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Cost efficiency of Japanese municipal hospitals: Three-component input distance error model

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Abstract

The aim of this paper is to analyze the allocative and technical inefficiency of the municipal hospitals in Japan by estimating the input distance function system. To capture the unobserved heterogeniety across the hospitals in relatively short panel data, this paper applies three-component error model. The result shows that technical inefficiency in unprofitable area is 6.5%, which implies elimination of technical inefficiency is quite small relative to the hospital's budget and physicians' shortage in rural area in Japan. Analysis of allocative ineeficiency reveals the overuse of capital equipments and the underuse of nursing labor power. These results are consistent with the non-cost-minimizing behavior model of hospitals.

Keywords: Hospital cost, input distance function, allocative inefficiency, technical inefficiency.

JEL Classifications: I11, C10

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1 Introduction

In this paper we analyze the technical and allocative inefficiency of public hospitals in Japan by means of estimating the input distance function. There has been a lot of literature on the analysis of the hospital cost inefficiency, such as (Ros01), (BE04), and (HPR02). Most of these recent researches employ either the stochastic cost frontier (SCF) approach, or the data envelopment analysis (DEA) approach applied to the input distance function. One of the characteristic features of the former is that it produces a direct estimate of hospital cost inefficiency index which is a mixture of allocation and technical inefficiencies. On the other hand, the latter produces technical inefficiency index estimate, without assuming any functional form on the hospital service production technology.

These approaches have been applied to the data of Japanese hospitals by many researchers. Among others, (Nak04) reports the technical efficency of Japanese public hospitals is 90% in 2002 based on data envelopment analysis. On the stochastic cost frontier approach, (Fuj01) reports the cost inefficiency of Japanese public hospitals is at least 21.1% in 1995.

As noted earlier, the cost inefficiency is considered to be a mixture of the technical inefficiency (radial shrinkage of inputs without reducing the output), and the allocative inefficency (corresponds to the difference between the marginal rate of technical substitution and the observed relative input price). (YBV95) measures the allocative inefficency by estimating the non-minimum cost function. This approach, however, considers no explicit technical inefficiency in the hospital service production process.

On the separate estimation of technical and allocative inefficiency, (RAFBL04) recently suggest to estimate modified version of the system of the *input distance function* and the cost share functions. (RAFBL04) derive this model by assuming bureaucratic behavior principle for public hospitals, and enable us to measure allocative inefficiency as explained later. Besides this preferable aspect of the model, it also has a practical usefulness in obtaining the two inefficiency estimates: The technical inefficiency appears only in the input distance function while the allocative inefficiency appears only in the share equations, so that we can assume a fairly simple distributional structure for the two sorts of inefficiency. These characteristics make the model estimation much easier. For the Japanese data, (Fuj06) applies this method to find there was almost no technical inefficiency but some allocative inefficiency.

As a matter of econometric specification, we improved (Fuj06) in the way that we utilize the panel structure of the data by means of the method proposed by (FO99). (FO99) adds an extra disturcance term to the composite error of the (cost) function to capture the random effect.

For the source of inefficiency, it seems that we can classify most of those previous studies listed above in three categories: Over-equipped in capital inputs, failure in allocation of labor inputs, and physician-induced demand. Among those, we focus on the first two problems, both of which are uniformly illustrated within the framework of input distance function system.

This paper is organized as follows. Section 2 presents the econometric model of estimating the technical and the allocative inefficiency of the public hospitals in Japan based on (RAFBL04). Section 3 explains the data used in this study, and Section 4 reports estimation results of the input distance function and derived measure of the two inefficiency separately. In the final section we summarize our findings.

2 Model

We first specify the translog input distance function as a modified version of (Nak03):

$$
\begin{aligned}
\ln 1 = {} & \ln D(X_{ht}, Y_{ht}, Z_{ht}) \\
= {} & \alpha_0 + \sum_k \alpha_k \ln X_{htk} + \frac{1}{2} \sum_k \sum_l \beta_{kl} \ln X_{htk} \ln X_{htl} \\
& + \alpha_Y \ln Y_{ht} + \frac{1}{2} \beta_{YY} \ln Y_{ht}^2 \\
& + \sum_k \beta_{kY} \ln X_{htk} \ln Y_{ht} \\
& + \sum_k \sum_j \beta_{kj} \ln X_{htk} \ln Z_{htj} + \sum_j \beta_{Yj} \ln Y_{ht} \ln Z_{htj} \\
& + \varepsilon_{ht}.
\end{aligned}
\tag{1}
$$

The main differences between our specification and that of (Nak03) are that we focus on the medical labor inputs and that we include observable service quality variables in the input distance function. The symbols are defined as follows: The kth labor input and the output of hospital h are denoted as X_{htk} and Y_{ht} respectively. We consider that the hospital service is different across hospitals, so Z_{hj}s captures observed characteristics of the hospital services. Since the input distance function in homogeneous of degree one in inputs, we put the following restriction on the parameter: $\sum_k \alpha_k = 1$ and $\sum_l \beta_{kl} = 0$ for all k. We also put the symmetric restriction: $\beta_{kl} = \beta_{lk}$ for all k and l.

The error term ε_{ht} is decomposed into three parts following by (FO99):

$$\varepsilon_{ht} = v_{ht} + u_h + w_h. \tag{2}$$

The first term in this error decomposition equation, v_{ht}, is the usual random disturbance term, and is assumed to have $\mathrm{N}[0, (\sigma_v)^2]$. The second term, u_h, stands for the technical inefficiency of the hospital, so that u_h distributes over the range of $u_h \geq 0$. The third term w_h captures unobserved heterogeniety in hospital production. Given (X_{ht}, Y_{ht}, Z_{ht}), the value of the distance function is equal to $\exp(u_h)$, so we employ $TIE = \mathrm{E}[\exp(u_h)]$ as our technical inefficiency index.

We assume u_h has an exponential distribution of which the density is $f(u) = \exp(-u/\sigma_u)/\sigma_u$, where $\sigma_u = \mathrm{E}(u)$. By doing so, the probability density of ε_h is given by

$$f(\varepsilon) = \frac{1}{\sqrt{T}\sigma_u \sigma_v^{T-1}} \Phi\left(\sqrt{T}\frac{\bar{\varepsilon}}{\sigma_0} - \frac{\sigma_0}{\sqrt{T}\sigma_u}\right) \phi\left(\frac{\sigma_0}{\sqrt{T}\sigma_u}\right)^{-1} \exp(-\bar{\varepsilon}/\sigma_u) \prod_{t=1}^{T} \phi\left(\frac{\varepsilon_t - \bar{\varepsilon}}{\sigma_v}\right), \tag{3}$$

where $\sigma_0 = \sqrt{\sigma_v^2 + T\sigma_w^2}$, $\bar{\varepsilon} = \sum_{t=1}^{T} \varepsilon_t / T$, and ϕ and Φ are the standard normal density and ditribution functions, respectively. With this assumption, the technical inefficiency index defined above is given explicitly by $TIE = 1/(1 - \sigma_u)$.

For the cost share equations, we set up the model following (RAFBL04). The technically efficient input mix $X_{ht}^{\mathrm{T}} = (X_{ht1}^{\mathrm{T}}, \ldots, X_{htK}^{\mathrm{T}})$ is obtained by radially shrinking the observed input mix. Therefore it satisfies $X_{htk}^{\mathrm{T}} = X_{htk}/d_{ht}$ for every k, where d_{ht} is the value of the input distance function ($d_{ht} \geq 1$). It is clear that the observed cost share S_{htk} satisfies $S_{htk} = W_{htk} X_{htk} / \sum_l W_{htl} X_{htl} \equiv W_{htk} X_{htk}^{\mathrm{T}} / \sum_l W_{htl} X_{htl}^{\mathrm{T}}$, where W_{htk} is the observed price of the kth input.

When there is no allocative inefficiency (that is, there is no pricing error in determining the input mix), X_{ht}^{T} is equal to the cost minimizing input mix, $X_{ht}^* = (X_{ht1}^*, \ldots, X_{htK}^*)$, so that

$$\frac{W_{htk}X_{htk}^{\mathrm{T}}}{\sum_l W_{htl}X_{htl}^{\mathrm{T}}} = \frac{\partial \ln D(X_{ht}, Y_{ht}, Z_{ht})}{\partial \ln X_{htk}} + \varepsilon_{htk}^0, \tag{4}$$

where the random disturbance term ε_{htk}^0 has zero mean. If, on the other hand, there exists persistent allocative inefficiency, the disturbance term has non-zero mean: $\mathrm{E}(\varepsilon_{htk}^0) = \mu_k \neq 0$.

Thus, in order to capture the persistent divergence of S_{htk} (or the left hand side of (4)) from $\partial \ln D(X_{ht}, Y_{ht}, Z_{ht})/\partial \ln X_{htk}$, we employ the following equation for the observed cost share:

$$S_{htk} = \mu_k + \alpha_k + \sum_l \beta_{kl} \ln X_{htl} + \beta_{kY} \ln Y_{ht} + \sum_j \beta_{kj} \ln Z_{htj} + \varepsilon_{htk}, \tag{5}$$

for every k, where the new disturbance term ε_{htk} now has zero mean. The positive (negative) value of μ_k means the hospital uses too much (too few) X_k relative to the cost-minimizing input X_k^*, therefore implies the existence of allocative inefficiency.

We assume ε_{htk} is composed of two disturbances:

$$\varepsilon_{htk} = v_{htk} + w_{hk}, \tag{6}$$

where $v_{htk} \sim \mathrm{N}(0, \sigma_{vk}^2)$ and $w_{hk} \sim \mathrm{N}(0, \sigma_{wk}^2)$, and are independent each other. With this distributional assumption, we are able to estimate all the parameters by the maximum likelihood estimation of the system (1) and (5).

3 Data

We collected our data from *The Yearbook of Public Firms, Edition for Hospital* (*Chihou Kouei Kigyou Nenkan Byouinhen*, in Japanese), Vol. 52 through 54 , edited by the Research Association of Local Public Firm Management (*Chihou Kouei Kigyou Keiei Kenkyu Kai*, in Japanese), published by the Institute of Local Finance (*Chihou Zaimu Kyoukai*, in Japanese). It reports financial data of the public hospitals in Japan for 2004-2006 fiscal years. Throughout this period 792 public hospitals existed.

Among those, there are specific-purpose hospital such as sanitariums and mental hospitals. Following (Nak03) we excluded those hospitals and limit our sample to general hospitals in order to control the quality of hospital services.

The input factors are, the number of physicians (X_{DOC}), the number of registered nurses (X_{RNS}), the number of practical nurses (X_{PNS}), and the fixed asset per bed (X_{AST}). The output is measured by the number of beds.

As the observed quality of hospital services, we use the number of clinical examinations per 100 patients (Z_{EXM}), the number of X-ray examinations per patients (Z_{RAD}). These two variables are affected by the types of diseases the patients suffer, so they are used to control the hospital's average severeness of diseases.

The cost share of factor input (S_{htk}) are obtained by dividing the cost on the input by sum of the labor costs on those three medical labor inputs and the cost associated to holding asset. The asset holding cost is calculated as the sum of depreciation cost, bond interest payment, bond issueing cost, and deplition const.

The data sources report each hospital was located either in the profitable area (mainly urban area) or in the unprofitable area (mainly rural area). It is natural to assume the inefficiency is affected by the hospital location, hence we estimate our model for each of the location groups. The final sample sizes are 123 for unprofitable area group, and 526 for the profitable area group.

Table 1 shows the descriptive statistics for each location group. The number of beds differs greatly between the two area groups: Hospitals in profitable areas have five times beds than those in unprofitable areas when compared at the mean of each sample. The numbers of clinical and X-ray examinations, both of which can be interpreted as indices of patients' average severeness of diseases, are about 1.75 and 2.24 times larger in the profitable areas than the corresponding values in the unprofitable areas. In spite of the large differences in scale and content of medical services between the two area groups, the value of medical equipments per bed differs only 1.7%. This can be interpreted as one of the characteristic results of national health policy in Japan so far placing importance on equity in regional hospital service provision.

In estimating our equations, all the right-hand side variables are divided by their

Definition	Unrofitable Area		Profitable Area	
	Mean	Std. Dev.	Mean	Std. Dev.
Number of physicians (X_{DOC})	3.664	1.449	32.165	26.946
Number of registered nurses (X_{RNS})	15.599	8.755	165.478	130.194
Number of practical nurses (X_{PNS})	8.295	3.833	13.062	10.870
Fixed asset (thousand yen per bed) (X_{AST})	18454.444	31180.679	18772.247	12988.740
Number of beds (Y)	61.753	20.689	305.337	184.971
Number of clinical examinations per 100 patients per day (Z_{EXM})	172.881	96.706	302.404	169.150
Number of X-ray examinations per 100 patients per day (Z_{RAD})	12.595	9.098	28.331	82.055
Sample size		123		526

Table 1: Definition and Descriptive Statistics of Variables

sample mean before taken logarithms.

4 Empirical Results

We estimated equations (1) and (5) by the maximum likelihood estimation method. The results are presented in Tables 2. We present the results for the conventional panel frontier model in which there is no systematic differences in unobserved hospital quality (hospital-specific effects w_h and w_{hk}s) as well, for comparison, by putting $\sigma_w = \sigma_{w,DOC} = \sigma_{w,RNS} = \sigma_{w,AST} = 0$. All of the estimates are correctly signed.

Location	Unprofitable Area		Profitable Area	
Hospital specific effect	Yes	No	Yes	No
Parameter	Estimate	Estimate	Estimate	Estimate
α_0	0.480	0.590**	−0.065***	−0.220***
	(0.399)	(0.235)	(0.017)	(0.006)
α_{DOC}	0.198***	0.203***	0.036***	0.036***
	(0.039)	(0.028)	(0.009)	(0.009)
α_{RNS}	0.629***	0.622***	0.795***	0.754***
	(0.040)	(0.026)	(0.011)	(0.010)
α_{AST}	0.003	0.038	0.032***	0.039***
	(0.052)	(0.027)	(0.007)	(0.005)
α_Y	−1.048**	−0.378	−1.052***	−0.967***
	(0.410)	(0.252)	(0.018)	(0.009)
α_{EXM}	−0.048	0.042	−0.032***	−0.049***
	(0.123)	(0.095)	(0.005)	(0.004)
α_{RAD}	−0.007	−0.160	−0.007	−0.011**
	(0.208)	(0.226)	(0.005)	(0.005)
$\beta_{DOC,DOC}$	0.114***	0.113***	0.123***	0.125***
	(0.006)	(0.005)	(0.002)	(0.002)
$\beta_{DOC,RNS}$	−0.070***	−0.078***	−0.091***	−0.095***
	(0.004)	(0.003)	(0.002)	(0.001)
$\beta_{DOC,AST}$	−0.021***	−0.021***	−0.022***	−0.027***
	(0.005)	(0.003)	(0.001)	(0.001)
$\beta_{DOC,Y}$	−0.027	−0.026***	−0.035***	−0.034***
	(0.018)	(0.007)	(0.002)	(0.001)
$\beta_{DOC,EXM}$	−0.010	−0.007**	0.001	0.002*
	(0.006)	(0.003)	(0.001)	(0.001)
$\beta_{DOC,RAD}$	−0.002	−0.009*	0.000	0.005***
	(0.008)	(0.005)	(0.001)	(0.001)
$\beta_{RNS,RNS}$	0.148***	0.176***	0.160***	0.198***
	(0.006)	(0.004)	(0.003)	(0.002)
$\beta_{RNS,AST}$	−0.016***	−0.038***	−0.050***	−0.079***
	(0.004)	(0.002)	(0.001)	(0.001)
$\beta_{RNS,Y}$	−0.004	−0.043***	−0.031***	−0.067***
	(0.020)	(0.009)	(0.004)	(0.002)
$\beta_{RNS,EXM}$	−0.003	−0.005	−0.003	0.000
	(0.006)	(0.005)	(0.002)	(0.001)
$\beta_{RNS,RAD}$	0.007	−0.007	−0.004***	−0.013***
	(0.007)	(0.004)	(0.001)	(0.001)
$\beta_{AST,AST}$	0.055***	0.089***	0.082***	0.116***
	(0.006)	(0.003)	(0.002)	(0.001)
$\beta_{AST,Y}$	0.067*	0.103***	0.086***	0.128***
	(0.036)	(0.017)	(0.003)	(0.002)
$\beta_{AST,EXM}$	0.013	0.012	0.003	−0.003**
	(0.009)	(0.008)	(0.002)	(0.001)
$\beta_{AST,RAD}$	0.002	0.025**	0.006***	0.013***
	(0.016)	(0.010)	(0.001)	(0.001)
$\beta_{Y,Y}$	−0.249	0.262	0.012	0.067***
	(0.275)	(0.178)	(0.022)	(0.016)
$\beta_{Y,EXM}$	−0.031	0.003	−0.011	−0.005
	(0.078)	(0.063)	(0.013)	(0.012)
$\beta_{Y,RAD}$	0.000	−0.064	−0.010*	0.005
	(0.133)	(0.144)	(0.005)	(0.005)

(continues to the next page.)

Location	Unprofitable Area		Profitable Area	
Hospital specific effect	Yes	No	Yes	No
Parameter	Estimate	Estimate	Estimate	Estimate
σ_v	0.075***	0.083***	0.064***	0.076***
	(0.003)	(0.003)	(0.001)	(0.001)
$\sigma_{v,DOC}$	0.022***	0.042***	0.013***	0.032***
	(0.001)	(0.001)	(0.000)	(0.000)
$\sigma_{v,RNS}$	0.021***	0.043***	0.018***	0.049***
	(0.001)	(0.001)	(0.000)	(0.001)
$\sigma_{v,AST}$	0.038***	0.072***	0.028***	0.064***
	(0.002)	(0.002)	(0.000)	(0.001)
σ_w	0.237***		0.143***	
	(0.074)		(0.007)	
$\sigma_{w,DOC}$	0.037***		0.031***	
	(0.003)		(0.001)	
$\sigma_{w,RNS}$	0.043***		0.051***	
	(0.005)		(0.002)	
$\sigma_{w,AST}$	0.069***		0.061***	
	(0.007)		(0.003)	
μ_{DOC}	0.074***	0.050**	0.194***	0.197***
	(0.028)	(0.023)	(0.009)	(0.009)
μ_{RNS}	−0.169***	−0.190***	−0.342***	−0.309***
	(0.030)	(0.024)	(0.013)	(0.010)
μ_{AST}	0.268***	0.258***	0.213***	0.212***
	(0.026)	(0.011)	(0.010)	(0.005)
TIE	1.065***	1.747***	1.189***	1.433***
	(0.374)	(0.260)	(0.024)	(0.050)
Log likelihood	2236.490	1903.080	11012.000	8764.730
Number of Observation	123	123	526	526

Note: ***, **, * indicate $p < 0.01$, $p < 0.05$, and $p < 0.10$, respectively. Standard errors in parentheses.

Table 2: Maximum Likelihood Estimation of Input Distance Function and Cost Share Equations

The comparison of models with and without hospital-specific effects reveals that the computed technical inefficiency reduces greatly if we consider the presence of hospital-specific effect. In unprofitable area, the computed amount of cost associated to the technical inefficiency becomes eleven times larger if we do not take into account the hospital-specific effect. This is consistent with the large standard deviations of hospital-specific errors (w, w_ks): They are more than twice as large as those of v and v_ks. Therefore the error decomposition model (2) and 5 well capture the unobserved service hetergeniety across the hospitals in our relatively short panels.

The estimated technical inefficiency index, TIE, of unprofitable area group is lower than that of profitable area group: The amount of cost that can be saved by eliminating technical inefficiency (which possibly causes reduction in quality) is only 6.5% in the former group and 19% in the latter group. In this sense, the input scale in unprofitable area is closer to the efficient level than in profitable area. [1] The difference between the intercept estimates for two areas might be partly explained by the difference in the operation scales.

On the allocative inefficiency, in both areas, the parameters μ_{DOC} and μ_{AST} are significantly positive while μ_{RNS} is significantly negative. Since $\mu_{RNS}, \mu_{PNS} < 0 < \mu_{DOC} < \mu_{AST}$ holds in both areas, it should be interpreted that the hospitals spend too much on fixed asset and too little on nursing labors in terms of cost minimization. As (RAL04) point out, it is natural to assume public hospitals to have non-cost minimizing behavior principle, such as preference not only on the cost or profit but also on the combination of input mix and output. Our estimate of the allocative inefficiency parameters are thus consistent with non-cost minimizing behavior rather than the simple cost-minimizing behavior. It also suggests the public hospitals may have stronger preference on the real asset (medical equipments or buildings) than on nursing in Japan.

[1] This result for unprofitable area is similar to (Nak03)'s DEA result, which reports the average technical efficiency (inverse of technical inefficiency) is 0.889.

5 Concluding Remarks

In this paper we considered input distance function of the public hospitals in Japan as well as the cost share functions derived from it, inspired by (RAFBL04). We estimated those as a system equations and obtained technical and allocative ineffiency measure. The main results are (i) the computed technical inefficiency gets much larger if we do not control the unobserved heterogeniety across the public hospitals even in the short panel. (FO99)'s three-component error model which was developed for cost frontier model plays good role in the analysis of technical inefficiency using input distance function system; (ii) the estimated technical inefficiency is 6.5% in the unprofitable area sample. The input scale may not be reduced without damaging quality given the alleged lack of physicians in rural areas in Japan; (iii) the pattern of allocative inefficiency shows underuse of nursing labors and overuse of assets like medical equipments and buildings.

The future research may include developing hospital utility model that coincides with the pattern of allocative inefficiency presented in this paper. The balanced budget behavior and subsidy financed investment on fixed asset would be an important view.

Finally, relaxing the assumption on the technical inefficiency distribution is yet important. Though the operation scales are quite different between the unprofitable and profitable area group, the big difference between the intercept estimates of the two samples implies alternative assumptions like truncated normal may fit well the data, hereby bring more reasonable difference between the estimates of intercepts and technical inefficiencies.

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