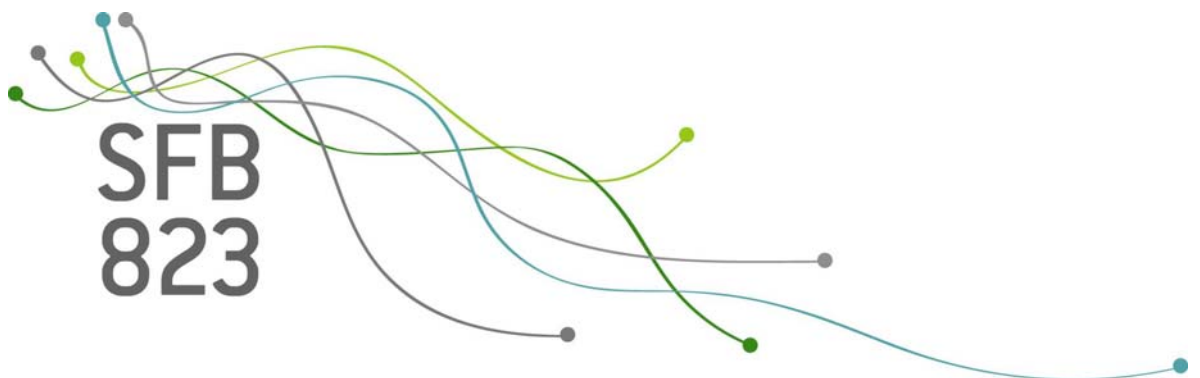# Factor substitution in hospitals: a DEA based approach

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Factor Substitution in Hospitals:
a DEA based approach

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Abstract

The substitutability of inputs to health production in hospitals has recently become an issue in Germany. New regulations concerning the renumeration of hospitals set incentives to reduce patients' length of stay and, in turn, to operate less care-intensive. Based on data at the individual hospital level from Germany, covering the years 2006 to 2008, we test whether substitutability of inputs and its change over time exhibits heterogeneity across different types of ownership. If found in the data, this may point at differently owned hospitals adapting differently to the new regulations. In order to avoid relying on input prices as regressors, which exhibit only very limited variation across hospitals, we pursue a price-free empirical approach by calculating technical elasticities of substitution from the multiplier representation of data envelopment analysis. The empirical analysis yields pronounces ownership-specific heterogeneity in the technical elasticity of substitution between physicians and nurses indicating that non-profit hospitals operate particularly 'physician-intensive'. Yet, this pattern is stable over the considered period.

Keywords: input-substitution, hospitals, technical elasticity of substitution, data envelopment analysis.

JEL classification: I12, C14.

1 Introduction

The provision of inpatient care is undergoing a radical change in Germany. While formerly a quasi administrative task, nowadays more and more hospitals are run in the manner of businesses. This goes along with increasing share of private hospital ownership. Yet, changes in the environment go beyond privatization alone. There is a steadily increasing pressure on hospitals of all ownership types to improve their efficiency for several reasons. First, beginning in 1993, annual rises in hospital expenditures (i.e., revenues from the hospital's point of view) were constrained by the growth rate of revenues of the social health insurance. Thus, hospitals' costs usually rise faster than their revenues and hospitals are constantly forced to improve their productivity. Second, the German federal states – although in charge of paying for investments of hospitals while health insurance companies account for the running costs – are investing decreasingly less. Thus, hospitals are required to generate profits in order to make own investments in new technologies. Third, while municipalities and churches as owners of not-for-profit hospitals used to be able to balance deficits of their hospitals in the past, this is typically not possible anymore.

Most importantly, however, the remuneration system for hospitals was radically reformed in 2004. Until then, hospitals' revenues depended on the patients' length of stay. The reform introduced a DRG based remuneration system, which no longer rewards length of stay but rather set strong incentives to keep patients' stay as short as possible. This implicitly changed the scope of hospitals in Germany. While before 2004 (short term) nursing has – at least implicitly – been one of the their genuine scopes,[1] this does no longer apply under the DRG remuneration system. Hence, besides pressing for operating more cost-efficiently in general, the new remuneration

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[1]In these times it was common practice, to keep patients some extra days in hospital until they were able to cope with their every day life, though no further medical treatments were carried out on these patients.

system sets incentives for adjusting input use. In particular, since nursing no longer pays off in its own right, reducing nursing staff might be a promising strategy to operate more profitable. Indeed, a significant decline in nursing staff can be observed over the last decade. While the number of full-time equivalent doctors increased by 21% between 2000 and 2009, the number of nurses decreased by 10% in the same period (Destatis, 2000, 2009). The focus of the present paper is on the question of whether substitutability of nursing staff varies for different types of hospital ownership. If such deviations are found in the data, one may conclude that – say privately owned hospitals – have better coped with the reformed remuneration systems and already reduced nursing staff.

From this perspective, factor demand and factor substitution become relevant objects of empirical research on the provision of inpatient care. How easily may nursing staff be substituted by other production factors such as medical staff, capital and medical supplies? The conventional econometric approach for answering this type of questions is to estimate a cost function – or a system of cost-share equations – and to calculate elasticities of substitution from the estimated coefficients attached to price-variables, in particular cross-products of logged factor prices. However, this elegant approach, which closely adheres to the underlying micro-economic theory, may often be ill-suited for being applied to real – in particular cross-section – data, as identification solely rests on variation in price data. Factor prices typically do not vary across hospitals. Moreover, observed variation in average factor cost may capture unobserved heterogeneity[2], rather than genuine exogenous price variation, rendering average factor cost invalid proxies for actual prices.

To circumvent the problem of insufficient or endogenous price variation, we pro-

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[2]Hospitals may, for instance, specialize on more severe cases and hence hire better skilled staff. Hence, higher average wages do not reflect exogenous price variation but the hospital's preference for well skilled personell.

pose an approach for estimation substitutability of input factors, that does not rest on estimating price coefficients. We rather pursue an approach that rests on data envelopment analysis (DEA) a non-parametric production model, which is formulated in terms of physical inputs and outputs rather than prices. DEA does not involve a concept of causality, as it is the case for econometric production models based on, for instance, estimating a production function. Hence, endogeneity of inputs and outputs is no caveat for DEA.[3] As DEA non-parametrically envelopes input-output combinations observed in the data, it estimates a multidimensional surface composed of numerous linear facets that can be interpreted as production possibility frontier. Movements in a certain direction along these facets, hence, capture how two inputs trade off against each other, leaving outputs and all other inputs unchanged. Thus, our approach rests on estimating the relevant slopes of these hyperplanes and using these estimates for calculation technical elasticities of substitution, which allow us for measuring the ease of substitution of nursing staff by other inputs to health production in hospitals.

The remainder of the paper is organized as follows. Section 2 introduces the data, Section 3 discusses the econometric approach, Section 4 reports and discusses the empirical results, and Section 5 concludes.

2   The Data

The data used for the empirical analysis originate from the German hospital and patient statistic (Deutsche Krankenhausstatistik), which is collected and administered by the Statistical Offices of the German Federal States. The hospital and patient statistic is an annual exhaustive survey of hospitals in Germany, with participation

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[3]This would apply to conventional regression approaches such as straight forward estimation of a production function.

in this survey being mandatory. Hence the information provided in the data is very close to being complete. Yet, due to data protection regulations, only a 70% random sample of all hospitals was made available to use. Confining the analysis to the years 2006, 2007, and 2008 and excluding observations with missing data, this leads to a sample of altogether 2 232 hospital-year observations.[4]

The data covers a wide range of hospital specific information. Most important, information on input use, such as the number of doctors, nurses, beds, and costs is available in the data on a very detailed basis. Personnel input is measured in full-time equivalents. Moreover, hospitals' technical equipment is documented in detail. Herr (2008) describes the data set in detail. As a major measure of a hospitals' service generation, the data comprise the number of treated cases per year. To make the output comparable over hospitals, cases should be weighted by severity. The case-mix-index (CMI) that officially exists since 2004 in Germany would be a preferred measure. However, it is not reported in the data. As an alternative, Herr (2008) generates a case-mix by comparing length of stay (LOS) of each case in a hospital with average LOS per diagnosis over all hospitals. However, since hospitals have an incentive to reduce length of stay in response to the recent reform, this does not seem to be a good measure in our case. We follow RWI (2010) and use imputed CMIs. To do this, we gather data on CMI and the detailed department and bed structure as provided by, e.g. Klauber et al. (2010) and Destatis (2009b) for the full sample of all German hospitals in each year. The coefficients from the regression of CMI on department structure, ownership type, and regional information are then used to calculate the predicted CMI for each hospital in the data set. Detailed regression results can be found in RWI (2010).

Finally, the ownership type is provided in the data set. We distinguish three

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[4]We also trim the data set by excluding hospitals with very high and very low average lengths of stay. This excludes, among others, highly specialized private hospitals that are not comparable to the normal general hospitals.

different types, i.e. private, private non-profit (e.g. church owned), and private for profit. With a share of 12%, private hospitals are underrepresented in our final data set (compared to about 30% in the full population). This is in particular due to the exclusion of highly specialized hospitals that are mainly private ones.

3   The Empirical Approach

3.1   DEA and Marginal Rates of Substitution

In order to analyze factor substitution without relying on variation in factor prices and without using endogenous factor demand as explanatory variables, we pursue a non-parametric data envelopment analysis based approach. Data envelopment analysis (DEA), first introduced by Charnes et al. (1978), is a well established non-parametric method for efficiency analysis. For a given sample of input and output combinations, i.e. a sample of production units, DEA envelopes the data by a convex, piecewise linear hull which is interpreted as the production possibility frontier. Typically, applications of data envelopment analyses aim at calculating efficiency scores $\theta \in (0, 1]$ for each production unit, which then can be compared or ranked on the basis of estimated efficiencies. These estimated scores are defined as the factor by with input use could be reduced with outputs left unchanged.[5] That is, θ measures the relative radial distance of an observed production unit from the estimated production possibility frontier that envelopes the data. In computational

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[5]This represents 'input-oriented' efficiency. DEA also allows for calculation 'output-oriented' efficiency, where efficiency scores $\theta^{out} \geq 1$ represent the factor by which output may be increased with input use left unchanged.

terms, DEA rests on solving the linear program

$$\min_{\theta,\lambda} \theta \qquad \text{subject to} \qquad (1)$$

$$\theta x_{m0} - \sum_{i=1}^{N} \lambda_i x_{mi} \geq 0 \quad m = 1, ..., M$$

$$\sum_{i=1}^{N} \lambda_i y_{li} - y_{l0} \geq 0 \quad l = 1, ..., L$$

$$\lambda_i \geq 0 \quad \forall i.$$

Here, y_l, with $l = 1, ..., L$, and x_m, with $m = 1, ..., M$, denote outputs and inputs of the analyzed production process. $i = 0, ..., N$ denotes observations, where the one under consideration is indexed by 0. If the solution θ^* takes the value 1, the relevant production units is technically efficient, i.e. it is located on the frontier. While (1) is the representation of DEA that – for computational reasons – is usually used for empirical applications, it is just the dual representation to

$$\max_{u,v} \sum_{l=1}^{L} u_l y_{l0} \qquad \text{subject to} \qquad (2)$$

$$\sum_{m=1}^{M} v_m x_{m0} = 1$$

$$\sum_{m=1}^{M} v_m x_{mi} - \sum_{l=1}^{L} u_l y_{li} \geq 0 \qquad i = 1, ..., N$$

$$v_m, u_l \geq 0 \qquad \forall m, l.$$

While (1) is the envelop representation, (2) is the multiplier representation, where both models are equivalent as the solution to the former $(\theta^*, \lambda_1^*, ..., \lambda_N^*)$ is mutually consistent with the solution to the latter $(u_1^*, ..., u_L^*, v_1^*, ..., v_M^*)$, (cf. Cooper et al., 2007, 51-52). Yet, for the analysis of factor substitution the multiplier form is the

relevant one. In an optimal solution to (2) at least one constraint i is binding. Hence,

$$\sum_{m=1}^{M} v_m^* x_{mi} - \sum_{l=1}^{L} u_l^* y_{li} = 0 \tag{3}$$

defines a hyperplane that represents a facet of the piecewise liner production possibility frontier. Hence, implicitly differentiating (3) yields an estimate for the marginal rate of substitution (MRS) between two inputs m and q, Thanassoulis et al. (cf. 2004, p. 102)

$$\text{MRS}_{mq} = -\frac{\partial x_m}{\partial x_q} = -\frac{v_q^*}{v_m^*} \tag{4}$$

Yet, ratios obtained from the multipliers form of the model can be interpreted as marginal rates of substitution and marginal rates of transformation, respectively (cf. Olesen and Petersen, 2003; Thanassoulis et al., 2004, p. 102). Figure 1 illustrates how estimates for MRS are derived from an estimated DEA production possibility frontier.

One problem with this approach is that v_m^* may take the value of zero, not allowing for calculating MRS. Zero multipliers indicate that the relevant facet of the estimated production possibility frontier is vertical (resp. horizontal) in the qm-plain. This implies that consumption of input q could still be reduced without cost, even though the relevant production unit operates at the efficiency frontier. Reductions in input consumption that can be archived by moving vertically (resp. horizontally) along the efficiency frontier are referred to as input slacks S_m^-. Output slacks S_l^+ are analogously defined, as additional output that can be achieved without extra-cost by moving along the frontier. Slack values are directly derived from the solution to
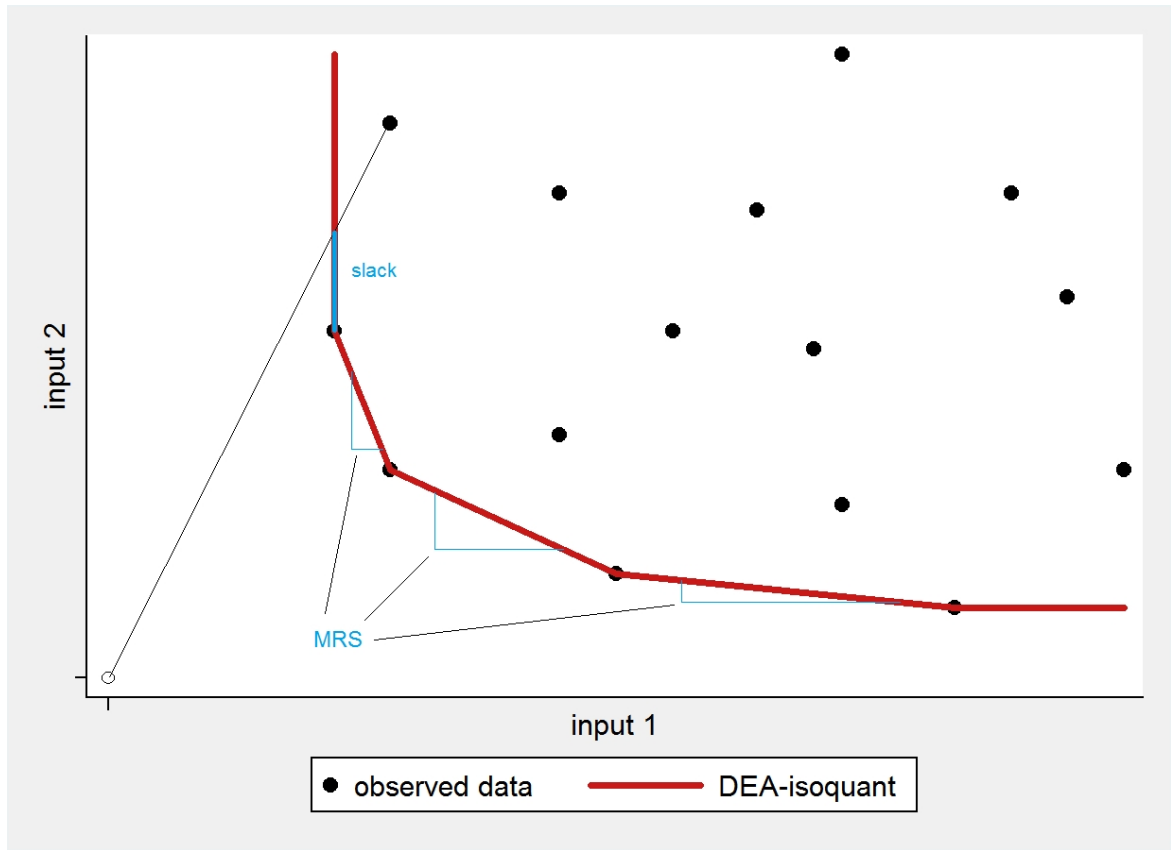
Figure 1: DEA based estimates of MRS

(1) as

$$S_m^- = \theta^* x_{m0} - \sum_{i=1}^{N} \lambda_i^* x_{mi} \quad m = 1, ..., M \tag{5}$$

$$S_l^+ = \sum_{i=1}^{N} \lambda_i^* y_{li} - y_{l0} \quad l = 1, ..., L \tag{6}$$

Slacks are directly linked to the multipliers obtained from (2) trough the complementary slackness theorem

$$v_m^* S_m^- = 0 \tag{7}$$

$$u_l^* S_l^+ = 0 \tag{8}$$

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In other words, the presence of input slacks renders multipliers zero which impedes our approach to estimating marginal rates of substitution. This is in line with theory, where the concept of factor substitution is well defined only for efficient production units. Thus, rather than using observed inputs and outputs for estimating MRS, we base the analysis on their fully efficient counterparts, i.e. $x_{m0}^{opt} \equiv \theta^* x_{m0} - S_m^-$ and $y_{l0}^{opt} \equiv y_{l0} + S_m^+$, and re-estimate v_m^*, which then less often[6] take zero values.[7] The suggested approach is similar to the one proposed by Cooper et al. (2000). However, the latter does not aim at measuring input substitution for fixed values of all other inputs, but assumes that of all other inputs (and outputs) are adjusted optimally. This in turn means that the substitutability is measured contingent on given prices for inputs and outputs.

3.2 Measuring the ease of Input-Substitution

Most applications addressing the issue of factor substitution use elasticities of substitution (ES) for measuring the ease of input-substitution. ES measures the local curvature of an isoquant. Hence, it is inconsistent with piece-wise linearity of DEA based production possibility frontiers, as locally the second derivative is either zero or undefined. One approach to overcome this caveat of DEA is to smooth the frontier estimated by DEA (cf. Nacif et al., 2009). Yet, this method is feasible only for small problems. We take a different approach by rather than using elasticities of substitution, we use the technical elasticity of substitution (TES) proposed by Fron-

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[6]Zero slacks, however, do not guarantee non-zero multipliers, cf. (7); moreover even non-zero multipliers may numerically still very close to zero.

[7]That is, we project any unit onto the efficiency frontier and remove any slacks. Hence all units are Pareto-Koopmans efficient. In applications focussing on slacks, one would typically not use slacks as defined in (5) directly. Rather, at an intermediate step, slacks S_m^-, S_l^+ and weights λ_i are re-estimated with θ^* kept fixed, by solving $\max_{\lambda, S_m^- S_l^+} (\sum_{m=1}^M S_m^- + \sum_{l=1}^L S_l^+)$ subject to $\theta^* x_{m0} - \sum_{i=1}^N \lambda_i x_{mi} = S_m^- \ \forall \, m$, $\sum_{i=1}^N \lambda_i y_{li} - y_{l0} = S_l^+ \ \forall \, l$, and $\lambda_i, \ S_m^-, \ S_l^+ \geq 0$. This yields the max-slack solution of (1).

del (2004). This measure is defined as $\text{TES}_q^m \equiv -\frac{\partial x_m}{\partial x_q} \frac{x_q}{x_m}$ and in our application is measured by

$$\widehat{\text{TES}}_q^m = -\frac{v_q^* \, x_q^{opt}}{v_m^* \, x_m^{opt}}. \tag{9}$$

TES simply re-formulates MRS in terms relative rather than relative changes and, hence, is not based on second derivatives of the estimated production possibility frontier and is consistent with DEA. TES measures substitution possibilities that are completely dictated by technology, since this measure – unlike elasticities of substitution – does not involve any optimality assumptions such as cost minimizing behavior. TES, for this reason corresponds to our 'price-free' approach. Another problem with DEA based measures of substitutability is that estimates of (4) are very sensitive to numerical inaccuracy and my for this reason suffer from a severe outlier problem. Moreover, zero weights may for some observations render estimated TRS infinite. For these reasons, rather than means, we calculate medians of estimates for (9) and compare them across ownership types.[8]

The solution for the multiplier representation $(u_1^*, ..., u_L^*, v_1^*, ..., v_M^*)$ is not unique, as those units that span the efficiency frontier adjoin several of its facets (e.g. Rosen et al., 1998). For this reason, MRS strictly speaking is undefined for these units and (9) measures substitution possibility along a single arbitrarily selected adjoining facet. This arbitrariness adds some noise to our empirical analysis. Yet, as we are not interested in estimating TES for particular hospitals but median TES for certain groups of hospitals, this represents a minor problem to our empirical application.

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[8]Standard errors for the estimated medians are bootstrapped.

3.3 Detection of Outliers

DEA – and related non-parametric methods in efficiency analysis – has frequently been criticized for being purely deterministic and hence being very sensitive to measurement error and outliers. A recent literature addresses this issue by suggesting so called partial frontier approaches. These approaches, namely order-m (Cazals et al., 2002) and order-α (Aragon et al., 2005; Daouia and Simar, 2007) efficiency analysis, envelope the data by a non-convex hull, but allow for units to be located beyond the estimated frontier, i.e. these units are 'super-efficient'. Here, $m \in \mathbb{N}^+$ and $0 < \alpha \leq 1$ serve as trimming parameters that determine the share of super-efficient units, where for extreme parameter values ($m \to \infty$; $\alpha = 1$) this share becomes zero. Daraio and Simar (2007) suggest a method for outlier detection based on the idea of increasing the value of m – respectively α – will linearly decrease the share of super-efficient units, if outliers are absent from the data. Strong deviations from linearity, therefore, indicate that those units still located beyond the frontier are indeed outliers und should not be included in the efficiency analysis. In our application, we initially run this (order-α based) based procedure on our data and excluded those hospitals identified as outliers from the subsequent data envelopment analysis.

3.4 Model Specification

The empirical application is based on a simple four-inputs-single-output technology. In detail, we regard the weighted number of cases, i.e. (predicted) CMI times the total number of cases, as a homogenized output from a hospitals' service generation. Three inputs are measured in purely physical units, i.e. in particular physicians, nurses, and beds. The former two variables account for part time work by being transformed to full time equivalents. Beds serve as proxy for capital use in

production. The forth input is medical supplies, that as a composite commodity cannot be measured in physical units. For this reasons expenditures divided by a relevant price index serve as measure for input consumption.[9] In order to account for heterogeneity in size and scope across hospitals when applying DEA, variable returns to scale rather than constant returns to scale are assumed.[10] DEA is carried out separately for each considered year in order to allow for changes in the production technology over time. Yet, hospitals of different type of ownership are pooled based on the assumption that ownership does not make a difference with respect to the production technology, yet it may matter for the efficiency. Standard errors for all results, in particular estimated median technical elasticities of substitution are bootstrapped.[11]

4   Results

4.1   Outlier Detection

In order to identify – and subsequently exclude – outliers in the data that may seriously bias any DEA based efficiency analysis we run a series of order-α efficiency analyses on the data. Figure 2 plots the share of super-efficient hospitals against the benchmark level α. No obvious discontinuity is to be seen directly from the plot which pointed at a certain fraction of seemingly extremely well performing hospitals representing outliers. We hence try three technical approaches to identify knickpoints in the plotted curve. The first is a global approach that is based on

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[9]The price indices are also taken from RWI (2010).

[10]In technical terms, this means that the additional restriction $\sum_{i=1}^{N} \lambda_i = 1$ enters the optimization problem (1) which is equivalent to adding a constant term $-u_0$ to the linear combination of outputs subject to maximization in (2); i.e. $\max_{u,v} \sum_{l=1}^{L} u_l y_{l0} - u_0$.

[11]The bootstrap does not encompass the data envelopment analysis but is performed conditional on the results obtained from DEA. This is done to avoid excessive computing time.

splitting the series into two parts and fitting a linear or quadratic function to each. The point of split that minimizes the BIC is regarded as point of discontinuity. The other approaches are local ones and are based on the series of differences in differences which serve as a non-parametric estimates of the curvature of the original series. The first searches for the minimum values of the twice differenced series that follow a non-negative value. The second looks for negative values that persist after repeatedly smoothing the series of differences in differences by running odd-spaced median smoothers. The latter and the global approach both suggest of roughly 0.91. Yet this corresponds to a share of outliers of more than 80 % which does not make much sense. Yet, the approach that rests on the rough twice differenced series suggests a value of α of 0.999 which corresponds to a share of outliers of just 8.6 %. Hence we exclude this relatively small fraction of well performing hospitals from the DEA.[12]

4.2   Estimated Efficiency for the Full Sample

Table 1 displays estimated mean and median DEA efficiency scores by year and type of ownership. Estimation results display limited variation in mean and median efficiency across types of ownership and years, with both taking values between 0.64 and 0.72. Nevertheless, for any year, private hospitals display the highest average technical efficiency where, in descriptive terms, efficiency differentials compared to non-profit hospitals are statistically significant. The latter also exhibit significantly lower efficiency compared to publicly owned hospitals. Yet, no significant public-private efficiency differential exists. This result is broadly in line with Herr et al. (2011) who use the same data source for the years 2002 to 2006 and

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[12]We also carried out the analysis for the entire sample and did not exclude any potential outliers. Some point estimates substantially differ from those reported in this section. Yet, in qualitative terms, this analysis yields similar results.
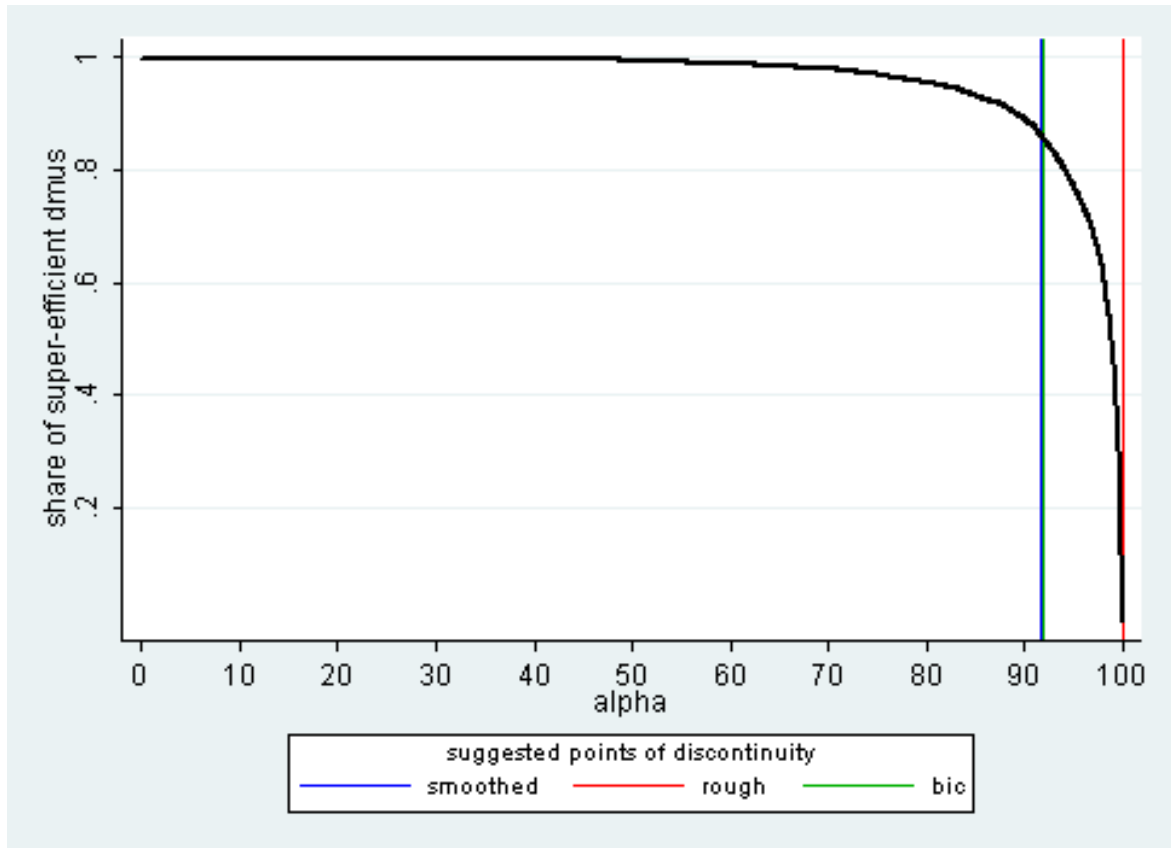
Figure 2: Detecting outliers using order-α partial frontier analysis

do not find significant differences in technical efficiency over ownership types.[13] Moreover, average efficiency has not significantly changed over time.

4.3 Estimated TES

In this subsection we report estimated median TES for the four inputs to production considered. Table 2 displays the estimated median of pooled TES. Here, a proportional change in the number of physicians (*docs*) may be compensated by small proportional changes in beds (*beds*) and medical consumables (*cons*). To a smaller

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[13]Overall, the results on ownership-type differences in technical efficiency in the recent literature on German hospitals is mixed, however. Herr (2008), using the same data set for the years 2001-2003, finds private hospitals to be less efficient while Werblow et al. (2010) find private hospitals to be more efficient than public ones.

Table 1: **Estimated DEA Efficiency Scores**

	public	non-profit	private
2006			
mean	0.670	0.652	0.689
median	0.644	0.632	0.663
s.e.	0.121	0.115	0.134
# of obs.	300	322	80
2007			
mean	0.681	0.653	0.682
median	0.661	0.645	0.671
s.e.	0.121	0.110	0.121
# of obs.	293	313	81
2008			
mean	0.687	0.661	0.718
median	0.663	0.650	0.697
s.e.	0.119	0.110	0.139
# of obs.	268	306	84

Notes: pooled DEA analysis assuming variable returns to scale.

degree this also holds for proportional changes in the number of nurses (*care*). Yet, a proportional decrease in the number of beds requires much larger proportional increase in the amount of medical consumables in order to keep hospital output constant. The result of hospital beds representing an input to hospital service production that is particularly hard to be substituted, seems to conflict with the notion of numerous excess beds existing in German hospitals. Yet, it might simply capture that the number of beds imposes a rigide cap on a hospitals capacity for acquiring cases.

The finding of a relatively small proportional increase in the number of nurses – and also beds and consumables – being sufficient for compensation for a much larger proportional decrease in the number of physicians takes one somewhat by surprise. It has, however, to be pointed out that this results does not hold for each individual hospital. Rather, individual estimates TESs exhibit distinctive hetero-

Table 2: **Estimated Median Pooled TES**

TES_{docs}^{care}	TES_{docs}^{beds}	TES_{docs}^{cons}	TES_{care}^{beds}	TES_{care}^{cons}	TES_{beds}^{cons}
0.276	0.002	0.002	0.045	0.055	3.640

geneity including very large estimates that by far exceed the value of one. But still, the estimate for median TES_{docs}^{care} points at large share of hospitals operating relatively 'physician intensive' rendering a further reduction of nursing, beds, or the use of consumables difficult. This in turn means that the problem of excess beds that can be saved without any impact on a hospital performance does not exist for the median hospital.

Table 3 displays estimated median TES separately by type of ownership an year. This reveals some differentials in the substitutivity of physicians and nurses across types of ownership. Here the surprisingly small estimate for TES_{docs}^{care}, found for the whole sample, is less pronounced for publicly owned hospitals. Private hospitals exhibit a relatively moderate median value, while for non-profit hospitals the corresponding value for TES_{docs}^{care} is extremely low. This indicates that ownership matters for input use in hospitals with non-profit hospitals operating particularly 'physician-intensive' while public hospitals seem to employ a more balanced input mix. This, however, has not necessarily to be attributed to a causal effect of ownership. It may also be that hospitals of different ownership-type perform different tasks, not captured by the output-measure used for this analysis, which makes them choose a different combination of input-factors. Besides TES_{docs}^{care} for which statistically significant median differentials are found for public compared to non-profit hospitals (all considered years), public compared to private hospitals (just 2006) and non-profit compared to private hospitals (just 2008), estimated technical elasticities of substitution do not systematically differ between types of ownership.

Considering changes in median TES over time, Table 3 does not indicate much

Table 3: **Estimated Median TES by Ownership and Year**

	public		non-profit		private	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
2006						
med. TES^{care}_{docs}	0.713	0.131	0.020	0.005	0.131	0.128
med. TES^{beds}_{docs}	0.007	0.008	0.000	0.000	0.001	0.006
med. TES^{cons}_{docs}	0.017	0.014	0.000	0.000	0.002	0.005
med. TES^{beds}_{care}	0.018	0.047	0.140	0.034	0.134	0.104
med. TES^{cons}_{care}	0.045	0.047	0.077	0.110	0.065	0.168
med. TES^{cons}_{beds}	3.170	0.555	3.081	0.663	3.528	0.568
2007						
med. TES^{care}_{docs}	1.043	0.227	0.071	0.016	0.384	0.303
med. TES^{beds}_{docs}	0.030	0.018	0.002	0.003	0.021	0.014
med. TES^{cons}_{docs}	0.041	0.040	0.002	0.002	0.048	0.039
med. TES^{beds}_{care}	0.016	0.056	0.073	0.053	0.017	0.273
med. TES^{cons}_{care}	0.021	0.074	0.052	0.104	0.038	0.217
med. TES^{cons}_{beds}	3.350	0.572	3.771	0.230	3.860	0.598
2008						
med. TES^{care}_{docs}	0.493	0.130	0.037	0.034	0.355	0.129
med. TES^{beds}_{docs}	0.006	0.012	0.000	0.001	0.032	0.016
med. TES^{cons}_{docs}	0.017	0.029	0.000	0.001	0.050	0.037
med. TES^{beds}_{care}	0.004	0.063	0.025	0.056	0.153	0.272
med. TES^{cons}_{care}	0.006	0.121	0.040	0.129	0.311	0.290
med. TES^{cons}_{beds}	3.653	0.566	4.203	0.321	4.217	0.566

Notes: pooled DEA analysis assuming variables returns to scale; S.E.s bootstrapped.

change. Only for TES^{care}_{docs} a statistically significant change is found for non-profit hospitals (2006 to 2007) and for public hospitals (2007 to 2008). Apart from these few cases, estimated technical elasticities of substitution are fairly stable over the considered period. This finding argues against the hypothesis of hospitals adapting to the new remuneration scheme by changing the composition of input use. In turn, this is also evidence against the hypothesis of hospitals, contingent on the type of ownership, adapt differently to altered incentives.

5 Conclusions

The present empirical analysis aims at measuring the substitutability of inputs in hospitals in Germany. The main focus is on the questions of whether substitutability differs across hospitals of different type of ownership and whether substitutability has changed over time. First of all, we want to test whether differently owned hospitals adapted differently to a recent change in hospital remuneration that set strong incentives to reduce the length of patients' stay and, in turn, set incentives to minimize the provision of care. In order to avoid relying on price variation for identifying substitutability of inputs, we calculated technical elasticities of substitution from the multiplier representation of data envelopment analysis.

As an initial result DEA yields some ownership specific heterogeneity in estimated efficiency scores, with privately owned hospitals being the most efficient. These efficiency differentials, however, are insignificant in statistical terms. This also holds for changes in efficiency over time. Estimated DEA based measures of input substitutability yield the somewhat puzzling result that for the median hospital physicians may be substituted at very low rate by nurses, and other inputs. This points at hospitals operating rather physician intensive and seems to indicate that hospitals input choice is inconsistent with cost minimization, since the high-cost input high-skilled labor (physicians) is – though technically easily feasible – not substituted by the low-cost input medium-skilled labor (nurses). The substitutability of physicians exhibits some heterogeneity across different types of ownership. Here, the results of physicians being easily substituted by nurses is first of all found for non-profit hospitals but not for private for-profit clinics. This seems to indicate that cost minimization is more relevant for the latter. Yet, the results does not indicate much change over time. This is evidence against the hypothesis that in the period 2006-2008 hospitals were still passing through a process to adapting to the

new DRG based remuneration systems and that profit-orientation matters for this process. In particular, the results do not point at privately owned hospitals – i.e. those that are explicitly operating for profit – moving to less care intensive service provision, in order to provide less care that under the DRG-based remuneration regime is no longer directly remunerated.

The empirical results have, however, to be interpreted with some caution. In particular the very small estimated values for the median technical elasticity of substitution between physicians and nurses remain a puzzle. One possible explanation is that the vast majority of hospitals are technically inefficient and do not operate on the production possibility frontier. Yet, the concept of input-substitution is properly defined only at the frontier. In the present analysis this issue was addressed by projecting observed input-output combinations on the estimated frontier and hence by basing the analysis on hypothetical efficient input consumption rather than it observed inefficient counterpart. However, this may result in numerous hospitals being projected on certain points at the production possibility frontier which – though technically efficient – are highly inefficient in economic terms. This economic inefficiency may result in the alleged ease of substituting physicians by other inputs.

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