the difficulty in tracking consecutive episodes, mortality-related indicators are affected by deficient case-mix control, and the ratio physicians/discharge just indicates resource intensity, not the effective quality of outcomes. Our quality measure is easy to obtain and considers the most relevant aspects of an outcome quality indicator.

Three out of four year dummy variables, when put together with a constant, should be able to capture time-effects (Preyra, 1998). However, without interaction with the production variables, the individual impacts are only mean-approached. It has become widespread to use total costs at constant prices[23]. However, this would make the time-binary and other variables not statistically significant since cost variability attributable to time, other than general inflation, would be omitted or redistributed among other variables – affecting estimators' efficiency. This would be a result of the inexistence of a suitable deflator for health-specific production-costs.

Central hospitals, located in the main urban areas, are larger than district hospitals on average and serve broader influence areas. These were designed to provide a wider range of specialized services, and benefit from scale and experience in most demanding and rare pathologies[24] – the CMI is generally higher than 1 (average of 1.34). These specificities justify *per se* a central-hospital dummy variable, which may also capture those case-mix effects unaccounted for by the CMI (e.g. more complex emergencies treated in central hospitals).

Among central hospitals, some provide teaching services, recognized by the literature as major costs-drivers. Teaching hospitals produce additional output (e.g. student days) and have specific facilities and human resources for education purposes – direct costs. Some resources are diverted for educational purposes, namely, physician time and extra treatment sophistication – indirect costs. After an extensive discussion of the impacts of teaching, Preyra (1998) decides not to describe it on the cost-function. As Aletras (1999), we account for this cost-driver in the

[23] Using the Consumer Price Index (CPI), the Health CPI, or the GDP Deflator (e.g. respectively, Menezes et al., 2006, Barros and Sena, 1998, Carreira, 1999).

[24] For example, *Santa Cruz* and *Santa Marta* hospitals are known to gather competences to execute complex surgeries such as heart transplants. This variable will capture increased costs such as the maintenance of specialized machines, or a greater intensity of use of expensive physicians.

simplest manner, i.e., with a teaching-hospital dummy variable[25]. This approach is unable to differentiate indirect from direct costs. However, further data and research would be needed to figure out the extent of the indirect costs and how incremental costs compare with savings from substitution of physician and nurse time by cheap resident and intern work.

Hospital centers result from mergers of separate hospitals, and typically continue to operate in non-contiguous buildings. Service redistribution and specialization is expected to take place, but Menezes et al. (2006) proved that this facility duplication causes higher variable costs, *ceteris paribus*. We also test this effect including a binary variable for multiple-buildings hospital centers.

The effectiveness of the EPE transformation in delivering efficiency to public hospitals is object of considerable attention in political and academic grounds (e.g. Gouveia et al., 2006; Menezes et al., 2006; Harfouche, 2008; Moreira, 2008). There is still mixed evidence that this institutional arrangement improved cost-efficiency. Since we are just interested in purifying the other variables from this effect, a dummy variable is again the approach used. The classification as EPE follows financial statements publishing criteria, not necessarily matching legal transformation dates.

As the result of the parsimony-concerned ad-hoc adaptation of the structural model presented above, the final functional form to be estimated is the following:

$$C(Y,K,Q) = \alpha_0 + \sum_{i=1}^{m} \alpha_i Y_i + \sum_{i=1}^{m}\sum_{j=1}^{m} \alpha_{ij} Y_i Y_j + \beta_1 B + \beta_2 B^2 + \sum_{i=1}^{m} \gamma_i B Y_i + \lambda Q + \sum_{d=1}^{n} \partial_d D_d$$

Where Y is the vector of the m>1 outputs considered, B is the fixed-factor represented by the BEDOR variable, Q is the quality indicator proposed, and D is the vector of n empirically meaningful dummy variables. The descriptive statistics are as follows:

[25] Administratively, only *Santa Maria*, *S. João* and *Universidade de Coimbra* hospitals were conceived as teaching hospitals, despite not being the only involving teaching activities.

Table 1 - Descriptive statistics (280 observations – full sample)

Variable	Description	Mean	S.D.	Min.	Max.
C	Sum of accounting costs (in million €) - (66-amortizations) - (68-financial costs and losses) - (69-extraordinary costs and losses)	58,3	63,1	1,70	311
INP	Number of inpatient days x inpatients case-mix index	95.653	108.962	1.230	599.516
EMO	Number of emergency episodes + number of outpatient visits	194.792	149.008	4.294	756.928
AMB	Number of programmed ambulatory surgeries	1.210	1.803	0	13.794
BEDS	Number of operating beds	310	278	8	1.548
BEDOR	Number of operating beds x beds occupancy-rate	239	223	4	1.214
CMI	Inpatients case-mix index	1,02	0,29	0,58	2,72
OR	Beds occupancy-rate	0,74	0,11	0,20	0,98
ALS	Inpatients average length-of-stay (in days)	7,61	3,13	2,70	47,90

3.3 The optimum

3.3.1 Estimation techniques

The panel-data model adopted was estimated by maximum-likelihood (ML), assuming random-effects. Panel-data treatment allowed the enlargement of a small cross-section of hospitals into a 280 observations sample – more efficient parameter estimators. However, the most attractive feature of panel-data estimation is that it solves the omitted variables problem. Each hospital may be assumed to have unobserved effects impacting its costs differently from any other hospital (e.g. *S. Paulo* hospital is installed in a convent). This idiosyncratic effect explains some of hospital's cost variability, but since is unobserved it is non-sense to estimate its partial effects on total costs. Being reasonable to assume that this effect is time-invariant and its impact on each hospital's costs is a constant, panel-data analysis exempts its estimation, avoiding coefficient bias simultaneously. The fundamental choice is whether the unobserved heterogeneity is a random-effect (a random variable picked from a normal distribution), or a fixed-effect (an estimated parameter). The random-effects model was chosen under the assumption that the correlation between the observed explanatory variables and the unobserved effect is zero[26]. When the assumptions of the random-effects model are satisfied, the estimator is consistent and more

[26] The general unobserved effects model may be described as: $y_{it} = x_{it}\beta + c_i + u_{it}, for\ t = 1,2,\dots,T$. In the random-effects case, c_i (unobserved heterogeneity) is attached to u_{it}, thus, it must be true that: $Cov(x_{it}, c_i) = 0$. In case of fixed-effects, c_i is detached from u_{it} and, consequently, is allowed to be arbitrarily correlated with the x_{it}.

efficient than fixed-effects. The Hausman test did not reject the null hypothesis of equality of the random and fixed-effects estimators at 5%. However, the estimation of the fixed-effects model is also recommended, at least for robustness testing purposes. The Breusch-Pagan Lagrange Multiplier test for random-effects accepted the random effects hypothesis[27]. The maximum-likelihood estimator is justified on the basis of the non-linearities of the functional specification and to prevent heteroskedasticity problems.

3.3.2 Estimation results[28]

The examination of covariance matrices and the estimation of the function with several combinations of variables confirmed the model detailed above, as estimated below (Table 2). The coefficients are difficult to interpret directly, which does not affect the function behavior. Except for the constant, the coefficients of the short-run function have the expected signs and reasonable magnitudes. Ideally, the constant might be interpreted as the fixed-costs of a non-central, non-teaching, single-building, non-EPE hospital. However, the main strengths of these functions are on describing the behavior around the sample means, not on the performance at points distant from these means[29]. The model's overall statistic significance is not rejected[30]. An alternative model specification, with disaggregated EMO and CHR included, is included in Appendix 2.

Conceptually, the long-run (LR) cost-function is derived by plugging the optimum levels of the fixed-factor in the short-run (SR) estimated technology – SR and LR coincide at the optimum. The SRC function is computed at the mean fixed factor (BEDOR=239), for comparative purposes. The intercept used for the LR and SRC cost-functions is the latest available (2006).

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[27] Under the null there are no hospital specific effects. The asymptotic Chi-square distribution with one degree of freedom results in a test statistic of 214.34.

[28] All the estimation results and hypothesis testing were obtained using the software package *STATA 10.0*.

[29] The negative sign would not prevent misinterpretation given that part of hospital financing is independent from its production and size. Hypothetically, at zero output and bed usage, the Ministry would still transfer 10 million €, i.e., 17% of the mean operating costs.

[30] The Likelihood Ratio test is of 534.14, for a Chi-square distribution with 22 degrees of freedom.

Table 2 - Short-run and Long-run cost-functions

C	Short-run (SR)			SRC	Long-run (LR)
	Coefficient		Standard error	Coefficient	Coefficient
Constant[a]	-10,00	*	3,23	-44,65	-5,94
INP	211,38	*	48,33	1.003,98	313,83
EMO	95,71	*	29,41	196,66	108,76
AMB	1.505,82		1.340,18	-6.065,60	527,15
INP^2	-0,0031	*	0,0008	-0,0031	-0,0000
INPxEMO	-0,0010	*	0,0003	-0,0010	-0,0002
INPxAMB	0,0524	*	0,0119	0,0524	-0,0064
EMO^2	0,0001		0,0001	0,0001	0,0001
EMOxAMB	0,0138	**	0,0064	0,0138	0,0063
AMB^2	-0,2063	**	0,0964	-0,2063	0,0743
BEDOR	55.236	**	27.125		
BEDOR^2	-894	*	174		
BEDORxINP	3,3163	*	0,6822		
BEDORxEMO	0,4224	*	0,1439		
BEDORxAMB	-31,6796	*	6,1897		
d2004[a]	1,06	**	0,54		
d2005[a]	2,43	*	0,60		
d2006[a]	3,21	*	0,66		
Q[a]	414	*	161	414	414
dcent[a]	21,40	*	3,66	21,40	21,40
dteach[a]	45,00	*	11,10	45,00	45,00
dncb[a]	7,55	*	2,36	7,55	7,55
depe[a]	8,82	*	2,46	8,82	8,82
OPTIMUM SIZE					
100% OR	233			239	Beds*
85% OR	274				
MEAN OR	315				

[a] in million €; * significant at 1%; **significant at 5%; ***significant at 10%

3.3.3 Estimated optimum

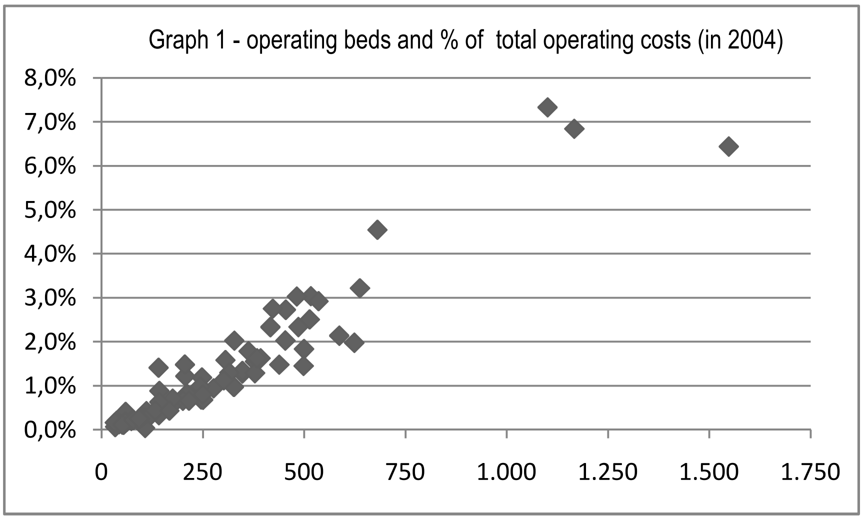
The optimum number of beds is obtained by equating to zero the FOC of the SR function with respect to BEDOR. Since an average 100% bed occupancy-rate (OR) is undeniably unrealistic, the optimum found should be expanded by the inverse of the desired bed occupancy-rate (OR*):

$$Beds^* = (1/OR^*)[(\beta_1 + \gamma_1 INP + \gamma_2 EMO + \gamma_3 AMB)/(-2\beta_2)]$$

For illustrative purposes, the optimum for the sample mean OR is shown along with the unrestricted 100% OR[31]. In the long-run, hospitals adjust the OR so that average costs are

[31] Since the distribution of OR is skewed, the median of 0.76 might have been chosen. The simple mean OR of 0.74 gives too much weight to small hospitals, with low average OR, but the difference is not relevant.

minimized, but the risk of seasonal or random bed shortages should also be prevented. Bagust et al. (1999) conclude that risks of bed shortages are discernible when acute-care hospitals have average OR above 85%. Thus, the LR function is computed for $OR^*=1$, but might alternatively be evaluated at the benchmark $OR^*=0.85$. To sum up, the derived optimum size for the entire sample of public hospitals is 233 beds. This reference value is real-world adjusted if divided by the prevailing, benchmark, or desired OR. The desired OR can be determined by researchers, but it is something that hospital managers should be able to fine-tune in accordance with of objective internal policies, or external recommendations. If expanded by the mean OR, the optimum BEDOR results in a 315 beds optimum, which is very close to the mean number of beds in the sample (310). This would be a direct sign of scale-efficiency of public hospitals if, as Graph 1 shows, the dispersion around the mean was not so high.



3.3.4 Robustness Analysis

This subsection tests the robustness of the results above by changing three sensitive foundations of the short-run cost-function: the inclusion of bed-outliers[32]; the estimation method; some adaptations made relative to Preyra and Pink (2006) – quality indicator and dummy variables. In order to dissipate eventual doubts, three additional cost-functions were estimated:

[32] The gap between the smallest and the largest hospital is of 1500 beds.

Table 3 - Robustness Analysis

C	**No bed-outliers**			**Fixed-effects**			**PP2006**		
	Coefficient		Standard error	Coefficient		Standard error	Coefficient		Standard error
Constant[a]	-8,06	***	4,38	14,2	***	8,09	-3,41		3,01
INP	179,65	***	103	109,95	***	56,54	220,23	*	52,33
EMO	128,35	**	56,13	46,27		47,98	91,41	*	32,41
AMB	-1.983,27		2.392,86	1.593,50		1.477,37	3.755,26	**	1.472,43
INP^2	-0,0031	**	0,0012	-0,0018	***	0,0011	-0,0034	*	0,0008
INPxEMO	-0,0007		0,0006	-0,0011	*	0,0003	-0,0008	**	0,0003
INPxAMB	0,0771	*	0,0279	0,0346	**	0,017	0,5642	*	0,0133
EMO^2	4.93e-06		0,0003	0,0003	*	0,0001	0,0002	*	0,0001
EMOxAMB	0,0226		0,0178	0,0079		0,0069	0,0042		0,0068
AMB^2	-0,4234	**	0,2144	-0,1266		0,1052	-0,0711		0,103
BEDOR	55.578		49.838	68.855	***	35.569	69.359	**	29.041
BEDOR^2	-807	**	359	-681	*	230	-896	*	194
BEDORxINP	3,3813	*	1,1614	2,3504	**	0,945	3,6114	*	0,7583
BEDORxEMO	0,1954		0,517	0,345	**	0,1529	0,2205		0,1526
BEDORxAMB	-33,692		20,622	-21,2898	*	8,1859	-33,5906	*	6,8602
d2004[a]	0,5		0,84	1,12	***	0,6	0,55		0,61
d2005[a]	1,48		0,93	3,38	*	0,69	2,11	*	0,67
d2006[a]	3,07	*	1,01	4,03	*	0,78	2,57	*	0,74
Q[a]	348		270	226		199			
dcent[a]	13,9	*	3,18						
dteach[a]									
dncb[a]	5,15	**	2,49						
depe[a]	4,69	***	2,66						
OPTIMUM SIZE									
100% OR	178			246			233		
85% OR	209			289			274		
MEAN OR	243			333			314		

[a] in million €; *significant at 1%; **significant at 5%; ***significant at 10%

In spite of the interactions of the size variable, it is still naïve to presume that the largest hospitals share the same technology with the smallest. Excluding bed outliers, i.e., keeping the observations within the range of a two-sided standard deviation from the mean number of beds (32<beds<588), the optimum decreases considerably. Since only 2 out of 30 hospitals excluded are below 32 beds, the largest hospitals have a considerable impact on the optimum initially derived. This is unsurprising since the largest hospitals, typically central hospitals, allow the CMI to approach the country average of 1. Besides the higher-than-average complexity, central hospitals receive plenty of patient transfers from small hospitals. Thus, these are essential pieces of the functioning of the system as a whole. The model is not completely robust to bed outliers, in the sense that the significance of some coefficients is destroyed. However, the exclusion of large hospitals from the sample would result in a bad description of the general hospital technology.

3.3.5 Sensitivity Analysis

Overall, the cost-function was proved robust to changes of its most sensitive features. As a consequence, the estimated SR cost-function can be applied to subsamples of interest with some degree of confidence. The subsamples proposed are: the most general hospitals (excluding D1 hospitals, C+D), district hospitals (excluding central hospitals, D+D1), and publicly-managed hospitals (excluding EPE-transformed hospitals, SPA)[33]. The function "No bed-outliers" is recovered from the last subsection. The new optimums are references for eventual partial requalification of the hospital network. The relevant data and estimation results for the subsamples proposed are in Appendix 3. Along with the optimums for the re-sampled estimates, the optimums for the SR function evaluated at the means of the subsamples were calculated:

Table 4 - Optimum new function, new sample / Optimum SR function, new sample

	C+D		D+D1		SPA		No bed-outliers	
100% OR	292	287	160	161	150	202	178	179
85% OR	344	338	188	189	176	238	209	211
MEAN OR	385	378	222	224	211	285	243	245

Three remarks should be made. First, the re-estimation of the cost-functions for the subsamples does not challenge the optimums resulting from the evaluation of the SR function at the means of the subsamples. Except for the SPA function, the largest optimum BEDOR divergence is of only 1.7% (for the C+D function). Drastic sample changes did not make the SR function obsolete, in the sense that optimums have shown persistence. Even the optimum of "No bed-outliers", that raised some doubts in the last subsection, is kept constant. Thus, when samples are large and

[33] Since the analysis of Central, D, or D1 separately would suffer from small-sample bias, we preferred to consider these skewed subsamples, without loss of economic appeal. EPE subsample also suffered from it in a large scale.

representative enough, the SR cost-function is a loyal technological description of administrative and bed subcategories of public hospitals, at least for optimum calculation purposes.

Second, the results suggest that SPA hospitals (60% of the sample) and EPE hospitals have different production frontiers. While the functional form adjusted satisfactorily to the SPA subsample, only 7 out of 21 coefficients were significant at the 10% level for the EPE subsample. Moreover, the optimum for the SPA function departs 26% from the optimum for SR function evaluated at the SPA subsample. The subsamples are small and it is beyond the scope of this study to analyze frontier divergences. The important aspect to retain is that the SR function may not be an appropriate technological description of management-type subsamples.

Last but not the least, picking the first remark attesting suitableness of the evaluation of the SR function at subsample means, and giving room to some loss of precision, the optimum size of 224 beds for district hospitals compares with the optimum of 241 found by Lima (2003). This may be reflecting the declining trend in bed usage in production of hospital care.

3.4 Economies-of-scale

Scale-economies are said to exist in a firm whenever an increase in output results in a less than proportional increase in total costs, i.e., mathematically, the average cost-function is negatively sloped. Despite independent from the increase in output being due to a merger, or a pure expansion, the existence of scale-economies is typically dependent on the level of output, i.e., mathematically, the cost-function is non-monotonic in its domain. Intuitively, if the average cost-function were monotonically decreasing at all levels of output, the scale-efficient long-run decision would be to concentrate the whole hospital network in a single mega-hospital (transportation and time costs disregarded). Still, it is realistic to presume that, up to some scale, fixed-costs are diluted among patients in a faster pace than organizational ineffectiveness costs rise. Moreover, cost-complementarities may push costs down further. On this basis, the hospital cost-function is convex and the following measure of short-run economies-of-scale seems appropriate:

$$ES(\rho, N) \equiv 1 - \frac{\hat{C}(\rho Y, \rho B, \rho Q)}{N\hat{C}(\rho\frac{Y}{N}, \rho\frac{B}{N}, \rho\frac{Q}{N})}$$, scale-economies if ES>0 (scale-diseconomies if ES<0)

Where Y is the vector describing the prevailing output mix, ρ is a percentage (of the reference output, fixed-factor and quality), and N is the number of identical hospitals that jointly produce the combined output. The long-run version of this measure just assumes that $\hat{C}$ is the LR function and, consequently, B is dropped. The following table presents the ES achieved when $\hat{C}$ is the SR function, Y is the mean output vector, B is the mean BEDOR, Q is at the mean (7.45 deaths per 1000 INP) and N=2. It is assumed that the service mix is held constant:

Table 5 – Short-run economies-of-scale (N=2)

ρ	ρxBEDOR	ES Min	Savings (million€/year)	ES Max	Savings (million€/year)
.25	60	0,019	0,2	0,360	18,4
.5	120	0,016	0,4	0,359	36,8
.75	179	0,013	0,5	0,358	55,1
1	239	0,011	0,5	0,357	73,3
1.5	359	0,005	0,4	0,356	109,6
3	717	-0,010	-1,6	0,350	216,7

Since the SR function allows different intercepts, which influence the scale-economies achieved and the pace at which they decay, the ES measure was bounded. ES Min is the lower bound and assumes that the intercept is equal to a proportion ρ for the merged hospitals and ρ/N for each of the N separate units. Scale-economies for N=2 decay from small to large sizes and vanish as the output and BEDOR reach twice the means. ES Max is the upper bound, for which N central, teaching, EPE, multiple-building hospitals become a single unit. This is a very unlikely output expansion since it assumes that all fixed-costs are cut N-1 times[34]. However, it illustrates how high ES could grow using the estimated functions. Given that BEDOR disregards costs of excessive capital, which may be substantial, and amortizations are fixed-costs excluded from C, ES Min (and even ES Max) may be underestimating the true scale-economies. Nevertheless, it

[34] For instance, a merger of N=2 teaching hospitals is unlikely to cut costs in half, for the same number of students. This is the result of describing teaching status by a dummy variable that captures the average costs of teaching.

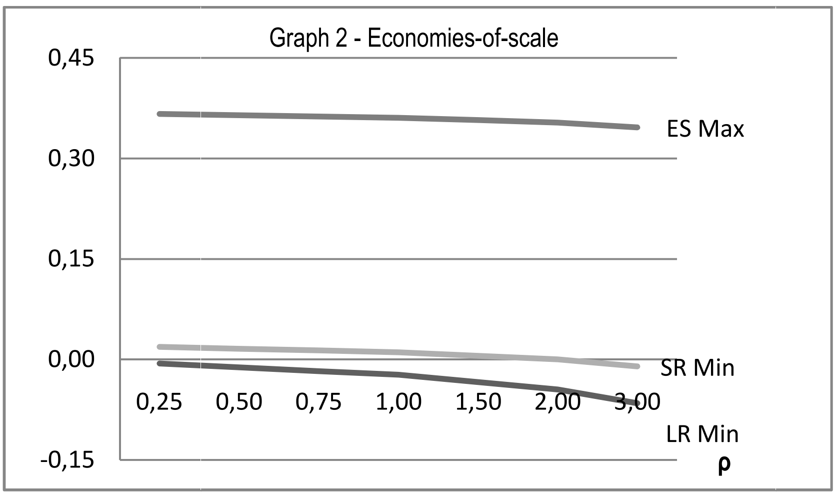
should be remembered that it is incorrect to interpret the intercept as a reliable estimator of the fixed-costs. The results should be used with caution, especially ES Max.

Concentration processes are truly attractive only when the gains spread well beyond the times at which hospitals are compromised with capital input rigidities. Thus, it is worthwhile to compute the long-run ES, i.e. apply the same method to the LR function:

Table 6 - Long-run economies-of-scale (N=2)

ρ	ρxBEDOR*	ES Min	Savings (in million€/year)	ES Max	Savings (in million€/year)
.25	58	-0,006	-0,1	0,366	19,1
.5	117	-0,012	-0,3	0,365	38,1
.75	175	-0,017	-0,6	0,363	57,0
1	233	-0,023	-1,1	0,361	75,7
1.5	350	-0,034	-2,6	0,357	112,7
3	699	-0,066	-10,3	0,346	220,2

The LR function finds scale-diseconomies for all levels of output. These aggravate as ρ grows, but not even the very small hospitals could gain from scale-expansions, which is counterintuitive. This may be a consequence of the bad performance of the cost-function at points distant from the means and Vitaliano (1987) suggests that the quadratic cost-function displays diseconomies-of-scale too often. In extremis, all “fixed-costs”, approached by the dummy coefficients, are cut in half and scale-economies become expressive, but, again, it is implausible. The permanence of the non-contiguous building dummy in the LR function is due to policy indetermination concerning this inefficient pattern. The following graph depicts both long-run and short-run ES:



Despite reservations, ES Min mimics the theoretical behavior of costs through the specifications chosen. ES Min reflects the gains which are due to the shape of the cost-function rather than to intercept shifts. These results are a warning for those attracted by the exploitation of short-run scale-economies. If a scale-expansion is undergone and nothing besides that changes, the long-run losses may end up outweighing the short-run gains and the aimed cost-efficiency is undermined. However, each expansion/contraction should be fit to real production data and facts, and analyzed *per se*. The next section is devoted to exemplify how.

3.5 Simulations

The current hospital network reconfiguration is an onerous and long-lasting process that is involving many capital-stock and organizational adjustments. This section illustrates how the method employed can be used to simulate real output expansions and contractions. It is tempting to choose for output expansions the mergers of 3 independent hospitals which resulted in *Centro Hospitalar Nordeste* (CHNE) and *Centro Hospitalar Lisboa Ocidental* (CHLO)[35], for two reasons: result in hospitals close to the turning-point of the short-run ES; the hospitals merged are not of dissimilar sizes and output levels (N=3 is a reasonable assumption). CHNE is almost 1.5 times the mean BEDOR, while CHLO is about the triple of that in 2003[36].

As example of an output contraction, the likely negative impact on demand for *Santa Maria* hospital (HSM) caused by the creation of a general acute-care 400-500 beds hospital in *Loures* town has been chosen. This town is currently within HSM´s influence area, but since HSM is a large central and teaching hospital, demand is not likely to decrease proportionately to new bed capacity. Not disregarding other creations and replacements around HSM´s influence area[37], a 1/3 demand decrease relative to 2006 seems a reasonable crude prediction. As before, ES Min

[35] CHNE is composed by *Mirandela*, *Bragança* and *Macedo de Cavaleiros* hospitals and CHLO amalgamated the central hospitals of *Santa Cruz*, *Egas Moniz* and *S. Francisco Xavier*.

[36] Data for 2003 is used because CHLO was created in 2004. Both hospital centers were legally EPE-transformed in late December 2005 (*Decreto-Lei nº 233/2005*).

[37] Creation of *Sintra* hospital, replacements of *Vila Franca de Xira* and *Cascais* hospitals.

and the corresponding savings for the SR and LR cost-functions are evaluated at the sample means (Table 1). ES Min for CHNE and CHLO are evaluated at the 2003 average output, BEDOR and quality of the hospitals that would later merge. The simulations for ρ=3.75 (HSM-related) compare 2006 data to two hypothetical hospitals: one with ρ*2/3; the other with ρ*1/3.

Table 7 - Economies-of-scale in mergers (N=3)

			SR function		LR function	
Data	ρ	ρxBEDOR	ES Min	Savings (million€/year)	ES Min	Savings (million€/year)
Mean	1,5	359	0,021	1,6	-0,050	-3,4
	3	717	0,000	0,0	-0,097	-13,7
	3,75	896	-0,034	-6,6	-0,077	-14,3
CHN	≈1,5#	345	0,160	3,9	-0,017	-0,4
CHLO	≈3#	711	0,078	12,0	0,020	3,2
2/3 HSM*	≈3,75##	892	-0,005	1,0	-0,005	1,1

2003 data and intercept; ## 2006 data and intercept

It is conservative to assume ES Min, i.e., fixed-costs as a proportion of the hospital size. Real gains may be higher in practice. Nonetheless, fixed-costs dilution is probably unimportant since the mergers were mainly of legal, management and organizational aspects - all hospital facilities were maintained operational. In line with the predictions of the SR function at the sample means, the SR at the average of the merging hospitals found mild support for CHNE. In contrast with predictions, CHLO is also viable. Based solely on scale considerations[38], the long-run ES Min measure shows consistent diseconomies-of-scale, which would have clearly rejected the potential sustainability of these mergers. However, this proves true only for CHNE. CHLO is sustainable, at least marginally (operates jointly with 98% of the costs of operating separately; savings of 3.2 million€/year). CHLO is composed of hospitals close to the optimum size (237 mean BEDOR). Differently from what Gonçalves (2008) suggested, CHLO had unambiguous potential scale-economies. Considering that gains are small, departure from this conclusion, i.e., cost-inefficiency, may easily be attributed to organizational ineffectiveness and adjustment costs. As a

[38] It is worth to remember that the rationale for mergers include non-economic objectives (integration of health-care view at the regional/local level, improvement of citizen accessibility, etc.).

matter of fact, operating costs of CHLO at constant 2003 prices (GDP deflator=1.02364) were lower in 2004 than in 2003, the opposite being true for CHNE.

In what concerns the HSM case, the SR and LR cost-functions predict substantial scale-diseconomies for ρ=3.75, which mean potential savings from a scale contraction of 1/3. Using real 2006 data these gains are smoother for both SR and LR functions, but still positive. Despite adjustment costs, it is predictable that the new *Loures* hospital will create scale-efficiency in provision of hospital care in HSM through downsizing inducement. However, the estimated (lower bound) savings of 1.1 million €/year represent only 0.4% of HSM's 2006 operating costs.

4. CONCLUSIONS

As medicine evolves and hospital treatments become less invasive, the relationship between intensity of use of beds and the size/production of a hospital is deteriorating. Meanwhile, and to be consistent with the literature, the beds variable seemed to be the best proxy available for the size of hospitals. The aim to estimate optimum bed-sizes for the Portuguese public hospitals was fulfilled through a production-theoretic quadratic cost-function, never applied to Portuguese data before. The functional form was inspired in Preyra and Pink (2006), but suffered significant transformations to improve its economic and econometric properties. The main transformations were conducted to conveniently account for the heterogeneity of the sample with respect to: bed occupancy-rates, average complexity/severity of patients, quality of service, teaching-hospital condition, amplitude of the portfolio of services, management type and building discontinuity.

Under the extreme assumption of 100% average bed occupancy-rates, it is estimated that the optimum size of the Portuguese public hospital is around 233 beds. The optimum should be expanded by the desired, prevailing, or benchmark occupancy-rates (e.g. the mean 74% implies an optimum around 315 beds). Once proved robust to its most doubtful foundations (e.g. the estimation method), the cost-function is re-estimated for some subsamples of interest. The optimum was shown sensitive to sample change. This exercise also demonstrated that the general short-run cost-function is an appropriate technological description of the subsamples of administrative categories, of hospitals around the mean, but not of management-types (SPA versus EPE) – the EPE transformation likely caused technological disruption in public hospitals.

The short-run cost-function predicts some room for scale-economies exploitation in hospitals up to twice the mean hospital, while the long-run cost-function shows increasing scale-diseconomies, even for the smallest hospitals. Policy-makers should take evidence of short-run gains from scale expansions with caution. As capital stocks are adjusted towards long-run optimum levels, scale-economies may vanish or even become negative. However, due to the potential for fixed-costs savings and to heterogeneous levels of efficiency of the hospitals merged, each output expansion/contraction through merger should be analyzed in isolation. The *Centro Hospitalar Lisboa Ocidental* (CHLO) and the *Centro Hospitalar Nordeste* (CHNE) had short-run potential savings from merging before being created. However, and despite its large combined size, only CHLO would have indicated sustainable gains over the long-run. Finally, it is estimated that *Santa Maria* hospital (HSM) has small but positive gains from 1/3 scale reduction, both in the short and in the long-run. This reduction may easily be induced by demand diversion to the forthcoming public hospitals within and around its influence area.

Future research should unveil which services should be put together in hospitals of the scale-efficient size we estimated, i.e., focus on scope-economies. This study estimates the efficient size of hospitals, but does not indicate where they should be located in territory. Considering demographic density data and average travel costs, future research could address the issue trying to find the optimal distance between hospitals. The "peak-load problem" stressed by Lynk (1995) should be addressed, particularly for those hospitals located in areas where the uncertain demand makes it more difficult to manage scale and occupancy-rates in a cost-efficient manner.

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Appendix 1 – Acronyms and abbreviations

ALS – Average length-of-stay of inpatients

AMB – Number of programmed ambulatory surgeries

BEDOR – Number of operating beds * occupancy-rate of operating beds

CHLO – *Centro Hospitalar de Lisboa Ocidental* (a specific local merger of independent central hospitals)

CHNE – *Centro Hospitalar do Nordeste* (a specific local merger of independent district hospitals)

CHR – Number of chronic/long-term treatment sessions (day-hospital sessions)

CMI – Case-mix index for inpatients

D – District hospitals

DEA – Data Envelopment Analysis

D1 – District Level 1 hospitals

EMO – Number of emergency episodes + number of outpatient visits

EPE – *Entidades Públicas Empresariais* (corporate public hospitals)

ES – Measure of scale-economies proposed

FOC – First-order conditions

GDP – Gross domestic product

HSM – *Santa Maria* central hospital

INP – Case-mix adjusted inpatient days

LR – Long-run derived cost-function

MES – Minimum-efficient-scale

OR – Occupancy-rate of operating beds

SA – *Sociedades Anónimas* (publicly-owned hospital companies)

SFA - Stochastic Frontier Analysis

SPA – *Sector Público Administrativo* (publicly-managed hospitals)

SR – Short-run estimated cost-function

Appendix 2 – Full model

Table 1A2 – Short-run full model

C	Full		
	Coefficient		Standard error
Constant[a]	-12,30	*	3,81
INP	209,51	*	53,34
EMR	164,51	**	78,86
OUT	255,37	*	64,87
AMB	-385,49		1.439,04
CHR	67,01		136,43
INP^2	-0,0017	***	0,0010
INPxEMR	0,0007		0,0007
INPxOUT	-0,0010		0,0010
INPxAMB	0,0200		0,0166
INPxCHR	-0,0018		0,0011
EMR^2	-0,0007		0,0005
EMRxOUT	0,0007		0,0007
EMRxAMB	0,0059		0,0146
EMRxCHR	-0,0028	*	0,0010
OUT^2	-0,0004		0,0004
OUTxAMB	0,0216	***	0,0127
OUTxCHR	0,0001		0,0019
AMB^2	-0,1744	***	0,1039
AMBxCHR	0,0182		0,0436
CHRxCHR	0,0016		0,0017
BEDOR	24.453		29.280
BEDOR^2	-514	**	220
BEDORxINP	1,8136	**	0,8672
BEDORxEMR	-0,4428		0,4266
BEDORxOUT	0,5845		0,4226
BEDORxAMB	-17,4683	**	7,9657
BEDORxCHR	1,0033	***	0,5458
d2004[a]	0,10		0,53
d2005[a]	1,35	**	0,61
d2006[a]	1,97	*	6,69
Q[a]	402	**	161
dcent[a]	17,50	*	4,28
dteach[a]	55,10	*	12,20
dncb[a]	5,60	**	2,27
depe[a]	7,64	*	2,60
OPTIMUM SIZE			
100% OR	207		
85% OR	244		
MEAN OR	280		

[a] in million €; *significant at 1%; **significant at 5%; ***significant at 10%

EMR – Number of emergency episodes

OUT – Number of outpatient visits

CHR- Number of chronic/long-term treatment sessions (day-hospital sessions)

Appendix 3 – Sensitivity analysis

Table 1A3 - Subsamples means

	C+D	D+D1	SPA	32<beds<588
INP	122.531	57.795	80.416	67.587
EMO	237.621	153.615	154.734	160.005
AMB	1.529	755	825	850
BEDS	391	227	256	242
BEDOR	303	172	194	184
CMI	1,04	0,92	1,01	0,99
OR	0,76	0,72	0,71	0,73
ALS	7,61	7,33	8,04	7,57
Observations	208	214	168	250

Table 2A3 - Sensitivity Analysis

C	C+D			D+D1			SPA		
	Coefficient		Standard error	Coefficient		Standard error	Coefficient		Standard error
Constant[a]	-15,9	*	5,66	-6,38	***	3,84	-7,48	**	3,32
INP	219,15	*	56,87	250,06		221,15	361,95	*	96,44
EMO	88,25	**	36,19	165,89	*	57,92	135,33	*	34,04
AMB	1.064,97		1.573,48	-3.176,02	***	1.728,96	6.811,97	*	1.814,59
INP^2	-0,0029	*	0,0009	-0,0103		0,009	-0,0028	**	0,0013
INPxEMO	-0,001	*	0,0003	-0,0018		0,0016	-0,0012	*	0,0004
INPxAMB	0,051	*	0,0133	0,0325		0,0823	0,0641	*	0,0207
EMO^2	0,0001		0,0001	0,0001		0,0002	0,0004	*	0,0001
EMOxAMB	0,0123	***	0,0073	0,0218	**	0,0109	-0,0527	*	0,0144
AMB^2	-0,1691		0,1081	-0,5832	**	0,2613	0,8575	*	0,2358
BEDOR	73.056	**	32.495	-618		82.986	-27.282		44.514
BEDOR^2	-888	*	198	-1.781	***	1.031	-922	*	279
BEDORxINP	3,1689	*	0,7808	9,0208		6,0469	3,1763	*	1,1511
BEDORxEMO	0,4349	*	0,16	0,3752		0,5488	0,4086	**	0,1872
BEDORxAMB	-29,7325	*	6,9691	-13,1248		27,5044	-19,0063	**	8,2473
d2004[a]	1,53	**	0,72	0,11		0,47	1,5	*	0,5
d2005[a]	3,39	*	0,81	1,13	**	0,53	1,82	*	0,53
d2006[a]	4,3	*	0,93	2,48	*	0,6	2,86	*	0,59
Q[a]	873	*	258	190		140	193		127
dcent	22,6	*	4,33				12,3	**	5,01
dteach[a]	50,4	*	13				60,9	*	12,2
dncb[a]	7,65	*	2,7	8,86	*	2,11	-0,09		4,17
depe[a]	9,2	*	2,91	2,43		3,37			

[a] in million €; *significant at 1%; **significant at 5%; ***significant at 10%