ESTIMATION OF THE EFFICIENCY OF JAPANESE HOSPITALS USING A DYNAMIC AND NETWORK DATA ENVELOPMENT ANALYSIS MODEL

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Abstract: This study evaluates the policy effect of the reformation of municipal hospitals in Japan. We focused on the efficiency improvement of not only the hospital itself but also separate internal organizations of a hospital. Hospitals have two heterogeneous internal organizations: the medical-examination section and administration section. The administration section carries out business management and the medical-examination section provides medical care services. We employed a dynamic and network data envelopment analysis model. The model makes it possible to estimate both the efficiencies of separate organizations and the dynamic changes of the efficiencies simultaneously. We found that there are positive policy effects. Additionally, we should focus on the administration section rather than the medical-examination section in reforming municipal hospitals in Japan.
Keyword: Dynamic and network data envelopment analysis model, municipal hospital, efficiency, production function

1. INTRODUCTION

Japanese municipal hospitals have faced financial crises for decades. In 2007, the Japanese government set guidelines for the reformation and facilitated restructure of hospital business by municipals. There are 9000 hospitals in Japan, half of which are owned by private not-for-profit organizations and half of which are run by public organizations. One thousand public hospitals are owned and operated by municipal governments, most of which have been in the financial red for a long time. Because Japanese local governments have huge cumulative deficits, they require municipal hospitals to have a sound financial foundation.

Harris [1] pointed out that a hospital can be considered two separate firms, in that it has two heterogeneous internal organizations: a medical-examination section and administration section. The administration section carries out business management activities to contain medical expenses within medical revenue. The medical-examination section provides various medical care services. These two organizations are mutual-exchange internal services. The administration section provides medical beds to the medical-administration section, and the medical-examination section repays the revenue through the use of medical beds for inpatient services.

Japanese hospitals have acute beds and long-term-care beds in various ratios. The large hospitals tend to concentrate on acute care services. In addition, physicians and surgeons belong to hospitals and are paid by hospitals as in the case of National Health Service hospitals in the United Kingdom. These physicians provide services not only to inpatients, but also to outpatients at the same hospitals.

Many problems that arise in municipal hospitals in Japan are in the form of a failure of the medical-examination section. The chief medical officer in charge of the medical-examination section is typically the target of criticism from the stakeholders of the hospital. The administration section tends to operate from behind closed doors and avoids blame for any failures. However, there has been no comparison of efficiency improvements between the administration section and medical-examination section. This study evaluates policy effects considering efficiency scores not only for the whole hospital organization but also for the administration section alone.

Data envelopment analysis (DEA) is a nonparametric method used in operations research to evaluate the efficiency performance of decision-making units (DMUs). It is a popular method with which to estimate the efficiency of hospitals [2]. Several previous studies have evaluated the efficiency of Japanese hospitals by DEA [3–7]. These studies used cross-sectional data of Japanese public hospitals and adopted mainly traditional DEA. The average D efficiency scores ranged from 0.8 to 0.9.

The purpose of this study is to assess the effect of reformation since 2007 and to consider further countermeasures to financial problems of Japanese municipal hospitals. The structure of this paper is as follows. The background and purpose of our study were discussed in this first section. The methods and data of analyses are discussed in the second section. The results of the analyses are presented in the third section. After the estimation of efficiency for our sample, we report D efficiency scores. The last section includes a discussion of the results and a view of future challenges.

2. METHOD AND DATA

2.1. Dynamic and network DEA

The traditional DEA model is often considered a "black-box" (BB) model, because it does not take account of the internal structure of DMUs. In contrast, the network DEA model can evaluate DMUs considering the internal transactions within a DMU using link variables. [8,9]. On the other hand, the dynamic DEA model can measure the efficiency score obtained from long-term optimization using carry-over variables, while the traditional DEA only focuses on a single period [8,10].

We could use network DEA to estimate sectional efficiencies in two sections of Japanese hospitals. However, in that case, we would not be able to observe efficiency changes in the two sections separately. Alternatively, we could employ dynamic DEA to observe efficiency change at the hospitals. However, we would not be able to differentiate efficiency scores for the two sections. Therefore, we cannot observe the dynamic changes in efficiency for two sections separately using either dynamic DEA or network DEA.

The dynamic and network DEA model (DN model) takes into account the internal heterogeneous organizations of DMUs for which divisions are mutually connected by link variables and trade internal products with each other. Additionally, each DMU has carry-over variables that take into account a positive or negative factor in the previous period. This model has the huge advantage of being able to evaluate the policy effect on the individual divisions of each DMU. We thus employ a dynamic DEA model involving a network structure proposed by Tone and Tsutsui [11]. This DN model with both link variables and carry-over variables can evaluate (1) the overall efficiency over the entire observed term, (2) dynamic change in the term efficiency and (3) dynamic change in the divisional efficiency. We can estimate the efficiency of each section individually and observe dynamic change simultaneously. Applying the DN model to Japanese hospital data, we illustrate the suitability of the DN model by highlighting advantages of the DN model over the traditional BB model.

2.2. Empirical Data

The data used in the empirical investigation are for 113 municipal hospitals in the period from 2007 to 2009 in balanced panel form. There are about 1000 municipal hospitals in Japan. However, there is huge heterogeneity among these hospitals. We selected municipal hospitals with more than 300 beds. Therefore, this sample may represent large acute hospitals owned by Japanese municipals. The data are collected from Annual Datebook of Local Public Enterprise published by the Ministry of Internal Affairs and Communications. It is a legal requirement for the local chief executive of municipals to submit audited financial statements to the ministry. Therefore, the data should be accurate. This accuracy is required for DEA that does not consider measurement errors in the data.

The objective function of the administration section is to realize a sound financial situation through labor inputs and capital inputs. The objective function of the medical-examination section is to provide a certain amount of medical service using hospital beds that are maintained by the administration at the same hospital.

The inputs, outputs, links and carry-over of the DN model are described below. For Division 1 (administration section), we adopted two labor inputs and two capital inputs. As labor inputs, we used both the number of administration officers and the number of maintenance officers. All labor inputs are full-time equivalents (FTEs). As capital inputs, we used both the interest cost for financial arrangements and the subsidy from the municipal to cover deficits. For the output of Division 1, we adopted the balance ratio of medical expenses to medical income; the break-even point has a value of 100 and a surplus has a value exceeding 100.

For Division 2 (medical-examination section), we adopted four labor inputs: the number of doctors, number of nurses, number of assistant nurses and number of medical technologists. All labor inputs are full-time equivalents (FTEs). As the outputs of Division 2, we adopted the number of inpatients per operation day, the number of outpatients per operation day and the number of beds in emergency units. It would be peculiar to include outpatients as an output of hospitals. In Japan, there is no gate-keeping system involving general practitioners. Therefore, hospitals accept a large number of outpatients to ensure potential inpatients. The number of beds in emergency units is used as a surrogate variable for emergency care service because we could not make a distinction between emergency-care patients and ordinary patients from the data source.

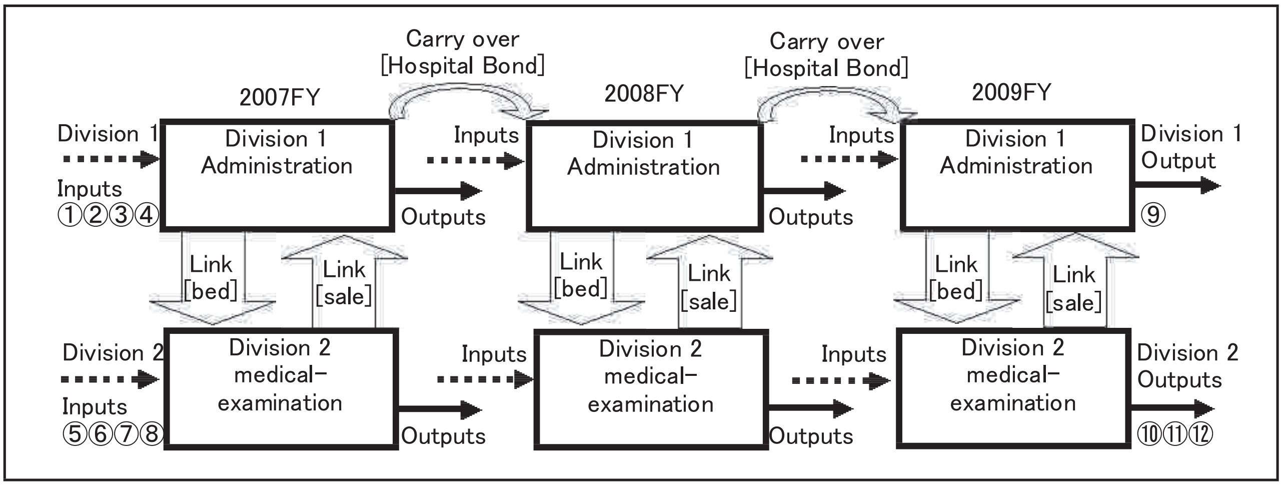

Figure 1: Inputs and outputs of the DN model

We set the number of beds as a link variable from Division 1 to Division 2. We assume that Division 1 is in charge of the funding and maintenance of medical beds. Division 1 supplies these beds to Division 2. Division 2 uses the medical beds and delivers medical care services to patients. In contrast, we set "average revenue per inpatient per day" as a link variable from Division 2 to Division 1. We assume that the average revenue is the consideration to be paid to Division 1 for the beds from Division 2 (Fig. 1).

We adopted a "fixed link", which means linking activity is kept unchanged. It would be quite unusual that the medical-examination section negotiates with the administration section to change the number of beds. The administration section has an incentive to maximize medical revenue and to activate all available beds. The average revenue per inpatient may represent the density of medical care services and is not negotiable between the two sections.

We set the balance account of the public enterprise bond (hospital bond) as undesirable (bad) carry-over. The hospital bond was chosen as carry-over because municipal hospitals issue the bond to raise funds for capital investment in hospital beds. The municipal hospital gradually redeems the issued bond from the surplus of hospital business.

Newly built hospitals are more attractive to patients but are a heavier fiscal burden in terms of repayment of the principal. Therefore, the account of the public enterprise bond as carry-over accurately reflects the competitive condition of the market in which patients can freely access any hospital in the Japanese health care system.

The inputs and outputs of the BB model are exactly the same as those of the DN model. There are eight kinds of inputs and four kinds of outputs. The variable for links and carry-over do not apply in the case of the BB model (Fig. 2).

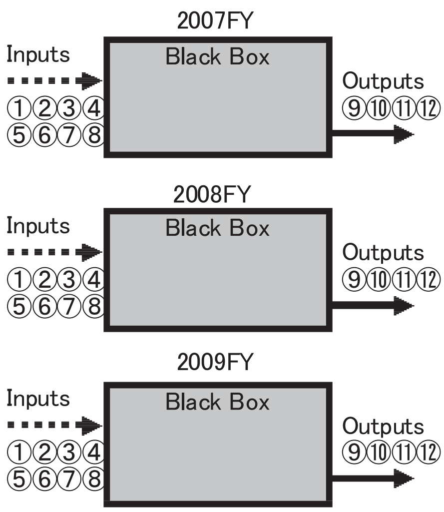

Figure 2: Inputs and outputs of the BB model

Table 1: Basic description of variables

			Variable Names	Average	S.D.	Max	Min	unite
Division1	Input	①	Number of administration officers	29.35	13.14	89.00	9.00	person
		②	Number of maintenance officers	17.96	15.54	83.00	0.00	person
		③	Interest cost per year	510	394	1,667	1	milion Yen
		④	Subsidy from municipal	23,678	17,585	89,700	2,800	milion Yen
	Output	⑨	Balance ratio of medical expense to medical income	85.72	11.92	114.40	49.10	index
Link(Div1→Div2)			Number of beds	482	180	1334	230	unite
Division2	Input	⑤	Number of doctors	62.17	35.89	166.00	6.00	person
		⑥	Number of nurses	314.41	152.76	800.00	79.00	person
		⑦	Number of assistant nurses	5.33	6.45	46.00	0.00	person
		⑧	Number of medical technologist	65.77	32.61	171.00	8.00	person
	Output	⑩	Number of inpatients per an operation day	378.14	156.79	964.00	73.00	person
		⑪	Number of outpatients per an operation day	742.14	425.64	2224.00	19.00	person
		⑫	Number of beds for emergency unites	14.09	14.73	66.00	0.00	unite
Link(Div2→Div1)			Average revenue per inpatient per day	16,822	6,629	31,841	3,661	Yen
Carry over			Balance account of the public enterprise bond	752,228	1,109,846	9,612,400	0	thousand Yen

According to the principle that a public hospital is expected to accomplish a policy goal with a minimum budget, we selected an input-oriented model. We adopted both constant returns to scale (CRS) and variable returns to scale (VRS) models in the analysis. Descriptive statistics of all variables in the analysis are provided in Table 1.

3. RESULTS

Table 2 and 3 presents key statistics of estimated efficiency scores obtained by the DN model and the BB model. On the Table 3, the first column gives the D efficiency score of the overall hospital organization as determined by the DN model. The second column gives the D efficiency score of the administration sections of the sample hospitals. The third column gives the D efficiency score of the medical-examination sections of the sample hospitals. We can compare efficiency scores obtained with the DN model with the scores obtained with the BB model in each year. The comparison highlights four findings about the policy effect on Japanese municipal hospitals.

First, the average overall efficiency obtained with the DN model was 0.798 (CRS model) and 0.854 (VRS model) in the case of 2007. In contrast, the average overall efficiency in 2007 estimated by the BB model was 0.962 (CRS model) and 0.977 (VRS model) and thus higher than that estimated by the DN model. In the same year, the ratio of efficient DMUs was 71.1% as determined by the BB model (CRS model, 2007), which was higher than the ratio determined by the DN model. According to the DN model, the ratio of efficient DMUs was 21.1%. The DN model was thus better able to detect inefficient DMUs than the BB model. The difference is due to the structures of the BB model and DN model. The average efficiency score estimated by the DN model is similar to the average efficiency estimated in previous studies on Japanese municipal hospitals [3],[4],[5],[6],[7].

Second, the dynamic change in efficiency scores from 2007 to 2009 is slightly less in the case of the BB model. The average efficiency score was 0.962 for 2007 and 0.960 for 2009 (CRS model). In contrast, the average efficiency score was higher in the case of the DN model. The average efficiency score was 0.798 for 2007 and 0.811 for 2009 (CRS model).

Table 2: D efficiency scores obtained with the BB model

model	Year	2007	2008	2009
CRS-I	Average	0.9618	0.9564	0.9603
	SD	0.0879	0.0883	0.0845
	Maximum	1	1	1
	Minimum	0.4966	0.5134	0.5273
VRS-I	Average	0.9766	0.9713	0.9761
	SD	0.0696	0.0746	0.0713
	Maximum	1	1	1
	Minimum	0.4973	0.5140	0.5312

We drew a tentative conclusion about the policy effect considering both the long-term change and heterogeneous internal organizations. It would be misleading to use the change in average efficiency scores determined by the BB model in evaluating policy effects. The advantage of the DN model is that it allows countermeasures to be taken separately for individual internal organizations of the individual hospital with heterogeneous internal structure.

Third, in the case of the BB model, it was impossible to differentiate efficiency between internal organizations. Because of the advantage of the network structure in the DN model, we can observe the efficiency change separately for different internal organizations using that model. The average estimated efficiency of the administration section changed from 0.779 for 2007 to 0.773 for 2009 (CRS model). In contrast, the average efficiency of the medical-examination section improved from 0.817 for 2007 to 0.849 for 2009 (CRS model). The direction of efficiency change differed for the administration section and medical-examination section. In detail, these results suggest that the policy effect would be positive for the medical-examination section on average.

Table 3: D efficiency scores obtained with the DN model

division	model	Year	2007	2008	2009
overall	CRS-I	Average	0.7984	0.8091	0.8112
		SD	0.1692	0.1755	0.1790
		Maximum	1	1	1
		Minimum	0.3921	0.3544	0.3970
	VRS-I	Average	0.8543	0.8538	0.8592
		SD	0.1601	0.1631	0.1678
		Maximum	1	1	1
		Minimum	0.4069	0.3784	0.4076
Division1 (admin)	CRS-I	Average	0.7793	0.7809	0.7739
		SD	0.2215	0.2342	0.2417
		Maximum	1	1	1
		Minimum	0.3931	0.4322	0.4150
	VRS-I	Average	0.8446	0.8321	0.8337
		SD	0.1974	0.2109	0.2196
		Maximum	1	1	1
		Minimum	0.3506	0.2963	0.2811
Division 2 (medical)	CRS-I	Average	0.8174	0.8374	0.8486
		SD	0.1720	0.1697	0.1652
		Maximum	1	1	1
		Minimum	0.2189	0.2767	0.2754
	VRS-I	Average	0.8641	0.8755	0.8847
		SD	0.1616	0.1574	0.1549
		Maximum	1	1	1
		Minimum	0.4021	0.4327	0.4356

Additionally, we investigated the individual hospital in terms of the relationship between dynamic changes for the two separate divisions. We examined the relationship between the efficiency scores in 2008 for the two sections using a scatter diagram (Fig 3).

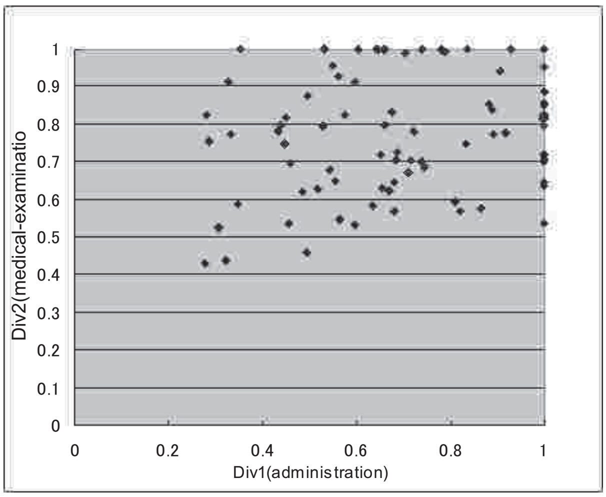

Figure 3: Scatter diagram of estimated efficiency scores of the administration section and medical-examination section (2008 financial year)

Despite the sections having similar average efficiencies, there was considerable difference in efficiency scores of the two sections on a case-by-case basis. Efficient DMUs on the administration side were sometimes quite inefficient on the medical-examination side, and vice versa. We thus could not confirm a clear relationship between the efficiency scores of the two sections.

In the case of the DN model, we can observe changes in the dynamic efficiency separately for each internal organization. The change in efficiency over the study period was relatively small in terms of the average value for each division. However, the situation was different for an individual municipal hospital.

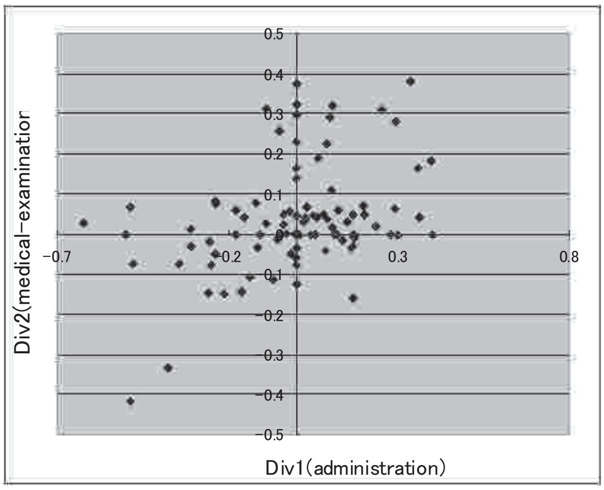

Figure 4: Efficiency change from the 2007 financial year to the 2009 financial year in each section

Figure 4 gives the numerical value of the dynamic efficiency change from 2007 to 2009 for each section separately. There were 53 hospitals (46.9% of sample hospitals) for which both divisions improved their efficiency score. Conversely, there were 19 hospitals (16.8% of sample hospitals) at which both divisions had worsening efficiency scores. There were 41 hospitals (36.7% of sample hospitals) at which the direction of efficiency change differed for the two divisions; among them, 27 hospitals had a worsening efficiency score for the administration section (65.8% of 41 hospitals). There were certain sizes of sample hospitals for which there was a decrease in efficiency in the administration section and improved efficiency in the medical-examination section. It would be misleading to use only the change in average efficiency scores to evaluate the policy effects. The advantage of the DN model is that it allows countermeasures to be taken separately for each internal organization of the individual hospital with heterogeneous internal structure.

4. DISCUSSION

There are two heterogeneous internal organizations in Japanese municipal hospitals. In this study, we estimated the dynamic change of efficiency scores of Japanese municipal hospitals in terms of the two divisions. The first division was the administration section, which is responsible for financial management. The second division was the medical-examination section, which provides medical services directly. The purpose of this study is to assess the change in the dynamic efficiency of the two internal organizations separately.

We employed the DN model presented by Tone and Tsutsui [11]. According to the results, we obtained three policy implications. First, the dynamic change in efficiency scores from 2007 to 2009 was a slight increase in the case of the DN model. On average, we would admit a positive policy effect on Japanese municipal hospitals.

Second, the average efficiency change of the administration section was negative. In contrast, the average efficiency of the medical-examination section improved. These results suggest that the policy effect on the medical-examination section would be positive on average. We would also need to focus on the efficiency improvement of the administration section in the future.

Third, when we looked at individual hospitals, an efficient DMU on the medical-examination side was sometimes quite inefficient on the administration side, and vice versa. The ratio of sample hospitals at which both divisions improved their efficiency score was 46.9%. Conversely, the ratio of sample hospitals at which both divisions had worsening efficiency scores was 16.8%. The ratio of sample hospitals at which the direction of change differed for the two divisions was 36.7%. Among these hospitals, the majority had a worsening efficiency score for the administration section. It would be misleading to use the change in average efficiency scores to evaluate policy effects.

From the obtained results, we note that we should focus on the administration section rather than the medical-examination section in reforming municipal hospitals in Japan. We also should consider taking separate countermeasures for different internal organizations of Japanese municipal hospitals.

This study is the first empirical application of the DN model, and there are thus limitations in this research. For example, we could not use both the variables of the "quality" of medical services and "severity" of patient conditions. Therefore, we assumed that the sample hospitals would be homogeneous in terms of quality of service and severity of patient conditions. We did narrow the range of samples according to the number of hospital beds to ensure the homogeneity of sample hospitals on some level. We should also examine omitted variables; e.g., the presence of large and costly medical devices such as magnetic resonance imagers (MRIs). However, it is difficult to introduce criteria for determining which device should be included in the input or output of the production function. Any future study will require a larger sample set and a more complicated model.

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