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Determinants and Probability Distribution of Inefficiency in the Stochastic Cost Frontier of Japanese Hospitals

by

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Abstract

The purpose of this paper is to estimate the cost inefficiency of Japanese municipal hospitals using the stochastic cost frontier approach. We assumed the hospital cost inefficiency has a truncated normal distribution in order to avoid the restrictive feature of the half-normal distribution. A model of hospital cost inefficiency in which the inefficiency is a function of some explanatory variables was defined. The stochastic cost frontier and the inefficiency model were estimated simultaneously. The result tells that the half-normal distribution is not appropriate for the inefficiency distribution of municipal hospitals in Japan. It is also found i) that the level of cost inefficiency is related to the government subsidy and the geographical location of the hospital; ii) that, when compared to the truncated normal cost inefficiency model, the half-normal model underestimates the marginal costs while it overestimates the cost inefficiency.

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I. Introduction

The objective of this paper is to analyze the degree and the determinants of the cost inefficiency of the municipal hospitals in Japan using the framework of the stochastic cost frontier (SCF) estimation method initiated by Aigner, Lovell and Schmidt (1977).

We have many previous works that utilized the SCF estimation to analyze the level and the determinants of the hospital cost inefficiency: Yamada, Yamada, Kim and Noguchi (1997, abbreviated as YYKN hereafter) analyzed the data of the municipal hospitals in Japan of 1993 fiscal year using the half-normal stochastic cost frontier; for researches based on non-Japanese data, there are Wagstaff(1989), Wagstaff and López (1996), and Zuckerman, Hadley and Iezzoni (1994). This paper makes certain improvements over these previous studies in the estimation of the SCF and in analyzing the factors of the cost inefficiency, as described below.

Those previous studies have assumed that the distribution of the cost inefficiency of the hospitals is a non-negative half-normal distribution.[1] In terms of the SCF estimation, this assumption has an advantage that it makes the likelihood function of the SCF simpler. At the cost of simplicity, however, it limits the probability distribution of the cost inefficiency to be such that the mode of the distribution is always zero and that there are greater number of hospitals that are relatively more efficient than those less efficient. There have been invented several ways to go beyond the restriction imposed by adopting a half-normal distribution for the distribution of inefficiency in econometrics.[2] Among others, in this paper we adopt the truncated normal distribution as a distribution of the cost inefficiency of the hospital.[3] It allows the mode of the distribution of the cost inefficiency of the hospitals to be any non-negative value by adding small modification to the half-normal SCF model. Thus it inclueds the half-normal distribution as a special case. With this distribution, we are able to investigate the cost inefficiency of the hospitals and analyze the determinants of the inefficiency under more general condition, and also able to test statistically the often used hypothesis that the cost inefficiency of the hospitals has the half-normal distribution.

Let us note another problem that the previous studies of the hospital cost inefficiency have involved: In analyzing the determinants of the cost inefficiency of hospitals, they estimated the SCF and obtain the estimates of the cost inefficiency of individual hospitals under the assumption that these individual cost inefficiencies are identically distributed, then at the second stage they provided models that explain the estimated cost inefficiency by other explanatory variables. As Battese and Coelli (1995) state in terms of technical inefficiency in the stochastic production function estimation, the model presented at the second stage may contradict the assumption of identical distribution of the cost inefficiency made at the first stage.

As they proposed, one can avoid this problem by estimating the stochastic production frontier and the equation that explains technical inefficiency simultaneously. In this paper we apply this method to the analysis of the determinants of the cost inefficiency of the municipal hospitals.

This paper is organized as follows: Section 2 presents the simultaneous estimation model of the SCF and the cost inefficiency equation. Section 3 explains briefly the data used in this paper. In Section 4 we report and interpret the parameter estimates of the model.

II. Model

As will be noted later, we observed the financial data of Japanese municipal hospitals for three fiscal years, from 1993 to 1995. We treat this data as a set of cross-sction data rather than treating as a single panel data, mainly because the data is short in the length of time periods. Hence, in this section, we develop the cross-sectional model of the SCF of individual municipal hospitals.

Our model of the individual hospital's cost and inefficiency is a stochastic frontier version of Battese and Coelli (1995).[4] The model is written as:

$$\begin{aligned} \log C_i &= \alpha_0 + \sum_{j}^{2} \alpha_j \log P_{ji} + \sum_{k}^{3} \beta_{1k} (Y_{1i})^k + \sum_{k}^{3} \beta_{2k} (Y_{2i})^k \\ &\quad + \sum_{m}^{M} \gamma_m \omega_{mi} + V_i + U_i, \qquad (1) \\ U_i &= Z_i \cdot \delta + W_i. \qquad (2) \end{aligned}$$

for the ith hospital ($i = 1, \ldots, N$).

Equation (1) is the long-run stochastic hospital cost frontier equation. C_i denotes the observed total cost of the hospital. We have two input prices: Wage rate, P_{1i}, and interest rate, P_{2i}.[5] Y_{1i} and Y_{2i} are, respectively, the number of inpatients and outpatients per day at the hospital, which measure the quantity aspects of the hospital outputs. Equation (1) has also the squared, and the cubed terms of the two variables as well. The functional form is essentially same as the one originally proposed by Grannemann, Brown and Pauly (1986), though our specification is relatively simpler in the sense that Equation (1) does not have the cross terms between the outputs (Y_{1i} and Y_{2i}).

We include the variables associated with the hospital characteristics and the quality of hospital services in Equation (1) as ω_{mi}'s, such as the number of clinical examinations per 100 patients (EXM), teaching hospital dummy ($TEACH$), the number of emergency beds ($NEMRG$), general hospital dummy (GEN), and the nursing standard dummy ($NSTD$). We can also add the bed standard dummy ($BSTD$) and the meal standard dummy ($MSTD$) to ω_{mi}'s in 1993 because of the availability of the data (hence $M = 7$ in 1993, $M = 5$ in 1994 and in 1995). V_i is a random variable that determines the position of the cost frontier of the ith hospital, so that it reflects the difference of the production technology among the hospitals. We assume V_i's ($i = 1, \ldots, N$) have i.i.d. normal distribution, $N(0, \sigma_v^2)$. U_i, is a non-negative random variable, associated with the cost inefficiency of the ith hospital, and its distributional assumption is explained below.

Equation (2) specifies the cost inefficiency of the hospital. Z_i is a vector of variables that explain the cost inefficiency of the hospital. In the choice of the variables in Z_i, we refer to the study of YYKN. We included the number of beds (BED), the number of bed squared, the inverse of bed occupancy rate (IO), the subsidy from the governmnent per patients (SUB), and the urban hospital dummy ($URBAN$).[6] [7] δ is a vector of parameters associated with the Z_i variables. W_i is a collection of the effects of other unobservable variables on U_i. We assume that W_i's and V_i's are independent.

Given Z_i, we assume that W_i is a random variable which is a truncation of the normal distribution $N(0, \sigma_w^2)$, such that the truncation point is $-Z_i \cdot \delta$ and that $W_i \geq -Z_i \cdot \delta$. Under this assumption, U_i is a non-negative truncation of the normal distribution $N(Z_i \cdot \delta, \sigma_w^2)$, and has the following density function:

$$f^{U_i}(U_i|Z_i) = \frac{1}{\sigma_w}\phi\left(\frac{U_i - Z_i \cdot \delta}{\sigma_w}\right)\Phi\left(\frac{Z_i \cdot \delta}{\sigma_w}\right)^{-1} \qquad (U_i \geq 0), \tag{3}$$

where ϕ and Φ are, respectively, the standard normal density and distribution functions. The distribution of U_i in our model is therefore not necessarily identical for all hospitals because each hospital has different value of Z_i and so different density of U_i. As suggested in Battese and Coelli (1995), we include a unit constant ($CONST$) in Z_i to avoid unnecessary restriction on our model.

Hence, if the coefficients of all non-constant variables in Z_i are zero, the distribution of U_i is identical for all hospitals. If, further, all the parameters in δ are zero, the distribution reduces to a non-negative half-normal distribution which has often been assumed for U_i. In this sense, our model is so general that it includes the models of the previous hospital cost inefficiency studies as a special case.

Under the assumptions on the inefficiency equation (2) described above, the density of $\epsilon_i = U_i + V_i$ given Z_i is written as:

$$f^{\epsilon_i}(\epsilon_i|Z_i) = \frac{1}{\sigma}\phi\left(\frac{\epsilon_i - \lambda Z_i \cdot \delta^*}{\sigma}\right)\Phi\left(\frac{Z_i \cdot \delta^* + \lambda\epsilon_i}{\sigma}\right)\Phi\left(\frac{\sqrt{1+\lambda^2}Z_i \cdot \delta^*}{\sigma}\right)^{-1}, \tag{4}$$

where $\sigma = \sqrt{\sigma_w^2 + \sigma_v^2}$, $\lambda = \sigma_w/\sigma_v$, and $\delta^* = \delta/\lambda$. Using this density, we can estimate the system of equations (1) and (2) by carrying out the maximum likelihood estimation of Equation (1), since the parameters of ϵ_i includes those of Equation (2).

Finally, we define the individual cost inefficiency index for the ith hospital by the conditional mean of the ratio of the wasteful cost to the efficient cost:

$$\begin{aligned} INEF_i &= \mathrm{E}\left[\left.\frac{C_i - C_i|_{U_i=0}}{C_i|_{U_i=0}}\right| Z_i\right] \\ &= \mathrm{E}\left[\exp(U_i)|\, Z_i\right] - 1 \\ &= \Lambda\left(\frac{Z_i \cdot \delta}{\sigma_w}\right)\Lambda\left(\frac{Z_i \cdot \delta}{\sigma_w} + \sigma_w\right)^{-1} - 1, \end{aligned} \tag{5}$$

where $\Lambda(\,\cdot\,) = \phi(\,\cdot\,)/\Phi(\,\cdot\,)$. Note $INEF_i$ is always non-negative due to $U_i \geq 0$. In regard to this definition of the inefficiency index, the following interpretation of the parameter δ (or δ^*, which is different from δ in the positive scalor factor λ) is possible. The derivative of $INEF_i$ with respect to Z_i is:

$$\frac{\partial INEF_i}{\partial Z_i} = (INEF_i + 1)\left[1 + \frac{\Lambda(Z_i \cdot \delta/\sigma_w + \sigma_w) - \Lambda(Z_i \cdot \delta/\sigma_w)}{\sigma_w}\right]\delta. \qquad (6)$$

Since the part inside the brackets is positive, if an element of δ is positive (negative), then the corresponding variable in Z_i will increase (decrease) the cost inefficiency index defined by Equation (5).

For the index of the cost inefficiency of the municipal hospital industry, we take the sample means of $INEF_i$ in each year.

III. Data

All of the data used in this study are collected from *The Yearbook of Public Firms, Edition for Hospital, Vol.* 41–43 (*Chihou Kouei Kigyou Nenkan Byouinhen*, in Japanese), edited by Research Association of Local Public Firm Management (Chihou Kouei Kigyou Keiei Kenkyu Kai, in Japanese), published by Institute of Local Finance (Chihou Zaimu Kyoukai, in Japanese). It reports the financial data of all the municipal hospitals in Japan.[8] The sample periods are from 1993 to 1995 fiscal years. We exclude those hospitals which lack necessary data. Final sample sizes of each year are $N = 955$ in 1993, $N = 945$ in 1994 and $N = 954$ in 1995. The definitions of the variables and their descriptive statistics are presented in Table 1.

IV. Empirical Result

We estimated the SCF equation (1) and the inefficiency equation (2) simultaneously for each of three cross-section data by the maximum likelihood estimation method. This model is referred to as the truncated normal model hereafter. For comparison, we also estimated Equations (1) and (2) by the same method, restricting δ^*'s to be zero, which is referred to as the half-normal model hereafter. The estimation results of the two models are reported in Table 2. Based on the parameter estimates of the truncated normal model, we tested the hypothesis that all of the coefficients of Z_i variables are zero, i.e.,

$$H_0: \quad \delta^*_{CONST} = \delta^*_{BED1} = \delta^*_{BED2} = \delta^*_{IO} = \delta^*_{SUB} = \delta^*_{URBAN} = 0.$$

The Wald test statistics are given in the last row of Table 2. As a result, we strongly rejected the hypothesis for each of the three years. Therefore, the use of the truncated normal distribution instead of the half-normal distribution is suggested in our model. It is further suggested that the distribution of the hospital cost inefficiency is not identical across hospitals: Parameter estimates derived from assuming an identical distribution for the cost inefficiency may be biased.

Let us look at the estimates of δ^*'s, the coefficients of Z_i variables, in the table. In each of the three years, δ^*_{BED1} is significantly positive while δ^*_{BED2} is significantly negative. According to these estimates, the quadratic function $(\delta^*_{BED1}) \times (BED) + (\delta^*_{BED2}) \times (BED)^2$ achieves its maximum at $BED \approx 5.1$, which is less than the minimum value of BED in our sample ($BED = 20$). Therefore, the larger hospital is more cost efficient in all the region of hospital size.

The inverse of bed occupancy rate, IO, reflects how inefficiently the hospital beds are utilized. However, in the estimates of δ^*_{IO} of each year, we do not observe strong evidence that the hospitals with more vacant beds are more cost inefficient.

The urban hospital dummy, $URBAN$, has significantly positive coefficient in all years. Municipal hospitals in urban areas may put emphasis on providing more sophisticated medical services than the ones in rural areas, and thus the positive coefficient of $URBAN$ reflects this attitude of municipal hospitals.

For the effect of the subsidy from the government per patients, which is a protection for the municipal hospital, the coefficient of SUB is significantly positive for all years. Hence, greater protection causes higher cost inefficiency.

Among the estimates of the SCF parameter, γ_{EXM}, γ_{NSTD}, γ_{MSTD} and γ_{BSTD} are significantly positive in both models for all years, except for γ_{BSTD} in the half-normal model in 1993. EXM reflects the complexity of the diseases of the patient at the hospital. $NSTD$, $MSTD$ and $BSTD$ are all related to the quality of the hospital services. Therefore, the signs of these estimates are as expected.

γ_{TEACH}, the coefficient of the teaching hospital dummy, is not significant. Hence, providing nursing education in the hospitals may not cost much relative to the total cost of the hospital.

The estimates of γ_{NEMRG}, the coefficient of the number of emergency beds, are positive. We observe that they are significant in the half-normal model while they are not in the truncated normal model. This may be because the effect of $NEMRG$ is partly reflected in IO, since the emergency hospitals must have extra capacity in bed.

γ_{GEN} is the coefficient of the general hospital dummy. The truncated normal model shows significantly positive value for the parameter, while the half-normal model shows no significant signs. The general hospital must treat wide variety of disease cases, and this leads to the higher cost compared to the non-general (specific) hospitals. Hence, in this sense, the truncated normal model exhibits more plausible estimate than the half-normal model.

α_1 and α_2, the coefficiencts of the prices of labor and capital, respectively, are smaller in the truncated normal model than in the half-normal model, though these estimates are not strongly significant in the former.

As for the parameters related to the output quantities, all of the parameters (β_{1k}'s and β_{2k}'s) are statistically significant. In both models, these parameters exhibit positive signs for the linear and the cubed terms, while they are negative for the squared terms.[9] Using these estimates, the estimated marginal cost can be obtained for each of inpatient and outpatient services. The sample means and the standard deviations of the estimates are presented in Table 3. According to the table, the half-normal model shows lower marginal costs than the truncated normal model does. For the marginal cost of inpatient care, it is about 8.3%, 17%, and 1.5% lower in 1993, in 1994 and in 1995, respectively, than the corresponding estimate from the truncated normal model. As for the outpatient care, it is about 25%, 30% and 36% lower in respective years.

Finally, we examine the level of cost inefficiency. In table 4 we report the sample means and the standard deviations of the individual hospital cost inefficiency index, $INEF_i$, defined in Equation (5).

According to the result of the truncated normal model, the mean cost inefficiency is 22.2% in 1993, 18.3% in 1994 and 21.1% in 1995. Suppose the individual cost inefficiency index is 21.1% for a hospital whose annual cost is 3764 million yens (sample mean of the total cost), it means that 656 million yens out of the hospital's total cost is inefficient.

Regarding the difference between the estimate by the truncated normal model and the one by the half-normal model, the former is smaller than the latter in any of the three time periods. Most remarkably, in 1994, the difference is 41.1 percent points.

V. Conclusion

In this paper we focused on the cost inefficency of municipal hospitals in Japan. To do so, we used a truncated normal distribution as a more general probability distribution for the hospital cost inefficiency than the works done before in this area. Also, we employed the approach that estimates the SCF and the inefficiency equation simultaneously to explore the determinants of the hospital cost inefficiency. The estimation result tells us that the distribution of inefficiency is not identical, and the usual assumption of the half-normal distribution which has often been used even in the field of health economics is not appropriate, at least for the municipal hospitals in Japan.

We found in the truncated normal model that the subsidy given to the hospital by the government and the location of the hospital are the main variables related to the hospital cost inefficiency: It is shown that subsidy increases the hospital cost inefficiency, and that the hospitals located in urban areas are more inefficient than the ones in rural areas.

The estimation results from the truncated normal and the half-normal hospital cost inefficiency models revealed that both of the estimates of the inefficiency index and the marginal costs take very different values to a large degree depending on the distribution assumed: We found that the half-normal model tends to overestimate the cost inefficiency and to underestimate the marginal costs.

In the cost inefficiency model we omitted variables such as drug usage and medical manpower, though they are obviously important in the hospital production process. Hence the future research may involve in the theoretical formulation of hospital cost inefficiency using these variables.

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Notes

[1] Though not a hospital, Vitaliano and Toren (1994) tried the exponential distribution to fit the frontier model to the data of U.S. nursing homes. However, they failed in obtaining a statistically significant estimate of the parameter of the distribution.

[2] Other candidates of the probabiilty distribution of the cost inefficiency may include, for example, the gamma distribution (Greene, 1990) and the Pearson family of truncated distribution (Lee, 1983).

[3] The use of truncated normal distribution in the estimation of SCF was proposed by Stevenson (1980). As long as I know, there have been no application of the distribution to the cost inefficiency term in the hospital stochastic cost frontier analysis.

[4] Battese and Coelli (1995) built their model for use of panel data. However, the simultaneous estimation approach can be directly applied to the case of cross-sectional analysis.

[5] Though the prices of medical materials are also important in the analysis, we treat them as omitted variables because we could not obtain the data.

[6] YYKN uses many more variables as Z_i, such as the numbers of various medical staffs per 100 beds, the drug margin ratio, and the number of operations per day. We limit the number of variables in Z_i either because the data is not available or in order to complete the iterative procedure in the estimation of our model.

[7] In YYKN, the urban hospital dummy appears in the SCF equation, not in the inefficiency equation. Since it is related to the geometric location of the hospital, it should not be included in the SCF equation which indicates the production technology of thè hospital.

[8] Hence, large part of our data of 1993 may be common to those used in YYKN.

[9] YYKN reports that the cubed term of inpatients has significantly negative

coefficient in their study.

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Table 1: Definitions and Descriptive Statistics of Variables

Variable	Definition	Mean	Std. Deviation
C	Annual Total Cost (million yens)	3764.168	3711.068
P_1	Average Salary of Workers (thousand yens/month)	571.308	59.617
P_2	(Depreciation+Interest Payment)/Bookvalue	0.117	0.246
Y_1	Number of Inpatients/Day	194.272	167.968
Y_2	Number of Outpatients/Day	518.924	440.496
EXM	Number of Clinical Examinations/(100 Patients)	235.76	147.547
$TEACH$	=1 if the hospital teaches nursing students, =0 otherwise	0.071	0.257
$NEMRG$	Number of Emergency Beds	6.153	9.274
GEN	=1 if general hospital, 0 otherwise	0.95	0.218
$NSTD$	=1 if the hospital meets some standard of nursing, =0 otherwise	0.88	0.318
$MSTD$	=1 if the hospital meets some standard of meal, 0 otherwise	0.984	0.124
$BSTD$	=1 if the hospital meets some standard	0.994	0.079
	of bed, 0 otherwise		0.079
BED	Number of Beds	239.338	190.234
IO	Inverse of Bed Occupancy Rate	1.389	0.522
SUB	Subsidy by the Government/(Patients/Day) (million yens)	0.877	1.501
$URBAN$	=1 if located in an urban area, 0 otherwise	0.817	0.386

Note: The means and the standard deviations of $BSTD$ and $MSTD$ are of the 1993 fiscal year. All other statistics are of the whole sample (1993–1995 fiscal years).

Table 2: Maximum Likelihood Estimations of SCF

Year	1993			
Model	Truncated Normal		Half-Normal	
Parameter	Estimate	Std. Error	Estimate	Std. Error
α_0	$4.79E+00^{***}$	$3.49E-01$	$2.17E+00^{***}$	$3.90E-01$
α_1	$2.98E-02$	$5.51E-02$	$4.33E-01^{***}$	$5.87E-02$
α_2	$2.52E-02^{**}$	$1.19E-02$	$4.11E-02^{**}$	$1.76E-02$
β_{11}	$6.76E-03^{***}$	$3.44E-04$	$8.20E-03^{***}$	$4.29E-04$
β_{12}	$-9.31E-06^{***}$	$8.77E-07$	$-1.24E-01^{***}$	$1.15E-06$
β_{13}	$5.24E-09^{***}$	$5.93E-10$	$6.83E-09^{***}$	$7.78E-10$
β_{21}	$2.59E-03^{***}$	$1.16E-04$	$2.07E-03^{***}$	$1.54E-04$
β_{22}	$-1.56E-06^{***}$	$9.45E-08$	$-1.27E-01^{***}$	$1.46E-07$
β_{23}	$3.01E-10^{***}$	$2.13E-11$	$2.58E-10^{***}$	$3.42E-11$
γ_{EXM}	$5.05E-02^{***}$	$4.73E-03$	$1.00E-01^{***}$	$6.61E-03$
γ_{TEACH}	$-4.49E-03$	$2.59E-02$	$1.34E-02$	$3.54E-02$
γ_{NEMRG}	$9.04E-04$	$8.18E-04$	$2.40E-03^{***}$	$7.23E-04$
γ_{GEN}	$2.59E-01^{***}$	$4.18E-02$	$3.87E-02$	$4.77E-02$
γ_{NSTD}	$1.88E-01^{***}$	$1.79E-02$	$2.60E-01^{***}$	$2.38E-02$
γ_{MSTD}	$1.47E-01^{***}$	$2.71E-02$	$2.01E-01^{***}$	$5.18E-02$
γ_{BSTD}	$1.98E-01^{***}$	$4.32E-02$	$8.02E-02$	$7.68E-02$
δ^*_{CONST}	$-6.75E+00^{***}$	$1.49E+00$		
δ^*_{BED1}	$2.70E+00^{***}$	$5.86E-01$		
δ^*_{BED2}	$-2.67E-01^{***}$	$5.72E-02$		
δ^*_{IO}	$5.40E-02$	$6.71E-02$		
δ^*_{SUB}	$5.22E-01^{***}$	$9.76E-02$		
δ^*_{URBAN}	$5.21E-01^{***}$	$1.40E-01$		
$1/\sigma$	$5.32E+00^{***}$	$1.98E-01$	$2.79E+00^{***}$	$7.24E-02$
λ	$6.48E-01^{***}$	$1.22E-01$	$2.53E+00^{***}$	$2.10E-01$
Log Likelihood	340.64		38.95	
Wald	32.19^{***}			

Note: $***$:p-value < 0.01, $**$:p-value < 0.05, $*$:p-value < 0.1. The Wald test statistics has $\chi^2(6)$ under the null hypothesis that all of δ^*'s are zero.

Table 2: (Continued)

Year	1994			
Model	Truncated Normal		Half-Normal	
Parameter	Estimate	Std. Error	Estimate	Std. Error
α_0	$4.69E+00^{***}$	$3.74E-01$	$3.06E+00^{***}$	$3.50E-01$
α_1	$7.34E-02$	$5.83E-02$	$2.77E-01^{***}$	$5.56E-02$
α_2	$8.02E-03$	$8.24E-03$	$1.31E-02$	$8.05E-03$
β_{11}	$7.06E-03^{***}$	$3.05E-04$	$8.24E-03^{***}$	$4.45E-04$
β_{12}	$-1.01E-05^{***}$	$7.87E-07$	$-1.24E-05^{***}$	$1.14E-06$
β_{13}	$5.73E-09^{***}$	$5.17E-10$	$6.67E-09^{***}$	$7.48E-10$
β_{21}	$2.46E-03^{***}$	$9.91E-05$	$2.20E-03^{***}$	$1.54E-04$
β_{22}	$-1.47E-06^{***}$	$8.46E-08$	$-1.39E-06^{***}$	$1.28E-07$
β_{23}	$2.85E-10^{***}$	$1.87E-11$	$2.80E-10^{***}$	$2.76E-11$
γ_{EXM}	$8.44E-02^{***}$	$8.57E-03$	$1.46E-01^{***}$	$1.20E-02$
γ_{TEACH}	$-1.71E-02$	$2.58E-02$	$5.88E-03$	$2.91E-02$
γ_{NEMRG}	$7.89E-04$	$8.09E-04$	$1.72E-03^{***}$	$6.02E-04$
γ_{GEN}	$2.54E-01^{***}$	$4.92E-02$	$-1.51E-02$	$5.14E-02$
γ_{NSTD}	$2.06E-01^{***}$	$1.82E-02$	$3.02E-01^{***}$	$1.82E-02$
δ^*_{CONST}	$-7.98E+00^{***}$	$2.10E+00$		
δ^*_{BED1}	$3.12E+00^{***}$	$8.15E-01$		
δ^*_{BED2}	$-3.03E-01^{***}$	$7.90E-02$		
δ^*_{IO}	$1.11E-01$	$1.13E-01$		
δ^*_{SUB}	$6.72E-01^{***}$	$1.52E-01$		
δ^*_{URBAN}	$5.57E-01^{***}$	$1.75E-01$		
$1/\sigma$	$5.50E+00^{***}$	$2.39E-01$	$2.32E+00^{***}$	$6.65E-02$
λ	$5.45E-01^{***}$	$1.31E-01$	$5.93E+00^{***}$	$4.07E-01$
Log Likelihood	354.20		9.17	
Wald	20.00^{***}			

Table 2: (Continued)

Year	1995			
Model	Truncated Normal		Half-Normal	
Parameter	Estimate	Std. Error	Estimate	Std. Error
α_0	$5.13E+00^{***}$	$3.72E-01$	$2.64E+00^{***}$	$4.40E-01$
α_1	$1.10E-02$	$5.74E-02$	$3.62E-01^{***}$	$6.88E-02$
α_2	$2.39E-02^{*}$	$1.31E-02$	$5.22E-02^{***}$	$1.60E-02$
β_{11}	$6.99E-03^{***}$	$3.32E-04$	$9.12E-03^{***}$	$3.66E-04$
β_{12}	$-9.79E-06^{***}$	$8.52E-07$	$-1.38E-05^{***}$	$1.00E-06$
β_{13}	$5.50E-09^{***}$	$5.58E-10$	$7.35E-09^{***}$	$6.72E-10$
BO	$2.56E-03^{***}$	$1.17E-04$	$2.07E-03^{***}$	$1.36E-04$
β_{22}	$-1.52E-06^{***}$	$9.02E-08$	$-1.38E-06^{***}$	$1.19E-07$
β_{23}	$2.91E-10^{***}$	$1.89E-11$	$2.89E-10^{***}$	$2.61E-11$
γ_{EXM}	$9.12E-02^{***}$	$7.71E-03$	$1.53E-01^{***}$	$1.06E-02$
γ_{TEACH}	$-2.70E-02$	$2.93E-02$	$-7.01E-03$	$4.05E-02$
γ_{NEMRG}	$1.08E-03$	$8.69E-04$	$2.66E-03^{***}$	$7.26E-04$
γ_{GEN}	$1.80E-01^{***}$	$4.97E-02$	$1.49E-02$	$4.70E-02$
γ_{NSTD}	$1.76E-01^{***}$	$2.53E-02$	$2.10E-01^{***}$	$3.74E-02$
δ^*_{CONST}	$-7.77E+00^{***}$	$1.72E+00$		
δ^*_{BED1}	$3.02E+00^{***}$	$6.66E-01$		
δ^*_{BED2}	$-2.93E-01^{***}$	$6.42E-02$		
δ^*_{IO}	$7.46E-02^{**}$	$3.51E-02$		
δ^*_{SUB}	$5.45E-01^{***}$	$9.97E-02$		
δ^*_{URBAN}	$5.38E-01^{***}$	$1.48E-01$		
$1/\sigma$	$5.22E+00^{***}$	$2.07E-01$	$2.83E+00^{***}$	$8.44E-02$
λ	$6.68E-01^{***}$	$1.24E-01$	$2.39E+00^{***}$	$2.58E-01$
Log Likelihood	335.51		40.30	
Wald	34.29^{***}			

Table 3: Sample Means of Estimated Marginal Costs

	Inpatient		Outpatient	
Year	Truncated Normal	Half-Normal	Truncated Normal	Half-Normal
1993	23.7(16.4)	21.8(12.9)	6.4(5.2)	4.8(4.1)
1994	25.2(16.4)	21.1(11.2)	6.3(5.4)	4.4(4.0)
1995	25.7(17.0)	25.4(13.9)	6.5(5.9)	4.2(5.2)

Note: Figures are in thousand yens/patient/day. Sample standard deviations are in parentheses.

Table 4: Sample Means of Inefficiency Index

Year	Truncated Normal (%)	Half-Normal (%)
1993	22.2(0.37)	41.0(−)
1994	18.3(0.34)	59.4(−)
1995	21.1(0.35)	39.5(−)

Note: Sample standard deviations are in parentheses. For the half-normal model, the inefficiency index is identical for all hospitals, because $Z_i \cdot \delta = 0$ for all i in the definition of $INEF_i$ (Equation (5)).