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Evaluation of the 2006 revision of the medical payment system in Japan by the Box-Cox transformation model and the Hausman test -An analysis of the length of the hospital stay for cataract operations-

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Abstract

The number of cataract patients in Japan has increased rapidly with the aging of the population. Therefore, controlling medical expenses by reducing the length of the hospital stay has become very important in the treatment of this disease. In this paper, we evaluate the effects of the 2006 revision of the medical payment system (DPC/PDPS) on the length of the hospital stay for cataract operations. For the analysis, the Box-Cox transformation model and the Hausman test are used. We analyze the data collected from 15 hospitals before and after the revision. The number of patients in the data set is 4,019.

Keywords: Diagnosis Procedure Combination (DPC), DPC/PDPS, inclusive payment system, cataract, length of stay (LOS), Box-Cox transformation model, Hausman test

1. Introduction

Since Japanese medical expenses have been increasing rapidly with the aging of the population, shortening the average length of stay (ALOS) by reducing long-term hospitalizations has become an important political issue in Japan. A new inclusive payment system based on the Diagnosis Procedure Combination (DPC) was introduced in 82 special functioning hospitals (i.e., university hospitals, the National Cancer Center and the National Cardiovascular Center) in April 2003 in Japan [10]. The DPC Evaluation Division of the Central Social Insurance Medical Council [5] now calls the new inclusive payment system based on the DPC the DPC/PDPS (per diem payment system), and we use this term and refer to hospitals participating in the DPC/PDPS as DPC hospitals throughout this paper.

Since April 2004, the DPC/PDPS has been gradually extended to general hospitals which satisfy the required conditions. The DPC/PDPS has been revised every two years since then. According to the DPC Evaluation Division [6], as of April, 2013, a total of 1,496 hospitals, comprising about 20% of the 7,528 general hospitals in Japan, had joined the DPC/PDPS. These hospitals had 474,981 beds, which represented more than half of the total number of beds (899,385 beds) in all general hospitals. (The data for general hospitals were obtained from the 2011 survey of hospitals.) Furthermore, additional 244 hospitals were preparing to join the DPC/PDPS (hereafter preparation hospitals). Table 1 gives the numbers of hospitals and beds by hospital size. The hospital size is measured by the number of beds in each hospital. A clear trend is evident in these data; namely, as the size of the hospitals becomes larger, the percentage of the DPC hospitals increases. Among small hospitals with fewer than 100 beds, only 5.7% joined the DPC/PDPS, and these hospitals had 10.3% of their beds in this category. On the other hand, among large hospitals with 500 or more beds, 65.1% were DPC hospitals, and these hospitals had more than three quarters (77.6%) of their beds in this category.

The introduction of the DPC/PDPS was one of the largest and most important revisions of the payment system since the Second World War. To ensure the effective use of medical resources, it is absolutely necessary to thoroughly analyze the DPC/PDPS and the revisions that have been implemented every two years. However, sufficient evaluations of the system have not yet been done. Empirical studies of the length of the hospital stay (LOS) and of medical payments using econometric models are necessary to evaluate the system correctly. A simple comparison of the ALOS by hospital is not sufficient; differences in types of disease must be considered, and the individual characteristics of patients and types of treatment must also be considered for

the same disease.

The Box-Cox [3] transformation model (hereafter, the BC model) is widely used to examine various problems in survival analysis, such as the LOS. However, since the error terms cannot have a normal distribution except when the transformation parameter is zero, the likelihood function under the normality assumption (hereafter, the BC likelihood function) is misspecified, and the maximum likelihood estimator (hereafter, the BC MLE) cannot be consistent. Alternative versions of the BC model have been proposed by various authors. However, in these versions the simplicity of the model is lost [14], and so these alternatives have not been widely used. Although the BC MLE is generally inconsistent, the BC MLE can be a consistent estimator if the "small σ" condition described in Bickel and Doksum [2] and the error terms are independent and identically distributed (i.i.d.) random variables. Nawata [8] proposed a new consistent estimator of the BC model. However, the estimator is inconsistent if the error terms are not i.i.d. random variables (hereafter non-i.i.d. case).

In this paper, we first consider a robust estimator that is consistent even for the non-i.i.d. case. Using these estimators, we consider Hausman [4] tests for the BC MLE; that is, we can determine whether we can use the BC MLE or not for the estimation of the model. We then evaluate the effects of the 2006 revision of the DPC/PDPS on the LOS and the medical payments for cataract operations（DPC category code: 020110). The number of cataract patients in Japan has increased rapidly with the aging of the population. According to a survey conducted by the Ministry of Health, Labour and Welfare [7], nearly 800,000 cataract operations are performed annually and nearly 2.5 billion yen are spent for cataract operations annually. In the case of cataract operations, a major change was made concerning the DPC classifications, the three periods, and the inclusive payments determined by the DPC/PDPS in the 2006 revision [12]. To evaluate the revision, we analyzed the data set obtained from 15 DPC hospitals (Hp 1-15） where one-eye cataract operations were performed both before and after the revision and the number of patients was more than 20 in each period. The number of patients in the data set is 4,019.

2. Estimators of the BC model

2.1 BC model

We consider the BC model

$$z_t = x_t'\beta + u_t, \quad y_t \geq 0, \qquad t = 1,2,\ldots,T, \tag{1}$$

$$z_t = \begin{cases} \dfrac{y_t^{\lambda}-1}{\lambda}, & \text{if } \lambda \neq 0, \\ \log(y_t), & \text{if } \lambda = 0, \end{cases}$$

where y_t is the LOS, x_t and β are the k-th dimensional vectors of the explanatory variables and the coefficients, respectively, and λ is the transformation parameter. The BC likelihood function is given by

$$\log L(\theta) = \sum_t \log f_t(\theta), \text{ and} \tag{2}$$

$$\log f_t(\theta) = \log\phi\{(z_t - x_t'\beta)/\sigma\} - \log\sigma + (\lambda - 1)\log y_t$$

where ϕ is the probability density function of the standard normal assumption, σ^2 is the variance of u_t and $\theta' = (\lambda, \beta', \sigma^2)$. The BC MLE is obtained as follows:

$$\frac{\partial \log L}{\partial \lambda} = 0, \quad \frac{\partial \log L}{\partial \beta} = \frac{1}{\sigma^2}\sum_t x_t(z_t - x_t'\beta) = 0, \text{ and} \tag{3}$$

$$\frac{\partial \log L}{\partial \sigma^2} = \sum_t \frac{(z_t - x_t'\beta)^2 - \sigma^2}{2\sigma^4} = 0.$$

Let $\theta_0' = (\lambda_0, \beta_0', \sigma_0^2)$ be the true parameter value of θ. Since $E[\frac{\partial \log L}{\partial \lambda}|_{\theta_0}] \neq 0$, the BC MLE is generally inconsistent. However, if the error terms are i.i.d. random variables and $\lambda_0\sigma_0/(1+\lambda_0 x_t'\beta_0) \to 0$ (in practice, $P[y_t < 0]$ is small enough), the BC MLE is not an only consistent but also efficient estimator and "small σ asymptotics" [2] of the BC MLE $\hat{\theta}_{BC}' = (\hat{\lambda}_{BC}, \hat{\beta}_{BC}', \hat{\sigma}_{BC}^2)$ are obtained by

$$\sqrt{T}(\hat{\theta}_{BC} - \theta_0) \to N[0, A^{-1}B(A')^{-1}], \tag{4}$$

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

2.2 Nawata's estimator

Nawata [8] considered the roots of the equations,

$$G_T(\theta) = \sum_t \Big[-\frac{1}{\sigma^2\lambda}[\{\frac{\log(\lambda x_t'\beta+1)}{\lambda} + \frac{z_t - x_t'\beta}{\lambda x_t'\beta+1}\}y_t^{\lambda} - z_t\}](z_t - x_t'\beta) \quad (5)$$

$$+\frac{1}{\lambda}\log(\lambda x_t'\beta+1) + \frac{z - x_t'\beta}{\lambda x_t'\beta+1} \Big] \equiv \sum_t g_t(\theta) = 0,$$

$$\frac{\partial \log L}{\partial \beta} = 0, \quad \text{and} \quad \frac{\partial \log L}{\partial \sigma^2} = 0.$$

$G_T(\theta)$ is obtained by the approximation of $\partial \log L / \partial \lambda$. If the first and third moments of u_t are zero, $E[G_T(\theta_0)] = 0$ is obtained, and the estimator obtained by Equation (5) is consistent. (Hereafter, I refer this estimator as the N-estimator.) The asymptotic distribution of the N-estimator $\hat{\theta}_N' = (\lambda_N, \beta_N', \sigma_N^2)$ is given by

$$\sqrt{T}(\hat{\theta}_N - \theta_0) \to N[0, C^{-1}D(C')^{-1}], \quad (6)$$

where $C = -E[\frac{\partial \ell_t(\theta)}{\partial \theta'}|_{\theta_0}]$,

$D = E[\ell_t(\theta_0)\ell_t(\theta_o)']$, $\ell_t(\theta)' = [g_t(\theta), \xi_t(\theta)', \varsigma_t(\theta)]$,

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

2.3 A robust estimator

The N-estimator is not consistent for the non-i.i.d. case. In this section, we consider a robust estimator which is consistent even for the non-i.i.d. case if $E(u_t \mid x_t) = 0$ and $E(u_t^3 \mid x_t) = 0$. Here, we use the first- and third-moment restrictions and consider the roots of the equations

$$M_T(\vartheta) = \sum_t m_t(\vartheta) = 0, \quad m_t(\vartheta) \equiv m(\vartheta, x_t, y_t) = (z_t - x_t'\beta)^3, \text{ and} \quad (7)$$

$$\sum_t x_t(z_t - x_t'\beta) = 0,$$

where $\vartheta' = (\lambda, \beta')$. Note that the second equation in (7) gives the least-squares estimator when the value of λ is given. Let $\vartheta_0' = (\lambda_0, \beta_0')$. Since $E[M(\vartheta_0)] = 0$, there exists a consistent root among the roots of (7). The

proof is given in Appendix A. Let $\hat{\vartheta}_R' = (\hat{\lambda}_R, \hat{\beta}_R')$ be the consistent root (hereafter, the robust estimator).

Let $\psi_t(\vartheta) = x_t(z_t - x_t'\beta)$ and $\omega_t(\vartheta)' = [m_t(\vartheta), \psi_t(\vartheta)']$. Suppose that $\frac{1}{T}\sum_t \frac{\partial \omega_t(\vartheta)}{\partial \vartheta'}|_{\vartheta_0}$ converges to a nonsingular matrix F in probability and $\frac{1}{T}\sum_t E[\omega_t(\vartheta_0)\omega_t(\vartheta_o)']$ converges to a nonsingular matrix H. Then the asymptotic distribution of $\hat{\vartheta}_R$ is given by

$$\sqrt{T}(\hat{\vartheta}_R - \vartheta_0) \to N[0, F^{-1}H(F')^{-1}]. \tag{8}$$

The proof is given in Appendix B.

Note that replacing A, B, C, D, F and H by $\lim_{\lambda_0 \to 0} A$, $\lim_{\lambda_0 \to 0} B$, $\lim_{\lambda_0 \to 0} C$, $\lim_{\lambda_0 \to 0} D$, $\lim_{\lambda_0 \to 0} F$ and $\lim_{\lambda_0 \to 0} H$, we can use the same formulas when $\lambda_0 = 0$.

3. Tests of the assumptions

3.1 A test of the "small σ" assumption

Since $G_T(\theta_0) = \frac{\partial \log L}{\partial \lambda}|_{\theta_0}$ under the "small σ" and i.i.d. assumptions are satisfied, $B = D$ and we get

$$\sqrt{T}(\hat{\lambda}_N - \hat{\lambda}_{BC}) \to N(0, \delta), \tag{9}$$

where $\delta =$ the first element of $(A^{-1} - C^{-1})B(A^{-1} - C^{-1})'$.

Hence we can perform a more precise test than a test where the asymptotic variance is calculated by a difference of two variances in the Hausman type test. Using $t = \sqrt{T}(\hat{\lambda}_N - \hat{\lambda}_{BC})/\sqrt{\hat{\delta}}$ as the test statistic, where $\hat{\delta}$ is the estimator of δ, we can test the "small σ" assumption; that is, we can test whether we can successfully use the BC MLE or not [11]. Since the rank of the variance-covariance matrix of $[\sqrt{T}(\hat{\lambda}_{BC} - \hat{\lambda}_N), \sqrt{T}(\hat{\beta}_{BC} - \hat{\beta}_N)']$ asymptotically becomes one, we cannot use any element of β in the

Hausman type test [13].

3.2 A test of the i.i.d. assumption

In the previous section, we consider the BC MLE and the N-estimators, however, they are not consistent for a non i.i.d. case even if the "small σ" assumption is satisfied. Therefore, it is also necessary to test the i.i.d. assumption using the robust estimator defined in Section 3. If both of the "small σ" and i.i.d. assumptions are satisfied,

$$\sqrt{T}(\hat{\lambda}_{BC} - \lambda_0) = \frac{1}{\sqrt{T}} a' \sum_t \ell(\theta_0) + o_p(1), \tag{10}$$

$$\sqrt{T}(\hat{\lambda}_N - \lambda_0) = \frac{1}{\sqrt{T}} c' \sum_t \ell(\theta_0) + o_p(1), \text{ and}$$

$$\sqrt{T}(\hat{\lambda}_R - \lambda_0) = \frac{1}{\sqrt{T}} d' \sum_t \omega(\vartheta_0) + o_p(1),$$

where a', c' and d' are the first rows of the A^{-1}, C^{-1} and D^{-1}. Therefore, the second test can be done as follows:

i) If the "small σ" is accepted, we compare the BC MLE and the robust estimator. The asymptotic variance of $\sqrt{T}(\hat{\lambda}_{BC} - \hat{\lambda}_N)$ is given by $a'Ba + d'Fd - 2a'E[\ell(\theta_0)\omega(\vartheta_0)']d$ and $E[\ell(\theta_0)\omega(\vartheta_0)']$ is estimated by $\frac{1}{T}\sum_t [\ell(\hat{\theta}_{BC})\omega(\hat{\vartheta}_{BC})']$ where $\hat{\vartheta}_{BC}' = (\hat{\lambda}_{BC}, \hat{\beta}_{BC}')$. We use the BC MLE if the i.i.d. assumption is accepted, and the robust estimator otherwise.

ii) If the "small σ" assumption is rejected, we compare the N-estimator and the robust estimator. The asymptotic variance of $\sqrt{T}(\hat{\lambda}_N - \hat{\lambda}_R)$ is given by $c'Bc + d'Hd - 2c'E[\ell(\theta_0)\omega(\vartheta_0)']d$. We use the N-estimator the i.i.d. assumption is accepted and use the robust estimator otherwise. Note that the N-estimator is not an efficient estimator, we cannot use a difference of two variances in this case.

4. Data and the summary of the 2006 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 86 hospitals in Japan from 2005 to 2007, from April to December of each year. For each patient, the DPC code, dates of hospitalization and discharge from the hospital, date of birth, sex, placement after hospitalization, ICD-10 code for the principal disease, purpose of hospitalization, presence of concurrent disease and the attending treatment if any, and medical payment amounts (including DPC-based, fee-for-service, and total payments) were reported [12].

In Japan, in addition to one-eye cataract operations (in which a single eye is operated on during a single period of hospitalization), two-eye cataract operations (in which both eyes are operated on during a single period of hospitalization) are also performed. It is to be expected that the two-eye operation would require a patient to stay in the hospital for a longer period of time. Therefore, we considered patients who underwent one-eye cataract operations only (the DPC code for this procedure after the 2006 revision is 020110xx97x0x0). To evaluate the effect of the 2006 revision of the DPC/PDPS, we used a data set obtained from 15 DPC hospitals (Hp 1-15) where one-eye cataract operations were performed both before (2005) and after the revision (2006 and 2007, hereafter 2006-7) and the number of patients was more than 20 in each period. For stays over 11 days, the per diem payment was determined through the conventional fee-for-service system in any case. Therefore, we only analyzed the data of patients whose stays were less than or equal to 11 days. A total of 4,019 patients were analyzed, 1,015 in 2005 and 3,004 in 2006-7.

In 2005, the ALOS was 4.36 days, the median was 4.0 days, the standard deviation was 1.60 days, the skewness was 0.942, and the kurtosis was 3.78 for all 1,015 patients. The maximum ALOS by hospital was 6.57 days (Hp 1), and the minimum was 2.10 days (Hp 5). The maximum was about 3.1 times larger than the minimum, and there were large differences among hospitals. In 2006-7, the ALOS was 4.08 days, the median was 4.0 days, the standard deviation was 1.08 days, the skewness was 0.906, and the kurtosis was 5.08 for all 3,004 patients. The maximum ALOS by hospital was 5.87 days (Hp 9), and the minimum was 2.40 days (Hp 5). The skewness and kurtosis values were large in some hospitals. The large values imply that there were patients who stayed in a hospital for long periods of time.

4.2 Summary of the revision for cataract operations

The 2006 revision of the DPC/PDPS contained a major change for cataract operations. Before the revision, different DPC codes were assigned depending on the

presence of concurrent diseases (without concurrent diseases： 0201103x01x000; with concurrent diseases： 0201103x01x010）, and the medical payments differed accordingly. After the revision, cataract operations were categorized under just one DPC code （020110xx97x0x） independent of the presence of concurrent diseases.

Furthermore, Periods I and II and the Specific Hospitalization Period were shortened, and the per diem inclusive payments were revised as well. The per diem inclusive payment in 2005 for patients without concurrent diseases was 2,509 points up to the third day of hospitalization, 1,855 points for the 4th-6th days, and 1,577 points for the 7th-10th days. For those with concurrent diseases, the per diem inclusive payment was 2,609 points up to the third day, 2,012 points for the 4th-7th days, and 1,710 points for the 8th-11th days. After the revision, the per diem inclusive payment became 2,418 points up to the second day, 1,787 points for the 3rd-4th days, and 1,519 points for the 5th-8th days for all cataract patients independent of the presence of concurrent diseases. In 2005, the inclusive payments for 7 days of hospitalization for patients without and with concurrent diseases were 14,669 and 15,875 points, respectively. On the other hand, the inclusive payment became 12,967 points after the revision. The inclusive payments were reduced by 1,702 points (11.6%) without concurrent diseases and by 2,908 points (18.3%) with concurrent diseases.

5. Results of estimation

When we analyzed the LOS, it was necessary to consider the characteristics of the patients and the types of principal disease as the explanatory variables. For the gender of patients, we used a Female Dummy (1: female, 0: otherwise). The numbers of male and female patients were 1,638 and 2,381, respectively. As a patient becomes older, the LOS tends to increase. Therefore, we used Age (the age of the patient) as an explanatory variable. The average and standard deviation of the age variable were 73.6 and 10.15, respectively. To analyze the impact of seasonal climate, we used a Winter Dummy (1: winter, 0: otherwise). The number of patients treated in winter was 400. The other variables representing the characteristics of the patients were: Concurrent (number of concurrent diseases), Complication (number of complications), Urgent Dummy（1: urgent hospitalization, 0: otherwise）, and Other Hospital Dummy (1: the patient was discharged to another hospital, 0: otherwise). A total of 359 patients had concurrent diseases. The average number of concurrent diseases for these patients was 1.84. A total of 120 patients had complications, and the average number of complications was 1.17. The numbers of patients who underwent urgent hospitalization and were discharged to other hospitals were 15 and 2, respectively.

Principal Disease Dummies based on the ICD-10 codes were used to analyze the effects of principal diseases. The base of the dummy variables was H25.0 (senile incipient cataract). The number of patients with H25.0 was 2,075, the number with H25.1 (senile nuclear cataract) was 177, the number with H25.2 (senile cataract, morgagnian type) was 19, the number with H25.8 (other senile cataract) was 48, the number with H26.0 (infantile and juvenile cataract) was 31, the number with H26.8 (other specified cataract) was 5, and the number with H26.9 (unspecified cataract) was 1,664. Fourteen Hospital Dummies (1: Hp k, 0: otherwise) were used to represent the influence of the hospital. The base of the hospital dummy variables was Hp4, where the number of patients was largest. To analyze the impact of the 2006 revision of the DPC/PDPS, which is the main purpose of this study, a 2006-7 Dummy（1: 2006-7; 0 otherwise）was used. After the revision, the existence of concurrent diseases no longer affected the inclusive payment. To analyze this effect, we added the product of the 2006-7 Dummy and Concurrent to the explanatory variables. The value of the empirical hazard function (=number of patients leaving on the t-th day/ number of patients staying that morning) showed two peaks as shown in Figure 1, one on the fifth day and the other on the eighth day (one week after the hospitalization). Therefore, we added the Day 8 Dummy (1: LOS is more or equal to 8 days; 0: otherwise). The transformation parameter tends to be underestimated when the LOS consists of a mixture of two different distributions, and this variable was excluded. Since the expected signs of the estimators were positive for Concurrent and Complication and negative for 2006-07 Dummy and (2006-7 Dummy × Concurrent), the one-tailed test was employed for these variables. The two-tailed test is used for other variables. Some hospitals were preparation hospitals in some parts of the sample period. We also added the Preparation Dummy (1: preparation hospital; 0 otherwise).

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

$$
\begin{aligned}
x_{ij}'\beta = {} & \beta_1 + \text{Female Dummy} + \beta_2 \text{Age} + \beta_3 \text{Winter Dummy} + \beta_4 \text{Concurrent} \\
& + \beta_5 \text{ Complication} + \beta_6 \text{ Urgent Dummy} + \beta_7 \text{ Other Hospital Dummy} \\
& + \beta_8 \text{ 2006-07 Dummy} + \beta_9 (\text{2006-7 Dummy} \times \text{Concurrent}) \\
& + \sum \beta_j \, j\text{-th Principal Disease Dummy} + \sum \beta_k \, \text{Hp}\, k \text{ Dummy} \\
& + \beta_\ell \, \text{Day 8 Dummy} + \beta_m \text{ Preparation Dummy}
\end{aligned}
\qquad (11)
$$

Tables 2, 3 and 4 present the results of the estimation by the BC MLE, N-estimator and robust estimators. The estimates of the transformation

parameters were $\hat{\lambda}_{BC}$ = 0.5241, $\hat{\lambda}_N = 0.4654$, and $\hat{\lambda}_R = 0.6634$ which were significantly smaller than 1.0; this result implied that some patients remained in the hospital for a long period of time.

We first tested the "small σ" assumption. We obtained $\hat{d}/\sqrt{n} = 0.0144$. Hence, the value of $t = \sqrt{T}(\hat{\lambda}_N - \hat{\lambda}_{BC})/\hat{d}$ was 4.063. Therefore, the "small σ" assumption was rejected at the 1% significance level in either case. I then tested the i.i.d. assumption. The value of $\sqrt{V(\hat{\lambda}_N - \hat{\lambda}_{BC})}$ was 0.0291 and $t = (\hat{\lambda}_R - \hat{\lambda}_N)/\sqrt{V(\hat{\lambda}_R - \hat{\lambda}_N)} = 6.808$, so the i.i.d. assumption was also rejected at the 1% significance level, indicating that the BC MLE could not be used in this study. The remainder of this paper is thus an analysis of the results of the robust estimator.

The estimate of $\hat{\lambda}_R$ was significantly smaller than 1.0; that implies some patients remained in the hospital for a long period of time. The estimates of the Female Dummy and Age were positive and significant at the 5% and1% level, respectively. That implies that the LOS becomes longer if a patient is female and the age becomes higher. The estimates of Concurrent and Complication were positive but not significant at the 5% level, so we did not admit the effects of these variables in this study. The estimates of Winter, Urgent, and Other Hospital Dummies were not significant at the 5% level. The estimates of the H26.0 and H26.8 Dummies were positive and significant at the 1% level. On the other hand, the estimates for the other types of diseases were not significant at the 5% level. For the estimates of the Hospital Dummies, the maximum was 1.034(Hp10), the minimum was -1.201 (Hp5), and the difference between the maximum and minimum values was 2.235 and was significantly large compared to the other types of variables. This means that there remained large differences among hospitals even if the influence of factors such as patient characteristics and types of principal diseases was eliminated. The estimate of the Day 8 Dummy was 2.043, and its t-value was 36.018. This means that many patients left the hospital after one-week hospitalization. These facts imply that it may be possible for some hospitals to reduce the LOS through the introduction of clinical paths and the proper management of hospitalization schedules [16]. The t-value of Preparation Dummy was -0.782 and the difference between the DPC and preparation hospitals was not admitted. The estimate of the 2006-7 Dummy was negative but not significant at

the 5% level. However, the estimate of the product of the 2006-07 Dummy and Concurrent was negative and at the 5% level. This means that the 2006 revision seems to have had the expected effect on the LOS for the presence of concurrent diseases.

6. Conclusion

In this paper, we analyzed the effect of the 2006 revision of the DPC/PDPS on the LOS and medical payments for single-eye cataract operations (DPC category code 020110) in Japan using the BC model. The Hausman test for whether we could use the BC MLE or not was used. We used the data of 4,017 patients collected from 15 DPC hospitals where cataract operations were reported both before and after the revision and where more than 20 patients underwent the operations in each period. We found that both "small σ" and i.i.d. assumptions were rejected and concluded that it is not proper to use the BC MLE for this data set.

We found that gender and age affected the LOS. As principal diseases, we found that H26.0 and H26.8 were significant. The ALOSs were significantly different among hospitals, despite the fact that the influence of patient characteristics was eliminated. The estimate of the Day 8 Dummy was significant, and its value was much larger than those of the other variables. The estimate of the 2006-7 Dummy and (2006-07 Dummy) $\times$Concurrent) was negative and significant. The 2006 revision seems to have had the expected effect on the LOS for the presence of concurrent diseases

It might have a significant impact on the medical payment for the cataract operations. The reduction in medical payments resulted in a reduction of hospital income. For some hospitals, the reductions were large, and these hospitals might face financial difficulties as a result of the revision. Patients could face serious difficulties if these hospitals were to go bankrupt. Therefore, to improve the DPC/PDPS, we must consider factors such as regional conditions [15], and we also need to perform the same analysis for other diseases. These are subjects for future studies.

Appendix A: Proof of the consistency

The proof of the consistency of the estimator is given using a modification of Nawata [9]. The following assumptions are made:

Assumption 1. $\{(x_t, u_t)\}$ are independent but not necessarily identically distributed. The distribution of u_t may depend on x_t.

Assumption 2. $\{u_t\}$ follow distributions in which the supports are bounded from below; that is, $f_t(u) = 0$ if $u \le -a$ for some $a > 0$ where $f_t(u)$ is the

probability (density) function. For any t, the following moment conditions are satisfied: (i) $E(u_t \mid x_t) = 0$, (ii) $E(u_t^3 \mid x_t) = 0$, and (iii) $\delta_1 < E(u_t^6 \mid x_t) < \delta_2$ for some $0 < \delta_1 < \delta_2 < \infty$.

Assumption 3. $\{x_t\}$ are independent, and $\delta_3 < E(x_t^2) < \delta_4$ for some $0 < \delta_3 < \delta_4 < \infty$. The distributions of $\{x_t\}$ and the parameter space of β are restricted so that $\inf_x(\lambda_0 x'\beta_0 + 1) > a \cdot \lambda_0$ and $\inf_{x,\vartheta}(\lambda\, x'\beta + 1) > c$ for some $c > 0$ in the neighborhood of $\vartheta_0' = (\lambda_0, \beta_0')$.

Assumption 4. $\frac{1}{T}\sum_t \frac{\partial \omega_t(\vartheta)}{\partial \vartheta'}|_{\vartheta_0}$ converges to a nonsingular matrix F in probability and $\frac{1}{T}\sum_t E[\omega_t(\vartheta_0)\omega_t(\vartheta_o)']$ converges to a nonsingular matrix H.

Assumption 5. (i) $\frac{1}{T}\sum_t x_t x_t'$ converges to a nonsingular matrix in probability and $\frac{1}{T}\sum_t x_t$ converges to a non-stochastic vector in probability, and (ii) $\frac{1}{T}\sum_t x_t z_t$, $\frac{1}{T}\sum_t x_t z_t^2$, $\frac{1}{T}\sum_t z_t x_t x_t'$ and $\frac{1}{T}\sum_t z_t^3$ and their first derivatives converge to (vectors of) continuous functions of λ in probability in the neighborhood of λ_0.

When λ is given, β is uniquely estimated by the least-squares method. Let $\hat{\beta}(\lambda)$ be the estimator. Let

$$h_T(\lambda) = \frac{1}{T} M_T\{\lambda, \hat{\beta}(\lambda)\} = \frac{1}{T}\sum_t \{z_t - x_t'(\sum_s x_s x_s')^{-1}(\sum_s x_s z_s)\}^3. \tag{12}$$

Under Assumption 5,

$$\hat{\beta}(\lambda) \xrightarrow{P} \beta(\lambda) \equiv \operatorname*{plim}_{T\to\infty}(\sum_t x_t x_t')^{-1}(\sum_t x_t z_t). \tag{13}$$

from Theorem 3.2.7 of Amemiya [1]. Therefore,

$$h(\lambda) \equiv \operatorname*{plim}_{T\to\infty} \frac{1}{T} M_T\{\lambda, \beta(\lambda)\} = \operatorname*{plim}_{T\to\infty} \frac{1}{T}\sum_t \{z_t - x_t'\beta(\lambda)\}^3 \tag{14}$$

exists and a continuous function of λ in the neighborhood of λ_0. From Theorema 3.2.5 of Amemiya [1],

$$\underset{T\to\infty}{p\lim} h_T(\lambda) = h(\lambda). \tag{15}$$

Let $h_T'(\lambda) = dh_T / d\lambda$. Then

$$h_T'(\lambda) = \frac{1}{T}\left[\frac{\partial M_T\{\lambda, \hat{\beta}(\lambda)\}}{\partial \lambda} + \frac{\partial M_T\{\lambda, \hat{\beta}(\lambda)\}}{\partial \hat{\beta}(\lambda)} \frac{\partial \hat{\beta}(\lambda)}{\partial \lambda}\right] \tag{16}$$

$$= \frac{3}{T}\sum_t \{z_t - x_t'\hat{\beta}(\lambda)\}^2 \left[\frac{1}{\lambda}\{y_t^\lambda \log(y_t) - z_t\} - x_t'(\sum_s x_s x_s')^{-1} \sum_s \frac{1}{\lambda}\{\log(y_s) y_s^\lambda - z_s\} x_s\right] \text{ if } \lambda \neq 0, \text{ and}$$

$$h_T'(\lambda) = \lim_{\lambda\to 0} h_T'(\lambda) = \frac{3}{2\cdot T}\sum_t \{z_t - x_t'\hat{\beta}(\lambda)\}^2 \left[\{\log(y_t)\}^2 - x_t'(\sum_s x_s x_s')^{-1} \sum_s \{\log(y_s)\}^2 x_s\right] \text{ if } \lambda = 0.$$

Therefore, $dh_T(\lambda)/d\lambda$ converges to $h'(\lambda) = dh/d\lambda$, which is a continuous function λ, in the neighborhood of λ_0 under Assumption 5.
When $\lambda = \lambda_0$, the model becomes an ordinary regression model and $\hat{\beta}(\lambda_0)$ is consistent. Hense

$$h(\lambda_0) = \underset{T\to\infty}{p\lim} \frac{1}{T} G_T(\theta_0) = \lim_{T\to\infty} \frac{1}{T}\sum_t u_t^3. \tag{17}$$

Since $E(u_t^3) = 0$, we get

$$h(\lambda_0) = 0, \tag{18}$$

by Theorem 3.3.1 of Amemiya [1].

Because $h_T(\lambda)$ and $h_T'(\lambda)$ are continuous functions of λ at $\lambda = 0$, we can treat the $\lambda = 0$ case the same as the $\lambda \neq 0$ case. From Assumption 5, $h'(\lambda)$ is continuous in the neighborhood of λ_0 and $h'(\lambda_0)$ does not become zero except in very special cases. Consequently, we can assume that $h'(\lambda_0) \neq 0$, and that there exists $\delta > 0$ such that $sign\{h'(\lambda)\} = sign\{h'(\lambda_0)\}$ and $|h'(\lambda)| \geq \gamma \equiv \frac{1}{2}|h'(\lambda_0)| > 0$ if $\lambda \in [\lambda_0 - \delta, \lambda_0 + \delta]$. By the mean value theorem, for any $\varepsilon \in (0, \delta)$,

$$h(\lambda_0 + \varepsilon) = h(\lambda_0 + \varepsilon) - h(\lambda_0) = h'(\lambda^*)\varepsilon \text{ and } h(\lambda_0 - \varepsilon) = h(\lambda_0 - \varepsilon) - h(\lambda_0) = -h'(\lambda^{**})\varepsilon \tag{19}$$

where λ^* and λ^{**} are values in $[\lambda_0 - \varepsilon, \lambda_0 + \varepsilon]$. Therefore,

$$sign\{h(\lambda_0 - \varepsilon)\} \neq sign\{h(\lambda_0 + \varepsilon)\}, |h(\lambda_0 - \varepsilon)| > \gamma\varepsilon, \text{ and } |h(\lambda_0 + \varepsilon)| > \gamma\varepsilon. \tag{20}$$

Since $h_T(\lambda_0 - \varepsilon) \xrightarrow{P} h(\lambda_0 - \varepsilon)$ and $h_T(\lambda_0 + \varepsilon) \xrightarrow{P} h(\lambda_0 + \varepsilon)$,

$$P\Big[\ sign\{h_T(\lambda_0-\varepsilon)\}\neq sign\{h_T(\lambda_0+\varepsilon)\},|\,h_T(\lambda_0-\varepsilon)|>0,\ \text{and}\ |\,h_T(\lambda_0+\varepsilon)|>0\ \Big]\to 1. \quad (21)$$

Here, $h_T(\lambda)$ is a continuous function of λ in the neighborhood of λ_0. From the intermediate value theorem, $h_T(\lambda)=0$ for some $\lambda\in[\lambda_0-\varepsilon,\lambda_0+\varepsilon]$ if $sign\{h_T(\lambda_0-\varepsilon)\}\neq sign\{h_T(\lambda_0+\varepsilon)\}$, $|\,h_T(\lambda-\varepsilon)|>0$ and $|\,h_T(\lambda_0+\varepsilon)|>0$. Therefore,

$$P[\text{ There exists }\hat{\lambda}\text{ such that }h_T(\hat{\lambda})=0\text{ and }\hat{\lambda}\in[\lambda_0-\varepsilon,\lambda_0+\varepsilon]\ ]\to 1. \quad (22)$$

Since (22) holds for any $\varepsilon\in(0,\delta)$, $h_T(\lambda)=0$ has a consistent root of λ_0. Since $\hat{\beta}(\hat{\lambda})$ is obtained by the least-squares method, it is a consistent estimator when $\hat{\lambda}\xrightarrow{P}\lambda_0$. Hence, there exists a consistent root among the roots of (7).

Appendix B: Proof of the asymptotic distribution

Since

$$\omega(\vartheta)=\sum_t\omega_t(\vartheta)=\begin{bmatrix}M_T(\vartheta)\\ \sum_t\psi_t(\vartheta)\end{bmatrix}, \quad (23)$$

we get

$$\sqrt{T}(\hat{\vartheta}_R-\hat{\vartheta}_0)=-[\frac{1}{T}\frac{\partial\omega}{\partial\vartheta'}|_{\vartheta^*}]^{-1}\frac{1}{\sqrt{T}}(\vartheta_0), \quad (24)$$

where ϑ^* is some value between $\hat{\vartheta}$ and ϑ_0. Here,

$$\omega_t(\vartheta_0)=\begin{bmatrix}u_t^3\\ x_tu_t\end{bmatrix}. \quad (25)$$

Therefore, $E[\omega_t(\vartheta_0)]=0$. Since the variables $\{\omega_t(\vartheta_0)\}$ are independent and the Lindberg condition is satisfied under Assumptions 2, 3 and 4 we obtain

$$\frac{1}{\sqrt{T}}\omega(\vartheta_0)\to N(0,H), \quad (26)$$

from Theorem 3.3.6 in Amemiya [1].

Since $\partial\omega/\partial\vartheta=\begin{bmatrix}\frac{3}{\lambda}\sum_t(z_t-x_t'\beta)^2\{z_t\log(y_t)-z_t\} & -3\sum_t(z_t-x_t'\beta)^2x_t'\\ \frac{1}{\lambda}\sum_t x_t\{z_t\log(y_t)-z_t\} & -\sum_t x_tx_t'\end{bmatrix}$, (27)

$$\frac{1}{T}\frac{\partial \omega(\vartheta)}{\partial \vartheta'}\Big|_{\vartheta^*} \xrightarrow{P} F,$$

from Theorem 4.1.4 in Amemiya [1]. From Theorem 4.1.3 in Amemiya [1], the asymptotic distribution of $\hat{\vartheta}_R$ is given by Equation (8).

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Table 1. Numbers of hospitals and beds by hospital size

Hospital sizes (numbers of beds)							
	less than 100	100–200	200–300	300–400	400–500	500 or more	total
Number of hospitals							
A: DPC Hospitals *	179	338	304	252	153	270	1,496
B: All general hospitals **	3,126	2,350	769	569	569	415	7,528
A/B (%)	5.7%	14.4%	39.5%	44.3%	26.9%	65.1%	19.9%
Total number of beds							
C: DPC Hospitals *	11,924	50,581	75,291	86,277	67,459	183,499	47,4981
D: All general hospitals **	116,262	193,237	111,703	139,231	102,341	236,611	899,385
C/D (%)	10.3%	26.2%	67.4%	62.0%	65.9%	77.6%	52.8%

Source: DPC Evaluation Division (2013).

*: As of April 2013.

**: 2011 survey data.

Table 2. Results of estimation (BC MLE)

Variable	Estimate	Standard error	t-value	Variable	Estimate	Standard error	t-value
Constant	1.8480	0.0607	30.4244	Hospital dummies			
FEMALE	0.0236	0.0108	2.1810	Hp 1	0.6458	0.0397	16.2684
AGE	0.002602	0.000624	4.1664	Hp 2	−0.5051	0.0139	−36.3771
Winter Dummy	−0.0254	0.0143	−1.7718	Hp 3	−0.4830	0.0231	−20.9097
Concurrent	0.0435	0.0343	1.2698	Hp 5	−1.0379	0.0610	−17.0085
Complication	0.0160	0.0209	0.7626	Hp 6	0.2673	0.0153	17.5042
Urgent Dummy	0.0329	0.1605	0.2049	Hp 7	0.0883	0.0355	2.4886
Other Hospital Dummy	−0.1189	0.0989	−1.2014	Hp 8	−0.2569	0.0528	−4.8631
2006-7dummy	−0.0591	0.0432	−1.3698	Hp 9	−0.0441	0.0264	−1.6740
(2006-7 Dummy) × concurrent	−0.0654	0.0364	−1.7975	Hp 10	0.8275	0.0323	25.6203
				Hp 11	−0.3153	0.0312	−10.1086
Principal disease dummies				Hp 12	−0.0784	0.0266	−2.9442
H25.1	−0.0273	0.0254	−1.0763	Hp 13	0.5283	0.0339	15.5949
H25.2	0.0771	0.1088	0.7092	Hp 14	0.4056	0.0738	5.4994
H25.8	0.0556	0.0546	1.0186	Hp15	0.4807	0.0372	12.9231
H26.0	0.4653	0.1030	4.5177	Day 8 Dummy	1.5965	0.0502	31.8047
H26.8	0.2530	0.0481	5.2656	Preparation Dummy	−0.0335	0.0451	−0.7434
H26.9	−0.0221	0.0198	−1.1147	λ	0.5241	0.0256	20.4359
R2	0.7026			LogL	−3801.93		

Table 3. Results of estimation (N-Estimator)

Variable	Estimate	Standard error	t-value	Variable	Estimate	Standard error	t-value
Constant	1.7705	0.0564	31.4000 **	Hospital dummies			
FEMALE	0.0214	0.0100	2.1517 *	Hp 1	0.5895	0.0359	16.4104 **
AGE	0.00240	0.00058	4.1666 **	Hp 2	−0.4697	0.0129	−36.3617 **
Winter Dummy	−0.0233	0.0132	−1.7575	Hp 3	−0.4497	0.0212	−21.1650 **
Concurrent	0.0400	0.0312	1.2815	Hp 5	−0.9761	0.0561	−17.3866 **
Complication	0.0146	0.0192	0.7599	Hp 6	0.2455	0.0140	17.5547 **
Urgent Dummy	0.0252	0.1485	0.1696	Hp 7	0.0810	0.0328	2.4701 **
Other Hospital Dummy	−0.0528	0.0399	−1.3221	Hp 8	−0.2416	0.0488	−4.9496 **
2006-7Dummy	−0.0528	0.0399	−1.3221	Hp 9	−0.0426	0.0243	−1.7502
(2006-7 Dummy) × concurrent	−0.0597	0.0331	−1.8001 +	Hp 10	0.7534	0.0287	26.2490 **
				Hp 11	−0.2944	0.0287	−10.2499 **
Principal disease dummies				Hp 12	−0.0753	0.0248	−3.0373 **
H25.1	−0.0253	0.0233	−1.0855	Hp 13	0.4820	0.0307	15.7009 **
H25.2	0.0712	0.0999	0.7131	Hp 14	0.3671	0.0682	5.3859 **
H25.8	0.0515	0.0499	1.0315	Hp15	0.4403	0.0343	12.8538 **
H26.0	0.4246	0.0949	4.4727 **	Day 8 Dummy	1.4396	0.0438	32.8679 **
H26.8	0.2353	0.0441	5.3369 **	Preparation Dummy	−0.0304	0.0418	−0.7267
H26.9	−0.0199	0.0182	−1.0953	λ	0.4654	0.0299	15.5699 **
R2	0.6999						

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Table 4. Results of estimation (Robust estimator)

Variable	Estimate	Standard error	t-value	Variable	Estimate	Standard error	t-value
Constant	2.0502	0.0733	27.9744	Hospital dummies			
FEMALE	0.0295	0.0131	2.2483	Hp 1	0.8022	0.0471	17.0411
AGE	0.00315	0.00076	4.1162	Hp 2	−0.6000	0.0164	−36.6003
Winter Dummy	−0.0313	0.0173	−1.8167	Hp 3	−0.5721	0.0281	−20.3377
Concurrent	0.0533	0.0429	1.2409	Hp 5	−1.2014	0.0767	−15.6600
Complication	0.0198	0.0258	0.7684	Hp 6	0.3273	0.0184	17.7642
Urgent Dummy	0.0559	0.1933	0.2892	Hp 7	0.1083	0.0427	2.5365
Other Hospital Dummy	−0.1542	0.1265	−1.2191	Hp 8	−0.2967	0.0643	−4.6147
2006-7dummy	−0.0772	0.0523	−1.4742	Hp 9	−0.0476	0.0320	−1.4884
(2006-7 dummy) *concurrent	−0.0816	0.0456	−1.7902	Hp 10	1.0341	0.0317	32.6546
				Hp 11	−0.3712	0.0387	−9.6047
Principal disease dummies				Hp 12	−0.0860	0.0316	−2.7176
H25.1	−0.0330	0.0313	−1.0551	Hp 13	0.6572	0.0395	16.6450
H25.2	0.0931	0.1331	0.6990	Hp 14	0.5136	0.0871	5.8961
H25.8	0.0668	0.0676	0.9883	Hp15	0.5925	0.0439	13.4823
H26.0	0.5787	0.1248	4.6374	Day 8 Dummy	2.0430	0.0567	36.0182
H26.8	0.3010	0.0599	5.0261	Preparation dummy	−0.0426	0.0545	−0.7821
H26.9	−0.0283	0.0244	−1.1598	Lambda	0.6634	0.0043	155.6181
R2	0.7090						

*: significant at the 5% level, +: significant at the 5% level (one-tailed test),

**: significant at the 1% level

Fig.1 Hazard Rate by the LOS