Heterogeneity in Hospitals' Responses to a Financial Reform: A Random Coefficient Analysis of The Impact of Activity-Based Financing on Efficiency

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Abstract

The paper examines the heterogeneity with respect to the impact of a financial reform - *Activity Based Financing* (ABF) - on hospital efficiency in Norway. Measures of technical efficiency and of cost-efficiency are considered. The data set is from a contiguous ten-year panel of 47 hospitals covering both pre-ABF years and years after its imposition.

Substantial heterogeneity in the responses, as measured by both estimated and predicted coefficients, is found. Rank correlations between the estimated/predicted coefficients of the ABF dummy and the pre-ABF/post-ABF efficiencies are examined. Overall, improvement seems to be more pronounced in technical efficiency than in cost-efficiency.

1 Introduction

Although not ubiquitous, numerous studies indicate negative effects of the introduction of DRG-based prospective funding on hospitals' length of stay (LOS) and positive effects on efficiency. Average effects on LOS differed, but were in the range of -3 to -9 % in US studies like Guterman and Dobson (1986) and Newhouse and Byrne (1988) as hospitals financed through Medicare shifted from activity-based retrospective funding to activity-based prospective payment from 1984. Effects on cost efficiency varied likewise between different studies but were in the range of 1-2 % in the study of Cromwell and Pope (1989) that utilized a sample of all PPS-financed hospitals that delivered adequate data, a total of 5700 units per year in the period 1981-1986. Results from European studies are equally divergent, but also here most studies indicate positive shifts in efficiency of reimbursement reforms that introduce prospective payment based on the DRG-system. In Austria, no effect on technical efficiency was found as funding shifted from per diem to global budgets based on the DRG-system in 1997 (Sommerguters-Reichmann 2000), while in Portugal the effect of the introduction of DRG-based funding on technical efficiency was positive (Dismuke and Sena 1999), in Finland positive (Linna 2000) and in Norway positive and in the range of 1-3 % (Biørn *et al.* 2003). Major European countries like the UK and Germany are now implementing DRG-based financing. However, as already concluded by Sloan (2000) in his review of not-for profit ownership and hospital behavior, many studies of hospital performance are plagued by endogeneity and neglected heterogeneity.

Hospitals' responses to financial reforms are usually modelled by one coefficient. Since this kind of model cannot represent any heterogeneity in hospitals' responses, it will lead to confined analyses. In this paper we address whether heterogeneity in hospitals' responses to financial reforms exists, examine its magnitude, as well as potential explanations of the heterogeneity. We utilize a panel data set that allows us to attribute differences in response to observed variables such as the reform in the financing systems and unobserved or latent variables. Examples of latent variables will be unmeasured differences in technical and physical conditions (building standards, equipment, etc.), differences in organization patterns and hospital culture, differences in quality, education and experience of doctors, nurses, administrators, owners, differences in output mix, differences in characteristics and needs of patients not captured by the DRG-system, etc. How elaborate the design of such an analysis can be depends on the structure of the panel data set, in particular the time-series length and the number of units.

Recent literature shows several studies that have taken observed heterogeneity into account. López-Casasnovas and Saez (1999) study the impact of teaching status on average costs in Spanish hospitals. From a multi-product hospital cost function they find that costs are 9 % higher in teaching hospitals than in non-teaching hospitals. Kessler and McClellan (2002) study whether hospital ownership and other aspects of hospital market composition affect health care productivity and find that higher market density of for-profit hospitals results in lower hospital expenditures for patients with acute myocardial infarction. However, only few studies address the effect of reforms in the reimbursement system on the heterogeneity in hospital response. A French study is of particular interest. Dormont and Milcent (2002) study the effect on hospital costs of introduction of a prospective payment system in French hospitals. They distinguish between transitory and time invariant unobservable hospital heterogeneity and find that transitory heterogeneity is far from negligible: its estimated standard error is found to be about 50 % of the estimated standard error for cost variability due to permanent unobservable heterogeneity between hospitals. Simulations based on their estimations show that a cost reduction of about 16 % can be expected from implementation of a payment system which allows for permanent unobserved heterogeneity and eliminate only transitory moral hazard.

This paper adds to the literature by studying the heterogeneous response of hospitals to a reform in the financing system from prospective global budgets to prospective activity based financing. We examine, first, the variation in efficiency, measured in various ways by data envelopment analysis (DEA), across a population of hospitals, and second, the heterogeneity in the impact of introducing Activity Based Financing (ABF) on hospital-specific efficiency in Norway at the middle of the 1990s. The data set is from a ten-year panel of 47 hospitals covering both pre-ABF years and years after its introduction. Data may therefore be said to describe the results of an interesting experiment. Issues discussed in analyzing these data econometrically are, inter alia: What characterizes hospitals for which this reform of the financing system has had its strongest and weakest impact? Has the efficiency of some hospitals been reduced by the reform? A review of the literature showed no previous studies of this issue. One reason may be that an analysis of this kind requires data for individual hospitals of a certain time-series length, which are often unavailable. Often data only exist for two years, one pre-reform year and one year after the reform has been effective for some time. In the present study, we in particular seek to take advantage of the 10-year/47-hospital structure of our data set in the following way: After having estimated, or predicted, the response coefficients we make their sample distribution subject to a statistical investigation jointly with the sample distribution of the efficiency measures. It follows from this that, unlike most other researchers in this field, we are not interested in average effects of the responses only and not only in heterogeneity in the intercept of the equations. Accordingly, heterogeneity will in the following refer to both intercept heterogeneity and heterogeneity in slope coefficients.

The following sections are disposed as follows: In Section 2, we present the theoretical model, derived from an assumption that each hospital manager chooses level of effort and the labor stock so as to maximize a hospital-specific objective function. The variation in this function's parameters represents the heterogeneity. The data and the construction of efficiency measures are described in Section 3. Descriptive statistics, inter alia relating to the ranking of the hospitals by measured efficiency, are also discussed. The econometric model version, interpreted as hospital-specific reduced-form equations derived from the optimizing conditions, is considered in Section 4. In Section 5 the empirical results are reported and discussed, and we, inter alia, take advantage of the fairly large number of units in the panel and the not too short time-series length by putting the joint distribution of the estimated or predicted coefficients and the efficiency measures in focus. Concluding remarks follow in Section 6.

2 Theoretical model

The theoretical model, which draws on the model framework in Biørn *et al.* (2003), is reformulated to take hospital-specific heterogeneity in its coefficient structure into account. The hospital's objective function contains three types of arguments: the utility from treating patients, the utility of profit and the disutility of effort. Hence, the function is of the same type as in models suggested by Chalkley and Malcomson (1998). The manager of hospital i is assumed to choose levels of effort, e_i, and the number of employees, v_i, in order to maximize

$$U_i = u_i[f_i(v_i, e_i)] + h_i[A_i + pf_i(v_i, e_i) - wv_i - K_i] - \gamma_i(e_i) \tag{1}$$

where $u_i(\cdot)$, $f_i(\cdot)$, $h_i(\cdot)$, and $\gamma_i(\cdot)$ are functions which jointly determine the form of the objective function. The function $f_i(v_i, e_i)$ expresses how the number of treated patients, n_i, in hospital i depends on the number of employees (only one type of employees is, for simplicity, assumed) and the level of effort in hospital i. Heterogeneity in the production function may for instance be related to heterogeneity in the quality of buildings and other physical assets. The function $u_i(\cdot)$ expresses the utility of treating patients, included to take intrinsic motivation into account. The function $h_i(\cdot)$ expresses the utility from profit, where A is a fixed income component, p is a fee received per treatment, w is gross expenditure per employee, and K is a fixed cost. Profit is included since, other things equal, a surplus adds to a manager's prestige and similarly, a deficit causes detriment to his prestige. Finally, the function $\gamma_i(\cdot)$ captures the manager's disutility of undertaking cost reducing efforts. Equation (1) reflects that hospital heterogeneity is involved not only in the production structure, but also in the disutility of effort, and in the potential trade-off between treatment of patients, profit and effort.

Proceeding with all the types of heterogeneity in (1) makes the comparative statics of the model intractable. Hence, for simplicity, we concentrate on heterogeneity in disutility of effort, and drop the hospital subscript on the functions $u_i(\cdot)$, $f_i(\cdot)$ and $h_i(\cdot)$ in the further derivations. For notational convenience we also omit the subscript on the variables. A parameter $\theta \in [0, 1]$ takes care of heterogeneity regarding the disutility of effort; the higher is θ the stronger is, *cet. par.*, the hospital's disutility. The objective function then becomes

$$U = u[f(v, e)] + h[A + pf(v, e) - wv - K] - \theta\gamma(e), \tag{2}$$

where the functions $u(\cdot)$, $f(\cdot)$, $h(\cdot)$, and $\gamma(\cdot)$ are assumed to be the same for all hospitals. The interpretation of the parameter θ can be indicated as follows: Say, for instance, that the system for physicians on call is considered to be reorganized to increase the number of surgeons available for elective surgery. The manager's disutility related to this effort depends on whether other types of personnel are available. If, for instance, anesthetist nurses are in short supply, the disutility of reorganizing the surgical activities increases both because several groups of personnel are involved, and because it may be hard to recruit additional personnel from outside. Then θ is supposed to be large. Hospital organizations also vary regarding mutual trust and cooperation between its management and its employees. If suggestions for organizational changes in general are met with strong opposition, θ is also supposed to be large.

We assume that $f(\cdot)$ has the following properties: $f_k(v,e)>0$, $f_{kk}(v,e)<0$ $(k=1,2)$, and $f_{12}(v,e) = f_{21}(v,e)>0$, subscript k denoting the partial derivative with respect to the kth argument. We also make standard assumptions regarding $u(\cdot)$, $h(\cdot)$, and $\gamma(\cdot)$: positive first derivatives and negative second derivatives (denoted by $'$ and $''$, respectively).

Maximizing (2) with respect to v and e gives, from the first-order conditions for an interior solution:

$$\begin{aligned} u'[f(v,e)]f_1(v,e) + h'[pf_1(v,e) - w] = 0, \\ u'[f(v,e)]f_2(v,e) + h'[pf_2(v,e)] - \theta\gamma'(e) = 0. \end{aligned} \tag{3}$$

The first of these equations implies that a necessary condition for obtaining an interior solution is $[pf_1(v,e)-w] < 0$, which means that the fee per treatment only covers a proportion of the cost of a marginal employee. This is in accordance with the kind of financing system we study. The second-order conditions are:

$$U_{vv} < 0, \qquad U_{ee} < 0, \qquad D = U_{vv}U_{ee} - U_{v,e}^2 > 0,$$

where U_{vv} and U_{ee} are the second-order derivatives of (2) with respect to v and e, respectively, and U_{ve} is the cross derivative. Equations (3) determine the optimal v and e as functions of the exogenous variables, *i.e.*, *reduced form equations*, of the form

$$\begin{aligned} v = g_v(p, w, A, \theta, \ldots), \\ e = g_e(p, w, A, \theta, \ldots). \end{aligned} \tag{4}$$

In particular, we find a negative effect of θ on e, while its effect on v is indeterminate.

We model the effect of introducing ABF as a change where *an increase in p occurs simultaneously with a decrease in A* such that the previously optimal number of patients, n^0, is still feasible. Differentiating the first-order conditions (3) with respect to p and A we find the effect on effort of a change to ABF to be:

$$\Delta = \frac{\partial e}{\partial p} - n^0 \frac{\partial e}{\partial A} = \frac{h'(\cdot)}{D}\{\theta\gamma'(e)[f_1(\cdot)f_{12}(\cdot) - f_2(\cdot)f_{11}(\cdot)] + h''(\cdot)[pf_1(\cdot) - w]wf_2(\cdot)\} > 0. \tag{5}$$

Hence, the introduction of ABF initiates an increase in effort. The intuition is that effort is now more rewarding in terms of treatments and profit, since an increase in effort results in increased income because of the increase in the number of treatments.

We are, in particular, interested in finding a relation between the initial level of effort that stems from heterogeneity in θ and the effect of ABF on effort, *i.e.*, the sign of $\partial\Delta/\partial\theta$. The model presented here provides us with an ambiguous sign of this derivative. On the one hand, a hospital with a small θ has a small marginal disutility of increasing e. This pulls in the direction of a larger increase in e compared with a hospital with a large θ. On the other hand a hospital with a small θ chooses a high e initially, which pulls in the direction of a relatively high marginal disutility of increasing e further. Hence, we cannot from standard economic theory decide whether hospitals with the highest level of initial effort or the hospitals with a catch-up potential are likely to show the highest effect on effort from the introduction of ABF. This ambiguity, which also applies to other types of heterogeneity considered in (1), is a primary motivation for the following econometric analysis.

3 Data and data construction

The data are panel data from 47 Norwegian hospitals in the years 1992–2001, collected by and compiled from the Norwegian Patient Register, Statistics Norway, SINTEF Unimed, and the Center of Health Administration at the University of Oslo. During this ten-year period, ABF was introduced gradually for all hospitals. Efficiency data are not available, however, so measures have to be constructed by certain procedures. Table 1 contains definitions of the explanatory variables and specifies the data sources. In this section, most attention will be given to describing the efficiency measures and the assumptions underlying their construction.

Two issues are involved in establishing measures of hospital efficiency from hospital and patient data: the measurement of outputs and inputs, and the choice of method when establishing efficiency measures from these data. We first discuss these two issues and then present descriptive statistics.

Input in and output from hospital production

Hospitals are multi-product firms, treating a variety of patients with a variety of inputs. There is no consensus about how to most accurately measure outputs of hospital production. Since the *conceptual* output, relative change in health, is unobservable, we proceed by measuring *health services*, rather than health.

Hospital inputs are measured as:

Physician FTEs (full-time equivalents): The physician input is measured as the number of FTEs per year. This is only an approximation to the number of hours actually worked, and may distort the efficiency measures if use of overtime varies substantially between hospitals and over time. Supplementary evidence suggests, however, that the number of hours worked per FTE is fairly constant over the sample period.

Other labour FTEs: All non-physician labour input is merged into one category. Attempts to use more detailed specification of labour input did not alter the results.

Medical expenses: Medical expenses are measured in NOK 1000, and deflated to 2000 prices.

Total running expenses: Total running expenses are used as alternative input measure when providing a measure of cost-efficiency (see below). Running expenses are measured in NOK 1000 and deflated to 2000 prices.

Norwegian hospital input and input cost data are imperfect in the sense that capital and its costs are not included. If the use of high-cost, efficiency-improving medical equipment has increased over the data period, the results are likely to overstate efficiency growth.

Hospital outputs are measured as:

Inpatient care: The number of discharges, adjusted for case-mix by weighting discharges by diagnosis related groups (DRGs). Day care is included in the measure of inpatient care.

Outpatient care: The number of outpatient visits weighed by the fee paid by the state for each visit. Thus a hospital's revenue from outpatient care is an approximation to the volume of outpatient care adjusted for case-mix. Outpatient revenues are included in the output vector of the DEA analysis to account for the numbers of outpatients. We are forced to use this value-related measure because data on its volume component are lacking for many of the large hospitals in the sample period. Since fees for outpatient services have increased, our efficiency measures will have a positive bias. Outpatient revenue measured in 1000 NOK (Norwegian Kroner) is deflated to 2000 prices.

The chosen output vector is highly aggregated. Thus there is an underlying assumption of constant marginal rates of transformation (MRT) between DRGs, *i.e.*, no (dis)economies of scope. We return to this when discussing the method used to obtain efficiency measures, below.

Descriptive statistics for the specific inputs and outputs are given in Table 3B.

Efficiency measures

The basic efficiency concept to be used is *technical efficiency (TE).* A hospital is said to be technically efficient if an increase in an output requires a decrease in at least one other output, or an increase in at least one input. Alternatively, a reduction in any input must require an increase in at least one other input or a decrease in at least one output. This is the usual Pareto-Koopmans notion of efficiency. The measures used in this paper originated with Farrell (1957) and were further developed for piecewise linear technologies by Färe and Knox Lovell (1978), Charnes, Cooper and Rhodes (1978), and Banker, Charnes and Cooper (1984). The non-parametric mathematical programming approach to be used in this paper has become known as Data Envelopment Analysis (DEA). A formal description is given in Appendix A.

One advantage of DEA is that it accommodates a setting with multiple inputs and multiple outputs more easily than parametric models. Moreover, this approach does not require a specific functional form for the technology or specific distributional assumptions for the efficiency measure. DEA measures of efficiency are susceptible to errors in the measurement of inputs and outputs. One way of dealing with this is to use bootstrapping techniques, or else also scrutinize data for possible errors. In order to establish efficiency measures from the DEA approach we have used data collected and checked for errors by Statistics Norway and the Norwegian Patient Register. Thus, we believe that sufficient care has been shown in securing the quality of the data.

A second issue is the relationship between the level of aggregation on the output and input side and the obtained efficiency measures. The model chosen in this paper is quite aggregated, only separating between inpatient and outpatient care. An alternative approach is suggested by Olesen and Petersen (2002), allowing MRTs to vary within probabilistic assurance regions. The resulting efficiency measures will, however, heavily depend on the specification of the assurance region. The measures obtained from the aggregated model chosen here correspond closely to the measures used by health authorities to monitor the sector. Thus we believe they are sufficient as dependent variables in an analysis of how hospitals react to policy changes.

We also express efficiency in terms of *cost-efficiency (CE)*, by measuring inputs in terms of costs. The measure applied equals Farrell's (1957) measure of total efficiency, *i.e.*, the product of technical and allocative efficiency. When applied over a period of time, however, a strict interpretation of this measure requires that nominal price and wage changes are correctly deflated. In our case the only available deflator also relates to sectors outside the health care sector. Thus changes in measured cost-efficiency may be due to wage and price increases that deviate from the increase in the price deflator, and not necessarily to suboptimal combinations of inputs.

For both TE and CE, *two versions* of the measures are considered, one imposing *constant returns to scale (CRS)* on the technology and one allowing for *variable returns to scale (VRS)*. Formally, CRS means that a proportional increase in a unit's inputs is *a priori* restricted to bring a proportional increase in all outputs; the scale of operation of the unit is immaterial. Under VRS, the scale of operation matters; a proportional increase in a unit's inputs will not necessarily bring a proportional increase in all outputs. The efficiency measures we consider therefore become:

CEV: Cost-efficiency, assuming VRS.
TEV: Technical efficiency, assuming VRS.
CEC: Cost-efficiency, assuming CRS.
TEC: Technical efficiency, assuming CRS.

Remarks on descriptive statistics

Table 2 contains descriptive statistics for the variables, *inter alia*, a decomposition into 'between hospital' (b) and 'within hospital' (w) variation expressed as shares of total variation. For the efficiency measures considered, 60–68 % of the variation is between-hospitals variation and 32–40 % is within-hospital variation. For the number of beds (BEDS) the between hospital variation is as large as 98 %, while for hospital budget per hospital bed (BUD) the between variation accounts for 39 % of the total. (Since, unfortunately, we do not have information on budget size, we approximate BUD by total hospital costs.) This gives clear evidence of heterogeneity in both efficiency and its potential explanatory variables. The large within share for the ABF dummy (97 %) reflects the fact the reform was introduced almost simultaneously: for 30 of the 47 hospitals ABF became effective from the year 1997, for another 12 from 1998, for two from 1999, and for the last three from 2000. Table 3A, containing annual means for the efficiency indicators, shows that on average *technical efficiency* decreases slightly from 1992 to 1996, increases substantially from 1996 to 1997 and then increases slightly from 1997 until 2000. *Cost-efficiency* improves slightly, with the notable exception of the years 1995–1996 and 1998–1999. In both cases, the decline is believed to result from exceptional wage increases. There is, however, a possibility of misinterpreting increased DRG-creep (changes in hospital record-keeping practices that increase case-mix indexes and thereby reimbursements) as changes in efficiency, since it is well known that hospitals, by changing their coding practices, can increase the case-mix index, thereby also hospital output, as it is measured in this paper. Since the 'correct' coding is not known, it is difficult to assess the exact effect of DRG-creep. We have, however, also recalculated efficiency by assuming no change in case-mix since the introduction of the reform. This leads to a somewhat lower growth in efficiency, but does not essentially alter our conclusions.

In Table 4, three kinds of correlation coefficients between the efficiency indicators are given: overall (two-dimensional correlation), across the $N = 47$ hospital-specific means (cross-sectional correlation), and across the $T = 10$ year-specific means (time-serial correlation). In all cases the association between the two indicators of technical efficiency (TEV, TEC) and between the two indicators of cost efficiency (CEV, CEC) is strong, in particular for the time-serial correlation. On the other hand, the TE and the CE indicators are not particularly highly correlated. Comparing TEC with CEC, we find, for example, 0.5569 for the overall correlation and 0.6807 for the between hospital correlation. Remarkable is the clearly *negative time-serial correlation between the TE indictors and the CE indicators.* For TEC and CEC the latter correlation coefficient is as low as -0.7493. A marked negative association is also visible from Table 3A and it may reflect that measured cost-efficiency also incorporates factors that are exogenous to the hospital management. Altogether, this supports our decision of having both kinds of efficiency in focus. Whether or not these changes in efficiency are related to the financial reform, and especially the heterogeneity of the responses across hospitals, will be examined in Section 5.

Table 5 presents hospital-specific (empirical) means of the efficiency measures and the quantitative exogenous variables, and its last column specifies the year in which ABF came into effect. Hospital size, as measured by BEDS, varies substantially, from regional hospitals with more than 900 beds, to local hospitals with less than 40 beds. The mean efficiency when assuming CRS (*i.e.*, CEC, TEC) is less than mean efficiency based on VRS (*i.e.*, CEV, TEV). This is quite reasonable since when assuming CRS within a DEA procedure, more restrictions are imposed than when VRS is allowed for, and hence fewer hospitals lie on the frontier.

Ranking of hospitals by efficiency

The ranking of the hospitals by efficiency changes substantially over the ten-year data period. The strength of association between efficiency in any two years can be measured by rank correlation coefficients (RCCs), *i.e.*, coefficients of correlation of the ranking numbers of the hospitals in the two years when arranged in descending or ascending order [cf. Zar (1972) and Kraemer (1974)]. Table 6 reports RCCs for all pairs of years for each efficiency measure. The RRCs of neighbouring years are in general high, but tend to decrease with increasing time distance. The year 1997, when the ABF reform became effective for the first hospitals, gives a characteristic example: The RCCs for this years against 1998, 1999, 2000, and 2001 are, respectively, (0.81, 0.72, 0.58, 0.33) for efficiency measure CEV, (0.81, 0.66, 0.53, 0.33) for CEC, (0.86, 0.58, 0.42, 0.29) for TEV, and (0.89, 0.69, 0.55, 0.48) for TEC.

4 Model and method

Our theoretical reasoning in Section 2 led to a reduced form, (4), which expresses hospital employment (v) and efficiency (e) as determined by, *inter alia*, the revenue per treated patient (w) and the fixed revenue of the hospital (A). On this background and in view of the data available, we assume that hospital efficiency is explained by the four variables defined in Table 1. How are these variables related to those in the theory-model in Section 2?

Standardized budget per hospital bed (BUD, where the standardization is done to account for differences in hospital size) can be associated with the variable A in the theory-model, The qualitative change in the financing system can be associated with the ABF dummy as well as with changes in the continuous variable w itself. We also include three variables intended to represent observed heterogeneity which shifts the form of the production function $f(v,e)$, and hence the 'reduced form' equation for efficiency, $e = g_e(\cdot)$: the share of patient-days with irregularly long lengths of stay (LONG), and the number of beds (BEDS). There are reasons to believe that LONG is beyond the hospitals' control, being affected by the volume and composition of formal care for the elderly in surrounding local governments. BEDS is intended to represent scale effects in the production structure not captured by the DEA-measures. We consider all the four explanatory variables as exogenous, which may be questioned for at least two of them. For example, improved *observed* efficiency may lead to increased budgets. A mechanism of endogenous selection would also be at work, to the extent that county councils may tend to start by imposing ABF on the hospitals from which they expected that the largest efficiency gains could be obtained. We believe that endogenous selection is not a problem since each county council introduced ABF for all of its hospital at the same time, and the expected increase in technical efficiency was not an issue in the debate about the timing of introduction.

Our basic econometric model is a regression model where the intercept and all slope coefficients are unit (hospital) dependent. This reflects the assumed heterogeneity of the functions $u_i(\cdot)$, $f_i(\cdot)$, $h_i(\cdot)$ and $\gamma_i(\cdot)$ defining (1), which occur in the first-order conditions (3) and therefore in the reduced form (4). The coefficient vector is considered either as fixed and unstructured or as random coefficients, *i.e.*, as realizations of independent drawings from a distribution characterized by its expectation vector, representing the average response, and its covariance matrix, representing the dispersion in the response around this average. The estimation method is hospital-specific OLS estimation for the fixed coefficient version and (feasible) generalized least squares (GLS) for the random coefficient version of the model. Other examples of micro-econometric analyses of technological heterogeneity using a panel data random coefficient approach are Biørn, Lindquist and Skjerpen (2002, 2003). Parallel results for the CEV, TEV, CEC, and TEC measures will be reported in order to assess the robustness of the conclusions to the way efficiency is measured. The basic equation for hospital i in year t, to be denoted the *efficiency equation*, has the form

$$\mathrm{EFF}_{it} = \beta_{0i} + \beta_{1i}\mathrm{BEDS}_{it} + \beta_{2i}\mathrm{BUD}_{it} + \beta_{3i}\mathrm{ABF}_{it} + \beta_{4i}\mathrm{LONG}_{it} + u_{it}, \quad \begin{array}{l} i = 1,\dots,N, \\ t = 1,\dots,T, \end{array} \tag{6}$$

where EFF_{it} is one of the variables $(\mathrm{CEV}_{it}, \mathrm{TEV}_{it}, \mathrm{CEC}_{it}, \mathrm{TEC}_{it})$.

The possible endogeneity of BUD is tested statistically in a simultaneous model by Hagen (1997) and in a single-equation dynamic model with lagged efficiency variables by

Hagen and Iversen (1999). While the first study finds no feedback from efficiency to budget size, the latter finds a minor effect, which can be interpreted as a cost compensation effect (counties compensate hospitals with increasing costs). Both studies find a strong and stable effect from budget size on efficiency, which is in line with the findings in this article.

The random coefficient model and its GLS procedure, implemented in a stepwise manner, is described in Appendix B, Sections 1–5. A single-equation version as well as a system version is implemented. The latter is used for joint estimation of the efficiency equations for the four indicators in order to improve estimation efficiency by exploiting the particular structure imposed on the disturbance matrix by the panel design. The convergence of iterative GLS estimation relies on empirical moments converging not too slowly towards their theoretical counterparts. Our relatively small sample size in conjunction with the evidence of somewhat heavy-tailed coefficient distributions (Table 8), suggests that convergence may be slow; see McCulloch (1986).

When the hospital-specific coefficients are considered as stochastic, they can be predicted by exploiting the panel structure; see Appendix B, Section 6, for a detailed description. Predicted hospital-specific coefficients will be considered in parallel with the hospital-specific fixed-coefficient OLS estimates when examining heterogeneity in the responses of the individual hospitals in the following.

5 Results

The main questions we seek to answer are (i) whether the introduction of ABF has significantly affected hospital efficiency, and (ii) whether the responses exhibit heterogeneity which varies in a systematic way.

Average effects

Table 7, panel A, contains, for each efficiency measure, the OLS estimate of the coefficient vector when assuming full homogeneity. This has the status as a benchmark case. Panel B gives GLS estimates of the *expected* coefficient vector in the random coefficient model for the four equations separately. Specific assumptions and technical details are given in Appendix B, Sections 1–5. Panel C contains coefficient estimates when these four coefficient vectors are estimated jointly by Feasible GLS, exploiting the restrictions on the covariance matrix of the composite disturbance vector implied by the panel-data random-coefficient design. The single equation GLS estimates have larger standard errors than the system GLS estimates, which agrees with the fact that the former method is less efficient. The coefficient estimate of the ABF dummy is positive for all efficiency indicators, and all three estimation methods considered. According to the OLS estimates the ABF has a stronger effect on technical efficiency (TEV, TEC) than on cost-efficiency (CEV, CEC), but the system Feasible GLS estimates of this coefficient does not show marked variation with the way in which efficiency is measured.

Hospital-specific effects

The marked hospital-specific heterogeneity of virtually all variables, displayed in Tables 2, 5 and 6, signalizes that Table 7 by far tells the whole story about how hospital efficiency responded to the ABF reform. Probably, more information could be extracted from the data by examining hospital-specific results.

Table C1 in Appendix C is a starting point. It contains OLS estimates and standard errors for each of the $N = 47$ hospitals, when taking the hospital-specific coefficients as non-stochastic (or considering inference as conditional on the values realized). Estimating four coefficients and an intercept from only $T = 10$ observations may give rise to a collinearity problem, depending on the design of the regressor covariance matrix. Attempts to extend the number of regressors to five or six, including other variables suggested by the theory-model in Section 2, resulted, however, in 'erratic' and imprecise coefficient estimates; see Neyman and Scott (1948) and Lancaster (2000) regarding the incidental parameter problem. Therefore four regressors seems to at the maximum, and *a priori*, we judge those included as the most relevant ones. Predicted hospital-specific coefficients obtained from the more structured and parsimonious random coefficient model have an advantage over the hospital-specific OLS estimates, because of this degrees-of-freedom problem. Formally, the predictions emerge as compromises between the GLS estimates of the overall mean coefficient and the hospital-specific estimates of the unrestricted coefficients.

Descriptive statistics relating to the distribution of the hospital-specific ABF-coefficient estimates in Table C1 are given in Table 8. The large (empirical) standard deviations give *prima facie* evidence of strong heterogeneity of how efficiency responds to the introduction of ABF. For CEV, the mean and median coefficients are 1.87 and 2.51, respectively, and the standard deviation is 6.38. For TEV the corresponding figures are (3.67, 2.01, 10.66), for CEC (2.44, 3.80, 5.83), and for TEC (4.00, 2.70, 8.29). The (empirical) skewness and kurtosis of the ABF coefficient estimates are also illuminating. A yardstick may be that if the latent coefficients were drawn from a normal (Gaussian) distribution, the theoretical counterparts to these statistics should have been 0 and 3, respectively. Positive skewness occurs in the equations for TEV and TEC, negative skewness for CEC. The ABF coefficient estimates in the equations for cost-efficiency, CEV and CEC, have slightly thicker tails than under normality (kurtosis 3.76 and 3.40, respectively), while the corresponding coefficient distributions for the technical efficiency variables, TEV and TEC, exhibit excess kurtosis (leptokurtosis) (kurtosis 5.59 and 4.35, respectively).

Table C2 displays the effect of the introduction of ABF on efficiency, reporting for each hospital and each indicator the OLS estimate, the t-value, and the predicted coefficient, along with its ranking numbers (in descending order). In all respects, the ranking varies with the way efficiency is measured. Often, however, the ranking of the estimates and the predictions is fairly close. The majority of estimates and predictions are positive, although with varying significance, but several negative values occur. Among the 47 hospitals, 27 have positive coefficient estimates and 30 positive predictions for the CEV indicator (panel a). The corresponding figures for the TEV indicator are 26 and 30 (panel b), for the CEC indicator 30 and 32 (panel c), and finally, for the TEC indicator 31 and 34 (panel d). Overall, the number of positive coefficient estimates and predictions is somewhat larger when considering efficiency measures assuming CRS than when allowing for VRS. The ranking of the t-values supplements this picture, and it frequently departs substantially from the ranking of the coefficients. Only about 15 % of the coefficient estimates are significantly positive according to t-tests. This low share may not come as a surprise in view of the short time-series length. For the efficiency indicator CEV, 6 t-values exceed 2 (roughly indicating *significantly* positive effect of ABF-dummy) and 3 are below -2 (roughly indicating significantly negative association). The corresponding figures for TEV are 7 and 3, for CEC 6 and 3, and for TEC 7 and 1.

The joint distribution of efficiency and ABF coefficients

Although the efficiency measures are involved in estimating and predicting the coefficient vectors, the joint distribution of the estimates and predictions on the one hand and the efficiency measures on the other deserves a closer examination. It is particularly interesting for the years immediately preceding and succeeding the financial reform. This is another way of taking advantage of the substantial number of hospitals in the panel.

Tables 9 and 10 reports *for each year* properties of the *joint* distribution across hospitals of efficiency and the estimated and predicted ABF coefficients. Certain 'marginal' properties of this distribution have been been displayed in Table 6 (the efficiency measures) and Tables 8 and C2 (the coefficients/predictions). We now consider their joint distribution and pose the following questions: (i) Is there a pattern in the ranking numbers of the year-specific efficiencies and the ABF coefficients? (ii) Do our 'data' support the hypothesis that the hospitals with the lowest pre-ABF efficiency had the strongest effect of the reform, or does it seem that those which were most efficient initially were been most strongly affected? Since efficiency is an endogenous variable, whose observations determine all coefficient estimates, including those for the ABF-dummy, there will be *small sample, within-hospital correlation* between the two entities. However, as we will use the results to examine *between-hospital correlation* and the observations from different hospitals are, by assumption, uncorrelated, such correlation is unlikely to bias our inference, *inter alia*, based on between-hospital rank correlations.

Table 9, Part A, contains RCCs between efficiency, on the one hand, and (a) the coefficient of the ABF dummy, (b) its t-value, and (c) the predicted coefficient, on the other. In Part B, RCCs 'translated' into t-values for examining the strength of the relationship. This rescaling is convenient by giving statistics which are approximately t-distributed with $N-2 = 45$ degrees of freedom under the null hypothesis of no association [see Zar (1972, p. 578) and Kraemer (1974, p. 114)]. A striking finding is that for all efficiency indicators, the RCCs shift positively from 1996 to 1997 and further shift positively from 1997 to 1998, *i.e.*, at about the time when ABF came into effect for the majority of the hospitals (cf. Table 4, column 1). In 1998, all t-statistics in Part B are between 3 and 6, which clearly supports that there is an association.

In Table 10 the *quartiles* of the distribution of the ABF coefficients are put in focus. This table specifies the time path of the efficiency indicators of the particular hospitals whose ABF coefficients are at the lower quartile (ranking number 36) and at the upper quartile (ranking number 12). The overall picture is somewhat mixed and the table does not invite a definite answer to question (ii) above. The results depend on (a) which efficiency indicator we consider, (b) whether estimated or the predicted coefficients are used when determining the 'upper-quartile' and 'lower-quartile hospitals', and (c) whether we look at the absolute efficiency or at its ranking number when examining whether the ABF reform contribute to an improvement or to a decline in the efficiency of the most and least efficient hospitals. In fact, different hospitals are usually picked out as 'upper-quartile' and 'lower-quartile hospitals', depending on which efficiency indicator we choose and on whether estimated or predicted coefficients are considered.

Overall, an improvement in efficiency from 1996 to 1997 is easiest to detect in the technical-efficiency measures. For instance, the *upper quartile hospital* with respect to the ABF coefficient *estimate* (Table 10, Part I) had an increase in its TEV measure from 89.9 in 1996 to 94.0 in 1997, and an increase in its TEC measure from 97.1 to 100.0 between the same years. For the ranking numbers, however, there is a *decline* from 6 to 10 in the first case and an increase from 2 to 1 in the second case. Considering the upper-quartile hospital as it is picked from the *predicted* coefficients (Part II) we find an increase in its TEV measure from 92.5 to 98.8 and an increase in its TEC measure from 70.9 to 78.0. Again, for the ranking numbers, however, we observe a *decline*, from 5 to 7, in the first case and an increase, from 33 to 27, in the second case. On the other hand, there are signs that the *lower-quartile hospital* had some deterioration of its cost-efficiency from 1996 to 1997: when judged from the *predicted* coefficients, a decline in CEV from 92.2 to 88.3 (ranking numbers 3 and 8, respectively), for CEC a decline from 81.2 to 76.6 (ranking numbers 18 and 34, respectively). Considering the *estimated* coefficient, the sign conclusion is the same for CEV, but differs from CEC, which again illustrates that the evidence is not very clear-cut.

6 Concluding remarks

Starting from a theoretical model for an optimizing hospital, we examine in this paper, using hospital-specific panel data, the heterogeneity in the impact of the introduction of Activity Based Financing (ABF) on hospital-specific efficiency in Norway during the middle of the 1990s. As part of the data compilation, measures of efficiency – its technical as well as its cost dimension – have been constructed.

When analyzing hospital data (in contrast to data for, say, regions) before and after administrative reforms, researchers often have access to data for only two years, one prior to the reform and one after its introduction. Our data set is richer in several respects, *inter alia* because it spans a ten-year period, in which a substantial number of units, 47, have been observed annually – giving contiguous hospital-specific time-series both before and after the financial reform. We take advantage of this data structure by after having estimated or predicted hospital-specific coefficients, analyze its distribution jointly with the distribution of pre-ABF and post-ABF efficiency measures.

In particular we examine (i) whether there is a systematic pattern in the ranking numbers of the year-specific efficiencies and the ABF coefficients and (ii) whether we can find support to the hypotheses that the hospitals with the lowest pre-ABF efficiency had the strongest response, or to its converse. Our theory-model predicts ambiguous signs for these effects. The rank correlation shifts positively at about the time when ABF financing was imposed on the hospitals. A closer investigation of the ranking numbers and the quartiles of the distributions give somewhat mixed results. They depend on the efficiency indicator considered, whether estimated or predicted coefficients are used, and whether we look at the absolute efficiency or its ranking number. Overall, it is in the technical-efficiency measures that an improvement in efficiency from the year when ABF came into effect, can be most easily detected.

TABLE 1. Explanatory variables. Definition and data source

Variable	Operationalization	Data source
ABF	dummy=1 if the hospital has an ABF contract with the county council in the current year	Center for Health Administration
BEDS	Number of hospital beds	Statistics Norway
BUD	Total hospital revenue per hospital bed	SINTEF Unimed, Statistics Norway
LONG	Share of total no. of inhospital days representing patients with irregularly long length of stay*100	Norwegian Patient Register

TABLE 2. Descriptive statistics for the complete panel

Variable	mean	std	min	max	skew	kurt	b	w
CEV	82.79	8.19	61.22	100	-0.1073	2.5949	0.6971	0.3029
TEV	84.39	9.63	60.85	100	0.0871	2.2896	0.6071	0.3929
CEC	80.13	8.04	58.57	100	-0.0687	2.7328	0.6776	0.3224
TEC	78.22	9.30	56.19	100	-0.1541	2.8362	0.6113	0.3887
ABF	0.447	0.498	0	1	0.2140	1.0458	0.0290	0.9710
BEDS	231.8	224.9	34	974	1.6058	4.9777	0.9857	0.0143
BUD	1846	407	951	3645	0.8877	4.7714	0.3915	0.6085
LONG	25.38	14.03	4.01	80.16	1.1893	4.2349	0.6971	0.3029

$b,\ w$ = between, within hospital variation as share of total variation:

$$b = \frac{T\sum_i(\bar{z}_{i\cdot} - \bar{z})^2}{\sum_i\sum_t(z_{it} - \bar{z})^2}, \quad w = \frac{\sum_i\sum_t(z_{it} - \bar{z}_{i\cdot})^2}{\sum_i\sum_t(z_{it} - \bar{z})^2}.$$

TABLE 3. Efficiency indicators. Descriptive statistics, by year

A. Mean values of constructed indicators

Year	CEV	TEV	CEC	TEC
1992	83.9	83.1	81.3	76.6
1993	85.1	83.1	82.4	76.6
1994	84.7	82.0	82.2	75.7
1995	85.6	82.4	83.1	76.0
1996	81.9	81.3	79.5	75.6
1997	81.9	85.3	79.9	79.5
1998	82.6	85.2	80.4	79.8
1999	79.7	85.5	76.7	79.8
2000	80.9	86.8	77.8	80.3
2001	81.8	89.2	78.0	82.3

B. Input and output variables in DEA analyses. Mean (standard deviation)

Year	Physician FTEs	Other labour, FTEs	Medical Expenses, 1000 NOK	Total running expenses, Mill NOK	Inpatient care, No. of DRG-weighted discharges	Outpatient care, 1000 NOK
1992	81.24 (89.34)	706.82 (736.54)	476.07 (594.37)	317.84 (314.27)	12609 (12590)	32346 (36728)
1993	84.66 (96.16)	720.07 (759.07)	526.85 (651.68)	325.69 (325.24)	13075 (13017)	33224 (38483)
1994	87.54 (101.07)	733.38 (772.07)	532.66 (700.56)	329.18 (329.29)	13085 (13059)	34255 (38847)
1995	93.03 (106.68)	762.92 (805.50)	563.32 (734.33)	343.13 (343.40)	13781 (13814)	36165 (41429)
1996	100.21 (116.74)	810.56 (883.15)	578.57 (785.35)	373.20 (388.23)	13951 (13959)	38474 (45429)
1997	107.76 (131.67)	837.05 (930.52)	615.29 (856.02)	404.78 (423.55)	14303 (14270)	46144 (53816)
1998	117.70 (145.22)	869.29 (967.47)	611.87 (807.67)	429.91 (452.31)	15318 (15536)	48788 (58044)
1999	123.23 (151.26)	901.10 (1005.89)	718.42 (951.63)	470.95 (491.49)	15917 (16095)	52437 (64276)
2000	129.63 (157.24)	934.48 (1038.48)	690.53 (887.20)	482.69 (497.35)	16356 (16285)	52881 (62142)

TABLE 4. Correlation coefficients of efficiency indicators

Overall (two-dimensional) correlation
($NT = 470$)

	CEV	TEV	CEC
TEV	0.6625		
CEC	0.9609	0.6248	
TEC	0.4781	0.8146	0.5569

Correlation between hospital-specific means
($N = 47$)

	CEV	TEV	CEC
TEV	0.8239		
CEC	0.9603	0.8049	
TEC	0.5464	0.7619	0.6807

Correlation between year-specific means
($T = 10$)

	CEV	TEV	CEC
TEV	-0.5948		
CEC	0.9747	-0.6929	
TEC	-0.6865	0.9816	-0.7493

TABLE 5. Hospital-specific means and year of ABF start

Hosp. no	BEDS	BUD	LONG	CEV	TEV	CEC	TEC	ABF start in year
1	304.0	1780.5	20.4	87.1	89.5	82.1	80.0	1997
2	50.9	1451.8	13.0	75.1	80.7	72.8	73.4	1997
3	120.6	1747.6	15.8	75.7	78.6	73.7	75.3	1997
4	176.5	1928.6	30.8	91.4	88.3	90.5	86.1	1997
5	68.9	1950.9	15.1	82.8	85.8	80.8	85.0	1997
6	279.2	1854.0	41.3	83.5	85.2	80.8	78.4	1997
7	98.9	1999.1	13.2	84.5	87.9	83.0	84.7	1997
8	107.5	1536.3	14.3	87.8	89.1	84.5	87.2	1997
9	859.4	1856.4	49.9	92.6	95.3	86.8	79.8	1997
10	134.6	1861.8	36.7	68.6	72.2	65.9	67.9	1997
11	482.3	1942.9	30.6	92.6	78.9	90.3	71.7	1997
12	117.6	2073.0	20.9	81.6	87.3	80.0	79.2	1997
13	207.7	1917.0	22.0	80.7	77.8	76.4	70.3	1997
14	44.7	2143.1	13.9	75.8	83.4	75.4	82.5	1997
15	203.6	2010.3	31.4	85.1	87.5	80.9	79.2	1997
16	368.9	2419.4	20.9	85.8	88.4	82.9	74.4	1997
17	493.9	2048.5	25.7	82.5	91.9	79.3	82.5	1997
18	361.9	1865.5	24.1	87.6	90.0	81.6	77.9	1999
19	89.1	1780.7	18.0	81.4	82.3	78.7	80.8	1999
20	530.0	2820.1	22.2	77.8	76.2	69.1	60.9	1997
21	793.8	2208.7	52.1	86.5	79.9	82.1	64.6	1997
22	443.9	1965.8	46.8	78.2	78.3	73.6	66.0	1997
23	197.9	1535.9	55.8	72.3	69.5	69.3	64.9	1997
24	47.1	1926.9	11.4	86.6	92.9	86.1	91.0	1997
25	40.4	1586.0	13.6	87.4	93.5	85.3	88.3	1997
26	306.9	1923.6	21.9	84.6	86.5	78.8	75.6	1997
27	77.8	1799.9	24.1	87.3	85.5	85.1	84.9	1998
28	36.8	2222.0	22.0	72.9	79.2	72.3	77.8	1998
29	73.1	1791.9	24.8	76.3	72.8	75.4	72.4	1998
30	315.6	1903.7	31.2	85.8	89.0	84.8	81.5	1998
31	78.6	1675.4	38.1	81.9	84.9	81.1	84.2	1998
32	56.6	1673.2	29.0	80.0	83.3	79.5	83.0	1998
33	64.0	1803.5	20.6	71.4	69.3	70.7	68.5	1998
34	113.0	1854.9	16.3	66.4	66.7	64.2	65.7	1997
35	244.7	1840.1	20.1	86.2	87.1	81.1	78.3	1997
36	66.5	1409.9	24.8	88.3	91.5	87.2	90.4	1997
37	323.1	1772.2	22.5	94.9	96.7	93.7	90.9	1997
38	242.4	1765.3	28.2	89.1	95.5	84.5	83.3	1997
39	651.9	1799.3	51.6	89.3	98.5	85.1	81.7	1997
40	66.0	1763.5	20.6	78.5	77.0	78.2	75.7	1998
41	89.1	1709.7	11.9	83.0	80.6	82.4	80.1	1998
42	56.5	1347.1	15.0	77.7	78.4	76.1	74.8	1998
43	154.8	1426.5	32.6	92.0	86.4	90.0	79.5	1998
44	939.3	1838.5	36.5	98.1	95.9	92.2	77.7	1998
45	51.8	1643.6	8.2	81.7	87.5	80.8	84.2	2000
46	47.0	1790.2	14.0	77.8	84.7	77.4	81.8	2000
47	215.0	1816.3	18.8	76.9	78.7	73.9	72.2	2000

TABLE 6. Rank correlation coefficients of efficiency across hospitals, by pair of years

A. Efficiency indicator: CEV

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1992	1.000									
1993	0.848	1.000								
1994	0.755	0.833	1.000							
1995	0.738	0.822	0.916	1.000						
1996	0.752	0.771	0.881	0.910	1.000					
1997	0.572	0.612	0.718	0.771	0.816	1.000				
1998	0.559	0.516	0.654	0.623	0.662	0.805	1.000			
1999	0.732	0.668	0.805	0.774	0.845	0.717	0.778	1.000		
2000	0.754	0.639	0.706	0.653	0.743	0.568	0.655	0.875	1.000	
2001	0.529	0.435	0.515	0.466	0.443	0.330	0.470	0.657	0.764	1.000

B. Efficiency indicator: TEV

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1992	1.000									
1993	0.875	1.000								
1994	0.758	0.789	1.000							
1995	0.676	0.648	0.827	1.000						
1996	0.514	0.534	0.624	0.796	1.000					
1997	0.452	0.468	0.627	0.694	0.830	1.000				
1998	0.475	0.463	0.688	0.748	0.751	0.862	1.000			
1999	0.491	0.546	0.695	0.641	0.579	0.577	0.755	1.000		
2000	0.390	0.438	0.507	0.526	0.452	0.415	0.600	0.778	1.000	
2001	0.386	0.397	0.435	0.398	0.248	0.287	0.450	0.634	0.595	1.000

C. Efficiency indicator: CEC

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1992	1.000									
1993	0.835	1.000								
1994	0.759	0.816	1.000							
1995	0.768	0.787	0.927	1.000						
1996	0.789	0.752	0.883	0.914	1.000					
1997	0.566	0.579	0.731	0.773	0.775	1.000				
1998	0.558	0.510	0.694	0.690	0.667	0.810	1.000			
1999	0.759	0.679	0.771	0.762	0.805	0.655	0.786	1.000		
2000	0.748	0.635	0.688	0.657	0.728	0.528	0.666	0.911	1.000	
2001	0.564	0.461	0.463	0.396	0.453	0.330	0.518	0.741	0.832	1.000

D. Efficiency indicator: TEC

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
1992	1.000									
1993	0.821	1.000								
1994	0.652	0.731	1.000							
1995	0.582	0.610	0.815	1.000						
1996	0.468	0.533	0.662	0.811	1.000					
1997	0.441	0.509	0.741	0.769	0.855	1.000				
1998	0.370	0.412	0.708	0.731	0.700	0.886	1.000			
1999	0.389	0.517	0.695	0.673	0.580	0.687	0.777	1.000		
2000	0.364	0.495	0.608	0.612	0.502	0.551	0.633	0.828	1.000	
2001	0.475	0.513	0.550	0.443	0.403	0.476	0.525	0.689	0.726	1.000

TABLE 7. Efficiency equations.

Coefficient estimates based on full sample

Standard errors in parenthesis*)

A. Homogeneous model. OLS estimates

	CEV	TEV	CEC	TEC
CONST	94.498 (1.945)	88.526 (2.476)	94.375 (1.945)	88.776 (2.476)
BEDS	2.093 (0.181)	1.652 (0.230)	1.482 (0.181)	-0.329 (0.230)
BUD	-7.919 (1.077)	-3.773 (1.371)	-8.774 (1.077)	-5.124 (1.371)
ABF	0.996 (0.843)	5.479 (1.073)	1.128 (0.843)	6.284 (1.073)
LONG	-0.094 (0.029)	-0.136 (0.036)	-0.078 (0.029)	-0.124 (0.036)

*) The OLS standard error estimates are obtained from the 'standard' formulae, which disregard coefficient heterogeneity, and hence are incomparable with those in panels B and C.

B. Heterogeneous, random coefficient model.
Single-equation GLS estimates of expected coefficients

	CEV	TEV	CEC	TEC
CONST	108.180 (12.282)	64.881 (15.053)	111.508 (11.679)	59.569 (14.654)
BEDS	-6.839 (12.068)	7.179 (12.999)	-8.217 (11.504)	9.724 (13.670)
BUD	-8.529 (2.693)	5.298 (3.554)	-10.408 (2.653)	4.666 (3.214)
ABF	1.458 (1.060)	2.895 (1.691)	2.031 (0.977)	3.651 (1.371)
LONG	-0.036 (0.066)	0.060 (0.112)	-0.056 (0.061)	0.042 (0.102)

C. Heterogeneous, random coefficient model.
System GLS estimates of expected coefficients

	CEV	TEV	CEC	TEC
CONST	110.821 (11.699)	77.532 (14.147)	112.859 (11.151)	69.986 (13.805)
BEDS	-3.466 (11.673)	-6.015 (12.341)	-6.886 (11.119)	-5.334 (13.082)
BUD	-9.563 (2.538)	5.424 (3.300)	-10.238 (2.519)	4.854 (2.961)
ABF	3.270 (0.948)	2.659 (1.567)	3.664 (0.869)	3.072 (1.232)
LONG	-0.050 (0.059)	0.003 (0.104)	-0.078 (0.055)	0.042 (0.094)

TABLE 8. Distribution of the $N = 47$ hospital-specific OLS estimates, each based on $T = 10$ observations. Descriptive statistics

A. Coefficients in equation for efficiency indicator CEV

	CONST	BEDS	BUD	ABF	LONG
Mean	124.896	-17.593	-10.892	1.869	-0.081
St.dev.	79.130	79.645	17.059	6.384	0.393
Skew	-0,000	-0.648	0.23	-0.414	-0.387
Kurt	7.501	8.073	5.035	3.764	4.176

B. Coefficients in equation for efficiency indicator TEV

	CONST	BEDS	BUD	ABF	LONG
Mean	68.802	4.545	4.525	3.670	0.053
St.dev.	96.462	84.588	22.549	10.655	0.711
Skew	-0.762	0.566	0.336	1.332	-0.248
Kurt	4.174	5.565	3.885	5.586	4.315

C. Coefficients in equation for efficiency indicator: CEC

	CONST	BEDS	BUD	ABF	LONG
Mean	126.705	-18.012	-12.431	2.443	-0.101
St.dev.	75.329	75.915	16.936	5.826	0.366
Skew	-0.327	-0.246	0.429	-0.517	-0.849
Kurt	6.983	7.376	4.730	3.403	4.634

D. Coefficients in equation for efficiency indicator TEC

	CONST	BEDS	BUD	ABF	LONG
Mean	58.195	8.755	4.762	3.995	0.060
St.dev.	93.969	89.624	20.157	8.289	0.641
Skew	-0.764	0.614	1.096	0.847	0.363
Kurt	4.981	5.383	4.473	4.358	4.810

TABLE 9. Strength of association between ABF coefficient and efficiency. Rank correlation across hospitals

A. Rank correlation coefficients

a. Estimated coefficient of ABF dummy versus efficiency, by year

Effic.ind.	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
CEV	0.224	0.127	0.183	0.150	0.126	0.380	0.624	0.265	0.331	0.318
TEV	0.043	-0.084	0.206	0.111	0.070	0.267	0.484	0.192	0.203	0.171
CEC	0.331	0.194	0.348	0.339	0.264	0.524	0.640	0.333	0.369	0.392
TEC	0.008	-0.112	0.293	0.174	0.017	0.284	0.518	0.301	0.283	0.143

b. t-value of ABF dummy coefficient versus efficiency, by year

Effic.ind.	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
CEV	0.164	0.066	0.127	0.101	0.059	0.342	0.596	0.214	0.261	0.258
TEV	0.015	-0.088	0.207	0.119	0.057	0.245	0.475	0.213	0.220	0.229
CEC	0.319	0.185	0.291	0.300	0.203	0.506	0.628	0.312	0.321	0.325
TEC	-0.028	-0.098	0.252	0.121	-0.025	0.238	0.447	0.226	0.199	0.065

c. Predicted coefficient of ABF dummy versus efficiency, by year

Effic.ind.	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
CEV	0.147	0.039	0.151	0.112	0.091	0.336	0.627	0.288	0.320	0.334
TEV	0.022	-0.117	0.204	0.136	0.109	0.253	0.481	0.202	0.192	0.148
CEC	0.217	0.103	0.298	0.269	0.202	0.494	0.670	0.341	0.349	0.387
TEC	-0.050	-0.198	0.237	0.131	-0.035	0.243	0.480	0.259	0.240	0.093

B. *t*-value counterpart to rank correlation coefficients

a. Estimated coefficient of ABF dummy versus efficiency, by year

Effic.ind.	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
CEV	1.541	0.856	1.249	1.020	0.849	2.759	5.353	1.843	2.352	2.247
TEV	0.286	0.563	1.411	0.752	0.469	1.860	3.713	1.310	1.391	1.161
CEC	2.356	1.326	2.488	2.416	1.840	4.125	5.583	2.370	2.666	2.858
TEC	0.050	0.754	2.052	1.185	0.116	1.984	4.063	2.117	1.980	0.967

b. t-value of ABF dummy coefficient versus efficiency, by year

Effic.ind.	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
CEV	1.118	0.445	0.855	0.678	0.393	2.438	4.983	1.472	1.816	1.793
TEV	0.099	0.595	1.418	0.801	0.380	1.692	3.626	1.465	1.514	1.579
CEC	2.259	1.261	2.039	2.113	1.389	3.935	5.418	2.200	2.271	2.302
TEC	0.190	0.659	1.746	0.818	0.170	1.644	3.351	1.554	1.366	0.434

c. Predicted coefficient of ABF dummy versus efficiency, by year

Effic.ind.	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
CEV	0.997	0.259	1.023	0.758	0.614	2.392	5.394	2.020	2.263	2.378
TEV	0.148	0.792	1.398	0.921	0.737	1.754	3.682	1.382	1.312	1.006
CEC	1.494	0.694	2.096	1.872	1.381	3.811	6.056	2.432	2.500	2.814
TEC	0.338	1.354	1.638	0.885	0.234	1.683	3.673	1.799	1.657	0.625

TABLE 10. Efficiency of hospital whose ABF coefficient is at the lower (L) and at the upper (U) quartile.

RL=ranking no. of L, RU=ranking no. of U (1=highest).
E=Estimated coefficient, P=Predicted coefficient

I. Quartiles related to *estimated* coefficients

A. Efficiency indicator: CEV. L=Hospital no. 41, U=Hospital no. 18

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	E	P
L	87.7	84.8	83.6	83.1	84.5	81.9	78.8	81.9	84.3	79.8	-1.7	-1.2
U	91.5	92.3	89.1	95.7	86.4	84.5	88.0	82.7	83.2	82.2	5.8	3.0
RL	18	25	28	31	17	27	35	16	16	30	36	35
RU	12	11	16	7	14	18	14	14	19	21	12	17

B. Efficiency indicator: TEV. L=Hospital no. 21, U=Hospital no. 9

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	E	P
L	82.7	77.2	71.1	74.7	73.6	75.7	80.1	80.2	99.9	83.6	-2.2	-2.0
U	100.0	96.0	94.9	94.4	89.9	94.0	94.8	96.1	93.0	100.0	6.8	4.8
RL	27	33	42	37	39	40	36	31	5	35	36	37
RU	3	5	5	5	6	10	10	8	17	2	12	13

C. Efficiency indicator: CEC. L=Hospital no. 24, U=Hospital no. 5

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	E	P
L	78.4	89.3	90.3	96.2	88.9	90.0	89.3	86.8	78.8	72.6	-1.2	0.0
U	78.4	80.7	84.4	85.5	80.6	84.9	81.7	77.0	80.7	74.6	6.3	5.3
RL	29	12	9	4	5	4	7	5	21	35	36	32
RU	30	28	18	16	21	11	23	24	17	29	12	9

D. Efficiency indicator: TEC. L=Hospital no. 3, U=Hospital no. 37

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	E	P
L	73.3	71.8	71.9	76.6	80.3	79.3	75.8	74.2	71.2	79.0	-1.2	-0.5
U	77.7	80.2	88.0	92.1	97.1	100.0	100.0	91.1	91.0	91.4	9.3	9.4
RL	30	33	34	23	11	21	31	35	37	31	36	39
RU	23	20	1	2	2	1	1	6	8	8	12	10

II. Quartiles related to *predicted* coefficients

A. Efficiency indicator: CEV. L=Hospital no. 43, U=Hospital no. 10

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	E	P
L	92.7	96.3	97.0	100.0	92.2	88.3	85.0	90.5	90.4	87.4	-1.3	-1.4
U	65.8	65.0	67.6	65.1	65.1	69.4	73.8	70.9	72.9	71.0	6.4	4.4
RL	9	3	2	2	3	8	17	3	6	12	34	36
RU	46	45	47	47	47	45	40	42	39	44	11	12

B. Efficiency indicator: TEV. L=Hospital no. 35, U=Hospital no. 38

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	E	P
L	100.0	95.9	91.3	89.7	77.7	81.5	82.5	84.7	83.2	84.3	-0.8	-1.9
U	100.0	98.1	95.4	92.6	92.5	98.8	97.4	92.0	100.0	88.7	10.9	5.0
RL	2	6	9	10	33	28	27	21	29	34	30	36
RU	5	3	4	7	5	7	9	15	2	26	9	12

C. Efficiency indicator: CEC. L=Hospital no. 19, U=Hospital no. 37

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	E	P
L	80.0	75.6	78.6	81.8	81.2	76.5	77.4	77.6	77.7	80.7	-4.9	-0.5
U	86.9	90.2	95.7	100.0	99.9	99.2	100.0	87.4	89.4	88.0	5.3	5.0
RL	27	40	34	28	18	34	32	20	23	15	41	36
RU	14	8	2	1	1	1	1	3	3	7	19	12

D. Efficiency indicator: TEC. L=Hospital no. 19, U=Hospital no. 44

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	E	P
L	82.3	78.8	74.9	80.0	78.6	78.6	77.1	82.7	84.4	90.9	-3.8	-0.2
U	71.2	74.4	71.2	72.7	70.9	78.0	87.5	89.0	81.5	80.6	10.4	8.9
RL	14	22	29	13	20	24	28	16	15	9	42	36
RU	32	28	36	35	33	27	11	7	23	28	11	12

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Appendix A: Constructing efficiency measures

Formally, the (TE and CE) measures are derived by first defining the reference technology relative to which efficiency is measured. Let $\boldsymbol{y} = (y_1, \ldots, y_m) \in \mathcal{R}_+^m$ denote a vector of outputs and $\boldsymbol{x} = (x_1, \ldots, x_n) \in \mathcal{R}_+^n$ denote a vector of inputs. We let N be the number of hospitals, $\boldsymbol{Y}$ is the $(N \times m)$ matrix of observed outputs, whose ith row represents $\boldsymbol{y}$ for hospital i, $\boldsymbol{X}$ is the $(N \times n)$ matrix of observed inputs, whose ith row represents $\boldsymbol{x}$ for hospital i, and $\boldsymbol{\lambda} = (\lambda_1, \ldots, \lambda_N)$ is the intensity vector for the N hospitals. Assuming CRS we can obtain a (scalar) measure of input-saving efficiency (for unit 0 say), θ, by solving the following LP problem:

$$\min_{\theta,\boldsymbol{\lambda}}(\theta) \quad \text{subject to} \quad \begin{cases} \boldsymbol{\lambda Y} & \geq & \boldsymbol{y}_0, \\ \boldsymbol{\lambda X} & \leq & \theta\, \boldsymbol{x}_0, \\ \boldsymbol{\lambda} & \geq & 0. \end{cases}$$

A measure of input saving efficiency assuming variable returns to scale is obtained by restricting the sum of the intensity variables to be equal to 1: $\boldsymbol{\lambda}\,\boldsymbol{\iota} = 1$, $\boldsymbol{\iota}$ denoting the $(N \times 1)$ unit vector.

The efficiency frontier is constructed from a pooled set of observations, *i.e.*, an intertemporal efficiency frontier is computed (Harris, Ozgen, and Ozcan, 2000, Tulkens and van den Eeckaut, 1993). We do this in order to be able to compare efficiency between years.

Appendix B: Estimation and coefficient prediction

In this appendix we describe the estimation procedures for the random coefficient multi-equation model (Sections 1–5) and the procedure for predicting the unit (hospital) specific coefficients from the estimation results (Section 6).

1. Model and notation. We consider a linear, static panel data regression model for N units (hospitals) observed in T periods (years), with G equations. Equation g has K_g regressors (including a one associated with the intercept) and a distinct coefficient vector, so that the total number of coefficients is $K = \sum_{g=1}^{G} K_g$. Let, for Equation g $(g = 1, \ldots, G)$, unit i $(i = 1, \ldots, N)$, period t $(t = 1, \ldots, T)$, the $(T \times 1)$ vector of observations of the regressand be $\boldsymbol{y}_{gi}$, the $(T \times K_g)$ regressor matrix be $\boldsymbol{X}_{gi}$ (including a vector of ones associated with the intercept), and $\boldsymbol{u}_{gi}$ be a zero mean $(T \times 1)$ vector of disturbances. We allow for unit-specific heterogeneity to be represented, for equation g, unit i, by the *random coefficient vector*

$$\boldsymbol{\beta}_{gi} = \boldsymbol{\beta}_g + \boldsymbol{\delta}_{gi}, \tag{B.1}$$

where $\boldsymbol{\beta}_g$ is a fixed constant vector and $\boldsymbol{\delta}_{gi}$ its random shift variable with zero mean. We assume that $\boldsymbol{X}_{gi}$, $\boldsymbol{u}_{gi}$, and $\boldsymbol{\delta}_{gi}$ are mutually independent, that $\boldsymbol{u}_{gi}$ and $\boldsymbol{\delta}_{gi}$ are independent and that

$$\mathsf{E}[\boldsymbol{\delta}_{gi}\boldsymbol{\delta}'_{hi}] = \boldsymbol{\Sigma}^{\delta}_{gh}, \quad \mathsf{E}[\boldsymbol{u}_{gi}\boldsymbol{u}'_{hi}] = \sigma^{u}_{gh}\boldsymbol{I}_T, \quad g, h = 1, \ldots, G, \tag{B.2}$$

where $\mathbf{0}_{m,n}$ is the $(m \times n)$ zero matrix and $\boldsymbol{I}_m$ is the m-dimensional identity matrix. Equation g for unit i is

$$\boldsymbol{y}_{gi} = \boldsymbol{X}_{gi}\boldsymbol{\beta}_{gi} + \boldsymbol{u}_{gi} = \boldsymbol{X}_{gi}\boldsymbol{\beta}_{g} + \boldsymbol{\eta}_{gi}, \quad \boldsymbol{\eta}_{gi} = \boldsymbol{X}_{gi}\boldsymbol{\delta}_{gi} + \boldsymbol{u}_{gi}, \quad \begin{matrix} g = 1,\dots,G, \\ i = 1,\dots,N. \end{matrix} \tag{B.3}$$

It follows from (B.2) that $\mathsf{E}[\boldsymbol{\eta}_{gi}\boldsymbol{\eta}'_{hi}] = \boldsymbol{X}_{gi}\boldsymbol{\Sigma}^{\delta}_{gh}\boldsymbol{X}'_{hi} + \sigma^{u}_{gh}\boldsymbol{I}_T$. Let

$$\boldsymbol{\Sigma}^u = \begin{bmatrix} \sigma^u_{11} & \cdots & \sigma^u_{1G} \\ \vdots & & \vdots \\ \sigma^u_{G1} & \cdots & \sigma^u_{GG} \end{bmatrix}, \quad \boldsymbol{\Sigma}^\delta = \begin{bmatrix} \boldsymbol{\Sigma}^\delta_{11} & \cdots & \boldsymbol{\Sigma}^\delta_{1G} \\ \vdots & & \vdots \\ \boldsymbol{\Sigma}^\delta_{G1} & \cdots & \boldsymbol{\Sigma}^\delta_{GG} \end{bmatrix}, \quad \boldsymbol{X}_i = \begin{bmatrix} \boldsymbol{X}_{1i} & \cdots & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & \cdots & \boldsymbol{X}_{Gi} \end{bmatrix},$$

of dimensions $(G\times G)$, $(K\times K)$, and $(GT\times K)$, respectively, and let $\boldsymbol{y}_i = (\boldsymbol{y}'_{1i},\dots,\boldsymbol{y}'_{Gi})'$, $\boldsymbol{\beta} = (\boldsymbol{\beta}'_1,\dots,\boldsymbol{\beta}'_G)'$, $\boldsymbol{\delta}_i = (\boldsymbol{\delta}'_{1i},\dots,\boldsymbol{\delta}'_{Gi})'$, $\boldsymbol{u}_i = (\boldsymbol{u}'_{1i},\dots,\boldsymbol{u}'_{Gi})'$, $\boldsymbol{\eta}_i = (\boldsymbol{\eta}'_{1i},\dots,\boldsymbol{\eta}'_{Gi})'$. We can then write the model more compactly as

$$\boldsymbol{y}_i = \boldsymbol{X}_i\boldsymbol{\beta} + \boldsymbol{\eta}_i, \qquad \boldsymbol{\eta}_i = \boldsymbol{X}_i\boldsymbol{\delta}_i + \boldsymbol{u}_i, \tag{B.4}$$

$$\mathsf{V}(\boldsymbol{\delta}_i) = \boldsymbol{\Sigma}^\delta, \quad \mathsf{V}(\boldsymbol{u}_i) = \boldsymbol{I}_T \otimes \boldsymbol{\Sigma}^u, \quad \mathsf{V}(\boldsymbol{\eta}_i) = \boldsymbol{\Omega}_i = \boldsymbol{X}_i\boldsymbol{\Sigma}^\delta\boldsymbol{X}'_i + \boldsymbol{I}_T \otimes \boldsymbol{\Sigma}^u, \tag{B.5}$$

where V denotes the covariance matrix and $\otimes$ is the Kronecker product operator.

2. First step, OLS, estimation of $\boldsymbol{\beta}_{gi}$ and $\boldsymbol{\beta}$. Consider first OLS estimation of the unit and equation-specific coefficients $\boldsymbol{\beta}_{gi}$ (in a fixed coefficients setting, or conditional on the unit-specific coefficient vector) and the full expected coefficient vector $\boldsymbol{\beta}$ (in a random coefficients setting). The vector of OLS estimators for unit i is [this presumes that $T > K_g$ for all g]

$$\widehat{\boldsymbol{\beta}}_i = \begin{bmatrix} \widehat{\boldsymbol{\beta}}_{1i} \\ \vdots \\ \widehat{\boldsymbol{\beta}}_{Gi} \end{bmatrix} = [\boldsymbol{X}'_i\boldsymbol{X}_i]^{-1}\boldsymbol{X}'_i\boldsymbol{y}_i = \begin{bmatrix} (\boldsymbol{X}'_{1i}\boldsymbol{X}_{1i})^{-1}\boldsymbol{X}'_{1i}\boldsymbol{y}_{1i} \\ \vdots \\ (\boldsymbol{X}'_{Gi}\boldsymbol{X}_{Gi})^{-1}\boldsymbol{X}'_{Gi}\boldsymbol{y}_{Gi} \end{bmatrix}, \; i = 1,\dots,N. \tag{B.6}$$

A first-step estimator of the *common expectation of the unit-specific coefficient vectors*, $\boldsymbol{\beta}$, based on observations of all units is the unweighted mean

$$\widehat{\boldsymbol{\beta}} = \tfrac{1}{N}\textstyle\sum_{i=1}^N \widehat{\boldsymbol{\beta}}_i = \tfrac{1}{N}\sum_{i=1}^N [\boldsymbol{X}'_i\boldsymbol{X}_i]^{-1}[\boldsymbol{X}'_i\boldsymbol{y}_i]. \tag{B.7}$$

3. First step estimation of $\boldsymbol{\Sigma}^u$ and $\boldsymbol{\Sigma}^\delta$ from OLS residuals. We construct

$$\widehat{\boldsymbol{u}}_i = \begin{bmatrix} \widehat{\boldsymbol{u}}_{1i} \\ \vdots \\ \widehat{\boldsymbol{u}}_{Gi} \end{bmatrix} = \boldsymbol{y}_i - \boldsymbol{X}_i\widehat{\boldsymbol{\beta}}_i, \qquad \widehat{\boldsymbol{U}}_i = \begin{bmatrix} \widehat{\boldsymbol{u}}'_{1i} \\ \vdots \\ \widehat{\boldsymbol{u}}'_{Gi} \end{bmatrix},$$

where element (g,t) in the $(G \times T)$ matrix $\widehat{\boldsymbol{U}}_i$ is the t'th OLS residual of unit i in the g'th equation. We estimate $\boldsymbol{\Sigma}^u$ and $\boldsymbol{\Sigma}^\delta$ by

$$\widehat{\boldsymbol{\Sigma}}^u = \tfrac{1}{NT}\textstyle\sum_{i=1}^N \widehat{\boldsymbol{U}}_i\widehat{\boldsymbol{U}}'_i, \qquad \widehat{\boldsymbol{\Sigma}}^\delta = \tfrac{1}{N}\sum_{i=1}^N (\widehat{\boldsymbol{\beta}}_i - \widehat{\boldsymbol{\beta}})(\widehat{\boldsymbol{\beta}}_i - \widehat{\boldsymbol{\beta}})'. \tag{B.8}$$

These estimators are consistent if both T and N go to infinity and are always positive definite; $\widehat{\boldsymbol{\Sigma}}^\delta$, however, is biased in finite samples. Other estimators exist; see Hsiao (2003, p. 146). Inserting $\widehat{\boldsymbol{\Sigma}}^u$ and $\widehat{\boldsymbol{\Sigma}}^\delta$ into (B.7), we get the following estimator of $\boldsymbol{\Omega}_i$:

$$\widehat{\boldsymbol{\Omega}}_i = \boldsymbol{X}_i\widehat{\boldsymbol{\Sigma}}^\delta\boldsymbol{X}'_i + \boldsymbol{I}_T \otimes \widehat{\boldsymbol{\Sigma}}^u, \qquad i = 1,\dots,N. \tag{B.9}$$

4. Second step, GLS, estimation of $\boldsymbol{\beta}_i$ and $\boldsymbol{\beta}$. Having estimated all the $\boldsymbol{\Omega}_i$'s from (B.9), (asymptotically) more efficient estimators of $\boldsymbol{\beta}_i$ than $\widehat{\boldsymbol{\beta}}_i$, and corresponding estimators of the common expected coefficient vector $\boldsymbol{\beta}$, can be obtained as follows. The GLS estimator of $\boldsymbol{\beta}_i$ and its covariance matrix are

$$\widetilde{\boldsymbol{\beta}}_i = [\boldsymbol{X}_i'\boldsymbol{\Omega}_i^{-1}\boldsymbol{X}_i]^{-1}[\boldsymbol{X}_i'\boldsymbol{\Omega}_i^{-1}\boldsymbol{y}_i], \tag{B.10}$$

$$\mathsf{V}(\widetilde{\boldsymbol{\beta}}_i) = [\boldsymbol{X}_i'\boldsymbol{\Omega}_i^{-1}\boldsymbol{X}_i]^{-1}, \qquad i=1,\dots,N. \tag{B.11}$$

A corresponding GLS estimator of $\boldsymbol{\beta}$ based on observations from all units is

$$\widetilde{\boldsymbol{\beta}}=\Big[\sum_{i=1}^N \mathsf{V}(\widetilde{\boldsymbol{\beta}}_i)^{-1}\Big]^{-1}\Big[\sum_{i=1}^N \mathsf{V}(\widetilde{\boldsymbol{\beta}}_i)^{-1}\widetilde{\boldsymbol{\beta}}_i\Big]=\Big[\sum_{i=1}^N \boldsymbol{X}_i'\boldsymbol{\Omega}_i^{-1}\boldsymbol{X}_i\Big]^{-1}\Big[\sum_{i=1}^N \boldsymbol{X}_i'\boldsymbol{\Omega}_i^{-1}\boldsymbol{y}_i\Big], \tag{B.12}$$

which is a matrix weighted mean of all the $\widetilde{\boldsymbol{\beta}}_i$'s and is the minimum variance linear unbiased estimator (MVLUE) of $\boldsymbol{\beta}$. Its covariance matrix is

$$\mathsf{V}(\widetilde{\boldsymbol{\beta}}) = \Big[\sum_{i=1}^N \mathsf{V}(\widetilde{\boldsymbol{\beta}}_i)^{-1}\Big]^{-1} = \Big[\sum_{i=1}^N \boldsymbol{X}_i'\boldsymbol{\Omega}_i^{-1}\boldsymbol{X}_i\Big]^{-1}. \tag{B.13}$$

The FGLS estimators of $\boldsymbol{\beta}_i$ (conditional on unit i) and $\boldsymbol{\beta}$ (unconditional mean) and their estimated covariance matrices are obtained by inserting (B.9) into (B.10)–(B.13).

5. Second step estimation of $\boldsymbol{\Sigma}^u$ and $\boldsymbol{\Sigma}^\delta$ from GLS residuals. The GLS estimators $\widetilde{\boldsymbol{\beta}}_i$ can be used to revise the estimators of the disturbance covariance matrices and the covariance matrices of the random coefficients obtained in the first step, *i.e.*, $\widehat{\boldsymbol{\Sigma}}^u$ and $\widehat{\boldsymbol{\Sigma}}^\delta$.

We construct the $(GT \times 1)$ GLS residual vector corresponding to $\boldsymbol{u}_i$ from

$$\widetilde{\boldsymbol{u}}_i = \begin{bmatrix} \widetilde{\boldsymbol{u}}_{1i} \\ \vdots \\ \widetilde{\boldsymbol{u}}_{Gi} \end{bmatrix} = \boldsymbol{y}_i - \boldsymbol{X}_i\widetilde{\boldsymbol{\beta}}_i, \qquad \widetilde{\boldsymbol{U}}_i = \begin{bmatrix} \widetilde{\boldsymbol{u}}_{1i}' \\ \vdots \\ \widetilde{\boldsymbol{u}}_{Gi}' \end{bmatrix}.$$

The second step estimator of $\boldsymbol{\Sigma}^u$ and $\boldsymbol{\Sigma}^\delta$ are

$$\widetilde{\boldsymbol{\Sigma}}^u = \tfrac{1}{NT}\sum_{i=1}^N \widetilde{\boldsymbol{U}}_i\widetilde{\boldsymbol{U}}_i', \qquad \widetilde{\boldsymbol{\Sigma}}^\delta = \tfrac{1}{N}\sum_{i=1}^N(\widetilde{\boldsymbol{\beta}}_i-\widetilde{\boldsymbol{\beta}})(\widetilde{\boldsymbol{\beta}}_i-\widetilde{\boldsymbol{\beta}})'. \tag{B.14}$$

Recompute the overall estimator of $\boldsymbol{\Omega}_i$ by

$$\widetilde{\boldsymbol{\Omega}}_i = \boldsymbol{X}_i\widetilde{\boldsymbol{\Sigma}}^\delta\boldsymbol{X}_i' + \boldsymbol{I}_T\otimes\widetilde{\boldsymbol{\Sigma}}^u, \qquad i=1,\dots,N. \tag{B.15}$$

Revised FGLS estimators of $\boldsymbol{\beta}_i$ and $\boldsymbol{\beta}$ and their estimated covariance matrices are obtained by inserting (B.15) into (B.10)–(B.13).

6. Prediction of coefficients. The random coefficient vector of unit i, $\boldsymbol{\beta}_i$, is predicted by means of

$$\boldsymbol{\beta}_i^* = \widetilde{\boldsymbol{\beta}} + \boldsymbol{\Sigma}^\delta\boldsymbol{X}_i'\boldsymbol{\Omega}_i^{-1}(\boldsymbol{y}_i - \boldsymbol{X}_i\widetilde{\boldsymbol{\beta}}) = \widetilde{\boldsymbol{\beta}} + \boldsymbol{\Sigma}^\delta\boldsymbol{X}_i'(\boldsymbol{X}_i\boldsymbol{\Sigma}^\delta\boldsymbol{X}_i' + \boldsymbol{I}_T\otimes\boldsymbol{\Sigma}^u)^{-1}(\boldsymbol{y}_i - \boldsymbol{X}_i\widetilde{\boldsymbol{\beta}}), \tag{B.16}$$

cf. Lee and Griffiths (1979, section 4) and Hsiao (2003, p. 147). It has the interpretation as the minimum variance linear unbiased predictor (MVLUP) of the stochastic variable $\boldsymbol{\beta}_i$. Combining (B.16) with (B.10) this predictor can be rewritten as

$$\boldsymbol{\beta}_i^* = \boldsymbol{A}_i\widetilde{\boldsymbol{\beta}}_i + (\boldsymbol{I}_K - \boldsymbol{A}_i)\widetilde{\boldsymbol{\beta}}, \tag{B.17}$$

where

$$\boldsymbol{A}_i = \boldsymbol{\Sigma}^\delta\mathsf{V}(\widetilde{\boldsymbol{\beta}}_i)^{-1} = \boldsymbol{\Sigma}^\delta\boldsymbol{X}_i'\boldsymbol{\Omega}_i^{-1}\boldsymbol{X}_i = \boldsymbol{\Sigma}^\delta\boldsymbol{X}_i'(\boldsymbol{X}_i\boldsymbol{\Sigma}^\delta\boldsymbol{X}_i' + \boldsymbol{I}_T\otimes\boldsymbol{\Sigma}^u)^{-1}\boldsymbol{X}_i. \tag{B.18}$$

Eqs. (B.17) and (B.18) show that the predictor $\boldsymbol{\beta}_i^*$ can be interpreted as a *matrix weighted mean of the unit-specific GLS estimator $\widetilde{\boldsymbol{\beta}}_i$ and the overall GLS estimator $\widetilde{\boldsymbol{\beta}}$.* The predictor is 'closer to' the unit-specific GLS estimator, *i.e.*, $\boldsymbol{A}_i$ is 'large' in relation to $\boldsymbol{I}_K$, (i) the 'larger' is the dispersion of the random coefficient vector, as measured by $\boldsymbol{\Sigma}^\delta$, and (ii) the 'more certain' is the unit-specific GLS estimator, as measured by the inverse of its covariance matrix $\mathsf{V}(\widetilde{\boldsymbol{\beta}}_i)^{-1} = \boldsymbol{X}_i'\boldsymbol{\Omega}_i^{-1}\boldsymbol{X}_i$. It is closer to the estimator of the common expected coefficient when $\boldsymbol{\Sigma}^\delta\mathsf{V}(\widetilde{\boldsymbol{\beta}}_i)^{-1}$ is 'small' relative to $\boldsymbol{I}_K$. Intuitively, this is quite reasonable. We obtain the numerical values of the predicted coefficients reported in the text by inserting (B.9), or (B.15), into (B.16).

Appendix C: Supplementary tables

TABLE C1. Hospital-specific OLS estimates and standard errors

a. Efficiency indicator: CEV

Hosp.	*Coefficient estimates*					*Standard errors*				
no.	CONST	BEDS	BUD	ABF	LONG	CONST	BEDS	BUD	ABF	LONG
1	100.699	0.230	-5.756	2.814	-0.269	16.187	3.139	11.631	6.093	0.309
2	86.642	-8.348	-2.162	-8.719	0.017	82.313	113.999	19.442	8.224	0.227
3	81.012	-5.143	-0.007	-7.255	0.290	19.272	10.576	6.083	3.188	0.373
4	200.091	-30.263	-33.957	8.634	0.192	48.734	19.658	11.506	3.896	0.261
5	136.937	-24.074	-16.418	5.727	-0.553	34.866	50.976	10.094	3.175	0.271
6	123.778	-6.310	-10.574	1.802	-0.097	74.555	27.405	6.195	3.587	0.128
7	137.160	-31.729	-15.551	8.934	0.408	65.339	62.708	7.805	8.823	0.481
8	90.581	6.015	-4.078	-4.647	-0.045	29.594	31.795	6.507	3.063	0.171
9	126.201	-5.753	2.423	4.252	0.184	62.295	3.467	14.532	6.713	0.379
10	64.650	-1.128	0.311	6.418	0.047	28.269	17.344	4.025	2.850	0.065
11	164.360	-0.597	-29.763	14.861	-0.603	108.782	8.409	23.770	9.168	1.034
12	187.316	-43.015	-23.581	8.027	-0.492	32.837	13.785	7.362	4.103	0.569
13	143.658	-11.182	-17.948	-1.016	-0.219	72.623	22.700	11.203	3.399	0.425
14	140.459	-75.025	-17.415	11.995	0.013	44.786	63.451	10.075	5.883	0.442
15	91.799	1.309	-8.636	-3.592	0.312	14.951	5.808	5.958	3.177	0.179
16	177.138	-12.831	-15.351	-0.965	-0.304	146.134	21.541	19.849	12.933	1.529
17	124.807	0.700	-18.728	7.891	-0.442	19.644	0.901	5.354	2.411	0.444
18	126.868	0.700	-21.186	5.776	-0.168	34.078	9.991	13.324	8.467	0.578
19	154.743	-108.522	10.423	-2.106	0.300	95.108	118.122	12.752	5.897	0.298
20	27.985	2.212	7.482	-8.142	0.952	78.542	6.500	14.691	13.740	1.032
21	165.131	-5.900	-15.685	8.673	-0.029	26.310	1.975	5.435	3.572	0.110
22	91.445	-2.124	-5.253	-0.948	0.150	29.461	3.230	8.291	3.685	0.103
23	118.570	-21.209	-3.345	-4.001	0.051	50.037	18.392	9.533	3.266	0.074
24	173.111	-110.220	-15.613	-1.447	-0.332	36.387	66.600	7.209	8.450	0.634
25	1.044	179.056	6.966	3.373	0.094	48.421	106.011	12.107	4.782	0.069
26	110.302	-10.766	19.273	-18.158	-0.943	80.830	18.655	13.960	6.870	0.478
27	398.845	-308.028	-44.050	8.520	0.166	240.620	253.102	28.208	10.219	0.303
28	98.610	-73.514	0.844	14.453	-0.287	77.994	139.864	17.397	7.047	0.221
29	144.860	-39.577	-16.880	-3.501	-0.324	48.515	38.345	13.631	5.683	0.280
30	178.378	-16.023	-28.331	4.900	0.318	41.522	7.101	10.015	3.385	0.218
31	140.245	-53.477	-9.942	2.598	-0.018	27.866	29.161	10.443	3.707	0.103
32	-77.612	165.278	32.675	-0.240	0.326	81.474	94.291	18.791	3.852	0.128
33	97.507	-3.259	-11.012	3.000	-0.262	52.321	40.061	14.314	4.033	0.235
34	128.845	-25.432	-16.135	0.401	-0.242	33.770	18.550	7.899	4.169	0.196
35	152.096	-17.672	-9.477	-0.063	-0.258	8.805	2.985	2.428	1.331	0.068
36	121.434	18.885	-28.092	5.561	-0.357	39.239	41.897	21.442	14.266	0.378
37	143.942	3.143	-24.341	4.295	-0.809	87.682	24.271	8.928	3.954	0.199
38	177.458	-20.984	-19.413	3.644	-0.179	98.071	20.666	21.345	4.687	0.468
39	126.730	-1.637	-17.334	2.507	0.061	40.231	6.288	5.002	2.578	0.252
40	-127.276	194.954	38.088	-5.418	0.589	81.681	118.840	13.533	14.466	0.605
41	106.601	-18.391	-6.570	-1.653	0.397	42.970	30.057	11.409	4.360	0.352
42	319.653	-244.882	-61.566	-4.616	-1.253	52.187	54.742	13.745	1.819	0.311
43	125.474	-8.221	-13.667	-1.324	-0.023	58.368	23.329	17.617	6.464	0.129
44	153.780	-3.636	-14.180	9.800	0.016	50.065	4.303	9.591	4.958	0.356
45	66.493	27.830	-1.112	5.328	0.192	26.135	31.071	7.735	3.474	0.319
46	151.080	-77.654	-19.321	1.721	-0.181	38.606	54.635	7.879	3.191	0.252
47	96.466	-0.670	-7.976	-0.255	-0.191	9.905	3.411	5.130	3.668	0.294

TABLE C1. Hospital-specific OLS estimates and standard errors (cont.)

b. Efficiency indicator: TEV

Hosp.	*Coefficient estimates*					*Standard errors*				
no.	CONST	BEDS	BUD	ABF	LONG	CONST	BEDS	BUD	ABF	LONG
1	65.103	0.632	8.572	2.977	0.282	16.269	3.155	11.690	6.124	0.311
2	72.822	10.344	2.517	-1.335	-0.030	53.826	74.546	12.714	5.378	0.149
3	82.950	11.460	-2.491	3.424	-0.987	39.536	21.696	12.479	6.540	0.765
4	91.315	-18.122	-1.525	4.874	0.955	60.036	24.216	14.175	4.799	0.322
5	224.311	-190.793	-9.940	10.883	0.457	77.315	113.037	22.384	7.039	0.602
6	139.955	-11.423	-3.523	2.378	-0.425	112.758	41.448	9.369	5.425	0.194
7	172.461	-62.240	-17.683	22.842	0.071	142.539	136.798	17.027	19.247	1.049
8	5.501	37.812	25.907	-5.214	0.400	49.330	52.998	10.846	5.105	0.285
9	132.893	-4.472	-5.421	6.759	0.151	46.117	2.567	10.758	4.969	0.280
10	59.801	12.960	-12.438	19.430	0.229	48.804	29.943	6.949	4.920	0.112
11	146.321	-2.474	-19.514	24.343	-0.971	121.836	9.418	26.622	10.268	1.158
12	135.177	-29.931	-11.645	8.941	0.333	43.659	18.328	9.788	5.456	0.757
13	-83.759	44.788	22.883	0.922	1.103	72.261	22.586	11.147	3.382	0.423
14	51.813	15.045	6.973	13.852	0.218	43.631	61.815	9.815	5.732	0.430
15	45.067	-4.067	22.291	-1.297	0.210	22.819	8.865	9.093	4.848	0.274
16	53.828	-7.784	14.951	-11.901	1.582	60.425	8.907	8.207	5.348	0.632
17	88.083	3.802	-2.344	5.432	-0.501	24.731	1.134	6.740	3.036	0.558
18	147.715	22.992	-55.364	42.520	-2.087	60.377	17.701	23.608	15.001	1.024
19	5.629	19.253	28.162	-3.827	0.582	84.678	105.168	11.354	5.251	0.265
20	-5.853	4.873	20.290	-12.204	0.229	110.739	9.165	20.714	19.373	1.455
21	67.662	-3.660	15.479	-2.248	0.157	69.667	5.230	14.392	9.459	0.290
22	10.420	5.799	15.242	-0.871	0.269	15.444	1.693	4.346	1.932	0.054
23	57.986	-5.171	9.815	0.109	0.119	70.850	26.043	13.498	4.625	0.105
24	187.763	-172.275	-6.395	-1.427	-0.060	30.185	55.249	5.980	7.010	0.526
25	5.989	138.989	17.374	5.356	0.082	50.483	110.525	12.623	4.986	0.072
26	37.133	2.425	35.580	-13.577	-0.901	71.913	16.597	12.420	6.112	0.425
27	211.673	-128.301	-19.561	11.552	0.175	440.895	463.764	51.686	18.725	0.556
28	-3.034	123.470	17.301	4.579	-0.156	94.584	169.616	21.098	8.546	0.268
29	157.952	-85.852	-8.888	-3.445	-0.206	48.672	38.469	13.675	5.702	0.281
30	51.094	15.020	7.164	-9.025	-0.626	38.987	6.668	9.404	3.179	0.204
31	-49.888	68.216	47.575	-0.453	0.044	47.473	49.679	17.791	6.316	0.175
32	-178.658	243.147	67.201	-3.606	0.459	73.261	84.786	16.897	3.464	0.115
33	32.784	40.460	8.309	-0.363	-0.203	48.246	36.941	13.200	3.719	0.216
34	126.582	-23.177	-14.219	2.005	-0.507	64.543	35.454	15.098	7.967	0.376
35	174.028	-24.515	-8.426	-0.800	-0.550	33.908	11.496	9.352	5.126	0.261
36	150.819	-88.846	1.998	2.343	-0.171	54.480	58.170	29.770	19.806	0.524
37	95.393	7.145	-5.495	2.575	-0.590	77.651	21.494	7.907	3.502	0.176
38	202.038	-26.338	-26.442	10.901	-0.050	162.595	34.262	35.388	7.771	0.776
39	123.274	0.633	-8.539	-0.183	-0.261	35.819	5.598	4.453	2.295	0.224
40	-234.410	272.894	55.529	-8.744	1.793	116.223	169.098	19.255	20.584	0.861
41	-2.422	55.985	15.344	-4.420	0.733	43.660	30.540	11.592	4.430	0.358
42	240.786	-167.347	-33.320	-2.415	-1.470	64.688	67.855	17.038	2.255	0.385
43	-57.153	60.958	27.482	-1.312	0.321	85.521	34.182	25.812	9.471	0.189
44	52.472	6.291	-14.666	15.475	0.139	39.863	3.426	7.636	3.948	0.284
45	2.848	81.506	21.649	4.214	0.730	31.212	37.106	9.237	4.149	0.380
46	121.947	-57.800	-7.324	6.284	0.123	37.795	53.488	7.714	3.124	0.247
47	17.461	21.295	-7.733	26.186	1.293	24.101	8.298	12.482	8.925	0.714

TABLE C1. Hospital-specific OLS estimates and standard errors (cont.)

c. Efficiency indicator: CEC

Hosp.	*Coefficient estimates*					*Standard errors*				
no.	CONST	BEDS	BUD	ABF	LONG	CONST	BEDS	BUD	ABF	LONG
1	107.071	-2.300	-7.644	5.842	-0.359	20.780	4.030	14.932	7.822	0.397
2	74.571	1.689	0.843	-8.042	0.014	83.127	115.126	19.634	8.305	0.229
3	105.086	-14.837	-7.836	-4.381	0.149	17.213	9.446	5.433	2.847	0.333
4	181.215	-22.220	-30.614	7.029	0.132	38.904	15.692	9.185	3.110	0.208
5	159.392	-53.731	-19.703	6.263	-0.411	33.447	48.901	9.683	3.045	0.260
6	155.856	-11.222	-21.824	5.656	-0.147	63.396	23.303	5.267	3.050	0.109
7	168.069	-53.051	-22.157	11.804	0.441	66.434	63.759	7.936	8.971	0.489
8	87.082	3.294	-2.074	-5.342	-0.016	23.011	24.722	5.059	2.381	0.133
9	132.226	-5.188	-5.818	5.541	0.145	42.455	2.363	9.904	4.575	0.258
10	89.691	-19.520	-0.019	3.440	0.021	34.081	20.910	4.853	3.436	0.078
11	134.867	1.446	-23.067	10.463	-0.391	98.998	7.652	21.632	8.343	0.941
12	211.542	-56.131	-27.283	7.879	-0.621	31.175	13.088	6.989	3.896	0.540
13	146.619	-13.381	-18.975	-0.748	-0.257	70.182	21.937	10.827	3.285	0.411
14	137.485	-72.627	-16.630	11.633	0.016	44.377	62.872	9.983	5.830	0.438
15	115.627	-7.999	-12.917	-0.169	0.243	10.343	4.018	4.122	2.198	0.124
16	200.753	-17.752	-19.058	1.475	-0.333	107.727	15.880	14.632	9.534	1.127
17	135.130	-0.461	-21.383	7.467	-0.525	20.938	0.960	5.706	2.570	0.473
18	121.068	3.889	-23.998	5.506	-0.433	35.207	10.322	13.766	8.747	0.597
19	130.686	-90.178	13.152	-4.891	0.356	78.933	98.032	10.583	4.894	0.247
20	78.991	-1.295	-6.256	3.959	0.570	49.632	4.108	9.284	8.683	0.652
21	133.951	-3.685	-12.932	6.552	0.051	21.091	1.583	4.357	2.864	0.088
22	73.930	-0.969	-1.202	-0.560	0.142	34.713	3.806	9.769	4.342	0.121
23	113.334	-19.804	-3.345	-6.358	0.061	50.818	18.679	9.682	3.317	0.075
24	173.618	-112.342	-15.915	-1.220	-0.296	36.911	67.560	7.313	8.572	0.643
25	-5.048	183.799	7.610	5.438	0.099	51.587	112.941	12.899	5.095	0.074
26	95.563	-7.736	15.443	-15.171	-0.692	64.329	14.847	11.111	5.468	0.380
27	354.943	-262.715	-39.620	8.170	0.109	254.645	267.854	29.852	10.815	0.321
28	83.715	-49.800	3.418	14.226	-0.290	78.547	140.856	17.520	7.097	0.223
29	140.070	-35.388	-17.520	-3.173	-0.248	43.911	34.706	12.337	5.144	0.253
30	194.346	-17.202	-32.100	4.904	0.125	32.363	5.535	7.806	2.639	0.170
31	123.938	-35.805	-9.065	0.979	0.003	31.334	32.789	11.743	4.169	0.116
32	-69.212	155.415	30.721	-0.209	0.326	78.620	90.988	18.133	3.717	0.123
33	113.253	-16.602	-14.857	2.934	-0.306	49.658	38.022	13.586	3.828	0.223
34	119.640	-22.615	-13.545	-1.319	-0.251	27.616	15.170	6.460	3.409	0.161
35	148.054	-16.294	-14.758	3.985	-0.096	14.170	4.804	3.908	2.142	0.109
36	134.436	7.404	-33.789	9.646	-0.378	36.881	39.379	20.153	13.408	0.355
37	123.410	13.808	-31.590	5.272	-0.933	96.375	26.677	9.813	4.346	0.218
38	132.706	-12.096	-13.300	5.411	0.066	100.427	21.162	21.858	4.800	0.479
39	148.665	-3.402	-21.810	4.314	-0.083	38.630	6.038	4.803	2.476	0.242
40	-126.768	195.173	37.461	-4.946	0.584	87.634	127.502	14.519	15.520	0.649
41	122.658	-29.253	-10.223	-0.601	0.296	57.684	40.349	15.316	5.853	0.472
42	317.452	-244.857	-60.155	-4.918	-1.339	54.780	57.463	14.428	1.910	0.326
43	146.498	-15.408	-22.651	0.068	-0.010	57.941	23.159	17.488	6.416	0.128
44	175.214	-6.845	-10.942	6.385	-0.032	38.331	3.294	7.343	3.796	0.273
45	56.600	38.560	1.446	3.807	0.127	25.412	30.211	7.521	3.378	0.310
46	159.224	-93.583	-20.279	2.466	-0.147	42.091	59.568	8.591	3.479	0.275
47	97.917	-2.733	-7.495	-1.665	-0.224	8.615	2.966	4.462	3.190	0.255

TABLE C1. Hospital-specific OLS estimates and standard errors (cont.)

d. Efficiency indicator: TEC

Hosp.	*Coefficient estimates*					*Standard errors*				
no.	CONST	BEDS	BUD	ABF	LONG	CONST	BEDS	BUD	ABF	LONG
1	72.760	-3.714	8.616	4.336	0.048	16.289	3.159	11.704	6.132	0.311
2	61.304	12.840	6.407	-6.211	-0.050	67.921	94.066	16.043	6.786	0.187
3	70.945	9.522	2.266	-1.239	-0.661	30.570	16.776	9.649	5.057	0.592
4	120.535	-15.965	-12.636	6.358	0.484	56.939	22.967	13.444	4.552	0.305
5	232.604	-201.484	-11.476	10.824	0.540	77.142	112.783	22.334	7.024	0.601
6	150.239	-18.957	-3.373	6.116	-0.380	91.457	33.618	7.599	4.400	0.158
7	120.121	-19.809	-10.315	14.248	-0.175	110.555	106.103	13.206	14.928	0.814
8	8.427	39.635	21.131	-4.032	0.402	52.150	56.027	11.466	5.397	0.302
9	152.657	-5.719	-21.593	12.483	0.203	47.426	2.640	11.063	5.110	0.288
10	68.106	4.782	-11.339	13.405	0.211	50.037	30.699	7.124	5.044	0.115
11	31.557	7.970	-2.996	16.206	-0.018	53.345	4.123	11.656	4.496	0.507
12	83.741	-7.851	-0.666	5.092	0.167	32.842	13.787	7.363	4.104	0.569
13	-33.917	27.514	14.662	-0.045	0.865	57.511	17.976	8.872	2.692	0.337
14	44.744	18.554	8.668	13.868	0.287	45.426	64.357	10.219	5.968	0.448
15	52.964	-13.885	24.233	0.470	0.175	25.937	10.077	10.336	5.511	0.311
16	35.900	-1.003	7.139	-3.309	1.271	44.364	6.540	6.026	3.926	0.464
17	112.479	0.435	-11.634	7.464	-0.467	23.179	1.063	6.317	2.845	0.523
18	53.945	23.087	-24.568	26.298	-0.896	39.837	11.679	15.576	9.898	0.676
19	6.259	25.105	24.587	-3.803	0.531	72.765	90.373	9.756	4.512	0.228
20	77.072	-1.403	0.287	0.477	-0.444	69.972	5.791	13.089	12.241	0.919
21	8.199	3.374	6.688	5.286	0.233	22.020	1.653	4.549	2.990	0.092
22	-2.028	5.051	18.363	-0.792	0.211	10.460	1.147	2.944	1.308	0.036
23	35.830	2.140	13.144	-1.272	0.095	50.511	18.567	9.623	3.297	0.075
24	190.692	-185.006	-6.220	0.006	-0.048	40.980	75.008	8.119	9.517	0.714
25	1.315	152.197	12.521	10.430	0.029	87.827	192.285	21.960	8.674	0.125
26	-4.073	15.737	28.589	-12.170	-0.802	49.087	11.329	8.478	4.172	0.290
27	219.855	-137.676	-20.006	11.150	0.154	432.287	454.710	50.677	18.359	0.545
28	-31.232	170.918	21.335	4.889	-0.146	100.497	180.218	22.416	9.081	0.285
29	161.903	-90.215	-9.062	-3.637	-0.236	50.540	39.945	14.200	5.921	0.292
30	67.336	11.189	-2.109	2.695	-0.584	45.781	7.830	11.043	3.733	0.240
31	-40.072	66.552	41.718	0.274	0.051	47.445	49.650	17.781	6.312	0.175
32	-185.403	251.659	68.061	-3.106	0.458	71.861	83.166	16.574	3.398	0.113
33	24.251	46.400	10.479	-0.068	-0.208	48.796	37.362	13.350	3.762	0.219
34	115.342	-16.648	-12.242	0.150	-0.502	63.441	34.849	14.840	7.831	0.369
35	186.003	-31.195	-10.572	1.296	-0.627	56.150	19.036	15.486	8.488	0.432
36	149.208	-84.854	-0.199	5.130	-0.188	68.795	73.454	37.593	25.011	0.662
37	47.230	30.880	-20.573	9.311	-1.080	149.006	41.246	15.173	6.720	0.338
38	139.845	-17.189	-11.361	6.878	0.063	96.539	20.343	21.012	4.614	0.461
39	56.560	-0.229	4.027	3.498	0.341	37.846	5.915	4.705	2.425	0.237
40	-259.857	288.061	61.325	-11.588	2.038	121.945	177.422	20.203	21.597	0.903
41	-7.874	60.713	16.130	-4.898	0.696	42.314	29.598	11.235	4.293	0.347
42	218.386	-149.062	-24.447	-3.029	-1.680	84.096	88.214	22.150	2.932	0.500
43	3.641	35.617	8.949	-0.079	0.244	57.790	23.098	17.443	6.400	0.128
44	34.841	3.503	3.005	10.389	0.008	73.182	6.289	14.019	7.248	0.521
45	-49.237	139.504	34.332	1.969	0.534	28.593	33.993	8.462	3.801	0.348
46	108.855	-57.730	-1.604	6.200	0.124	54.745	77.475	11.173	4.525	0.357
47	23.217	18.121	-13.850	29.843	1.557	27.745	9.553	14.369	10.274	0.822

TABLE C2. Coefficient of ABF dummy.
Ranking numbers and other supplementary statistics, by hospital

Hosp.	*Efficiency indicator: CEV*						*Efficiency indicator: TEV*					
no.	Est. coef.	Rank no.	t-value	Rank no.	Pred. coef.	Rank no.	Est. coef.	Rank no.	t-value	Rank no.	Pred. coef.	Rank no.
1	2.814	22	0.462	25	2.759	20	2.977	20	0.486	21	3.284	20
2	-8.719	46	-1.060	41	-6.906	46	-1.335	34	-0.248	34	-0.473	32
3	-7.255	44	-2.276	45	-5.546	45	3.424	19	0.524	20	3.520	18
4	8.634	7	2.216	4	6.149	8	4.874	16	1.016	15	3.176	21
5	5.727	13	1.804	9	4.852	10	10.883	10	1.546	10	9.622	9
6	1.802	25	0.502	24	1.445	24	2.378	22	0.438	22	1.640	25
7	8.934	5	1.013	14	3.789	13	22.842	4	1.187	13	13.823	5
8	-4.647	42	-1.517	44	-3.384	41	-5.214	42	-1.021	42	-4.025	43
9	4.252	18	0.633	22	3.351	15	6.759	12	1.360	12	4.797	13
10	6.418	11	2.252	3	4.366	12	19.430	5	3.949	1	14.905	4
11	14.861	1	1.621	10	8.176	4	24.343	3	2.371	6	17.973	2
12	8.027	9	1.956	8	7.297	6	8.941	11	1.639	9	7.680	10
13	-1.016	33	-0.299	35	-0.909	34	0.922	25	0.273	23	1.489	26
14	11.995	3	2.039	6	9.613	3	13.852	7	2.417	5	12.114	7
15	-3.592	39	-1.131	42	-2.902	40	-1.297	32	-0.268	35	-0.780	34
16	-0.965	32	-0.075	31	-1.877	37	-11.901	45	-2.225	46	-3.351	41
17	7.891	10	3.273	1	6.114	9	5.432	14	1.789	8	4.725	14
18	5.776	12	0.682	21	2.966	17	42.520	1	2.835	4	20.799	1
19	-2.106	37	-0.357	36	1.213	25	-3.827	40	-0.729	40	-1.017	35
20	-8.142	45	-0.593	39	-3.795	42	-12.204	46	-0.630	39	-6.253	44
21	8.673	6	2.428	2	6.358	7	-2.248	36	-0.238	33	-2.022	37
22	-0.948	31	-0.257	34	-0.352	33	-0.871	31	-0.451	37	1.699	24
23	-4.001	40	-1.225	43	-2.518	39	0.109	26	0.024	26	0.614	29
24	-1.447	35	-0.171	32	-0.141	31	-1.427	35	-0.204	32	-0.273	31
25	3.373	20	0.705	19	2.803	18	5.356	15	1.074	14	5.694	11
26	-18.158	47	-2.643	47	-12.480	47	-13.577	47	-2.221	45	-7.780	46
27	8.520	8	0.834	16	10.197	2	11.552	8	0.617	18	11.574	8
28	14.453	2	2.051	5	11.975	1	4.579	17	0.536	19	4.423	17
29	-3.501	38	-0.616	40	-2.076	38	-3.445	38	-0.604	38	-2.066	38
30	4.900	16	1.447	12	3.208	16	-9.025	44	-2.839	47	-7.355	45
31	2.598	23	0.701	20	1.823	22	-0.453	29	-0.072	27	-3.283	40
32	-0.240	29	-0.062	29	0.001	30	-3.606	39	-1.041	43	-2.748	39
33	3.000	21	0.744	18	2.802	19	-0.363	28	-0.098	29	0.271	30
34	0.401	27	0.096	27	0.530	2	2.005	24	0.252	24	2.168	23
35	-0.063	28	-0.047	28	-0.143	32	-0.800	30	-0.156	31	-1.903	36
36	5.561	14	0.390	26	1.742	23	2.343	23	0.118	25	3.478	19
37	4.295	17	1.086	13	3.748	14	2.575	21	0.735	17	2.679	22
38	3.644	19	0.777	17	1.094	26	10.901	9	1.403	11	5.037	12
39	2.507	24	0.972	15	1.948	21	-0.183	27	-0.080	28	1.166	27
40	-5.418	43	-0.375	37	-5.441	44	-8.744	43	-0.425	36	-13.490	47
41	-1.653	36	-0.379	38	-1.223	35	-4.420	41	-0.998	41	-3.791	42
42	-4.616	41	-2.538	46	-3.845	43	-2.415	37	-1.071	44	-0.666	33
43	-1.324	34	-0.205	33	-1.403	36	-1.312	33	-0.138	30	1.072	28
44	9.800	4	1.976	7	7.653	5	15.475	6	3.920	2	12.238	6
45	5.328	15	1.534	11	4.665	11	4.214	18	1.016	16	4.430	16
46	1.721	26	0.539	23	0.324	29	6.284	13	2.012	7	4.544	15
47	-0.255	30	-0.069	30	0.518	28	26.186	2	2.934	3	16.698	3

TABLE C2. Coefficient of ABF dummy (cont.)
Ranking numbers and other supplementary statistics, by hospital

Hosp.	*Efficiency indicator: CEC*						*Efficiency indicator: TEC*					
no.	Est. coef.	Rank no.	t-value	Rank no.	Pred. coef.	Rank no.	Est. coef.	Rank no.	t-value	Rank no.	Pred. coef.	Rank no.
1	5.842	13	0.747	23	5.383	8	4.336	22	0.707	21	4.939	16
2	-8.042	46	-0.968	41	-6.050	46	-6.211	45	-0.915	44	-4.015	45
3	-4.381	40	-1.539	43	-3.073	41	-1.239	36	-0.245	35	-0.485	39
4	7.029	9	2.260	3	5.150	11	6.358	15	1.397	13	4.813	17
5	6.263	12	2.056	4	5.324	9	10.824	9	1.541	9	9.584	8
6	5.656	14	1.854	10	4.303	16	6.116	17	1.390	14	4.254	21
7	11.804	2	1.316	13	4.972	13	14.248	4	0.954	19	9.999	7
8	-5.342	44	-2.243	45	-3.688	42	-4.032	43	-0.747	40	-2.461	43
9	5.541	15	1.211	16	4.370	15	12.483	7	2.443	6	9.189	11
10	3.440	25	1.001	20	3.062	24	13.405	6	2.657	3	10.276	6
11	10.463	4	1.254	14	6.299	5	16.206	3	3.605	1	14.090	2
12	7.879	7	2.023	5	7.357	4	5.092	20	1.241	17	4.724	18
13	-0.748	35	-0.228	36	-0.500	37	-0.045	32	-0.017	33	0.877	31
14	11.633	3	1.996	7	9.310	3	13.868	5	2.324	7	11.625	4
15	-0.169	31	-0.077	32	0.051	31	0.470	28	0.085	27	1.060	30
16	1.475	28	0.155	29	-0.134	33	-3.309	40	-0.843	41	4.107	22
17	7.467	8	2.905	1	5.740	6	7.464	13	2.623	5	6.370	14
18	5.506	16	0.629	26	1.969	26	26.298	2	2.657	4	11.631	3
19	-4.891	41	-0.999	42	-0.477	36	-3.803	42	-0.843	42	-0.240	36
20	3.959	23	0.456	27	4.241	17	0.477	27	0.039	29	1.751	28
21	6.552	10	2.288	2	5.191	10	5.286	18	1.768	8	6.406	13
22	-0.560	33	-0.129	34	0.729	28	-0.792	35	-0.606	38	2.603	27
23	-6.358	45	-1.917	44	-4.310	44	-1.272	37	-0.386	36	-0.105	35
24	-1.220	36	-0.142	35	0.001	32	0.006	31	0.001	31	1.198	29
25	5.438	17	1.067	19	4.786	14	10.430	10	1.202	18	9.390	9
26	-15.171	47	-2.775	47	-10.032	47	-12.170	47	-2.917	47	-5.609	46
27	8.170	6	0.755	22	9.346	2	11.150	8	0.607	22	10.959	5
28	14.226	1	2.004	6	11.444	1	4.889	21	0.538	23	4.293	19
29	-3.173	39	-0.617	40	-1.957	40	-3.637	41	-0.614	39	-1.576	40
30	4.904	20	1.859	9	3.314	22	2.695	24	0.722	20	2.604	26
31	0.979	29	0.235	28	0.750	27	0.274	29	0.043	28	-2.132	42
32	-0.209	32	-0.056	31	0.092	30	-3.106	39	-0.914	43	-1.939	41
33	2.934	26	0.766	21	2.781	25	-0.068	33	-0.018	34	0.677	33
34	-1.319	37	-0.387	38	-0.582	38	0.150	30	0.019	30	0.605	34
35	3.985	22	1.860	8	3.191	23	1.296	26	0.153	26	-0.307	37
36	9.646	5	0.719	24	4.062	19	5.130	19	0.205	25	5.105	15
37	5.272	19	1.213	15	5.021	12	9.311	12	1.386	15	9.369	10
38	5.411	18	1.127	17	4.172	18	6.878	14	1.491	10	3.908	23
39	4.314	21	1.743	11	3.818	20	3.498	23	1.442	11	3.145	24
40	-4.946	43	-0.319	37	-4.795	45	-11.588	46	-0.537	37	-10.375	47
41	-0.601	34	-0.103	33	-0.233	34	-4.898	44	-1.141	46	-3.133	44
42	-4.918	42	-2.575	46	-3.803	43	-3.029	38	-1.033	45	-0.397	38
43	0.068	30	0.011	30	-0.594	39	-0.079	34	-0.012	32	0.742	32
44	6.385	11	1.682	12	5.420	7	10.389	11	1.433	12	8.893	12
45	3.807	24	1.127	18	3.584	21	1.969	25	0.518	24	2.817	25
46	2.466	27	0.709	25	0.673	29	6.200	16	1.370	16	4.285	20
47	-1.665	38	-0.522	39	-0.235	35	29.843	1	2.905	2	18.097	1