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Takeda, Midori and Xie, Jun and Kurita, Kenichi and Managi, Shunsuke

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Advancing Hospital Sustainability: A Multidimensional Index Integrating ESG and Digital Transformation

Midori Takeda1*, Jun Xie1*, Kenichi Kurita1,2, Shunsuke Managi1**

1 Urban Institute and Department of Urban and Environmental Engineering, School of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, 819-0395, Japan
2. Advanced Asian Archaeology Research Center and Faculty of Social and Cultural Studies, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, 819-0395, Japan

* These two authors contributed equally to this work
** Correspondence: managi@doc.kyushu-u.ac.jp

Abstract

Today, most healthcare costs in Japan depend on insurance premiums and public funds. Since the working population supports both groups, it will be difficult to maintain medical expenses in the future due to further declining birth rates and an aging society. Therefore, the sustainability of hospitals is a serious issue. While many methods have been developed to evaluate hospital performance and effectiveness, only some have been used to evaluate sustainability. Against this background, this study develops a comprehensive evaluation system that integrates ESG and digital transformation (DX) into a hospital efficiency and effectiveness assessment. We utilize open databases on hospital performance, financial reports, and scraped information disclosed on hospital websites. SBM (slack-based model)-DEA and super efficiency SBM-DEA were combined to assess hospital sustainability, including overall sustainability and three dimensions of hospital efficiency, effectiveness, and ESG/DX. The results showed that ESG/DX performance, efficiency, and effectiveness positively correlated with hospital sustainability in all groups of hospitals. It also showed that while effectiveness and ESG/DX performance positively contribute to operational efficiency in smaller hospitals, ESG/DX performance negatively contributes to profitability. In rehabilitation hospitals, effectiveness contributes negatively to profitability, indicating that improving effectiveness requires more significant costs than in other hospitals. These findings indicated that while ESG, DX, and effectiveness improve hospital sustainability, the costs of promoting ESG/DX are significant for smaller and rehabilitation hospitals. This index could benefit hospital management and policy recommendations regarding promoting ESG and DX.

Highlights

- A comprehensive hospital sustainability index was developed, including operational efficiency, effectiveness, and ESG/DX.
- For small hospitals, effectiveness and ESG/DX practice were shown to contribute positively to operational efficiency, while ESG/DX practice contributed negatively to profitability.
- In rehabilitation hospitals, effectiveness contributes negatively to profitability, indicating that improving effectiveness may be a significant cost.
- The implementation of ESG and DX and improved effectiveness may contribute to hospital sustainability.

Keywords

Hospital; Sustainability; ESG; SBM-DEA; Super-efficiency DEA

1. Introduction

Global spending on healthcare has continued to increase due to the increasing sophistication of medical care and the growing aging of society [1-3]. In addition, in response to the COVID-19 pandemic, healthcare spending as a percentage of gross domestic product (GDP) has risen sharply since 2020 [1, 2]. Among OECD countries, the country with the highest healthcare spending is the United States, with 18.8% of GDP, followed by Canada at 12.9% and Germany at 12.8%. Japan has 11.1% (11th out of 38 countries), with an average of 9.7% and a range of 4.6-18.8% [1]. The significant expenditure on healthcare, especially in an aging society, raises concerns about the economic and social sustainability of the healthcare system.

The Japanese healthcare system is characterized by all citizens being covered by public medical insurance, which enables them to receive high-quality medical care at a low out-of-pocket cost [4]. On the other hand, the rising burden of public expenditures and social insurance premiums is raised as a problem [4]. Because of the above, as a system specific to Japan, large costs are spent to improve quality, and efficient use of medical resources and sustainability assessment are essential. The integration of sustainability and efficiency in healthcare services is pivotal in addressing the contemporary challenges of environmental impact, economic feasibility, and social responsibility. However, most literature focuses on the hospital productivity or quality[5, 6], and studies on quantifying the ESG (or sustainability) quality of hospital healthcare services are rare.

To fill this void, this study aims to develop a comprehensive index of hospital sustainability that integrates environmental, social, and governance (ESG) factors and digital transformation (DX) into conventional hospital efficiency and effectiveness evaluations. Using the estimated hospital sustainability index, we address the following questions: What is the significance of ESG/DX issues for hospital sustainability, and how are ESG/DX practices linked to hospital operational efficiency and profitability? For this purpose, we constructed a dataset by combining disclosed ESG/DX information on hospital websites, financial data, and an open database of hospital performance. Given the unique Japanese healthcare system, we focused on hospitals in Japan and estimated the multidimensional sustainability of 155 hospitals, covering large, small-scale, rehabilitation, and chronic-care hospitals. The main findings show that ESG/DX practices are an integral part of the sustainability index and are comparable to some indicators of clinical and financial efficiency. Although clinical effectiveness is the most important factor for hospital efficiency, ESG/DX practices are positively correlated to hospital operational efficiency and have been adopted as a differentiating strategy in the healthcare sector. However, ESG/DX practices are negatively related to profitability in the short run, which is often found in other industries. Although the idea of corporate sustainability is widely rooted in many industries, hospitals, as public services, are still at the early age of promoting ESG/DX practices, which may result in high costs without a commensurate financial return. We also found that improving the effectiveness of rehabilitation hospitals may result in a significant financial burden. To our knowledge, this is the first attempt to empirically evaluate hospital sustainability that integrates efficiency, effectiveness, and ESG/DX. By introducing ESG/DX factors into the evaluation system, this study offers a comprehensive picture of hospital sustainability, providing practical implications for improving ESG/DX practices in hospitals.

The remainder of this paper is organized as follows. The next section presents the literature review. The third section explains the methodology and data. The fourth section presents the empirical results. The fifth section concludes this paper.

2. Related Literature

Our paper contributes to several strands of hospital healthcare service. First, our paper is more closely related to hospital sustainability. Recent studies have elucidated various dimensions of this integration, ranging from infrastructure and patient care to economic and urban planning considerations as follows:

Hospital Sustainability Using DEA: Pederneiras et al. (2023) utilized a hybrid Data Envelopment Analysis (DEA) approach to assess the sustainability of Portuguese public hospitals [7]. Their innovative methodology incorporated decision-maker preferences and criteria interactivity, providing a comprehensive evaluation from environmental, social, and economic perspectives. The study revealed that while a significant portion of hospitals exhibited efficiency in these areas, only one was found to be entirely sustainable.

Impact of Rural Hospital Mergers on Service Lines: Henke et al. (2021) explored the consequences of rural hospital mergers for the availability of inpatient service lines [8]. Their analysis of hospital discharge data indicated that merged hospitals often eliminate some service lines, potentially reducing healthcare access in rural communities.

Quantifying Hospital Services by Carbon Footprint: Alshqaqeeq et al. (2020) focused on the environmental aspect of hospital sustainability by quantifying hospital services through their carbon footprint [9]. This approach is crucial for addressing growing environmental concerns, and the healthcare sector has made significant contributions to carbon emissions. Their findings emphasize the need for hospitals to adopt more environmentally sustainable practices.

Systematic Review of Environmental Sustainability in Hospitals: McGain and Naylor (2014) systematically reviewed the environmental impacts of hospitals [10]. Their research encompassed a range of factors, including architectural design, device use, and clinical practices. This review identified gaps in the current understanding of hospital sustainability, indicating the need for more detailed assessments to guide policy and decision-making.

Second, this paper relates to the literature on hospital efficiency analysis. Most hospital efficiency studies use the Data Envelopment Analysis (DEA) approach as follows:

Incorporation of Quality in Efficiency Analysis: Shimshak, Lenard, and Klimberg (2009) introduced an innovative approach to DEA by integrating quality metrics into the analysis [11]. This modification of the conventional DEA model aims to provide a more holistic efficiency assessment.

Efficiency Analysis in Crisis Conditions: The study by Henriques and Gouveia (2022) utilized value-based DEA to assess the impact of the COVID-19 pandemic on the efficiency of Portuguese hotels [12]. Although applied to the hospitality sector, this approach offers relevant insights for hospital efficiency analysis, particularly under crisis conditions. This study highlights the importance of adaptability and resilience as efficiency metrics during unprecedented challenges.

Advanced Statistical Methods in Efficiency Evaluation: Staat (2006) employed a DEA bootstrap methodology to assess the efficiency of hospitals in Germany [13]. This approach underscores the importance of employing robust statistical techniques in efficiency analysis. Bootstrapping in DEA addresses the variability and uncertainty inherent in efficiency scores, providing more statistically reliable results.

Identifying Determinants of Hospital Efficiency: Chang's (1998) research focused on identifying determinants of hospital efficiency, particularly in government-owned hospitals in Taiwan [14]. Understanding these determinants is crucial for policy formulation and management decisions.

Link Between Quality Improvement and Efficiency: Chang et al. (2011) explored the relationship between quality improvement initiatives and hospital productivity in their study on the Taiwan Quality Indicator Project [15]. This research is pivotal in demonstrating how quality indicators directly impact efficiency and productivity in the healthcare sector.

These studies provide a multidimensional view of hospital sustainability and efficiency, highlighting the importance of integrated approaches considering environmental, economic, and social factors. These findings suggest that while progress has been made, there are still considerable challenges and opportunities for improvement in the healthcare sector.

This study provides a more comprehensive assessment of hospital sustainability than did previous studies. In addition to assessing clinical efficiency, effectiveness, and safety, this study analyses hospital sustainability by integrating data on financial efficiency and ESG and DX disclosure rates. This would provide important insights into the relationship between each of these dimensions, as well as suggestions for improving hospital sustainability.

Third, our paper is related to healthcare services in Japan. Then, we review the related literature on the healthcare system in Japan to explain the uniqueness of the system.

Healthcare system compared to other countries: As a system, Japan, Germany, and France have social insurance systems, while the United Kingdom provides public insurance services through a tax system [16]. The United States is dominated by private insurance, with state- and public-run programs including Medicare for individuals older than 65 and disabled people and Medicaid for low-income individuals [17, 18].

Healthcare Insurance System in Japan: The Japanese healthcare insurance system is based on Kokumin-Kaihoken, a nationwide universal health coverage (UHC) public insurance system. The Japanese UHC (JP-UHC) is one of the world's most comprehensive healthcare systems [19, 20]. The JP-UHC covers all necessary medical expenses, including doctor visits, hospitalization, surgery, and prescription drugs. Patients typically pay 30% of the medical costs, but some exemptions are provided for infants and elderly individuals, depending on their income level. Premiums are calculated based on income, with lower premiums for those with lower incomes.

According to the Ministry of Health, Labour and Welfare in Japan, total medical expenses in 2019 amounted to 44.4 trillion yen (= 331 billion dollars), with 49.4% of medical expenses covered by insurance premiums from the insured and employers, 38.3% by public expenses, and 11.7% by the patient's out-of-pocket payments [21].

The JP-UHC focuses on preventive medical care and early detection of illness. As a result, Japan has one of the longest life expectancies in the world and a low infant mortality rate. The JP-UHC is a model for effective and comprehensive healthcare. Moreover, the system still faces challenges, such as an aging population and rising healthcare costs [22, 23]. As a significant disadvantage, social insurance premiums are rising annually, and the burden is concentrated on the working-age population [24].

Medical Fee Payment System in Japan: Central to Japan's healthcare financing is the Medical Fee Payment System, which comprises two primary components: the Fee-For-Service (FFS) system and the Diagnosis Procedure Combination (DPC) payment system [25]. The FFS system has been a traditional component since the establishment of the current health insurance system in 1961 [26]. The system functions by reimbursing healthcare providers based on a point system. A specific number of points are allocated to each service, pharmaceutical product, or medical device provided; these points are then converted into monetary compensation based on values set by the Ministry of Health, Labour, and Welfare (MHLW).

DPC (Diagnosis Procedure Combination): The DPC system, introduced in the early 2000s, represents a significant evolution in Japan's healthcare payment system [27]. The DPC system was developed to standardize and increase transparency in healthcare in response to growing concerns about healthcare costs, length of stay, and the needs of an aging population. The aim is to improve the overall quality of care, reduce variation between hospitals, and reduce the average length of stay.

The DPC system is notable for its extensive use of coding based on diagnosis categories and procedure groups. Like the Diagnosis-Related Groups (DRG) system used in the United States, the DPC system assigns codes primarily based on combinations of diagnoses and procedures [28].

Despite its benefits, the DPC system has also presented challenges. It has decreased the average length of hospital stays but has been associated with increased healthcare costs in some sectors. Additionally, there are concerns about the potential for hospitals to increase the number of inpatients due to the per-diem rate structure. The complexity of the reimbursement process for medical technologies under this system has also been noted, particularly in capturing the full extent of innovation in new technologies and creating new functional categories or medical procedure codes [25].

In summary, the Japanese healthcare system is generous, and patients can receive high-quality medical services at a low out-of-pocket cost. Patients can receive services at almost the exact cost at any hospital. For this reason, unlike analyses in other countries, this study did not compare cost differences between hospitals. The demand for medical services is expected to increase due to an aging society, and it is essential to distribute limited medical resources efficiently and sustainably. A new assessment of hospital evaluation in this study will contribute to reconsidering the nature of hospitals.

3. Methodology

3.1 Concept of the Hospital Sustainability Evaluation System

Our objective was to develop and analyze an evaluation methodology encompassing sustainability, including ESG, DX, and financials, and hospitals' traditional functional and qualitative evaluation. Hospital sustainability, which was the objective of the evaluation in this study, was categorized into three dimensions: "Efficiency," "Effectiveness," and "ESG/DX" (Figure 1). The "Efficiency" dimension considers efficiency in healthcare and financial efficiency. "Effectiveness" is considered clinical effectiveness and safety in healthcare. In addition to considering environmental, social, and governance factors, "ESG/DX" considered the degree of digital transformation. The variables used for each are shown in Table 1. The model is based on the DEA model described in the next section, which scores each hospital on "hospital sustainability" and three dimensions.

3.2 DEA model

The DEA model has been widely used for performance evaluation in the healthcare sector [29], as well as sustainability issues such as carbon emissions [30]. In this study, multiple DEA models are applied to assess hospital performance in terms of efficiency, effectiveness, ESG performance, and integrated sustainability [31]. We start with the BCC model [32] as the basic model and then extend it to estimate sustainability using additive models. **Equation (1)** illustrates an input-oriented (variable return to scale) VRS BCC model. Here, X indicates the inputs, and Y indicates the outputs. s denotes the slacks.

$$\max \quad \theta^* - \varepsilon s^+ - \varepsilon s^-$$

$$\text{Subject to } \theta^* x_0 = X\lambda + s^-$$
$$y_0 = Y\lambda - s^+$$
$$\sum_{j=1}^{n} \lambda = 1,\ \lambda \geq 0,\ s^- \geq 0, s^+ \geq 0 \qquad (1)$$

The non-radial model computes the individual inefficiency of inputs and outputs rather than considering the same proportional changes in radial models [33]. Furthermore, the additive DEA approach allows us to decompose the inefficiency of inputs and outputs [34]. We applied a slack-based model (SBM) [35, 36] to estimate hospital sustainability. Furthermore, given the possible undesirable outputs, we use the SBM-DEA model with undesirable outputs to estimate sustainability [37, 38], as shown in **Equation (2)**. x_{io} denotes the inputs, y_{r0}^g denotes the outputs, and y_0^b denotes the undesirable outputs.

$$\rho^* = \min \frac{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{io}}}{1 + \frac{1}{s_1 + s_2}\left(\sum_{r=1}^{s_1} \frac{s_r^g}{y_{r0}^g} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{r0}^b}\right)}$$

$$\text{Subject to } x_0 = X\lambda + s^-$$
$$y_0^g = Y^g\lambda - s^g$$
$$y_0^b = Y^b\lambda + s^b$$
$$s^- \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0 \qquad (2)$$

We further applied super efficiency SBMs to distinguish the units on the efficient frontier [39, 40]. As shown in Equation (3), ρ^* measures the nearest distance from DMU (x_0, y_0) to the efficient frontier constructed without itself. Here, the undesirable outputs are treated as inputs. All the performance evaluations were conducted by subgrouping the hospitals, which included Group 1, Group 2, rehabilitation, and chronic-care hospitals. These hospital subgroups were categorized based on the Japan Council for Quality Health Care (JCQHC) classification. Group 1 was defined as a small to medium-sized hospital that supports regional medical care in a relatively small area, such as a daily living area. Group 2 was defined as a core hospital that supports regional medical care, mainly acute-stage medical care, in a relatively large area, such as a secondary medical care area. Rehabilitation hospitals provide rehabilitation medical care, and chronic-care hospitals provide chronic care through medical treatment beds. All the models are under variable returns to scale. The results consist of the SBM-DEA model and super-efficiency SBM results. Higher scores indicate better performance.

$$\rho^* = \min \frac{1 + \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{io}}}{1 - \frac{1}{s}\sum_{r=1}^{s} \frac{s_r^+}{y_{r0}}}$$

Subject to $x_0 = \sum_{j=1,j\neq 0}^{n} x_j\lambda_j - s^-$

$$y_0 = \sum_{j=1,j\neq 0}^{n} y_j\lambda_j + s^+$$
$$s^- \geq 0, s^+ \geq 0,, \lambda \geq 0 \quad (3)$$

3.3 Data and sample

The indicators of the inputs and outputs are summarized in **Table 1**. We separately evaluated the efficiency, effectiveness, ESG/DX, and overall sustainability scores based on multiple DEA models. We collected all the indicators from 4 data sources. Efficiency and effectiveness items are from publicly available accreditation reports from the Hospital Function Survey Japan in 2021 and JCQHC reports as of 2022. The JCQHC reports provide a thorough qualitative assessment of clinical effectiveness and safety. Our models incorporate relevant assessment items in the dimensions, including quality improvement, medical treatment, clinical function, patient safety, and infection control (see sub-indicators in **Table 1**). All the items are evaluated on a four-point scale from best to worst (S, A, B, and C). We then quantified these grades into points ranging from 4 to 1. The sub-indicator points are the average of the corresponding items, and the indicator points are the sum of the sub-indicators. ESG data were collected from the official hospital homepage website. We used 8 items from DX, 11 items from the environmental domain, 16 items from the social domain, and 6 items from the governance domain (for details, see **Appendix Table A1**). The degree of transparency for each domain is determined by detecting the keywords related to each item from the contents disclosed on the hospital homepages. Each item is assigned a value of 1 if relevant keywords are identified and 0 if not. To avoid bias, we did not consider keyword frequency because it is not directly linked to effort. This study focuses solely on the transparency of ESG/DX, which is determined by summing related items. The social and governance sub-indicators collected from JCQHC reports include local collaboration, accessibility, and governance assessment. The indicator points are the sum of the sub-indicators. To incorporate them into the DEA model, we add one point to the DX and Environmental indicators to ensure that their minimum value is not zero. Similarly, 0.1 points are added to the indicator 'Average days of inpatient.' The hospital's financial information (fixed assets, current assets, operating expenses, and operating revenues) was provided by Nikkei Media Marketing Inc. After excluding hospitals with missing values, we ultimately included a sample of 155 hospitals in the Kyushu region in Japan (Figure 2).

4. Empirical results

4.1 Estimated hospital performance

Table 2 presents the estimated results of hospital performance in terms of efficiency, effectiveness, ESG/DX, and sustainability, along with the financial indicators used in the regression analysis. Hospitals with scores less than 1 are measured by the SBM-DEA, and those with scores greater than 1 are estimated by the super-efficiency SBM to distinguish the hospitals on the efficient frontier. The results indicate that hospital efficiency was the lowest at 0.04, while it was the highest at 2.38. The ESG/DX scores exhibit the highest standard deviation among all groups, indicating significant variances in hospital ESG/DX performance. In practice, the promotion of ESG activities in hospitals is still at an early stage. Only a few hospitals are aware of sustainability issues and are improving their transparency on ESG/DX, which leads to great disparities in ESG/DX performance.

[insert **Table 2** here]

Figure 3 shows the correlation between the four hospital performance scores. There is a strong positive relationship between efficiency, effectiveness, and sustainability scores, the most important components in sustaining hospital operations. ESG/DX scores also showed positive relationships with other scores but more weakly, indicating a lack of ESG awareness in hospitals. Although some large hospitals have begun to link their operations to sustainability and disclose information to stakeholders, most hospitals are still less engaged in sustainability activities. We will further investigate the financial implications of ESG practices in the next section. By comparing hospital performance in different regions (see **Figure 4**), we found that the hospital with the highest score (2.04 point sustainability score) was located in the developed region Fukuoka. There are fewer hospitals with high scores in Saga, Kumamoto, and Oita than in other areas (see details in **Appendix Table A3**).

[insert **Figure 3** here]
[insert **Figure 4** here]

Figure 5 shows the inefficiency of each input and output by hospital group. Here, a negative value indicates the degree to which the variable needs to be improved, and a positive value is calculated based on super-efficiency SBM, indicating the degree to which it outperforms the variable. Clinical effectiveness and average inpatient days exhibit greater inefficiency variances than other assessment indicators, making them the most critical components in determining hospital sustainability [41]. The DX and ESG indices also exhibited similar variances as did the key indicators of hospital efficiency.

[insert **Figure 5** here]

4.2 Financial implications of ESG transparency in hospitals

Based on the estimated performance scores and financial indicators, we specified regression models to examine how ESG/DX performance and effectiveness performance are related to efficiency and ROA. As shown in **Table 3**, as expected, the effectiveness scores presented significant and positive effects on hospital efficiency for all hospital groups. ESG/DX performance is also found to be positively related to hospital efficiency, indicating that ESG/DX transparency could be an important factor in hospital operations. The positive effect is stronger for small- to middle-scale hospitals (Group 1). However, we did not find significant relationships for other hospital groups based on the limited sample size.

For the relationships with profitability, both effectiveness and ESG/DX performance present a negative linkage with ROA but with great heterogeneity across the types of hospitals (see **Table 4**). Efforts to enhance effectiveness may impose a great financial burden on rehabilitation hospitals. On the other hand, better ESG/DX performance comes at a cost and may have a negative impact on short-term financial performance in small- to middle-scale hospitals, which is consistent with the findings of prior studies on firms in other sectors [42]. These results suggest that hospitals, like other businesses, need help in promoting ESG practices despite being public services.

5. Discussion and Conclusion

This study established a comprehensive evaluation system for hospital sustainability that includes ESG and DX, which have yet to be examined. To date, hospital evaluations have been dominated by efficiency assessments for management purposes and effectiveness and quality of care assessments for healthcare. In addition to integrating efficiency and effectiveness, this evaluation model, which integrates ESG and DX, is highly novel. Correlation analysis of the respective evaluation indicators revealed that ESG activities in hospitals were positively correlated with efficiency, effectiveness, and sustainability.

In the last decade, numerous companies have incorporated ESG practices into their corporate sustainability strategies. Investors perceive companies with inadequate ESG performance to be at greater risk [43]. However, considering ESG performance in hospitals has been rare due to the lack of financial incentives in the capital market. Our regression model and correlation analysis indicated that hospital ESG activities positively contribute to efficiency in small hospitals (Group 1) but negatively contribute to ROA. One possible reason for the improvement in efficiency is that ESG activities and DX may have improved the work environment, resulting in increased efficiency.

On the other hand, more efficient hospitals may have introduced ESG activities and DX. Regarding ROA, smaller hospitals may have made a negative contribution to ROA due to an increased ratio of investment to profitability when implementing ESG activities and DX. In this case, improving the working environment through ESG and DX may lead to a positive return in the long term. However, it is also possible that hospitals with higher profit margins and more leeway are more likely to implement ESG and DX.

Second, for all hospital groups, high effectiveness contributed to efficiency. The correlation between efficiency and healthcare quality, such as effectiveness and safety, has varied, with the correlation varying positively or negatively depending on the hospital size or being weak [44, 45]. These differences may be due to differences in the variables used and differences in the healthcare systems in different countries. The regression model also showed that effectiveness contributed to efficiency in hospitals in the Kyushu region, regardless of hospital size.

In rehabilitation hospitals, greater effectiveness contributed negatively to ROA. These findings suggested that ROA could be significantly reduced to increase the effectiveness of rehabilitation hospitals. Based on our findings, further accumulation of data may clarify causal relationships and resolve hospital management and sustainability issues.

The sample size for this study was small due to data collection limitations. In addition, because of the multiple variables used for input and output, many hospitals are on the frontier in SBM-DEA; thus, super efficiency SBM-DEA was used to find differences among such hospitals. Using super-efficiency DEA, we can show the distribution of inputs and outputs for each hospital group as inefficiency-efficiency. Furthermore, an increase in the number of hospitals in the future will make it possible to identify additional differences between hospitals.

Another limitation of this study is that it was a cross-sectional study, making it difficult to estimate causal relationships. The causal relationship should be verified in future studies by accumulating panel data. In addition, the ESG information scraped from the official hospital homepage website was calculated based solely on the presence or absence of information disclosure via keywords. Therefore, we cannot examine the extent to which ESG activities are undertaken. Detailed questionnaires should be administered in the future to verify the results. In addition, open data from the JCQHC were used to evaluate the effectiveness of this study. Due to the limitations of the data we collected, we could only examine the Kyushu region in Japan; therefore, regional differences at the national level in Japan need to be examined in the future.

Additionally, most ESG/DX indicators in our rating framework focus only on the level of disclosure, which does not capture ESG/DX performance. Although some larger hospitals started to disclose their ESG practices at this stage, it is still challenging to collect more detailed quantitative ESG performance data. Our findings suggest that ESG practices are an integral part of the sustainability index and are becoming a differentiating strategy in the healthcare sector. Future studies can evaluate hospital sustainability by collecting more detailed performance data.

Hospital sustainability issues, including ESG concerns, are often overlooked in the public sector, particularly from an investment standpoint. Despite the prevalence of responsible investment in recent years, our findings indicate that hospitals may encounter similar ESG challenges as other businesses in the short term. However, evaluating the value of hospitals beyond the capital market presents a challenge. This study encourages future research to evaluate the social value of hospital sustainability practices and their short-term financial impact.

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Table 1. Indicators of hospital performance evaluation

Indicators	Sub-indicators	Mean	SD	Min	Max	Variable type	Efficiency	Effectiveness	ESG/DX	Sustainability
Number of beds		170.71	128.32	27.00	1137.00	Input	Yes	Yes	Yes	Yes
Number of doctors		22.38	28.05	3.73	270.80	Input	Yes	Yes	Yes	Yes
Number of employees		254.07	208.58	26.00	1658.00	Input	Yes	Yes	Yes	Yes
Number of outpatients		172.96	140.05	1.97	842.86	Output	Yes	Yes		Yes
Number of inpatients		151.98	107.39	8.65	718.05	Output	Yes	Yes		Yes
Average days of inpatient		54.68	64.95	4.50	556.93	Undesirable output	Yes	Yes		Yes
Clinical effectiveness		8.56	0.52	6.84	9.61	Output		Yes		Yes
	Quality improvement	2.76	0.29	2.00	3.40					
	Medical treatment	2.91	0.13	2.42	3.09					
	Clinical function	2.90	0.18	2.18	3.33					
Safety		5.49	0.41	4.46	6.33	Output		Yes		Yes
	Patient safety	2.83	0.15	2.31	3.23					
	Infection control	2.66	0.31	2.00	3.33					
Digital transformation		1.74	1.12	1.00	7.00	Output			Yes	Yes
Environmental	Environmental disclosure	2.12	1.22	1.00	8.00	Output			Yes	Yes
Social		9.91	2.81	4.43	17.00	Output			Yes	Yes
	Social disclosure	4.08	2.67	0.00	11.00					
	Local collaboration	2.91	0.34	2.00	4.00					
	Accessibility	2.92	0.18	2.43	3.43					
Governance		5.69	1.30	2.48	8.23	Output			Yes	Yes
	Governance disclosure	2.90	1.26	0.00	5.00					
	Governance assessment	2.79	0.18	2.23	3.23					
Fix assets (million Yen)		4734.44	6324.33	64.96	34453.41	Input	Yes		Yes	Yes
Current assets (million Yen)		2729.27	3968.14	226.68	24461.30	Input			Yes	Yes
Operation cost (million Yen)		5363.98	6967.41	411.42	35298.21	Input	Yes		Yes	Yes
Revenue (million Yen)		5566.28	7406.41	335.50	37262.28	Output				Yes

Notes: Descriptive statistics by hospital group can be found in **Appendix Table A2**.

Table 2. Basic statistics of the estimated results by hospital group and financial indicators

	# of hospitals	Mean	SD	Min	Max
Full sample					
Efficiency score	155	0.93	0.33	0.04	2.38
Effectiveness score	155	0.97	0.20	0.07	1.54
ESG/DX score	155	0.89	0.36	0.26	2.05
Sustainability score	155	1.09	0.17	0.13	2.04
ROA (%)	155	1.38	5.18	-20.58	29.54
leverage (%)	154	192.25	203.11	3.57	586.14
Group 1 hospital					
Efficiency score	84	0.84	0.33	0.04	2.38
Effectiveness score	84	0.91	0.2	0.07	1.37
ESG/DX score	84	0.77	0.35	0.26	1.93
Sustainability score	84	1.05	0.18	0.13	2.04
Group 2 hospital					
Efficiency score	30	1.08	0.24	0.74	1.84
Effectiveness score	30	1.03	0.16	0.74	1.52
ESG/DX score	30	1.07	0.29	0.31	2.05
Sustainability score	30	1.13	0.16	1.01	1.82
Rehabilitation hospital					
Efficiency score	20	0.98	0.3	0.28	1.4
Effectiveness score	20	1.01	0.21	0.58	1.54
ESG/DX score	20	1.05	0.34	0.29	1.71
Sustainability score	20	1.14	0.11	1.01	1.39
Chronic hospital					
Efficiency score	21	1.05	0.36	0.32	1.77
Effectiveness score	21	1.06	0.19	0.52	1.54
ESG/DX score	21	0.98	0.38	0.3	1.79
Sustainability score	21	1.17	0.19	1.02	1.7

Notes: The financial leverage is winsorized at the levels of 10% and 90%.

Table 3. Relationship between ESG performance, effectiveness, and efficiency scores

	Dependent variable: Efficiency				
	Full sample	**Group 1 hospital**	**Group 2 hospital**	**Rehabilitation hospital**	**Chronic-care hospital**
ESG/DX	0.092*	0.129*	-0.009	0.196	-0.245
	(0.054)	(0.077)	(0.121)	(0.182)	(0.168)
Effectiveness	1.184***	1.185***	1.354***	1.086***	1.155***
	(0.094)	(0.133)	(0.253)	(0.270)	(0.363)
Hospital group fixed	Yes				
Location fixed	Yes	Yes	Yes	Yes	Yes
Observations	155	84	30	20	21
R^2	0.609	0.575	0.713	0.672	0.74
Adjusted R^2	0.579	0.529	0.603	0.481	0.599

Notes: *p<0.1; **p<0.05; ***p<0.01

Table 4. Relationship between ESG performance, financial effectiveness, and ROA

	Dependent variable: ROA				
	Full sample	**Group 1 hospital**	**Group 2 hospital**	**Rehabilitation hospital**	**Chronic-care hospital**
ESG/DX	-2.208*	-4.189**	-0.793	-3.802*	-1.358
	(1.218)	(1.863)	(3.463)	(1.982)	(2.660)
Effectiveness	-0.882	-2.131	2.378	-7.479**	-0.277
	(2.137)	(3.237)	(7.199)	(2.952)	(5.209)
Leverage	-0.005**	-0.004	-0.008*	-0.007*	-0.005
	(0.002)	(0.003)	(0.005)	(0.003)	(0.005)
Hospital group fixed	Yes				
Location fixed	Yes	Yes	Yes	Yes	Yes
Observations	154	84	30	19	21
R^2	0.182	0.213	0.318	0.694	0.516
Adjusted R^2	0.112	0.117	0.011	0.449	0.193

Notes: *p<0.1; **p<0.05; ***p<0.01

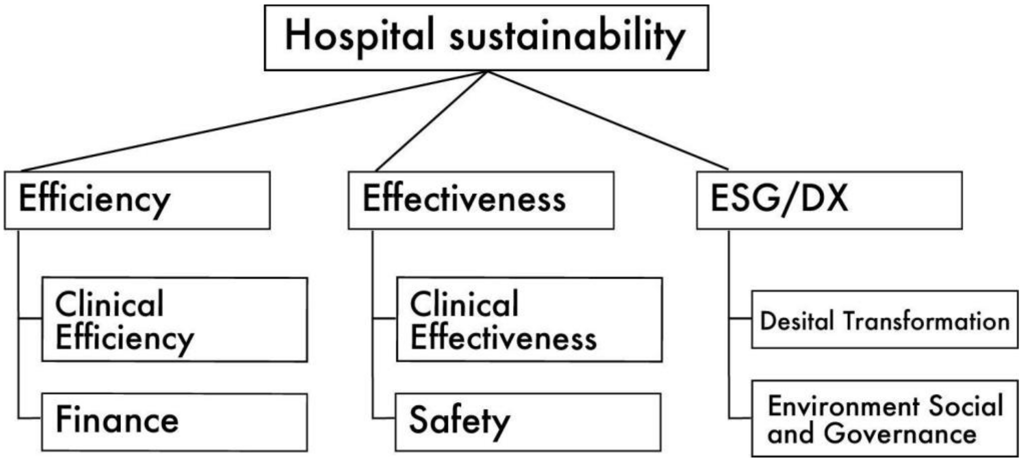

Figure 1. Conceptual image of the hospital sustainability index, dimensions, and assessment items

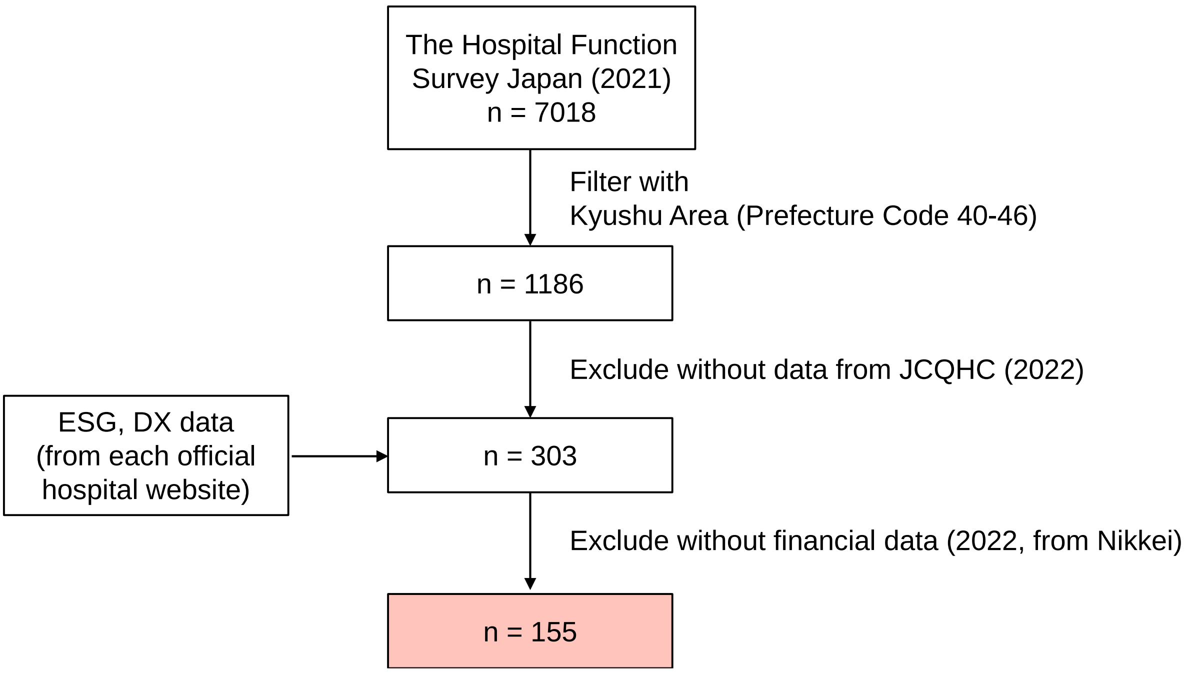

Figure 2. Flowchart of the study population.

The analysis was performed at 155 hospitals in the Kyushu region of Japan.

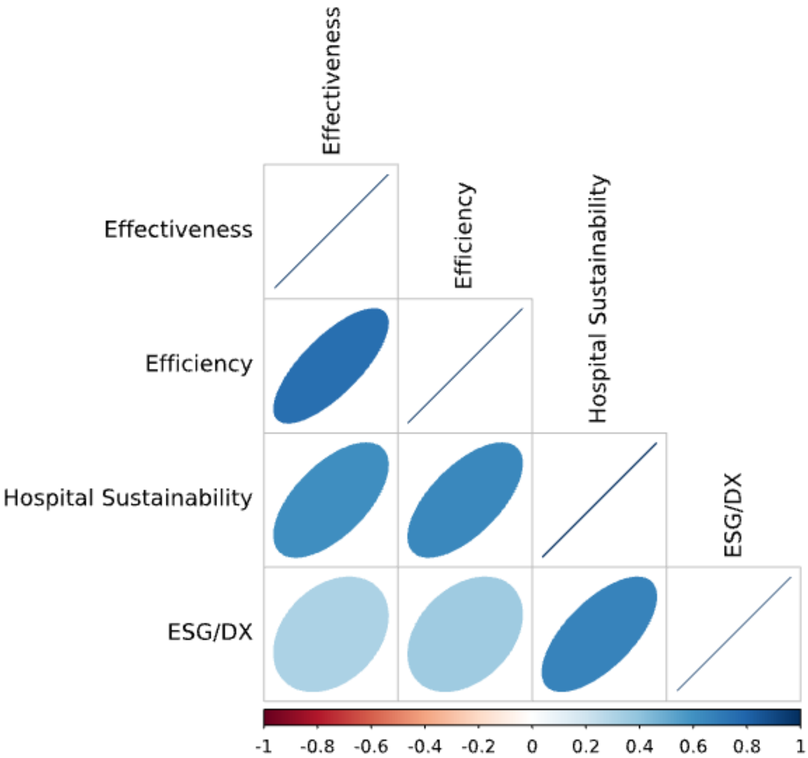

Figure 3. Correlations between hospital performance scores.

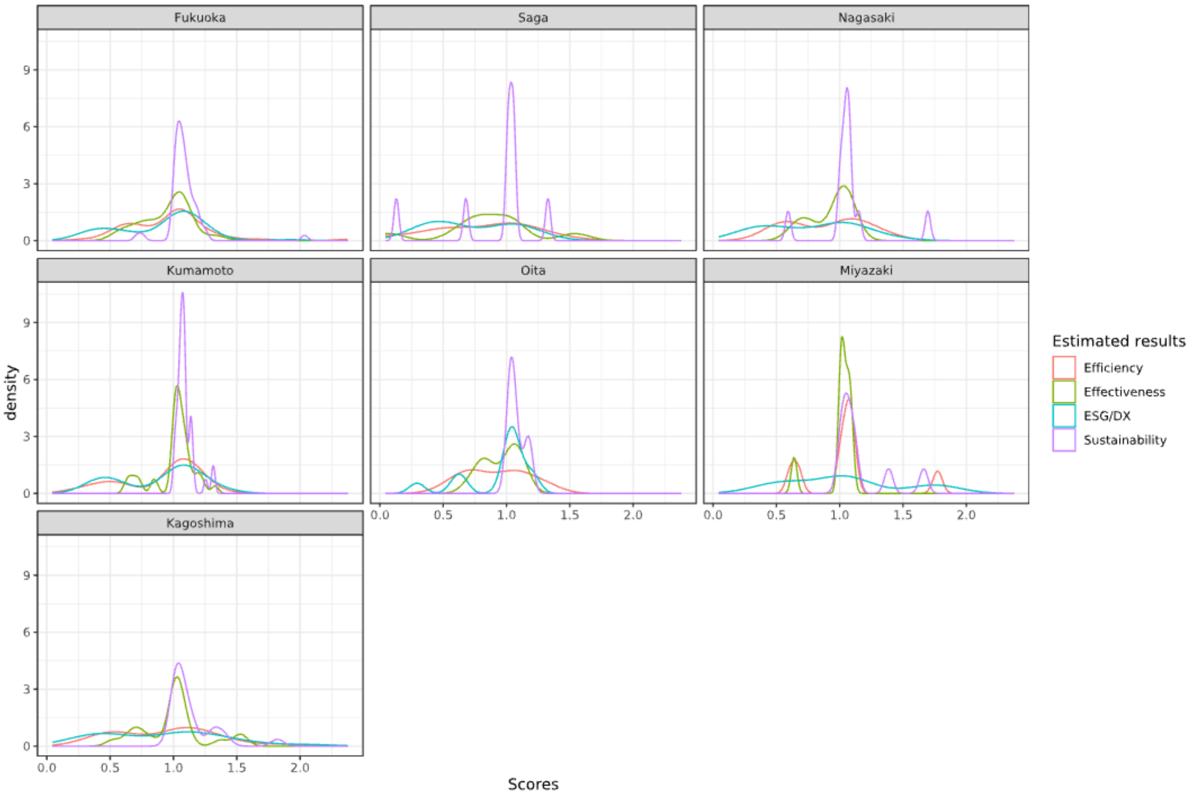

Figure 4. Distribution of hospital performance scores by region.

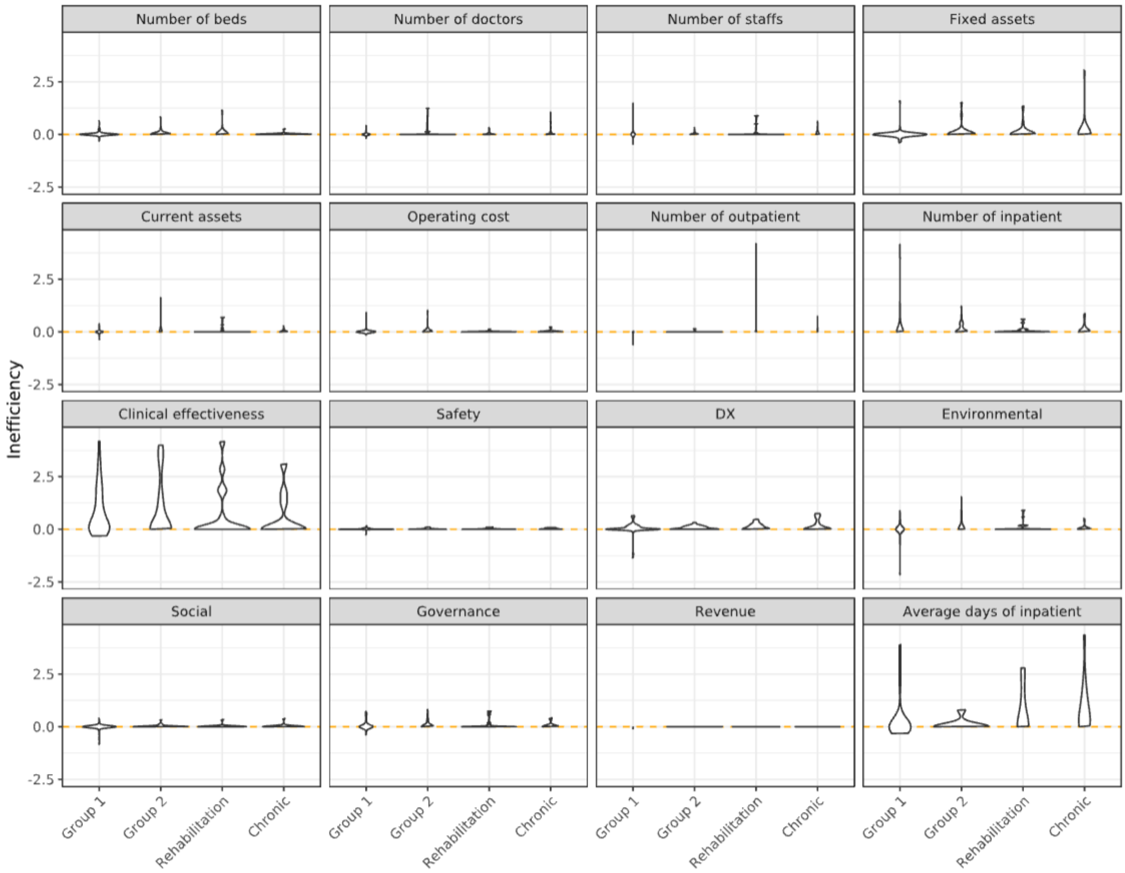

Figure 5. Inefficiency of inputs/outputs by hospital group

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Appendix

Table A1. Sustainability assessment items

Categories	Detailed items
Digital transformation	Telemedicine
	Online reservation system
	Application
	SNS account
	Software
	da_vinci
	Robot operation
	Database
Environmental	SDGs
	Sustainability
	Recycle
	Waste
	Resource use
	Ecology
	Energy saving
	Renewable
	CO2 reduction
	Electricity
	Environmental audit
Social	Work-life balance (WLB)
	Education policy
	Career support
	Burden reduction
	Women's active engagement
	community contribution
	Social contribution
	Palliative care
	Home medicine care
	Shuttle bus
	volunteer
	Workplace experience

	Night childcare Regular health checkup Job stress check Harassment Local collaboration (3 items) Accessibility (6 items)
Governance	Compliance Second opinion Privacy Personal information Informed consent Medical record disclosure Operation and management assessment (22 items)

Table A2. Basic statistics by hospital group

		Group 1 hospital (N = 84)				Group 2 hospital (N = 30)				Rehabilitation hospital (N = 20)				Chronic hospital (N = 21)			
Indicators	**Sub-indicators**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Number of beds		122.96	71.81	27	525	283.47	189.21	70	1137	166.7	83.82	54	418	204.43	130.15	95	638
Number of doctors		14.15	8.35	3.99	47.3	58.06	47.33	8.16	270.8	13.55	6.77	4.89	31.1	12.7	10.23	3.73	48.4
Number of employees		175.48	103.31	26	632	522.02	297.61	132.4	1658	226.88	84.47	89.8	483.6	211.59	138.6	76.5	654.3
Number of outpatients		157.38	88.22	4.43	385.69	351.87	172.16	87.17	842.86	72.09	56.01	1.97	174.18	75.78	60.43	3.29	195.71
Number of inpatients		107.13	61.93	8.65	342.96	250.78	131.67	60.78	718.05	149.15	74.45	46.69	351.37	192.9	132.77	63.88	605.19
Average days of inpatient		36.76	24.98	4.5	115.9	20.21	8.11	10.86	41.86	65.89	20.16	41.5	114.31	164.91	115.72	49.19	556.93
Efficacy		8.42	0.51	6.87	9.2	8.88	0.36	8.23	9.61	8.86	0.31	8.35	9.57	8.37	0.59	6.84	9.1
	Quality improvement	2.7	0.28	2	3.25	2.86	0.26	2.4	3.2	2.92	0.25	2.4	3.4	2.68	0.29	2.2	3.2
	Medical treatment	2.88	0.13	2.42	3	2.98	0.07	2.77	3.08	2.98	0.06	2.91	3.09	2.85	0.16	2.46	3
	Clinical function	2.84	0.17	2.25	3.09	3.03	0.14	2.67	3.33	2.96	0.13	2.75	3.17	2.84	0.21	2.18	3.09
Safety		5.45	0.4	4.54	6	5.61	0.34	4.87	6.33	5.68	0.33	5.1	6.23	5.29	0.49	4.46	6.08
	Patient safety	2.83	0.14	2.38	3	2.82	0.12	2.54	3	2.92	0.13	2.77	3.23	2.77	0.23	2.31	3.08
	Infection control	2.62	0.32	2	3	2.79	0.25	2.33	3.33	2.77	0.24	2.33	3	2.52	0.33	2	3
Digital transformation		1.6	0.93	1	6	2.6	1.61	1	7	1.5	0.76	1	3	1.33	0.58	1	3
Environmental	Environmental disclosure	2.15	1.22	1	8	2.5	1.38	1	8	1.75	1.16	1	6	1.81	0.87	1	5
Social		9.55	2.54	4.43	16.14	11.49	3.2	5.67	17	9.43	2.79	5.67	16	9.6	2.71	5.05	15.62
	Social disclosure	3.83	2.43	0	10	5.5	2.98	0	11	3.25	2.81	0	10	3.86	2.46	0	9
	local collaboration	2.83	0.29	2	3.33	3.06	0.33	2	3.67	3.13	0.31	2.67	4	2.84	0.4	2.33	3.33
	accessibility	2.88	0.17	2.43	3.29	2.93	0.19	2.57	3.43	3.05	0.12	2.86	3.29	2.9	0.18	2.57	3.29
Governance		5.67	1.18	2.48	7.82	6.15	1.41	2.82	8.23	5.57	1.41	3	8	5.25	1.42	2.57	7.09
	Governance disclosure	2.93	1.14	0	5	3.27	1.36	0	5	2.65	1.42	0	5	2.52	1.33	0	4
	Governance assessment	2.74	0.15	2.45	3.09	2.88	0.15	2.52	3.23	2.92	0.11	2.64	3.05	2.73	0.24	2.23	3.09
Fix assets		2296.93	2217.19	64.96	16655.89	11720.16	9703.13	1137.14	34453.41	6269.02	6718.66	787.68	24346.49	3043.43	2159.5	182.29	7737.74
Current assets		1567.93	1671.49	226.68	10108.72	6275.81	6947.39	669.79	24461.3	3110.68	3420.78	633.32	12018.26	1944.87	1795.86	280.66	8642.42
Operation cost		2873.3	2647.22	411.42	20954.76	12909.25	10530.92	1344.3	35298.21	7015.14	7879.02	1601.96	29626.13	2975.24	2182.47	789.81	9206.64
Revenue		2924.43	2715.91	335.5	21419.62	13629.82	11249.86	1585.75	37262.28	7276.36	8372.7	1491.32	31639.58	2985.69	2214.13	812	9465.11

Table A3. Estimated hospital performance by region

	# of hospitals	Mean	SD	Min	Max
Fukuoka					
Efficiency score	54	0.97	0.34	0.28	2.38
Effectiveness score	54	0.95	0.19	0.53	1.37
ESG score	54	0.9	0.34	0.26	1.93
Sustainability score	54	1.09	0.16	0.71	2.04
Saga					
Efficiency score	9	0.79	0.41	0.04	1.36
Effectiveness score	9	0.85	0.39	0.07	1.54
ESG score	9	0.73	0.33	0.35	1.21
Sustainability score	9	0.93	0.34	0.13	1.33
Nagasaki					
Efficiency score	12	0.9	0.3	0.52	1.37
Effectiveness score	12	0.93	0.16	0.64	1.1
ESG score	12	0.78	0.36	0.3	1.36
Sustainability score	12	1.07	0.24	0.59	1.7
Kumamoto					
Efficiency score	37	0.9	0.31	0.18	1.34
Effectiveness score	37	1.01	0.16	0.63	1.33
ESG score	37	0.89	0.32	0.37	1.43
Sustainability score	37	1.09	0.07	1.01	1.32
Oita					
Efficiency score	12	0.92	0.25	0.55	1.3
Effectiveness score	12	0.96	0.14	0.71	1.12
ESG score	12	0.93	0.27	0.29	1.21
Sustainability score	12	1.08	0.06	1.02	1.18
Miyazaki					
Efficiency score	9	1.05	0.33	0.61	1.77
Effectiveness score	9	1	0.14	0.64	1.09
ESG score	9	1.04	0.47	0.42	1.79
Sustainability score	9	1.16	0.22	1.01	1.66
Kagoshima					
Efficiency score	22	0.94	0.39	0.38	1.84
Effectiveness score	22	1	0.25	0.52	1.54
ESG score	22	0.92	0.48	0.3	2.05
Sustainability score	22	1.15	0.2	1	1.82