An Empirical Study on the Allocative and Technical Efficiencies of Taiwan's Hospitals*

Kuan-Chen Chen**, Chung-I Lin***, Kuo-Jui Huang****

Abstract

Previous studies have largely overlooked the issue of resource allocation management in hospitals. Distortions in hospital input prices may lead to misallocated resources and economic efficiency losses. This research evaluates the technical efficiency (TE) and allocative efficiency (AE) of 81 general hospitals in Taiwan using balanced panel data from 2013 to 2017. Within the framework of the translog shadow cost frontier model, this study employs the maximum likelihood method to simultaneously estimate both forms of efficiencies. The empirical

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findings indicate average cost savings of 22.84% and 25.50% attributable to TE and AE, respectively. The results further reveal that allocative inefficiency stems from excessive capital utilization and insufficient labor use. The sample hospitals also benefit from both scale economies and scope economies. Hospital managers are encouraged to enhance their managerial abilities and carefully consider their input combinations to address allocative inefficiencies, thereby improving overall operating efficiency.

Keywords: resource allocation, allocative efficiency, technical efficiency, translog shadow cost frontier, scale and scope economies.

JEL classification: I1, L3, D24, D61

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I. Introduction

A. Background and motivation

Medical institutions belong to a labor-intensive industry. Facing increasing competition in Taiwan's medical environment, hospitals strive to reduce costs to sustain operations. Therefore, optimizing medical staff utilization has become a critical strategy for hospital managers to lower production costs, giving rise to "sweat hospitals." According to the National Health Insurance Administration, 111 hospitals received over NT$600 million in health insurance premiums in 2014, of which 97 hospitals (87%) reported profits. However, the average (medium) ratio of personnel costs at all levels to hospital costs decreased compared to 2013.[1]

Although most hospitals reported profits, the proportion of personnel costs for medical staff relative to total expenditures declined. This trend indicates increased labor intensity, reflected in heightened workloads, longer working hours, or both for medical personnel. Many hospitals rely on this strategy to maintain profitability. In Taiwan, general hospitals, as

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[1] National Health Insurance Administration News (2015/12/29) https://www.nhi.gov.tw/News_Content.aspx?n=FC05EB85BD57C709&sms=587F1A3D9A03E2AD&s=4885C636E3E48F87

relatively large institutions, can strongly influence employees' wages. Under such circumstances, input prices, including wages for medical personnel, do not adjust rapidly to market conditions, resulting in resource distortions. One adverse consequence is that hospitals struggle to allocate optimal proportions of inputs based on prevailing factor prices.

Since 1995, Taiwan has operated a mandatory-enrollment, single-payer National Health Insurance (NHI) program. Currently, NHI contracts with more than 90% of medical institutions nationwide (100% of hospitals). As the program sets fixed payment prices for medical services, most medicines and medical equipment used in hospitals are constrained by health insurance pricing. This limitation prevents contracted hospitals from adjusting the prices of medicines and services at their discretion. Consequently, employees' salaries and fringe benefits respond slowly to market conditions, leading to input misallocation in the country's hospital service industry. This study examines the issue of input distortions and estimates the costs associated with resource misallocation in Taiwanese hospitals.

Taiwan's health insurance payment system significantly influences the medical industry's business model, public access to medical care, and doctors' practices. Under the global budget payment system, hospitals' services and expenses are capped within a specific range, compelling operators to implement strict cost control and personnel reductions. In this context, personnel costs, which constitute the largest portion of operating expenses, are often sharply reduced, deteriorating the quality of medical care and working conditions. These challenges motivate this study to estimate technical efficiency (TE) and allocative efficiency (AE) using a cost function framework.

B. Literature related to theoretical models

Economic efficiency (EE), also referred to as X-efficiency, of a firm (hospital) is defined as the product of TE and AE, i.e., EE = TE × AE. Examining AE is crucial for empirical studies on hospitals. Excluding possible allocative inefficiency from a cost frontier may result in biased parameter estimates for this frontier (Atkinson and Cornwell, 1994; Kumbhakar and

Wang, 2006). Subsequent measures derived from these estimates, such as cost efficiency score, returns to scale, and input price elasticity, may therefore be invalid (Kumbhakar and Wang, 2006; Huang et al., 2023), potentially leading to overestimation of EE (Huang et al., 2011).

In March 2018, 300 members of the Union of Chiayi Christian Hospital protested against exploitative working conditions. The hospital's chairman noted that the hospital had achieved surpluses in all the past years without incurring any losses. Since 2014, its total assets have increased by 1.86 times. Although fixed and current assets had grown significantly, its personnel costs had risen by only 1.56 times. Hospitals primarily reserve profits to develop tangible assets, as demonstrated by this case, where the hospital accumulated assets while neglecting personnel contribution to its growth. Consequently, a significant disparity emerged between the growth of personnel costs and total assets, leading to the industry being labeled as "sweat hospitals." The pricing of hospital services, particularly the valuation of labor services, has become severely distorted.

Hospitals are not-for-profit institutions whose objectives, apart from patient care, include improving operational performance. EE is applicable in the hospital industry, as cost reduction serves as a critical behavioral goal. This study employs an econometric method (i.e., the stochastic frontier approach (SFA)) to estimate hospitals' shadow cost frontiers. It evaluates TE and AE simultaneously, assessing whether labor or capital is overused or underused in Taiwan's general hospitals.

Following the framework established by Atkinson and Halvorsen (1984), Atkinson and Cornwell (1994), Kumbhakar (1996), Huang (2000), Huang et al. (2011), and Huang et al. (2014), this study introduces shadow input prices to examine input misallocation. Shadow input prices differ from actual input prices because institutions, constrained by factors such as government regulation or market power, cannot readily adjust their input prices or quantities. Institutions determine various input quantities based on the ratio of two shadow input prices and the marginal rate of technical substitution between the same two inputs. However, the resulting input combination does not necessarily minimize costs because shadow input prices deviate from actual prices, leading to allocative inefficiency and cost wastage.

Previous research on hospital performance has mainly focused on evaluating TE, with relatively limited attention paid to AE (Li and Rosenman, 2001; Rosko, 1999, 2001, 2004). A cost function that does omit allocative inefficiency implicitly assumes that the sample hospitals have achieved AE, which is a relatively strong assumption. However, investigating AE is crucial, particularly in the healthcare industry, where input and/or output prices are often subject to government regulations and market conditions are not perfectly competitive. These regulatory constraints result in slower adjustments of prices, contributing to resource distortions. Therefore, this study applies the stochastic shadow cost frontier model to measure both TE and AE for hospitals in Taiwan. This approach identifies whether labor and capital inputs are excessive or deficient (in terms of hiring), guiding hospital managers on reallocating input mixes to achieve cost minimization.

C. Purpose and significance

This study collected balanced panel data from 81 general hospitals in Taiwan from 2013 to 2017. The study applies SFA to estimate the hospitals' shadow cost frontier using maximum likelihood estimation (MLE), which is extended in three aspects to provide further insights into their performance. First, this study explicitly addressed allocative inefficiency by introducing shadow input prices into the cost frontier, thus evaluating the extent to which hospital managers optimally utilize their input mix. The validity of employing EE in healthcare institutions, which are subject to regulation and market imperfection, was argued, as cost reduction may serve as an appropriate behavioral objective. The EE score provides a better measure for regulators and managers compared to the TE score, as the latter overlooks the significance of input misallocation.

Second, the economies of scale and scope were assessed from the parameter estimates of the shadow cost frontier. In response to the increasingly competitive domestic medical environment, hospitals in Taiwan seek to expand their operational scale to lower their long-run average cost, thus enhancing their business viability, which requires the presence of scale economies. Additionally, hospitals are broadening the range of medical services offered and actively expanding their financial sources, primarily focusing on non-patient income. Therefore, unlike previous studies, this paper incorporates additional non-patient income into the output category. This product diversification can assist hospitals in sharing fixed costs, leading to service cost advantages and promoting scope economies.

Third, this study analyzed and compared hospital performance across various levels of accreditation, ownership types, and regional business divisions. Previous comparative analyses on the operating efficiency of Taiwan's hospitals have primarily focused on hospital ownership (Chang et al., 2004; Hu and Huang, 2004; Chen et al., 2019), classifying the sample hospitals as teaching or non-teaching institutions (Chen and Hsiao, 2020) or by the level of accreditation (Chen, 2006; Yu et al., 2007; Chen et al., 2016) to compare their TE scores. There appears to be a gap in the literature regarding the joint investigation of TE and AE of Taiwan's hospitals. Therefore, this study examined the average TE and AE of hospitals in different regions, accreditation levels, and ownership types.

The rest of this paper is organized as follows. Section II reviews the relevant literature. Section III formulates a translog stochastic shadow cost frontier incorporating TE and AE. Section IV describes the dataset and presents sample statistics. Section V conducts the empirical analysis and discusses the estimation results. The final section concludes the paper.

II. Literature review

A. Comparison between the SFA and DEA method

There are two popular approaches to gauge a decision-making unit's (DMU's) EE: the non-parametric approach, also known as data envelopment analysis (DEA), and the parametric approach of SFA. The former uses mathematical programming techniques to construct an efficient frontier enveloping all observed data. One advantage of DEA is that it does not require specifying a functional form for the production (distance) or cost function, thereby avoiding any possible misspecification of the functional form. However, its efficiency estimates are susceptible to the influence of random shocks. The parametric SFA, pioneered by Aigner et al. (1977), applies econometric methods to estimate a pre-specified production, cost, or profit frontier. Since the SFA model contains two error terms—a one-sided error term to reflect technical inefficiency and a standard disturbance term to accommodate random shocks—the issue of random shocks can be addressed. However, its primary disadvantage is that the true production (cost or profit) function is unknown a priori, which may result in functional form misspecification. Both the non-parametric and parametric approaches have their strengths and weaknesses.

To the best of our knowledge, all previous studies evaluating the performance of Taiwan's hospitals, such as Li and Wang (1998), Chen (2006), Yu et al. (2007), Chang et al. (2004), Chen et al. (2016), and Chen et al. (2019), have used DEA. These studies define input items as the number of doctors, nurses, and hospital beds and the output items as the number of outpatients, emergency cases, surgeries, and inpatients per day. In this approach, they assess hospital TE rather than AE, which requires the availability of input (output) price information. Since price information is available from hospital financial statements, the shadow cost frontier was estimated for the sample hospitals. This enables the evaluation of both TE and AE, allowing the often-overlooked issue of resource misallocation in this industry to be investigated. This approach provides valuable policy implications for the government and hospital authorities.

Taiwan's hospitals operate in an industry that the government highly regulates. They must comply with national healthcare policies and adhere to strict regulations regarding the procurement of medical supplies. Additionally, the intervention of NHI in the market affects the prices of medical services and drugs, adding complexity to the healthcare market. In response to the imperfectly competitive market environment, Liu et al. (2023) analyzed profit inefficiency in airlines and measured the shares of technical and allocative inefficiencies. However, given the unique characteristics of hospitals, this study estimated hospital cost efficiency rather than profit efficiency.

B. Hospital operating efficiency

Most previous research evaluating foreign hospital performance based on cost function has focused solely on TE (Li and Rosenman, 2001; Rosko, 1999, 2001, 2004), neglecting the role of AE, which limits researchers' ability to address resource distortion issues. This study followed Atkinson and Cornwell (1994), who introduced shadow input prices into the stochastic cost frontier to estimate the hospitals' TE and AE. The concept of shadow input prices has been adopted by Kumbhakar (1996), Huang (2000), Huang et al. (2011), Huang et al. (2014), Ahmad and Burki (2016), and Al-Hadi et al. (2019), among others.

Selecting appropriate input and output variables is crucial when using SFA to evaluate hospitals' performance. Hospital income sources primarily stem from patient and non-patient activities. Non-patient activity income generally comes from food courts, parking fees, donations, and investment income. McKay and Gapenski (2009) studied 77 for-profit and 66 non-profit hospitals in Florida, covering 2003 to 2005. They found that non-patient activities accounted for 5.4% of total revenue, which, though modest, still positively impacted hospital operational performance.

Singh and Song (2013) reached a similar conclusion for California hospitals. Furthermore, 40% of the sample hospitals reported losses in patient activities, with 25% relying on non-patient activities to offset these losses. Hospitals in Taiwan also seek additional income from non-patient activities. For instance, Linkou Chang Gung Memorial Hospital received a total balance of NT$4.358 billion in 2016, with only NT$457 million from patient activities. In contrast, the non-patient surplus amounted to NT$3.901 billion.[2] The growing importance of non-patient income may reflect a hospital's degree of product diversification. To fully and

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[2] National Health Insurance Administration News (2018/03/13)
https://www.mohw.gov.tw/cp-3792-40151-1.html

accurately describe a hospital's production process, this study defines non-patient income as a type of output in addition to patient income.

Several studies have compared the operating efficiency of Taiwan's hospitals across different ownership types. For instance, Chang et al. (2004) concluded that private hospitals outperformed public ones in 1996 and 1997, particularly regional and district hospitals. However, private hospitals without intensive-care units outperformed their public counterparts. Hu and Huang (2004) analyzed 80 hospitals in Taiwan with more than 250 beds in 2001. They found that public hospitals had relatively low efficiency scores and suggested that increasing the utilization rate of wards could improve efficiency. Additionally, expanding the number of expensive equipment and beds could further enhance hospital efficiency. However, a comparison of the productivity of public hospitals with that of non-public hospitals from 2008 to 2014 by Chen et al. (2019) supports the idea that public hospitals exhibited better productivity performance. This suggests that public hospitals experience faster rates of productivity growth and outperform non-public hospitals in terms of technology gaps and quality improvement.

Some studies focus on teaching hospitals specifically. For example, Chen and Hsiao (2020) analyzed the productivity changes in teaching and non-teaching hospitals in Taiwan from 2008 to 2014, finding that both types of hospitals improved over time. However, the improvement in teaching hospitals was less evident than in non-teaching hospitals, possibly because teaching hospitals provide medical services and have additional responsibilities related to teaching and research.

Finally, several studies have examined hospital performance based on different accreditation levels. For instance, Chen (2006) constructed the Malmquist productivity index, based on service quality, to assess the productivity gains of 40 medical centers and regional hospitals from 1994 to 1998. The study found that the long-term productivity changes of the sample hospitals slightly declined due to a decline in technology. Yu et al. (2007) studied the factors influencing efficiency changes in both medical centers and regional hospitals in 2002. They found that increasing the bed utilization rate significantly enhanced the overall efficiency of hospitals. They also noted no significant differences in overall efficiency between public and private hospitals and regions. Chen et al. (2016) analyzed the productivity gains of medical centers, metropolitan hospitals, and local community hospitals from 2007 to 2010, finding that the productivity and quality of district hospitals grew over time, mainly due to improvements in technology, efficiency, and the technology gap.

The existing literature employs DEA to assess hospital efficiency and productivity changes. However, the issue of AE remains largely unexplored. This paper aims to fill this gap by using SFA to estimate both TE and AE, enabling analysis and comparison of hospital performance across different ownership types, accreditation levels, and regional business divisions.

III. Research methods

A. Shadow cost function

The standard translog cost frontier is expressed as:

$$
\begin{aligned}
\ln TC &= \ln C^*(Y,W) + u + v \\
&= \alpha_0 + \sum_{i=1}^{3}\alpha_i \ln Y_i + \sum_{j=1}^{3}\beta_j \ln W_j + \frac{1}{2}\sum_{i=1}^{3}\sum_{k=1}^{3}\alpha_{ik}\ln Y_i \ln Y_k + \frac{1}{2}\sum_{j=1}^{3}\sum_{k=1}^{3}\beta_{jk}\ln W_j \ln W_k \\
&\quad + \sum_{i=1}^{3}\sum_{j=1}^{3}\gamma_{ij}\ln Y_i \ln W_j + \theta_1 t + \frac{1}{2}\theta_2 t^2 + \sum_{i=1}^{3}\phi_i t \ln Y_i + \sum_{j=1}^{3}\xi_j t W_j + u + v
\end{aligned}
\tag{1}
$$

Here, TC is the total expenditure of a hospital; Y_1, Y_2, and Y_3 denote three outputs (outpatient and emergency income, inpatient income, and non-patient activity income, respectively); W_1, W_2, and W_3 represent the prices of three inputs (labor, capital, and medical material); and t refers to the time trend. The notation $u \sim N^+(0,\sigma_u^2)$ indicates a non-negative input-oriented technical inefficiency, assumed to have a half-normal distribution, while $v \sim N(0, \sigma_v^2)$ is a two-sided error term with a normal distribution. Following convention, this study further defines $\lambda = \sigma_v / \sigma_u$ and $\sigma^2 = \sigma_u^2 + \sigma_v^2$.

Allocative inefficiency may exist in this industry due to price controls and the slow adjustment of production procedures arising from market imperfection. To account for this, this study recommends using the shadow input price (W_j^*), as employed by Atkinson and Cornwell (1993, 1994), Kumbhakar (1996, 1997), Huang and Wang (2004), and Huang et al. (2011) to characterize hospitals' allocative inefficiency. The relationship between the actual input price (W_j) and the shadow price (W_j^*) is expressed as:

$$W_j^* = h_j W_j, \quad j = 1, 2, 3 \tag{2}$$

where h_j is a positive, unknown parameter that represents the degree of allocative inefficiency. A value of $h_j = 1$ means that the j^{th} factor is allocatively efficient with AE = 1 and $h_j \neq 1$ indicates a lack of AE for the j^{th} factor that is either overused or underused (see below). Because a cost function must be homogeneous of degree one in input prices, one of the three input prices, say, the i^{th} price, should be arbitrarily selected to normalize the cost function, leaving the remaining two h's to be estimable. Specifically, h_i must be normalized to be equal to unity, and the i^{th} input is designated as the numéraire.

This study arbitrarily selects the labor input price (W_1) to normalize the shadow cost frontier. Therefore, the estimated allocative inefficiency parameter is a relative value to the numéraire, i.e., labor. If $h_j < 1$, the hospital overuses the j^{th} input relative to the i^{th} input. In contrast, a value of $h_j > 1$ reveals that the hospital underuses the j^{th} input again relative to the numéraire.

The technically inefficient hospital is assumed to minimize its shadow cost function:

$$C^{**}\left(Y,\frac{W^*}{b}\right)=\min\left(\frac{W^*}{b}(bX)\mid F(bX,Y)=0\right)$$
$$=\frac{1}{b}C^*(Y,W^*) \tag{3}$$

where $0<b\le 1$ reflects the presence of technical inefficiency. The case where b = 1 indicates that the hospital produces on its production boundary and is fully technically efficient. The closer the value of b is to zero, the more technically inefficient the hospital becomes. Factor b can be viewed as a measure of the extent of input-oriented technical inefficiency. The production transformation function, denoted by $F(\cdot,\cdot)$, describes the technical relationship between multiple inputs and multiple outputs.

B. Cost share function

Using Shephard's Lemma, the relationship between the actual cost share (S_j) and the shadow cost share (S_j^*) can be expressed as follows:

$$S_j=S_j^*+\varepsilon_j=\partial\ln C^{**}/\partial\ln W^*+\varepsilon_j$$
$$=\beta_j+\sum_{k=1}^{3}\beta_{jk}\ln W_k^*+\sum_{i=1}^{3}\gamma_{ij}\ln Y_i+\sum_{j=1}^{3}\xi_j t+\varepsilon_j,\qquad j=1,2,3 \tag{4}$$

Here, $\varepsilon_j\sim N(0,\sigma^2_{\varepsilon_j})$ is a random disturbance term with a normal distribution. Finally, the actual (log)cost (ln$C$) and the shadow (log)cost are related as follows.

$$\ln C=\ln C^{**}+\ln\sum_j h_j^{-1}S_j^*$$
$$=-\ln b+\ln C^*(Y,W^*)+\ln\sum_j h_j^{-1}S_j^* \tag{5}$$

In Eq. (5), $-\ln b$ represents the increase in the actual logarithmic cost of the hospital incurred by the input-oriented technical inefficiency, which corresponds to the term of *u* in Eq. (1). The expression $\ln C^*(Y,W^*)$ is substituted by the translog cost function $\ln C^*(Y,W)$ from Eq. (1), but the input prices W_j's, need to be replaced by $h_j W_j / W_1$, *j* = 2, 3. The term $\ln \sum_j h_j^{-1} S_j^*$ represents the increase in the actual logarithmic costs due to allocative inefficiency. Readers may refer to Atkinson and Cornwell (1994) and Huang (2011) for detailed derivation.

The composite error of $\varepsilon = u + v$, shown in Eq. (1), is appended to Eq. (5). The (log)cost function becomes a regression equation that can be simultaneously estimated alongside the share equations from Eq. (4) to estimate the unknown parameters *h*'s. Estimating Eq. (5) alone cannot identify the allocative inefficiency parameters (h_j, *j* = 2, 3). To address this issue, this study proposes estimating the share equations from Eq. (4) simultaneously. Three inputs are classified in this study, with one (i.e., medical material) treated as a quasi-fixed factor due to the unavailability of its price information. Furthermore, one of the cost share equations must be excluded, as the sum of all cost shares has to be equal to unity, resulting in a singular covariance matrix of the random errors in these share equations. Therefore, only one cost share equation needs to be included in the econometric model, which comprises two regression equations: the cost share equation from Eq. (4) and the shadow cost frontier from Eq. (5).

C. Efficiency measurement

This econometric model should be estimated simultaneously using MLE. Once the parameter estimates of the shadow cost frontier are obtained, they can be used to calculate the measures of TE, AE, and EE, as well as economies of scale (SE) and scope (SC) for each hospital. If SE prevails in this industry, the representative hospital operates on the decreasing portion of its long-run average cost curve. Thus, the hospital should expand its operation scale to benefit from economies of scale. Conversely, if scale diseconomies exist, reducing the hospital's production scale is recommended to lower its long-run average cost. The economies of scale are defined as follows:

$$\mathrm{SE} = \frac{C(W,Y)}{\sum_{g=1}^{3} Y_g C_g(W,Y)}, \quad g = 1,2,3 \tag{6}$$

Here, $C_g(W,Y) = \partial C(W,Y)/\partial Y_g$. If SE > (<) 1, the hospital exhibits increasing (decreasing) returns to scale. A value of SE = 1 indicates constant returns to scale, meaning that the hospital operates at the lowest long-run average cost.

The existence of economies of scope implies that hospitals should diversify their medical services to share the costs of expensive equipment across various medical activities. The benefits of resource sharing and risk diversification help reduce the long-term average production cost. If scope diseconomies are present in this industry, the sample hospitals should focus on providing professional services. The economies of scope are formulated as follows:

$$\mathrm{SC} = \frac{C(Y_1,0,0,W) + C(0,Y_2,0,W) + C(0,0,Y_3,W) - C(Y,W)}{C(Y,W)} \tag{7}$$

A value of SC > (<) 0 indicates the existence of scope economies (diseconomies). A limitation of the translog function is the failure to take a logarithm with respect to zero. Some scholars address this by replacing the value of zero with 10%, say, of the minimum value for the output (Mester, 1987; Huang and Wang, 2004), as shown below:

$$SC = \frac{C(Y_1 - 2\in_1, \in_2, \in_3, W) + C(\in_1, Y_2 - 2\in_2, \in_3, W) + C(\in_1, \in_2, Y_3 - 2\in_3, W) - C(Y,W)}{C(Y,W)} \tag{8}$$

Here, $\in_g$, $g = 1, 2,$ and 3 are equal to 10% of the minimum value of the g^{th} output.

As a complement to the preceding modified SC measure, this study also calculated the measure of the cost complementarities (CC) proposed by Baumol et al. (1982), which is defined as $\mathrm{CC}_{jm} = \partial^2 C(Y,W) / \partial Y_j \partial Y_m$, $\forall j \neq m$. This measure evaluates how the marginal cost of output j is affected by the production of an additional unit of output m. Economies of scope prevail if weak complementarities are found for all pairs of outputs, i.e., $\mathrm{CC}_{jm} < 0, \forall j \neq m$.[3]

IV. Data description

A. Data resource

Unbalanced panel data were compiled from the financial statements of hospitals released by the National Health Insurance Administration,[4] from 2013 to 2017. The dataset initially contains 605 hospital-year observations. Of these, 39 observations with incomplete financial data are excluded. Additionally, 53 observations from non-general hospitals were removed to ensure comparability among the sample hospitals. Therefore, the analysis focused on examining the performance of general hospitals, resulting in a balanced panel data that includes 81 general hospitals and 405 observations in total.

Based on the hospital accreditation levels, 80 observations belong to academic medical centers, 281 to metropolitan hospitals, and the remaining 44 observations to local community hospitals. Regarding ownership types, 143 observations are from public hospitals, while 262 are from non-public hospitals. The Taiwan government divided the island into six major medical business divisions. There are 90 observations from the Taipei business division, 50

[3] In the case of a three-output translog cost function, scope economies are confirmed if two out of the three pairs of CC_{jm} are negative, as demonstrated by Berger et al. (1987).

[4] The National Health Insurance Administration publishes the financial statements of hospitals receiving health insurance benefits exceeding NT$600 million from 2013 to 2015 and those of hospitals receiving more than NT$400 million from 2016 to 2017.

from the North District business division, 100 from the Central District business division, 90 from the South District business division, 15 from the East District business division, and 60 from the Kaohsiung and Pingtung business division.

B. Variable definition and descriptive statistics

Table 1 lists the input and output variables of the hospitals used in this study. Labor and capital are identified as variable inputs. Labor includes the number of doctors, nurses, medical personnel, and other staff. Since the number of employees is not available in the financial statements, this study used total assets net of fixed assets as the proxy for labor.[5] The price of labor (W_1) is calculated as the ratio of personnel expenses within operation cost, which includes salaries and related welfare benefits for medical personnel, to total assets net of fixed assets. The capital input of hospitals mainly includes the number of beds, medical equipment, and computer equipment, which are aggregated into net fixed assets. Capital expenditures include depreciation and rental expenses, which are divided by net fixed assets to obtain the price of capital (W_2). Although medical supplies, particularly medical drugs, are essential inputs for hospitals, the large number of drug types makes it impractical to compute the unit price of drugs. Therefore, medical supplies are defined as a quasi-fixed input. Three outputs are recognized: outpatient and emergency income, inpatient income, and non-patient income.

Table 2 presents the descriptive statistics of the relevant variables, with all dollar-valued variables deflated by the consumer price index (CPI), with the base year set to 2016. According to Table 2, the primary income for hospitals comes from outpatient and emergency income (Y_1), with an average value of NT$2.796 billion, followed by inpatient income (Y_2), which has an average value of NT$2.286 billion. The average value of non-patient income (Y_3) is

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[5] Workforce data is available only for 2015, during which the correlation coefficient between the number of employees and total assets was calculated to be 0.89. This finding suggests that using total assets net of fixed assets as a proxy for labor is acceptable.

NT$305 million, with a minimum value of NT$1 million and a maximum value of NT$10.098 billion. The variation in Y_3 is quite significant, making it an essential revenue source for at least some hospitals. Including non-patient income as an output is recommended, allowing hospitals to diversify into non-medical businesses. This inclusion may impact hospitals' managerial capabilities and productivity and improve their long-term development.

Table 1 Variable definitions

Variable	Definition
Total expenditure (TC)	TC = personnel expenses + depreciation expenses + rental expenses
Outpatient and emergency income (Y_1)	Derived from financial statement data
Inpatient income (Y_2)	Derived from financial statement data
Non-patient income (Y_3)	Derived from financial statement data
Labor price (W_1)	W_1 = personnel expenses / (total assets net of fixed assets)
Capital price (W_2)	W_2 = (depreciation expenses + rental expenses) / net fixed assets
Expenses of medical supplies (qfix)	Derived from financial statement data
Time (t)	t = financial year–2012
Medical business division (dist)	Taipei business division, North District business division, Central District business division, South District business division, East District business division, and Kaohsiung and Pingtung business division
Accreditation level (level)	Academic medical centers, metropolitan hospitals, and local community hospitals
Public or private (type)	Public and non-public hospitals

Note: The sample period spans 2013 to 2017; accordingly, t takes values from 1 to 5.

Table 2 Descriptive statistics

Variable	Mean	Standard deviation	Minimum	Maximum
TC*	2,043.7100	2,291.3900	6.2803	14,162.8000
Outpatient and emergency income* (Y_1)	2,796.4800	3,230.7500	8.4165	20,945.8000
Inpatient income* (Y_2)	2,286.9200	2,652.6500	3.1016	13,712.7000
Non-patient income* (Y_3)	305.3130	818.5750	1.3669	10,098.1000
Labor* (X_1)	5,577.7700	13,783.5000	82.2691	126,337.0000
Capital* (X_2)	3,711.1500	5,146.2400	9.7672	25,864.6000
Labor price (W_1)	1.0053	0.8490	0.0003	5.4607
Capital price (W_2)	0.2188	0.6206	0.0061	8.3866
Expenses of medical supplies* (qfix)	1,595.0800	1,969.0900	4.3912	11,052.2000

Note: *: Measured by millions of NTD and deflated by Taiwan’s CPI with the base year of 2016.

V. Empirical results

A. Translog cost function estimation

The software of TSP version 5.1 was used to simultaneously estimate Eq. (4) and Eq. (5) via MLE. Table 3 presents the coefficient estimates. Fourteen out of 32 estimated parameters are statistically significant, at least at the 10% level. Including a time trend (linear, squared, and interaction terms with other variables) in the cost function enables the estimation of technical changes, defined as the partial derivative of (log)total costs with respect to the time trend. The mean rate of technical change is 0.0152, implying that the representative hospital’s cost frontier shifts upward over time, reflecting a technical regression rate of 1.52% per annum.[6] Hospitals often compete based on quality or engage in a medical arms race when facing competitors (Robinson and Luft, 1985). To attract more customers and increase their market share, hospitals invest in medical equipment, quality-improving technologies, cost-saving innovations, and novel facilities. Consequently, technological regression is prevalent in this industry.

The estimated value of allocation parameter h is equal to 0.1344, which is statistically significant at the 1% level and supports the presence of factor misallocation and allocative inefficiency. Since this estimate is less than one, it indicates that the sample hospitals inefficiently overuse capital relative to labor, suggesting that hospitals tend to overutilize capital goods while underutilizing labor.[7] The prices of either or both capital and labor in this industry may be distorted by the implementation of the NHI program, such that the relative input price between labor and capital is greater than it would otherwise. Doctors, nurses, and other medical employees in Taiwan's hospitals face excessively long working hours and unequal work intensity, primarily due to the underemployment of labor. The problem of "sweat hospitals" is likely to persist for some time and is consistent with the current situation in this industry.

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[6] The same measure was computed for each year, revealing negative values in the first two years and positive values in the remaining three years, showing an increasing trend. These findings indicate that the sample hospitals are experiencing technical regression. Additionally, the partial derivative of the cost function with respect to the input price was calculated, yielding a positive average value, which is consistent with the microeconomic theory.

[7] The estimated value of h being less than unity causes the iso-cost line to become steeper, resulting in an optimal choice where capital (labor) tends to be greater (less) than otherwise.

Table 3 Parameter estimates of the translog shadow cost function

Variable	Parameter estimate	Standard error
Constant	26.3812	16.5012
h	0.1344***	0.0208
$\ln Y_1$	–6.2835*	3.6862
$\ln Y_2$	–2.2770	5.9290
$\ln Y_3$	0.5628	0.6867
$\ln(W_2/W_1)$	0.8871***	0.1650
ln(qfix)	6.8497	6.2559
$1/2*(\ln Y_1)*(\ln Y_1)$	0.1716	0.7467
$1/2*(\ln Y_2)*(\ln Y_2)$	0.1762	0.9624
$1/2*(\ln Y_3)*(\ln Y_3)$	0.0032	0.0221
$(\ln Y_1)*(\ln Y_2)$	0.6385	0.6412
$(\ln Y_1)*(\ln Y_3)$	–0.3081**	0.1474
$(\ln Y_2)*(\ln Y_3)$	–0.3183**	0.1303
$1/2*\ln(W_2/W_1)* \ln(W_2/W_1)$	0.0674***	0.0040
$(\ln(W_2/W_1))*(\ln Y_1)$	–0.0299	0.0353
$(\ln(W_2/W_1))*(\ln Y_2)$	0.0070	0.0365
$(\ln(W_2/W_1))*(\ln Y_3)$	0.0133***	0.0038
1/2*(ln(qfix))*(ln(qfix))	–0.1719	0.7534
$\ln(qfix)*\ln Y_1$	–0.2568	0.6812
$\ln(qfix)*\ln Y_2$	–0.4295	0.8785
$\ln(qfix)*\ln Y_3$	0.6338***	0.1882
$\ln(qfix)*\ln(W_2/W_1)$	–0.0084	0.0329
t	–1.2949**	0.5811
1/2*t*t	0.0168	0.0311
$t* (\ln Y_1)$	0.2371**	0.1022
$t*(\ln Y_2)$	0.0875	0.0950
$t*(\ln Y_3)$	–0.0295	0.0184
$t* \ln(W_2/W_1)$	0.0070	0.0053
t* ln(qfix)	–0.2467*	0.1283
σ^2	0.2959***	0.0484
λ	0.8026**	0.3276
σ_Ω^2	0.0063***	0.0003
Log-likelihood	–98.228	

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

B. Efficiency scores

The above parameter estimates were then used to compute various efficiency measures, such as TE, AE, and EE. Table 4 shows that the average TE score is 0.7716, implying that hospitals can save up to 22.84% of their current cost by producing on the production frontier and achieving full technical efficiency. The average AE measure is 0.7450, indicating that the sample hospitals can achieve an additional cost reduction of up to 25.5% by hiring an input mix according to the cost minimization rule. Since hospitals overutilize capital relative to the amount of labor, it is recommended that they reduce capital input and increase their staff size to achieve AE and reduce production costs. Expanding this industry's workforce can effectively reduce hospital employees' overtime and work pressure, lowering medical negligence and indirectly improving medical quality for all patients.

Table 4　Various measures of efficiency scores and scale and scope economies

	Mean	Standard deviation	Minimum	Maximum
AE	0.7450	0.0314	0.7105	0.8597
TE	0.7716	0.0568	0.4457	0.8190
EE	0.5751	0.0517	0.3175	0.7041
SE	1.3980	8.4163	–5.9977	164.9188
SC	9.62E+24	5.84E+25	1.37E+05	6.96E+26
CC_{12}	5.25E–08	6.53E–07	1.52E–10	1.03E–05
CC_{13}	–1.68E–08	6.74E–08	–6.51E–07	2.32E–07
CC_{23}	–1.44E–07	2.74E–06	–5.51E–05	2.67E–07

Under the total budget payment system implemented by the NHI, the increase in diagnosis and treatment volume has diluted the point value paid to hospitals, forcing hospital managers to adopt cost-saving measures. These measures lead Taiwanese doctors and nursing staff to work long hours and receive unequal wages. Medical staff in Taiwan are overworked due to a shortage of doctors and nurses in hospitals. Lee et al. (2018) demonstrated that insufficient nursing staff in hospitals is related to patient outcomes and patient safety, and these negative impacts may increase hospital cost burdens by nearly $200 million. As this empirical result suggests, regulatory constraints and the inability of hospitals to quickly adjust prices according to market conditions will lead to the misallocation of resources. These distortions prevent the achievement of allocative efficiency in hospitals.

Currently, one health insurance point is worth less than NT$1,[8] forcing doctors and nurses to see more patients to achieve the same revenue from the NHI. Faced with the increasing demand from health insurance patients, hospitals can only absorb the rising labor costs without adjusting their medical pricing strategy, exacerbating the workforce gap. To establish a more dynamic and resilient medical system, the government should increase the total health insurance budget, reasonably adjust medical staff remuneration, and recruit additional staff to improve hospital operating efficiency.

The average EE measure is 57.51%, indicating that hospitals could save 42.49% of their existing cost if they attain X-efficiency. It is noted that X-inefficiency stems from allocative inefficiency (25.50%) and technical inefficiency (22.84%) in the hospitals under study. The translog cost frontier was also estimated with the imposition of full allocative efficiency, where the allocation parameter h equals unity. The average EE score under this assumption is 74.49%.[9] It is evident that excluding allocative inefficiency from the cost frontier leads to

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[8] Under the total budget payment system, the settlement and estimated points value of each contracted medical institution, https://www.nhi.gov.tw/ch/cp-5773-4d180-2767-1.html

[9] Note that the average EE score is equivalent to the TE score. These results are not displayed to conserve space but are available upon request from the authors.

overestimating the EE measure and deviating from reality. This finding is consistent with the work of Kumbhakar and Wang (2006). Moreover, the mean rate of technical change is –0.0044, implying that the representative hospital's cost frontier shifts downward over time, with technical progress occurring at a rate of 0.44% per year. This finding differs from the previous case, where the cost frontier accounted for both allocative and technical inefficiencies. The preclusion of the allocative efficiency from a cost frontier model tends to bias the parameter estimates and incorrectly suggests technological progress. The preceding results support the notion that allocative inefficiency is equally important in determining X-inefficiency. It is suggested that hospitals optimize their input mix and improve their managerial abilities to enhance economic efficiency.

Next, the measures of SE, SC, and CC were calculated. Table 4 shows that the average SE measure is 1.3980, indicating the presence of scale economies. The sample hospitals are suggested to expand their production scale to benefit from scale economies. This would reduce their long-run average costs as the production scale increases. The average SC measure is greater than zero,[10] and the average values of CC_{12}, CC_{13}, and CC_{23} are 5.25E–08, –1.68E–08, and –1.44E–07, respectively. Scope economies prevail in this industry, allowing hospitals to offer a wide range of medical services.

Product diversification in hospital activities also helps reduce production costs, primarily through resource sharing among different outputs (services), such as personnel training costs, computer systems, and patient database management systems. Singh and Song (2013) argued that hospitals rely on non-patient income to offset losses from patient activities, which can help hospitals improve operational performance. However, previous empirical studies do not

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[10] The average SC measure is 9.62E+24. This exceptionally large value arises from zero values in Eq. (7) with 10% of the minimum value in Eq (8). This substitution may lead to extreme SC values, as highlighted by Berger and Humphrey (1991) and Mester (1993). To address this issue, the measures of weak cost complementarities (CC) were calculated following the approach proposed by Baumol et al. (1982).

provide strong evidence of scope economies, particularly between patient and non-patient services. It is asserted that the sample hospitals under consideration benefit from both scale and scope economies.

C. Efficiency of different types of hospitals

Table 5 presents the average efficiency scores for different levels of accredited hospitals. It reveals that local community hospitals have the highest TE, AE, and EE among the three groups, with mean scores of 0.7939, 0.7604, and 0.6036, respectively. Hospitals with different accreditation levels exhibit significantly different average scores of TE, AE, and EE. Metropolitan hospitals have the lowest TE and EE values (0.7630 and 0.5696), suggesting that this type of hospital should focus on improving its managerial abilities. Both metropolitan and local community hospitals adopt technology with increasing returns to scale, as their average SE measures are greater than unity. In addition, scope economies prevail in those two types of hospitals. Expanding production scale and providing various medical services benefit these hospitals in terms of cost savings.

Academic medical center hospitals perform the worst in AE with a mean value of 0.7342, indicating that these hospitals experience severe input inefficiency. This may be due to large hospitals being able to afford expensive pioneering medical equipment, resulting in overinvestment in capital. Conversely, they typically control labor costs in response to NHI payments, leading to rigidity and an inability to respond promptly to market conditions, causing labor to be underused. It is suggested that medical centers hire more labor and reduce capital to enhance their AE and save production costs. Medical centers cover multiple functions, such as research, teaching, providing internships, and performing major surgeries. Therefore, their fixed limited medical staff should prioritize outpatient visits, treating mild diseases, intensive care services, and clinical medical research (Lin et al., 2020). A severe resource misallocation is found in this industry, as the sample hospitals require more labor force, especially in academic medical centers.

Table 5 Average efficiency scores of different levels of accredited hospitals

	Mean	Standard deviation	Minimum	Maximum	*p*-value
Academic medical centers					
TE	0.7912	0.0333	0.6571	0.8190	< 0.0001
AE	0.7342	0.0160	0.7106	0.7859	< 0.0001
EE	0.5809	0.0282	0.4734	0.6291	0.0002
SE	0.6630	0.2580	0.3005	1.7766	
SC	3.44E+25	1.11E+26	3.52E+15	6.96E+26	
CC_{12}	1.49E–09	1.02E–09	1.52E–10	4.89E–09	
CC_{13}	7.06E–11	6.01E–09	–3.60E–08	1.65E–08	
CC_{23}	–2.01E–09	1.07E–08	–8.88E–08	1.49E–08	
Metropolitan hospitals					
TE	0.7630	0.0632	0.4457	0.8190	
AE	0.7460	0.0315	0.7105	0.8597	
EE	0.5696	0.0569	0.3175	0.7041	
SE	1.5834	9.9753	–5.9977	164.9188	
SC	4.59E+24	3.82E+25	1.37E+05	4.18E+26	
CC_{12}	3.67E–08	4.91E–07	4.42E–10	8.23E–06	
CC_{13}	–1.59E–08	7.04E–08	–6.51E–07	2.32E–07	
CC_{23}	–2.07E–07	3.29E–06	–5.51E–05	1.82E–07	
Local community hospitals					
TE	0.7939	0.0265	0.7261	0.8190	
AE	0.7604	0.0426	0.7119	0.8326	
EE	0.6036	0.0381	0.5211	0.6620	
SE	1.4499	2.5329	–0.1801	15.6238	
SC	1.12E+23	7.45E+23	1.13E+06	4.94E+24	
CC_{12}	2.46E–07	1.55E–06	5.05E–10	1.03E–05	
CC_{13}	–5.38E–08	9.12E–08	–4.28E–07	5.29E–08	
CC_{23}	–1.12E–09	7.97E–08	–1.90E–07	2.67E–07	

Note: The *p*-values shown in the last column test whether the measures of TE, AE, and EE are significantly different among different hospital groups using the *F*-test. Moreover, the same tests between each pair of hospital types are also significant, at least at the 5% level.

The average SE measure of academic medical center hospitals is less than one (SE = 0.6630), indicating the prevalence of scale diseconomies. It is advantageous for medical centers to decrease their scale of operations to reduce their long-run average cost. The average values of CC_{12}, CC_{13}, and CC_{23} are 1.49E–09, 7.06E–11, and –2.01E–09, respectively. Since only one value is negative, weak cost complementarity is not present. The primary responsibility of medical centers is to diagnose and treat severe and acute patients. It is suggested that medical centers refrain from diversifying their medical outputs and instead focus on providing specialized medical services to continue assisting patients with acute and severe diseases, thereby strengthening the functions of their services.

Table 6 shows various performance scores for public and non-public hospitals. It reveals that the average TE, AE, and EE measures differ significantly between the two groups. Public hospitals are more technically efficient than non-public hospitals, with mean TE scores of 0.7847 versus 0.7645, and exhibit stronger managerial abilities than non-public hospitals. In contrast, non-public hospitals outperform public hospitals in allocative efficiency, with mean AE scores of 0.7574 versus 0.7239, making non-public hospitals more X-efficient than public hospitals, with mean EE scores of 0.5798 versus 0.5678. Public hospitals are regulated and supervised by the governments in terms of their personnel, accounting, and procurement systems. These systems are often criticized as being rigid and limiting decision-making, which can lead to resource distortion. For instance, public hospitals cannot offer excellent medical staff with market-equivalent or even higher salaries due to civil service law restrictions. Non-public hospitals, however, have more flexible personnel systems to attract outstanding talents. It is also difficult for public hospitals to lay off incompetent employees, as the process is lengthy. Resource reallocation in public hospitals tends to take longer, which adversely affects their AE and EE.

The empirical results of this study verify that the managerial abilities of public hospitals exceed those of non-public ones, consistent with the findings of Folland and Hofler (2001), Herr (2008), and Mutter and Rosko (2008). Chen et al. (2019) showed that public hospitals in Taiwan perform better than non-public ones in terms of productivity growth. However, these studies ignore the role of allocative efficiency in hospitals, and the failure to account for it in the cost frontier biases the parameter estimates (Kumbhakar and Wang, 2006). It is suggested that non-public hospitals improve their managerial abilities to optimize their input mix when achieving the given output quantities. In contrast, public hospitals can more effectively promote AE by quickly adjusting their resource allocation.

Table 6　Average efficiency scores of public and non-public hospitals

	Mean	Standard deviation	Minimum	Maximum	*p*-value
Public hospitals					
TE	0.7844	0.0436	0.6380	0.8190	0.0008
AE	0.7239	0.0178	0.7105	0.8200	< 0.0001
EE	0.5678	0.0341	0.4647	0.6587	0.0353
SE	1.0303	1.3941	0.2940	12.5491	
SC	5.76E+24	4.07E+25	9.71E+05	3.93E+26	
CC_{12}	3.10E–09	5.39E–09	1.52E–10	3.52E–08	
CC_{13}	–1.85E–08	7.05E–08	–6.51E–07	1.99E–08	
CC_{23}	–2.58E–08	1.34E–07	–1.39E–06	3.02E–08	
Non-public hospitals					
TE	0.7645	0.0624	0.4457	0.8190	
AE	0.7574	0.0310	0.7106	0.8597	
EE	0.5798	0.0592	0.3175	0.7041	
SE	1.6034	10.4574	–5.9977	164.9188	
SC	1.18E+25	6.62E+25	1.37E+05	6.96E+26	
CC_{12}	8.13E–08	8.21E–07	4.46E–10	1.03E–05	
CC_{13}	–1.63E–08	6.64E–08	–4.28E–07	2.32E–07	
CC_{23}	–2.14E–07	3.44E–06	–5.51E–05	2.67E–07	

Note: The *p*-values shown in the last column are testing for the hypotheses of whether TE, AE, and EE measures are significantly different between the two groups using a *t*-test.

Figure 1 illustrates the trends of the average efficiency measures of TE, AE, and EE across Taiwan’s six medical business regions. During the sample period from 2013 to 2017, the average TE scores fluctuated considerably in the North and East District business divisions, while the remaining divisions remained relatively stable. The mean AE for the North District business division remained smooth, while those for the other five divisions showed an upward trend. Apart from the North and East District business divisions, EE varied across time without any clear trend. Based on TE, AE, and EE, hospitals in the Central District business division performed the best among the six divisions. Conversely, the Taipei business division performed the worst in TE and EE, while the East District business division had the lowest mean AE score.

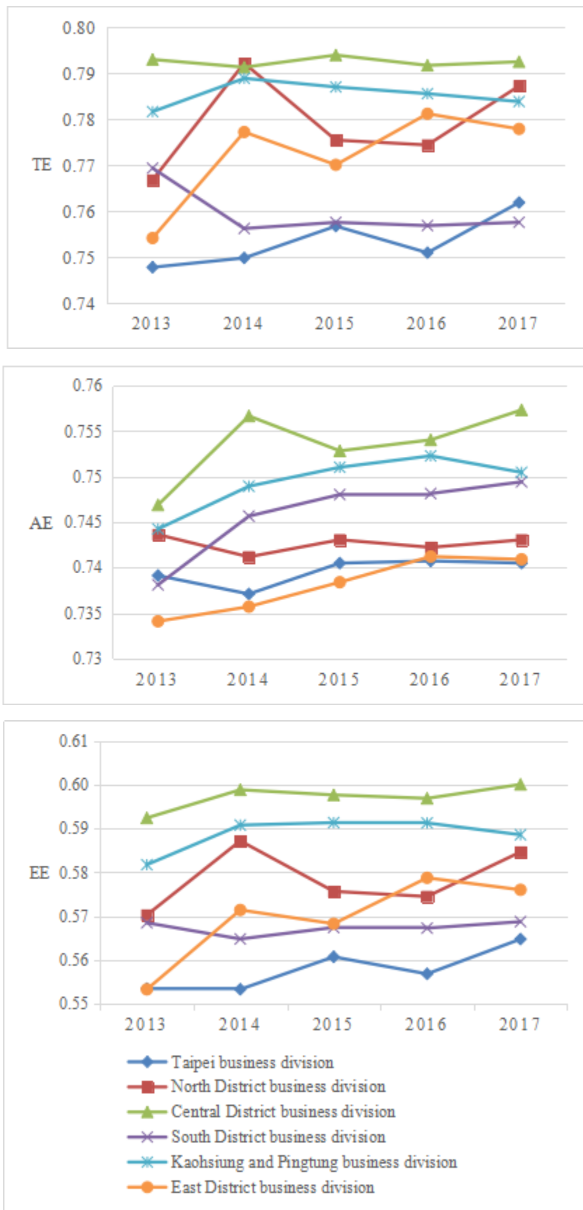

Figure 1　The average TE, AE, and EE over time and across districts

VI. Conclusions

Most previous research on hospitals' operational performance emphasizes the singular measure of TE without addressing the issue of AE, which hampers the accurate assessment of AE and EE. The current paper employs a translog cost frontier to provide insights into Taiwan's hospital industry's TE, AE, and EE values. The panel data consists of 405 general hospitals spanning from 2013 to 2017. The potential cost savings for achieving TE and AE are estimated at 22.84% and 25.50%, respectively. The sample hospitals tend to overutilize capital and underutilize labor. These findings could guide hospital managers in adjusting the allocation of inputs to achieve cost savings. Economies of scale and scope prevail in this industry, supporting the expansion of production scale and diversification of services.

It is noted that appropriate input and output data are crucial to ensuring accurate estimation results. Unfortunately, the data sources used in this study come from hospitals' financial statements, where certain relevant variables, such as the quantities of patient person-times, number of beds, and quantity of drugs, are unavailable. This limitation restricts the ability of this study to provide further insights into efficiency. Moreover, environmental variables should be embraced in future studies, such as relevant health insurance payment policies, labor qualities (the ratio of female workers, years of schooling, and education), and hospitals' internal organizational or institutional aspects. These factors may also impact the AE, TE, and EE of the sample hospitals. Lastly, to capture the complexity of healthcare industry efficiency, AE analysis in the context of hospitals should incorporate a multi-dimensional perspective that considers various market structures. Building on the insights of Liu et al. (2023), the imperfectly competitive market environment in which hospitals operate will offer a more robust analysis of resource allocation and profit efficiency in Taiwanese hospitals.

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臺灣醫院配置與技術效率之實證研究*

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摘　要

過去鮮少關注醫院的資源分配問題。若醫院的投入價格扭曲，可能存在資源配置不當，導致經濟效率的損失。本研究旨在衡量臺灣醫院的技術和配置效率，並探究勞動力和資本的投入是否存在過多或不足。在 translog 影子成本邊界模型下，本研究應用最大概似法同時估計醫院的技術和配置效率。資料取自衛生福利部中央健康保險署公開之醫事服務機構財務報表，資料期間爲 2013-2017 年，共計 81 家醫院，405 筆觀察值。本研究評估臺灣醫院之技術效率和配置效率分別爲 77.16% 和 74.50%，其中配置效率低下源於資本的過度使用和勞動力的使用不足。此外，本研究樣本醫院存在規模經濟和範疇經濟。在分類比較中發現，地區醫院之技術和配置效率最高，公立醫院的技術效率高於非公立

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醫院，而非公立醫院在配置效率方面則優於公立醫院。由於存在配置效率低下，本研究建議醫院管理者應關注醫院的要素投入組合，將有助於提升臺灣醫院的整體經濟效率。

關鍵詞：資源配置、配置效率、技術效率、translog 影子成本邊界、規模經濟與範疇經濟
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