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An Econometric Analysis of Hospital Length of Stay for Cataract Operations in Japan by the Box-Cox Transformation Model and Hausman Tests: Evaluation of the 2010 Revision of the Medical Payment System*

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Abstract

The Japanese medical costs for cataract treatments reached 270 billion yen in fiscal year 2012. Since the length of stay (LOS) in hospital is much longer than other major countries, controlling the medical costs by reducing LOS becomes an important issue in Japan. In this paper, we evaluated the effects of the 2010 revision of the Japanese medical payment system (DPC/PDPS) on LOS for cataract operations. The Box-Cox transformation model, Nawata's estimators and Hausman tests were used in the analysis. To evaluate the effects, we analyzed a dataset obtained from 34 DPC hospitals (Hp1-34) where one-eye cataract operations were performed both before (April 2008-March 2010) and after (April 2010-March 2012) the 2010 revision and there were more than 500 patients. The dataset contained information from 32,593 patients. We did not admit the effect of the 2010 revision in this study, and there were large differences LOS among hospitals, even after removing the influences of factors such as patient characteristics and types of principal diseases.

Keywords

Diagnosis Procedure Combination (DPC), Cataract, Length of Stay (LOS), Box-Cox Transformation Model

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*How do we sustain the Japanese medical system?

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1. Introduction

A medical inclusive payment system based on the diagnosis procedure combination (DPC) was introduced in April 2003. The DPC classified diseases, treatments and conditions of patients by 14 digits and was originally developed in Japan. The DPC-based inclusive payment has been called the DPC/PDPS (DPC/per diem payment system) since December 2010 [1]. As of April 2013, a total of 1496 hospitals (hereafter DPC hospitals), comprising about 20% of all general hospitals in Japan, had joined the DPC/PDPS. These hospitals had 474,981 beds, more than half of the total number of beds in all general hospitals [2]. For details of the DPC/PDPS, see Nawata *et al*. [3]. Since DPC hospitals are required to satisfy certain rather costly conditions [4], it is difficult for small hospitals to join the DPC/PDPS. As a result, the percentage of DPC hospitals increases as the hospital size becomes larger. For example, among small hospitals with fewer than 100 beds, just about 5% were the DPC hospitals. On the other hand, among large hospitals with 500 or more beds, nearly two thirds were the DPC hospitals [2]. The revisions of DPC/PDPS have been implemented every other year. However, sufficient evaluations of the system have not yet been conducted for these revisions. Empirical studies of hospital length of stay (LOS) using econometric models are necessary to evaluate the system correctly.

According to the Ministry of Health, Labour and Welfare [5], the medical costs for cataract were 270 billion yen in fiscal year (April-March) 2012 in Japan. The 76,577 cataract operations were done for 48,235 cases and their direct costs were 8.03 billion yen in June 2012 [6]. In Japan, two-eye cataract operations, in which both eyes are operated on during a single period of hospitalization, are also performed. Therefore, the number of operations becomes larger than that of cases. It is estimated that about 920 thousand cataract operations costing nearly 100 billion yen are done annually. Cataract operations are usually carried out on a same-day basis, without any hospitalization in major countries ([7], pp. 100-101). The long LOS is one of the most noticeable characteristics of cataract operations and controlling medical costs by reducing LOS is a very important issue in Japan.

In this paper, we evaluate the effects of the 2010 revision of the DPC/PDPS on LOS for cataract operations using the Box-Cox [8] transformation model (hereafter, BC model), estimators proposed by Nawata [9] [10] and Hausman tests. The BC model is widely used to examine various econometric problems especially when the distribution has a heavy tail on the right side. For details and examples of the BC model, see Hossain [11] and Sakia [12]. The maximum likelihood estimator under the normality assumption (hereafter, BC MLE) is used for the estimation of the BC model. Since the BC model is just a simple regression model when the transformation parameter is given, it can be easily estimated by the least squares and scanning methods. However, the BC MLE is not generally consistent. Various researchers have proposed alternate methods of the BC model and BC MLE [13]-[15]. However, since their methods are rather complicated [16], they have not been widely used. Although the BC MLE is generally inconsistent, it can be a consistent estimator if the error terms are homoscedastic and the "small σ" assumption [17] is satisfied. Nawata [9] proposed a new consistent estimator of the BC model. However, the estimator is inconsistent if the error terms are heteroscedastic. Large biases of the BC MLE under heterogeneity were reported [16]. Therefore, heteroscedasticity is a very important problem in the BC model. Especially, for the LOS, variances are often very different even among hospitals. Powell [18] proposed a semiparametric estimator based on the moment restriction. Although Powell's estimator is consistent with heteroscedasticity, it performs quite poorly. More recently, Nawata [10] proposed an estimator that was consistent with heteroscedasticity.

Using Nawata's [9] [10] estimators, Hausman [19] tests are done for the BC MLE; that is, we determine whether or not we can use the BC MLE for the estimation of the BC model. Hausman tests compare two (vectors of) estimators, $\hat{\theta}$ and $\tilde{\theta}$. $\hat{\theta}$ is consistent with the null hypothesis but inconsistent with alternative hypothesis, and $\tilde{\theta}$ is consistent both with null and alternative hypotheses. The test statistic is given by $(\hat{\theta}-\tilde{\theta})'V(\hat{\theta}-\tilde{\theta})^{-1}(\hat{\theta}-\tilde{\theta})$ and its asymptotic distribution is the chi-square distribution with degrees of freedom p under the null hypothesis where p is the dimension of $\hat{\theta}$ and $\tilde{\theta}$.

In the case of cataract operations, major changes were made concerning the DPC classifications and the inclusive payments determined by the DPC/PDPS in the 2010 revision. To evaluate these changes, we analyzed the dataset obtained from 34 DPC hospitals (Hp1-34) where one-eye cataract operations were performed both before (April 2008-March 2010) and after (April 2010-March 2012) the 2010 revision, and more than 500 patients were operated in the sample period. The dataset of 32,593 patients were used in the analysis.

2. Estimators of the BC Model

2.1. BC Model

Suppose that LOS of patient t is given by the BC model.

$$z_t = x_t'\beta + u_t, \quad y \geq 0, \qquad t = 1, 2, \cdots, T,$$

$$Z_t = \pi \begin{cases} \dfrac{y_t^{\lambda} - 1}{\lambda}, & \text{if } \lambda \neq 0, \\ \log\left(y_t\right), & \text{if } \lambda = 0, \end{cases} \tag{1}$$

where y_t is the LOS, x_t and β are the vectors of the explanatory variables and coefficients, respectively, and λ is the transformation parameter. The likelihood function under the normality assumptions is given by

$$\log L(\theta) = \sum_t \log f_t(\theta), \text{ and } \log f_t(\theta) = \log \varphi\left\{\left(z_t - x_t'\beta\right)/\sigma\right\} - \log\sigma + (\lambda - 1)\log y_t, \tag{2}$$

where φ is the probability density function of the standard normal assumption, σ^2 is the variance of u_t, and $\theta' = \left(\lambda, \beta', \sigma^2\right)$. We can obtain the BC MLE is obtained by maximizing Equation (2). Let $\theta_0' = \left(\lambda_0, \beta_0', \sigma_0^2\right)$ be the true parameter values of θ. Since $E\left[\left.\dfrac{\partial \log L}{\partial \lambda}\right|_{\theta_0}\right] \neq 0$, the BC MLE is generally inconsistent. However, if the error terms are homoscedastic and $\lambda_0\sigma_0 / \left(1 + \lambda_0 x_t'\beta_0\right) \to 0$ (in practice, $P\left[y_t < 0\right]$ is small enough, and it is referred to as the "small σ" assumption in the rest of the paper), the BC MLE can be a consistent and efficient estimator, and "small σ" asymptotics [17] of the BC MLE $\hat{\theta}_{BC}' = \left(\hat{\lambda}_{BC}, \hat{\beta}_{BC}', \hat{\sigma}_{BC}^2\right)$ are obtained by

$$\sqrt{T}\left(\hat{\theta}_{BC} - \theta_0\right) \to N\left[0, A^{-1}B\left(A'\right)^{-1}\right], \tag{3}$$

where $A = -\dfrac{1}{T}E\left[\left.\dfrac{\partial^2 \log L}{\partial\theta\partial\theta'}\right|_{\theta_0}\right]$, and $B = E\left[\left.\dfrac{\partial \log f_t}{\partial\theta}\right|_{\theta_0} \left.\dfrac{\partial \log f_t}{\partial\theta'}\right|_{\theta_0}\right]$.

2.2. N-Estimator

Nawata [9] considered the roots of the equations,

$$\begin{aligned} G_T(\theta) &= \sum_t \left[-\frac{1}{\sigma^2\lambda}\left[\left\{\frac{\log\left[\lambda x_t'\beta + 1\right]}{\lambda} + \frac{z_t - x_t'\beta}{\lambda x_t'\beta + 1}\right\} y_t^{\lambda} - z_t\right]\left(z_t - x_t'\beta\right) + \frac{1}{\lambda}\log\left(\lambda x_t'\beta + 1\right) + \frac{z - x_t'\beta}{\lambda x_t'\beta + 1}\right] \\ &\equiv \sum_t g_t(\theta) = 0, \quad \frac{\partial \log L}{\partial \beta} = 0, \text{ and } \frac{\partial \log L}{\partial \sigma^2} = 0. \end{aligned} \tag{4}$$

$G_T(\theta)$ is obtained by the approximation of $\partial \log L / \partial\lambda$ under the "small σ" assumption. If $\left|u_t / \left(\lambda_0 x_t{}'\beta_0 + 1\right)\right|$ is small and $\lambda_0 \neq 0$, we get

$$\begin{aligned} \log y_t &= \frac{1}{\lambda_0}\log\left(\lambda_0 x_t'\beta_0 + 1 + \lambda_0 u_t\right) = \frac{1}{\lambda_0}\left\{\log\left(\lambda_0 x_t'\beta_0 + 1\right) + \log\left(1 + \frac{\lambda_0 u_t}{\lambda_0 x_t'\beta_0 + 1}\right)\right\} \\ &\approx \frac{1}{\lambda_0}\log\left(\lambda_0 x_t'\beta_0 + 1\right) + \frac{u_t}{\lambda_0 x_t'\beta_0 + 1}. \end{aligned} \tag{5}$$

Therefore, we get

$$\begin{aligned} \left.\frac{\partial \log L}{\partial \lambda}\right|_{\theta_0} &\approx -\frac{1}{\sigma_0^2\lambda_0}\sum_t\left[\left\{\frac{\left(\lambda_0 x_t'\beta_0 + 1\right)\log\left(\lambda_0 x_t'\beta_0 + 1\right)}{\lambda_0} - x_t\beta\right\}u_t + \log\left(\lambda_0 x_t'\beta_0 + 1\right)u_t^2 + \frac{\lambda_0 u_t^3}{\lambda_0 x_t'\beta_0 + 1}\right] \\ &\quad + \sum_t\left\{\frac{1}{\lambda_0}\log\left(\lambda_0 x_t'\beta_0 + 1\right) + \frac{u_t}{\lambda_0 x_t'\beta_0 + 1}\right\} = G_T\left(\theta_0\right). \end{aligned} \tag{6}$$

If the third moments of u_t are zero (since we can include the constant term in explanatory variables, we can assume that the first moment of the error terms is zero without loss of generality under homoscedasticity), $E\left[G_T(\theta_0)\right]=0$. Therefore, the estimator obtained by Equation (4) is consistent (hereafter, N-estimator). The asymptotic distribution of the N-estimator $\hat{\theta}'_N=\left(\lambda_N,\beta'_N,\sigma_N^2\right)$ is given by

$$\sqrt{T}\left(\hat{\theta}_N-\theta_0\right)\to N\left[0,C^{-1}D\left(C'\right)^{-1}\right], \tag{7}$$

where $C=-E\left[\left.\frac{\partial \ell_t(\theta)}{\partial \theta'}\right|_{\theta_0}\right]$, $D=E\left[\ell_t(\theta_0)\ell_t(\theta_0)\right]$, $\ell_t(\theta)'=\left[g_t(\theta),\xi_t(\theta)',\varsigma_t(\theta)\right]$,

$\xi_t(\theta)=\frac{1}{\sigma^2}x_t\left(z_t-x_t'\beta\right)$, and $\varsigma_t(\theta)=\frac{\left(z_t-x_t'\beta\right)-\sigma^2}{2\sigma^2}$.

2.3. Robust Estimator

The N-estimator is not consistent under heteroscedasticity. Nawata [10] proposed a robust estimator that is consistent even under heteroscedasticity if the first and third moments are zero. The estimator is obtained from the roots of the equations,

$$M_T(\vartheta)=\sum_t m_t(\vartheta)=0,\ \ m_t(\vartheta)\equiv m\left(\vartheta,x_t,y_t\right)=\left(z_t-x_t'\beta\right)^3,\ \text{and}\ \sum_t x_t\left(z_t-x_t'\beta\right)=0, \tag{8}$$

where $\vartheta'=\left(\lambda,\beta'\right)$. Let $\vartheta_0'=\left(\lambda_0,\beta_0'\right)$. Since $E\left[M\left(\vartheta_0\right)\right]=0$, there exists a consistent root among the roots of Equation (8). Let $\hat{\vartheta}_R'=\left(\hat{\lambda}_R,\hat{\beta}_R'\right)$ be the consistent root (hereafter, robust estimator) and $\omega_t(\vartheta)'=\left[m_t(\vartheta),\psi_t(\vartheta)'\right]$. Then, the asymptotic distribution of $\hat{\vartheta}_R$ is given by

$$\sqrt{T}\left(\hat{\vartheta}_R-\vartheta_0\right)\to N\left[0,F^{-1}H\left(F'\right)^{-1}\right], \tag{9}$$

where $F=p\lim_{T\to\infty}\frac{1}{T}\sum_t\left.\frac{\partial\omega_t(\vartheta)}{\partial\vartheta'}\right|_{\vartheta_0}$, $H=\lim_{T\to\infty}\frac{1}{T}\sum_t E\left[\omega_t\left(\vartheta_0\right)\omega_t\left(\vartheta_0\right)'\right]$, $\psi_t(\vartheta)=x_t\left(z_t-x_t'\beta\right)$, and

$\omega_t(\vartheta)'=[m_t(\vartheta),\psi_t(\vartheta)']$.

3. Hausman Tests for the BC Model

3.1. A Test of the Homoscedasticity and "Small σ" Assumptions

We first test the null hypothesis consisting of the homoscedasticity and "small σ" assumptions. Since $G_T\left(\theta_0\right)=\left.\frac{\partial\log L}{\partial\lambda}\right|_{\theta_0}$ under the null hypothesis, we get,

$$\sqrt{T}\left(\hat{\lambda}_N-\hat{\lambda}_{BC}\right)\to N\left(0,\delta_1\right), \tag{10}$$

where $\delta_1=(1,1)$ element of $\left(A^{-1}-C^{-1}\right)B\left(A^{-1}-C^{-1}\right)'$.

Let $\hat{\delta}_1$ be the estimator of δ_1 and $t=\sqrt{T}\left(\hat{\lambda}_N-\hat{\lambda}_{BC}\right)\Big/\sqrt{\hat{\delta}_1}$. Since $t\to N(0,1)$ under the null hypothesis, we can test this assumption using t as the test statistic [4]. As pointed out by Nawata and McAleer [20], we cannot use two or more parameters in the Hausman test. We can use the BC MLE if the null hypothesis is accepted.

3.2. A Test of Homoscedasticity

The N-estimator is not consistent under heteroscedasticity. Therefore, it is necessary to test the homoscedasticity assumption if the null hypothesis in the previous section is rejected. The null hypothesis is homoscedasticity. For this test, we use the N-estimator and robust estimator. Under the null hypothesis,

$$\sqrt{T}\left(\hat{\lambda}_N-\lambda_0\right)=\frac{1}{\sqrt{T}}c'\sum_t \ell\left(\theta_0\right)+o_p\left(1\right),\ \text{and}\ \sqrt{T}\left(\hat{\lambda}_R-\lambda_0\right)=\frac{1}{\sqrt{T}}f'\sum_t \omega\left(\vartheta_0\right)+o_p\left(1\right), \tag{11}$$

where c and f are the first columns of C^{-1} and F^{-1}, respectively. The asymptotic distribution of $\sqrt{T}\left(\hat{\lambda}_N-\hat{\lambda}_R\right)$ is given by

$$\sqrt{T}\left(\hat{\lambda}_N-\hat{\lambda}_R\right)\to N\left(0,\delta_2\right), \tag{12}$$

where $\delta_2=c'Bc+f'Hf-2c'E\left[\ell\left(\theta_0\right)\omega\left(\vartheta_0\right)'\right]f$. Using $t=\sqrt{T}\left(\hat{\lambda}_N-\hat{\lambda}_{BC}\right)\Big/\sqrt{\hat{\delta}_2}$ where $\hat{\delta}_2$ be the estimator of δ_2 and we can get the test statistic as before. We use the N-estimator if the homoscedasticity assumption is accepted, and the robust estimator otherwise [21].

4. Data and Summary of the 2010 Revision for Cataract Operations

4.1. Data

In this study, we use data from the Section of Health Care Economics of Tokyo Medical and Dental University. The data were collected from over 100 Japanese hospitals between 2008 and 2012, from April to March of each fiscal year. Various information (nearly 200 items) for individual patients was available. More precisely, we could get information of patients' genders and ages, dates of hospitalization, medical costs, DPC code, International Classification of Diseases 10th revision (ICD-10) codes determined by the World Health Organization (WHO) for the principal diseases, medical treatments and operations, comorbidities, complications, and placements after hospitalization [12]. The ICD-10 codes classify diseases by one alphabet and three digit numbers.

We considered only patients who underwent one-eye cataract operations without secondary treatments of article kidney. The DPC codes for this procedure were 020110xx97x0x0 and 020110xx97xxx0 before (April 2008-March 2010) and after (April 2010-March 2012) the 2010 revision. The original dataset contained information from 42,925 patients. Since the distribution of LOS had a heavy tail on the right side as shown in **Figure 1**, we used the BC model rather than the ordinary least squares model. Among these patients, we used the dataset obtained from 34 DPC hospitals (Hp 1-34) where operations were performed both before and after the revision to evaluate the effect of the 2010 revision of the DPC/PDPS, and where more than 500 were operated in the sample period. These hospitals had 32,595 patients. **Table 1** shows LOS by hospital. The average length of stay (ALOS) was 3.51 days and the standard deviation was 2.84 days for all 32,595 patients. The maximum ALOS by hospital was 6.12 days (Hp 23), and the minimum was 2.0 days (Hp 11). The maximum was more than 4 days longer than the minimum, and there were large differences among hospitals.

4.2. Summary of the 2010 Revision for Cataract Operations

The 2010 revision of the DPC/PDPS contained major changes for cataract operations. Before the revision, dif-

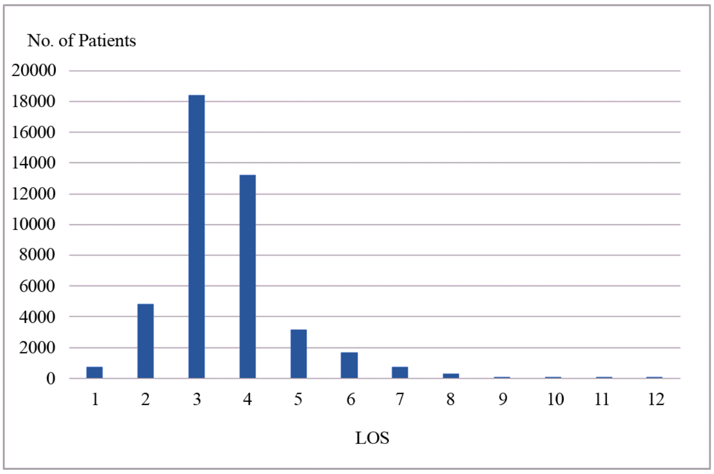

Figure 1. Distribution of LOS.

Table 1. LOS by hospital.

Hospital	No. of Patients	LOS		Hospital	No. of Patients	LOS	
		ALOS	S.D.			ALOS	S.D.
Hp 1	544	3.83	1.18	Hp 18	683	3.46	0.64
Hp 2	755	3.00	0.96	Hp 19	603	2.90	0.72
Hp 3	594	3.37	1.05	Hp 20	544	2.85	0.66
Hp 4	691	3.00	0.67	Hp 21	735	3.16	1.44
Hp 5	780	3.21	0.79	Hp 22	1428	3.85	1.16
Hp 6	2123	2.80	0.72	Hp 23	513	6.12	1.32
Hp 7	570	2.13	0.59	Hp 24	1160	5.75	1.86
Hp 8	951	3.02	0.25	Hp 25	1326	2.97	1.45
Hp 9	951	3.23	0.58	Hp 26	705	2.62	0.96
Hp 10	1388	3.99	0.19	Hp 27	1035	4.12	1.05
Hp 11	516	2.00	0.26	Hp 28	2627	3.42	0.94
Hp 12	855	3.20	0.71	Hp 29	875	4.00	1.53
Hp 13	762	3.04	0.45	Hp 30	1143	3.89	0.97
Hp 14	607	4.00	0.17	Hp 31	1119	4.04	1.29
Hp 15	1626	3.68	0.56	Hp 32	1175	3.72	0.63
Hp 16	1156	3.13	0.47	Hp 33	513	3.87	0.88
Hp 17	669	3.00	0.33	Hp 34	873	4.16	1.04
All	32,595	3.51	2.84				

S.D.: Standard Deviation.

ferent DPC codes were assigned depending on the presence or absence of secondary treatments of article kidney (without secondly treatments 020110xx97x0x0; with secondly treatments: 020110xx97x1x0), and the medical payments differed accordingly. After the revision, cataract operations were categorized under just one DPC code (020110xx97xxx0) independent of the presence of secondary treatments of article kidney.

The Periods I and II and the Specific Hospitalization Period were changed, and the per diem inclusive payments were revised. The per diem inclusive payment in 2008-9 for patients without the secondary treatments was 2363 points for the first day, 1900 points for the 2nd and 3rd days, and 1615 points for the 4th-7th days. For those with the secondary treatments, the per diem inclusive payment was 2829 points up to the 2nd day, 2091 points for the 3rd and 4th days, and 1777 points for the 5th-7th days. After the revision, the per diem inclusive payment became 2237 points up to the 2nd day, 1627 points for the 3rd day, and 1464 points for the 4th-6th days for all cataract patients independent of the secondary treatments (10 yen per point are paid to a hospital.)

5. Results of Estimation

When we analyze LOS, we need to consider the characteristics of the patients and the types of principal disease as the explanatory variables. The data of 32,923 patients without missing values in explanatory variables were used for the analysis. For the gender of patients, we used a Female dummy (1: female; 0: otherwise). The percentage of female patients was 56.3%. Costs of hospitalization (including opportunity costs) tend to decrease with patient age. Therefore, we used Age (age of a patient) as an explanatory variable. Japan has employed the public health insurance system and all Japanese have been required to attend some types of the insurances. During the sample period, percentages of direct payments by patients changed at age 70; that is, 10% for patients age 70 or older and 30% for patients younger than age 70. Therefore, we added Age 70 (1: age 70 or over; 0:

otherwise) dummy. (Note that the payments of patients have been increased to 20% for patients age 70 - 74 since April 2014.) The average and standard deviation of ages were 73.6 and 10.0, respectively. For representing conditions of patients, Comorbidities (number of comorbidities), Complications (number of complications), and Non-planned (1: hospitalization was not planned in advance; 0: otherwise), Outpatient (1: patient was outpatient before hospitalization; 0: otherwise) and Other Hospital (patient was introduced by another hospital; 0: otherwise) dummies were used. 45.4% and 38.1% of patients had comorbidities and complications, respectively. The average numbers of comorbidities and complications were 1.77 and 1.40, respectively, for these patients. 0.67%, 92.4% and 45.4% of patients were non-planned hospitalizations, outpatients and introduced by other hospitals, respectively.

To analyze the impact of seasonal climates, we used Winter (1: winter, December to February; 0: otherwise) and Summer (1: summer, July and August; 0: winter) dummies. The percentages of patients treated in winter and summer were 20.9% and 22.4%, respectively. To analyze influences of the 2010 revision of the DPC/PDPS, After 2010 dummy (1: after April 2010; 0: otherwise) was used. 54.6% of patients were operated after April 2010. Trend (time trend) was added to evaluate the progress and improvement of cataract operation technologies. If the LOS exceeds the Specific Hospitalization Period, the payment system becomes the conventional fee-for-service system. Therefore, we added the Specific Period dummy (1: over the Specific Hospitalization Period, 0: otherwise) and 1.0% of patients stayed over the Specific Hospitalization Period.

Principal Disease dummies based on the ICD-10 codes were used to analyze the effects of principal diseases. The definitions and percentages of patients were as follows. H25.0: senile incipient cataract, 53.0%; H25.1: senile nuclear cataract, 16.7%; H25.2: senile cataract, morgagnian-type, 1.2%; H25.8: other senile cataract, 5.5%; H25.9: senile cataract, unspecified, 5.9%; H26.0: infantile and juvenile cataract, 6.2%; H26.9 (unspecified cataract) 8.3%; H26_other: other H26 cataracts including H26.2: complicated cataract, H26.3: drug-induced cataract, H26.4: After-cataract; H26.8: other specified cataract, 0.5%; H27: Other disorders of lens 0.9%; and H28: Diabetic cataract 1.7%. The base of the ICD-10 dummies was H25.0. Thirty four hospital dummies (1: Hp k; 0: otherwise) were used to represent the influence of the hospital. To evaluate the effects of hospitals directly, we used 34 hospital dummies and a constant term is not included.

Thus $x'_{ij}\beta$ of Equation (1) becomes

$$\begin{aligned} x'_{ij}\beta = {} & \beta_1\text{Female} + \beta_2\text{Age} + \beta_3\text{Age 70} + \beta_4\text{Comorbidities} + \beta_5\text{Complications} + \beta_6\text{Non} - \text{planned} \\ & + \beta_7\text{Outpatient} + \beta_8\text{Other Hospital} + \beta_9\text{Winter} + \beta_{10}\text{Summer} + \beta_{11}\text{After 2010} + \beta_{12}\text{Trend} \\ & + \beta_{13}\text{Specification Period} + \sum \beta_j\, j\text{-th Principal Disease dummy} + \sum \beta_k \text{Hp}k\text{dummy}. \end{aligned} \tag{13}$$

Tables 2-4 present the results of the estimation by the BC MLE, N-estimator and robust estimators. The estimates of the transformation parameters were $\hat{\lambda}_{BC} = 0.4975$, $\hat{\lambda}_N = 0.5455$ and $\hat{\lambda}_R = 0.5480$. We first tested the homoscedasticity and "small σ" assumptions. We obtained $\hat{d}/\sqrt{n} = 0.0104$ and the value of $t = \left|\sqrt{T}\left(\hat{\lambda}_N - \hat{\lambda}_{BC}\right)/\hat{d}\right|$ became 4.618. Therefore, the homoscedasticity and "small σ" assumptions were rejected at the 1% significance level and the BC MLE should not be used for this dataset. We then tested the homoscedasticity. The value of $\sqrt{V\left(\hat{\lambda}_R - \hat{\lambda}_N\right)}$ was 0.0139 and $t = \left(\hat{\lambda}_R - \hat{\lambda}_N\right)/\sqrt{V\left(\hat{\lambda}_R - \hat{\lambda}_N\right)} = 0.1793$, so the homoscedasticity was accepted at the 5% significance level. Therefore, the remainder of this paper was thus an analysis of the results of the N-estimator.

The estimate of $\hat{\lambda}_N$ was significantly smaller than 1.0, suggesting some patients remained in hospitals for a long period of time. The estimate of Female dummy was positive and significant at 1% level. The estimates of Age and Age 70 were positive and significant at the 1% and 5% level, respectively. These results implied that the LOS was longer for females and for older patients, and lower payments for patients age 70 or over prolonged LOS. The estimates of Comorbidities and Complications were positive and significant at the 1% and 5% levels, and comorbidities and complications prolonged LOS. The estimates of Non-planned and Other Hospital dummies were not significant. Although the estimate of Winter dummy was negative and significant at the 1% level, the estimate of Summer dummy was not significant. This implies that the LOS became shorter in winter but not in summer. The estimate of After 2010 dummy was not significant and so we did not admit the effect of the 2010 revision in this study. The estimate of Trend was significant at the 1% level and it was admitted that the LOS became shorter as time went. Both estimate and t-value were quite large for the Specific Period dummy.

Especially, the estimated value was 2.009 that was much bigger than those of other explanatory variables. As explained earlier, the payment system becomes the fee-for-service system and daily payments do not decrease any more once the LOS exceeds the Specific Hospitalization Period. This is a big problem that must be considered in the future revision of the medical payment system.

Table 2. Results of estimation (BC MLE).

Variable	Estimate	S. E.	t-Value	Variable	Estimate	S. E.	t-Value
λ	0.4975	0.0008	597.95		Hospital dummies		
Female	0.0157	0.0046	3.3924	Hp 8	1.4208	0.0373	38.0913
Age	0.0020	0.0004	5.2884	Hp 9	1.0708	0.0369	29.0240
Age 70	0.0177	0.0082	2.1690	Hp 10	1.5800	0.0377	41.9391
Comorbidities	0.0175	0.0027	6.4202	Hp 11	1.6951	0.0379	44.7246
Complications	0.0120	0.0051	2.3604	Hp 12	2.0643	0.0372	55.4672
Non-planned	0.0091	0.0424	0.2150	Hp 13	0.9389	0.0381	24.6556
Outpatient	−0.0060	0.0143	−0.4226	Hp 14	1.5839	0.0406	39.0227
Other hospital	0.0246	0.0053	4.6147	Hp 15	1.4916	0.0381	39.1309
Winter	−0.0175	0.0059	−2.9417	Hp 16	2.0957	0.0361	58.1109
Summer	−0.0056	0.0057	−0.9825	Hp 17	1.9107	0.0371	51.5692
After 2010	−0.0110	0.0101	−1.0872	Hp 18	1.6337	0.0369	44.2872
Trend	−0.0044	0.0004	−10.3059	Hp 19	1.5402	0.0378	40.7977
Specification period	1.8344	0.0485	37.8000	Hp 20	1.8141	0.0380	47.7816
	ICD10 dummies			Hp 21	1.4923	0.0394	37.9169
H25.1	−0.0576	0.0116	−4.9672	Hp 22	1.4468	0.0404	35.8548
H25.2	0.1211	0.0260	4.6646	Hp 23	1.5303	0.0496	30.8566
H25.8	0.1193	0.0156	7.6270	Hp 24	1.9468	0.0382	50.9259
H25.9	0.0014	0.0127	0.1107	Hp 25	2.7548	0.0421	65.4205
H26.0	0.0051	0.0089	0.5667	Hp 26	2.6971	0.0379	71.1094
H26.9	−0.0154	0.0102	−1.5152	Hp 27	1.4463	0.0421	34.3405
H260_other	−0.0012	0.0301	−0.0386	Hp 28	1.3117	0.0441	29.7703
H27	0.3257	0.0450	7.2319	Hp 29	2.0882	0.0385	54.2596
H28	0.0290	0.0151	1.9236	Hp 30	1.8052	0.0383	47.1347
	Hospital dummies			Hp 31	2.0204	0.0387	52.2444
Hp 1	1.9214	0.0422	45.5392	Hp 32	1.9645	0.0387	50.8138
Hp 2	1.5155	0.0365	41.5498	Hp 33	2.0521	0.0390	52.6034
Hp 3	1.6417	0.0436	37.6836	Hp 34	1.9165	0.0372	51.4824
Hp 4	1.4998	0.0379	39.5703	Hp 35	2.0189	0.0417	48.4038
Hp 5	1.6782	0.0386	43.4681	Hp 36	2.1462	0.0390	55.0943
Log L		−36872.7		R^2		0.5214	

S.E.: Standard Error.

Table 3. Results of estimation (N-estimator).

Variable	Estimate	S. E.	t-Value	Variable	Estimate	S. E.	t-Value
λ	0.5455	0.0103	53.0075**		Hospital dummies		
Female	0.0166	0.0049	3.3862**	Hp 8	1.4651	0.0398	36.7889**
Age	0.0021	0.0004	4.9213**	Hp 9	1.0997	0.0397	27.7208**
Age 70	0.0185	0.0087	2.1152*	Hp 10	1.6303	0.0400	40.7765**
Comorbidities	0.0186	0.0029	6.3482**	Hp 11	1.7535	0.0402	43.6104**
Complications	0.0129	0.0054	2.3827*	Hp 12	2.1443	0.0396	54.1364**
Non-planned	0.0120	0.0462	0.2603	Hp 13	0.9618	0.0412	23.3406**
Outpatient	−0.0061	0.0152	−0.4020	Hp 14	1.6345	0.0432	37.8295**
Other hospital	0.0266	0.0057	4.6623**	Hp 15	1.5363	0.0409	37.5806**
Winter	−0.0183	0.0063	−2.9115**	Hp 16	2.1782	0.0385	56.5955**
Summer	−0.0061	0.0059	−1.0337	Hp 17	1.9817	0.0393	50.4034**
After 2010	−0.0121	0.0109	−1.1124	Hp 18	1.6875	0.0392	43.0990**
Trend	−0.0047	0.0004	−10.4228**	Hp 19	1.5889	0.0402	39.5720**
Specification period	2.0086	0.0766	26.2310**	Hp 20	1.8796	0.0403	46.6811**
	ICD10 dummies			Hp21	1.5396	0.0418	36.8044**
H25.1	−0.0603	0.0123	−4.8995**	Hp 22	1.4912	0.0432	34.5517**
H25.2	0.1283	0.0277	4.6295**	Hp 23	1.5899	0.0525	30.2667**
H25.8	0.1276	0.0173	7.3831**	Hp 24	2.0204	0.0406	49.7181**
H25.9	0.0017	0.0135	0.1247	Hp 25	2.8873	0.0457	63.2331**
H26.0	0.0055	0.0096	0.5725	Hp 26	2.8287	0.0418	67.6036**
H26.9	−0.0165	0.0108	−1.5215	Hp 27	1.4997	0.0446	33.6354**
H26_other	−0.0023	0.0318	−0.0724	Hp 28	1.3552	0.0469	28.8770**
H27	0.3513	0.0491	7.1546**	Hp 29	2.1720	0.0410	52.9848**
H28	0.0304	0.0159	1.9108	Hp 30	1.8696	0.0406	46.0660**
Hospital dummies				Hp 31	2.1010	0.0415	50.6297**
Hp 1	1.9948	0.0449	44.4601**	Hp 32	2.0403	0.0410	49.7178**
Hp 2	1.5628	0.0385	40.6083**	Hp 33	2.1376	0.0413	51.7371**
Hp 3	1.6984	0.0464	36.5824**	Hp 34	1.9878	0.0395	50.3022**
Hp 4	1.5471	0.0402	38.4490**	Hp 35	2.0977	0.0443	47.3915**
Hp 5	1.7354	0.0409	42.4261**	Hp 36	2.2325	0.0417	53.5646**
R^2		0.5262					

S.E.: Standard Error; *Significant at the 5% level; **Significant at the 1% level.

For the estimates of the Hospital dummies, the maximum was 2.887 (Hp 25) and the minimum was 0.962 (Hp 5); the difference between the maximum and minimum values was 1.925 and it was much larger than the estimates of other variables except the Specific Period dummy. This indicated that there remained large differences among hospitals, even after removing the influences of factors such as patient characteristics, types of principal diseases and the revision of the DPC/PDPS. Although the medical society may express strong disapproval, it may be necessary to give hospitals additional strong incentives suggested by Nawata *et al*. [3] to reduce LOS in the future

Table 4. Results of estimation (robust estimator).

Variable	Estimate	S. E.	t-Value	Variable	Estimate	S. E.	t-Value
λ	0.5480	0.0086	63.4627	Hospital dummies			
Female	0.0167	0.0049	3.4033	Hp 8	1.4674	0.0379	38.6713
Age	0.0021	0.0004	5.1772	Hp 9	1.1012	0.0408	26.9743
Age 70	0.0185	0.0087	2.1239	Hp 10	1.6330	0.0404	40.4068
Comorbidities	0.0186	0.0029	6.3979	Hp 11	1.7566	0.0396	44.3643
Complications	0.0129	0.0054	2.3833	Hp 12	2.1486	0.0393	54.6837
Non-planned	0.0122	0.0460	0.2651	Hp 13	0.9631	0.0423	22.7470
Outpatient	−0.0061	0.0153	−0.4002	Hp 14	1.6372	0.0424	38.6394
Other hospital	0.0267	0.0057	4.6957	Hp 15	1.5387	0.0414	37.1543
Winter	−0.0184	0.0063	−2.9161	Hp 16	2.1826	0.0402	54.3058
Summer	−0.0062	0.0060	−1.0285	Hp 17	1.9854	0.0387	51.2730
After 2010	−0.0122	0.0109	−1.1134	Hp 18	1.6904	0.0389	43.4834
Trend	−0.0047	0.0005	−10.2747	Hp 19	1.5914	0.0411	38.7172
Specification period	2.0182	0.0310	65.0857	Hp 20	1.8831	0.0402	46.8150
ICD10 dummies				Hp 21	1.5421	0.0411	37.5485
H25.1	−0.0604	0.0123	−4.9036	Hp 22	1.4935	0.0422	35.3793
H25.2	0.1286	0.0277	4.6379	Hp 23	1.5931	0.0422	37.7682
H25.8	0.1280	0.0168	7.6095	Hp 24	2.0244	0.0392	51.6100
H25.9	0.0017	0.0136	0.1252	Hp 25	2.8945	0.0409	70.7500
H26.0	0.0055	0.0095	0.5762	Hp26	2.8357	0.0382	74.2823
H26.9	−0.0165	0.0109	−1.5216	Hp 27	1.5026	0.0383	39.2291
H26_other	−0.0024	0.0319	−0.0741	Hp 28	1.3575	0.0414	32.8156
H27	0.3527	0.0492	7.1641	Hp 29	2.1764	0.0391	55.7079
H28	0.0305	0.0160	1.9132	Hp 30	1.8730	0.0385	48.6815
Hospital dummies				Hp 31	2.1053	0.0381	55.2556
Hp 1	1.9987	0.0419	47.7363	Hp 32	2.0444	0.0395	51.7759
Hp 2	1.5653	0.0392	39.9387	Hp 33	2.1422	0.0372	57.6289
Hp 3	1.7014	0.0419	40.6275	Hp 34	1.9916	0.0385	51.7000
Hp 4	1.5496	0.0398	38.9573	Hp 35	2.1019	0.0422	49.8172
Hp 5	1.7384	0.0402	43.2364	Hp 36	2.2371	0.0401	55.7694
R^2		0.5264					

S.E.: Standard Error.

revision of the DPC/PDPS.

6. Conclusions

In this paper, we analyzed the effect of the 2010 revision of the DPC/PDPS on LOS for single-eye cataract operations (DPC category code 020110) in Japan using the BC model. The dataset contained information for 32,973 patients collected from 34 DPC hospitals where cataract operations were reported both before and after the 2010 revision and there were more than 500 patients. The sample period was from April 2008 to March 2012. We first performed the Hausman tests to determine whether or not we could use the BC MLE using Nawata's [9] [10] estimators. We found that the null hypothesis consisting of the homoscedasticity and "small σ" assumptions was rejected and the BC MLE should not be used for this dataset. On the other hand, the homoscedasticity assumption was accepted and we used N-estimator [9] in the analysis.

Our results indicated that the factors which affected the LOS were the gender, age, comorbidities and complications, introduced by other hospitals, winter, time trend and Specific Hospitalization Period. As principal diseases, we found that H25.1, H25.2, H25.8 and H27 were significant. The ALOS values were significantly different among hospitals, even after removing the influences of patient characteristics and types of principal diseases. The estimate of After 2010 dummy was not significant, so we did not admit the effect of the 2010 revision in this study. Since the LOS of Japanese hospitals is quite long among major countries, incentives to hospitals to reduce their ALOS are very important. However, desirable incentives have not been known yet. These are subjects for future studies.

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