Efficiency Comparison of Public and Private Hospitals before and after the COVID-19 Pandemic: The Case of Hubei, China

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Abstract

Background The persistence and spread of the COVID-19 pandemic adversely affected the efficiency of hospitals with different ownership. This article aims to compare the differences and changes in technical efficiency of public and private hospitals before and after the pandemic.

Methods We collected institutional and operational data for all 519 general hospitals (including 243 public and 356 private hospitals) in Hubei province China from 2019 to 2021. Using the slacks-based measure model (SBM), we measured and compared technical efficiency. The effect of the pandemic on hospital efficiency was examined with a two-way fixed effect model and a lasso regression model. PSM, Tobit regression was used for robustness testing.

Results Public hospitals were much more efficient than private hospitals both before and after the epidemic in Hubei. The mean efficiency score of public and private hospitals was 0.52 and 0.26 in 2019, 0.37 and 0.22 in 2020, 0.44 and 0.24 in 2021. The difference in efficiency between public and private hospitals was significant in 2019 and 2021 (p<0.001). Public hospital efficiency showed a faster recovery in the face of the epidemic.

Conclusions Public hospitals run by the administrative system have shown greater efficiency and played a major role in the fight against the pandemic. The country's public health protection network should be fortified and efforts should be made to promote the high-quality development of public hospitals. The widening of the overall gap between public and private hospitals appeared. In the post-epidemic era, private hospitals need to prioritize finding the right positioning and offering highly specific medical services in China.

1 Background

The COVID-19 pandemic has substantially impacted healthcare systems' demand, resource utilization (efficiency) and hospital operations[1, 2]. According to the IHME (Institute for Health Metrics and Evaluation), there were 6.9 million reported deaths and 17.2 million estimated deaths from COVID-19 as of 31 May 2022[3]. Most countries may face growing poverty and a lack of access to healthcare, especially LMIC [4]. The cost of business disruption, along with lingering coronavirus disease (COVID-19) costs, has led to the insolvency of numerous public and positive hospitals[5]. The China Health Care Statistics Yearbook (2021) shows that 23,500 non-public medical institutions nationwide lost 130 billion yuan a year, with a mean loss of 5.53 million yuan per institution[6].

Fluctuations in healthcare demand have an impact on hospital efficiency, creating uncertainty regarding the most efficient use of installed capacity[7, 8]. As the coronavirus disease (COVID-19) pandemic worsens, the rising number of corona infections has resulted in the appearance of the so-called operational bottleneck[2], which means that even when hospitals are operating at full capacity, patients will have to wait for care, putting a strain on limited health resources[9]. For example, the Irish government negotiated an arrangement with 19 private hospitals to use their capacity for three months to relieve pressure on the public system in February 2020[10]. However, according to data from the National Treatment Purchase Fund, as of June 2020, when the agreement expired, 84,223 people were waiting for inpatient or day case treatment, 15,561 of whom had been waiting for more than 12 months, and 584,399 people waiting for outpatient appointments, 219,712 of whom had been waiting for more than 12 months. A total of 35,878 persons were on the waiting list for inpatient or day-case endoscopic appointments[11]. Similar situations are occurring around the world. Faced with the reality of a severe short supply of medical services, it is critical to promote rational resource allocation and improve the efficiency of medical services[12].

Hospitals are the most essential component of the medical and healthcare system, which can be divided into two types based on their nature: public hospitals and private hospitals. The relationship between hospital efficiency and
ownership structure has been investigated[13–16]. Some studies have used data envelopment analysis (DEA) to assess the technical efficiency difference between public and private hospitals, finding conflicting empirical results [17–26]. These studies only explored the pre-pandemic situation. Empirical studies during the COVID-19 pandemic are lacking.

In China, Public medical institutions have traditionally dominated the medical service industry[27]. During the COVID-19 pandemic, public hospitals accounted for 91.2% of all designated hospitals[28]. However, private hospitals have grown quickly after nationwide healthcare reform in 2009, owing to the rapid release of Chinese healthcare needs. On the one hand, the industry scale growth rate of private hospitals (20%) far exceeds that of public hospitals (7%), which is around three times that of public hospitals (see Fig. 1). As of 2021, the total number of hospitals is 36,570, with 11,804 being public and 24,766 being private. In comparison to 2020, the number of public hospitals declined by 66, while the number of private hospitals climbed by 1,242. On the other hand, the number of professional physicians in private hospitals nearly doubled between 2015 and 2019, accounting for a sharp increase in the proportion of all physicians (15.9% in 2015 and 21.2% in 2021)[6]. Private hospitals have adequate medical staff and beds, but their role in this pandemic has been restricted. The same situation exists in Hubei, the province with the richest medical resources in central China, and the trend is even more pronounced.

Based on the foregoing, the present study seeks to address the following research question:

RQ1: Are there efficiency differences between public and private hospitals in China before and after the pandemic, and how much do they differ?

RQ2: How should the public and private hospitals address the growing demand post-pandemic?

RQ3: What policies should the government formulate to promote the development of public and private hospitals based on their performance in the fight against the pandemic?

The rest of the study is organized as follows. Section 2 reviews the literature on the efficiency comparison between public and private hospitals. Section 3 presents the study design, data and methodology. Section 4 reports the results of descriptive statistics, technical efficiency, and regression analysis. Section 5 presents discussions, and Section 6 concludes the paper by summarizing the study insights, limitations, and future research.

2 Literature Review

The idea of privatizing services has been put forth as a way to increase healthcare access, effectiveness, and quality[15]. This calls into question how well private hospitals perform in comparison to public hospitals. Researchers have extensively employed DEA to analyze hospital performance and measure the efficiency of various types of healthcare organizations, including public hospitals[29–34] and private hospitals[35–38].

In the United States, the hospital sector is one of the rare industries where three different types of ownership (public, private non-for-profit (PNFP), and private for-profit (PFP)) have coexisted for many years. Theoretically, private hospitals could outperform public ones if the necessary conditions and competitive forces were there. However, actual data, primarily from the United States, contradicts such a claim[39–41]. Y Shen et al conducted a meta-analysis by including 40 papers between 1990 and 2007 and concluded that there was no significant difference in efficiency between public and private hospitals, but for-profit hospitals were less efficient than non-profit hospitals[20].

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There may be different incentives available to private providers in most European health markets since they are both less competitive and more inclusive than those in the United States[42, 43]. Evidence from Italy, Germany, the United Kingdom, France, Greece, Austria, Spain, and Portugal between 2000 and 2017 are combined in the Florien et al. review. According to the majority of data, public hospitals are either more efficient than private hospitals or at least as efficient[15]. However, Herrera et al. found nine relevant articles of sufficient quality after reviewing 5918 references between 2002 and 2013. Quality and economic indicators, like efficiency, were not significantly different between PNFP and public providers, as well as PFP and public providers[44]. Czypionka et al. investigated the efficiency of 128 public and private not-for-profit hospitals in Austria since 2010. As measured by technical efficiency, private non-profit hospitals perform better than public hospitals[22].

The efficiency of Chinese healthcare providers is also a matter of concern. In recent years, the number of providers has increased while the caseload has been falling[45]. Scholars tend to evaluate the efficiency of public general hospitals or primary care institutions[46–49]. There is little Chinese literature comparing the efficiency of public and private hospitals. By applying DEA models to assess the efficiency of 232 public and private hospitals in Beijing during the period 2012–2017, Jing et al. found that the technical efficiency and scale efficiency of public hospitals were much higher than that of private hospitals. However, the pure technical efficiency of public hospitals was lower than that of private hospitals after matching propensity scores, though the scale efficiency remained higher than that of private hospitals. [26].

The general conclusion from earlier review studies is contradictory. Public hospitals are more effective than private ones, according to some research, while others found no discernible difference. In general, it seems that PNFP hospitals surpass PFP hospitals in terms of quality and efficiency, coming closer to public hospitals in this regard[14]. Even when ownership is not the primary focus of the study, ownership is usually acknowledged to have an impact on hospital operations in the empirical literature on hospital behaviour. The underlying impact of ownership appears to depend on the institutional framework, and there are notable variations between markets, locations and time, according to a general conclusion drawn from the studies.

3 Methods

3.1 Setting and study design

Hubei province is located in central China, with a resident population of 57.75 million, a nominal GDP of US$787 billion (RMB 5 trillion) in 2021, a per capita GDP (nominal) of over US$13,000 and a wealth of medical resources[50]. Wuhan, the provincial capital, is the political, cultural and economic centre of central China and was the first region in China to report an outbreak. This study, based on a study of the distribution of healthcare resources in Hubei Province, China, aims to investigate and compare the technical efficiency changes in public and private hospitals before and after the COVID-19 pandemic. Firstly, we compared the differences between public hospitals and private hospitals on each indicator. After efficiency measurement (slacks-based measure model SBM), we compared the differences in efficiency between public and private hospitals for three years (2019–2021). The impact of the pandemic on the efficiency of hospitals under different ownership was examined. To exclude the effects of provider size, region of affiliation, and period, we used a two-way fixed effects model with the inclusion of provider-related control variables. Lasso regression[51] was applied to filter variables and exclude the effect of covariance on the results. Finally, for robustness testing, we used propensity score matching[52], changing the regression method to Tobit regression[53], and changing the efficiency measure in three ways (BCC-DEA) [54] to verify the robustness of our results.
3.2 Data Collection

We collected institutional information on all 599 general hospitals (243 public hospitals and 356 private hospitals) in Hubei Province from 2019 to 2021. According to the standard "Classification and code of health institutions (organizations)" (WS 218–2002) promulgated in 2002, code A100 means General hospitals. According to the standard "Classification and code of economic type" (GB/T 12402–2000), economic type codes “11”, and “12” mean public hospitals, and the rest are private hospitals. Forty private hospitals’ data are unavailable for 2019 and 2020. They are not excluded in this paper to avoid artificial sampling errors. There are three main sources of data, (i) the health information system of the Health Commission of Hubei Province; (ii) questionnaires (iii) on-site research, interviews, and telephone inquiries. If there are differences in the data from different data sources, this study adopts the first-line data from medical institutions’ sources.

3.3 Variables

Our variables mainly include (i) efficiency scores. Input indicators include the number of physicians, the number of nurses, and the number of beds. Output indicators include the number of outpatient and emergency visits and the number of inpatients. (ii) Economic type (ownership). Public and private hospitals, defined according to the standard (WS 218–2002) with (GB/T 12402–2000). (iii) Control variables. Including personnel-related variables (number of physicians, number of nurses), diagnosis and treatment-related variables (number of beds, number of emergency visits, number of inpatients), revenue indicators (emergency outpatient revenue, inpatient revenue), district, and period.

3.4 Data Processing and Statistical Analysis

We used R statistical software, version 4.1.2, to carry out all of our statistical studies. Efficiency estimating was done with the package. Two-way fixed effects were done with the lme4 package. Lasso regression was done with the glmnet package. Propensity score matching was done with the MatchIt package. Tobit regression was done with the AER package. Graphics were created by the ggplot2 package.

Stage 1. Descriptive statistics and univariate analysis were conducted. P-value was reported to examine whether there was a statistically significant difference in variables between public and private hospitals. Categorical variables were compared with the use of chi-square analysis. Continuous variables were compared with the use of independent t-test.

Stage 2. The slacks-based measure model (SBM) was used to estimate efficiency scores. Assuming there are n DMUs, DMU\(_j\) (j = 1, ..., n) consumes m semi-positive inputs \(x_{ij}, i = 1, 2, ..., m\) and generate s semi-positive outputs \(y_{rj}, r = 1, 2, ..., s\). According to (Tone, 2001), the SBM efficiency of DMU\(_0\) was determined as follows:

\[
\min \frac{1 - \frac{1}{m} \sum_{i=1}^{m} \frac{s_i^+}{x_{i0}}}{1 + \frac{1}{s} \sum_{i=1}^{s} \frac{s_i^-}{x_{r0}}}
\]

Subject to:

\[
\sum_{j=1}^{n} x_j \lambda_j + s^- = x_0,
\]
where \( \lambda_j \) denotes the intensity variable and indicates the importance of DMU_0; input and output slacks are represented as \( s^- \) and \( s^+ \), respectively. As shown in model (1), the first two sets of constraints show that slacks \( s^- \) and \( s^+ \) report the distances between DMU_0 and the efficient frontier in the input and output directions. Furthermore, the objective function is to minimize the SBM efficiency of DMU_0 by maximizing slacks \( s^- \) and \( s^+ \). As a consequence, the SBM model always assigns a far projection to each inefficient DMU on the efficient frontier.

Stage 3. To reveal the difference in efficiency between public and private institutions, we built the following regression model.

\[
Eff_i = \alpha_0 + \alpha_1 Pub + \beta X + \mu_m + \epsilon_i
\]

Here \( Eff \) represents the efficiency scores of health institutions calculated in stage 2. \( Pub \) represents whether it is a public hospital. \( X \) represents a set of control variables. \( \mu \) represents fixed effect. \( \epsilon \) represents a random perturbed variable. In all subscripts, \( i \) represents the facility and \( m \) represents the county. We report the results of four regressions: baseline regression, the inclusion of fixed effects, the inclusion of control variables, and post-lasso regression.

We built the following regression model to expose the correlation between public and private hospitals separately between efficiency scores and the effect of the COVID-19 pandemic.

\[
Eff_i = \alpha_0 + \alpha_1 Cov + \beta X + \mu_m + \epsilon_i
\]

\( Cov \) represents the effect of the COVID-19 pandemic, which the year. The model’s other definitions are identical to those in Eq. (2).

Stage 4. To verify the robustness of the results, we followed three lines of thought. (i) PSM [52] was used to mitigate bias caused by large gaps in institutional characteristics.

Let

\[
Eff_i (1) = \text{Efficiency score of public medical institution}
\]

\[
Eff_i (0) = \text{Efficiency score of private medical institution}
\]

Impact of ownership,

\[
\Delta Eff_i = Eff_i (1) - Eff_i (0)
\]

However, either \( Eff_i (1) \) or \( Eff_i (0) \) is observable for each case.
Let $Pub$ indicate public medical institution,

$Pub = 1$; If the hospital is a public medical institution.

$Pub = 0$; Otherwise.

Average treatment effect of public medical institutions,

$$ ATT = E \{ Eff_i (1) - Eff_i (0) | X, Pub = 1 \} = E \{ Eff_i (1) | X, Pub = 1 \} - E \{ Eff_i (0) | X, Pub = 1 \} $$

$$ = E \{ Eff_i (1) | X, Pub = 1 \} - E \{ Eff_i (0) | X, Pub = 0 \} $$

$$ - E \{ Eff_i (0) | X, Pub = 1 \} - E \{ Eff_i (0) | X, Pub = 0 \} $$

$X$ = Vector of control variables by applying the same equation as Eq. (2).

This measure of impact is referred as the ‘average impact of the treatment on treated’.

In the above expression, $E \{ Eff_i (0) | X, Pub = 1 \}$ is not observed.

let $P(X) = P(D = 1 | X)$ be the probability of public medical institutions.

PSM constructs a comparison group by matching observations with similar values of $P(X)$ of whether to be the public medical institution, with two assumptions.

$$ E \{ Eff_i (0) | X, Pub = 1 \} - E \{ Eff_i (0) | X, Pub = 0 \} = 0 $$

$$ 0 < P(X) < 1 $$

Equation (5) is known as ‘Conditional Mean Independence’ which indicates that after controlling $X$, the average outcomes of those without public medical institutions are identical to the public medical institution in a counterfactual situation that they would have not been a public medical institution. While expression (6) assures valid matches by assuming that $P(X)$ is well-defined for all values of $X$.

(ii) In terms of the explained variables, we used BCC-DEA to measure institutional efficiency and conduct regression analysis again. (iii) On the regression model, we used Tobit regression instead because the efficiency is the truncated data taking the value 0 to 1.

4 Results

4.1 Descriptive results

Table 1 demonstrates the relationship between public and private hospitals in terms of each variable. As can be seen, in addition to the number of institutions, all of them (the number of doctors, number of nurses, number of beds,
number of outpatient emergency visits, number of inpatients, the expense of outpatients, and expense of inpatients) are significantly higher in public hospitals than in private hospitals (p < 0.001).

Table 1
Descriptive statistics and univariate analysis in Hubei province, 2019–2021

<table>
<thead>
<tr>
<th>Variables</th>
<th>Public</th>
<th>Private</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of institutions</td>
<td></td>
<td></td>
<td>0.51</td>
</tr>
<tr>
<td>2019</td>
<td>243(33.3)</td>
<td>316(32.0)</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>243(33.3)</td>
<td>316(32.0)</td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>243(33.3)</td>
<td>356(36.0)</td>
<td></td>
</tr>
<tr>
<td>Number of doctors</td>
<td></td>
<td></td>
<td>.000</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>229.01(308.13)</td>
<td>23.39(48.20)</td>
<td></td>
</tr>
<tr>
<td>Number of nurses</td>
<td></td>
<td></td>
<td>.000</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>380.72(540.80)</td>
<td>38.10(80.97)</td>
<td></td>
</tr>
<tr>
<td>Number of beds</td>
<td></td>
<td></td>
<td>.000</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>711.57(882.27)</td>
<td>106.35(142.91)</td>
<td></td>
</tr>
<tr>
<td>Number of outpatient and emergency visits</td>
<td></td>
<td></td>
<td>.000</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>376302.57(677195.29)</td>
<td>29853.96(77827.00)</td>
<td></td>
</tr>
<tr>
<td>Number of inpatients</td>
<td></td>
<td></td>
<td>.000</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>24274.45(36133.07)</td>
<td>2245.75(4571.42)</td>
<td></td>
</tr>
<tr>
<td>Expense of outpatients</td>
<td></td>
<td></td>
<td>.000</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>111731.18(272390.41)</td>
<td>7637.16(24107.67)</td>
<td></td>
</tr>
<tr>
<td>Expense of inpatients</td>
<td></td>
<td></td>
<td>.000</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>289985.18(762860.86)</td>
<td>14267.63(51870.38)</td>
<td></td>
</tr>
</tbody>
</table>

### 4.2 Efficiency scores

As verified by the t-test, public hospitals are significantly more efficient than private hospitals. In 2019, the mean efficiency score of public hospitals is 0.52 and private hospitals is 0.26 (t = 11.68, p < 0.001). In 2020, they are respectively 0.37 and 0.22 (t = 8.44, p < 0.001). In 2021, the mean efficiency score was 0.44 for public hospitals and 0.24 for private hospitals (t = 10.72, p < 0.001) (see Fig. 2). Fig. 2 Hospital efficiency score of public hospitals and private hospitals.

Changes in the efficiency of public and private hospitals in Hubei province from 2019 to 2021 can be seen in Fig. 3. For public hospitals, the efficiency of most areas shows a significant decline in 2020 but picks up in 2021. The trend of private hospitals is consistent with public hospitals over the years, which is less pronounced than public hospitals. However, in some places, the efficiency shows a rise and then a decline (Zhuxi County in the northwest) or a continuous decline (Jiansi County in the southwest). Regionally, hospitals in the northwestern, central, and eastern regions are more efficient.
4.3 Regression analysis of efficiency and hospital ownership

(m1) is the baseline regression that yields a significant correlation between efficiency and ownership ($\beta=0.204, p < 0.001$), The ownership explains 16.2% of the difference in efficiency. (m2) is the result of fixed effects which controlled period and district. It is consistent ($\beta=-0.231, p < 0.001$). (m3) adds institutional-level control variables and the result is still significant while the $\beta$ value decreases ($\beta=-0.076, p < 0.001$). The number of nurses, the expense of outpatients, the expense of inpatients, and the number of inpatients were found to be associated with efficiency. (m4) is regression results after filtering variables by Lasso regression ($\lambda = \text{lambda.1se}$) ($\beta=-0.110, p < 0.001$), which can be seen that R2, AIC, and BIC decreased compared to (m3), but not by much. (see Table 2)
### Table 2
Result of Two-way fixed effects and Lasso regression analysis

<table>
<thead>
<tr>
<th></th>
<th>(m1)</th>
<th>(m2)</th>
<th>(m3)</th>
<th>(m4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic regression</td>
<td>Fixed effect</td>
<td>Control variables</td>
<td>Post-Lasso</td>
</tr>
<tr>
<td>(Intercept)</td>
<td>0.445***</td>
<td>0.469***</td>
<td>0.054</td>
<td>0.280***</td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td>(0.031)</td>
<td>(0.029)</td>
<td>(0.028)</td>
</tr>
<tr>
<td>Ownership (ref: Public hospitals)</td>
<td>-0.204***</td>
<td>-0.231***</td>
<td>-0.076***</td>
<td>-0.110***</td>
</tr>
<tr>
<td></td>
<td>(0.011)</td>
<td>(0.011)</td>
<td>(0.010)</td>
<td>(0.010)</td>
</tr>
<tr>
<td>Number of doctors</td>
<td>-0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of nurses</td>
<td>-0.000***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expense of outpatients</td>
<td>0.031***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expense of inpatients</td>
<td>0.004***</td>
<td>0.010***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of beds</td>
<td>-0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of outpatient and emergency visits</td>
<td>-0.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of inpatients</td>
<td>0.000***</td>
<td>0.000***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1717</td>
<td>1717</td>
<td>1717</td>
<td>1717</td>
</tr>
<tr>
<td>R²</td>
<td>0.162</td>
<td>0.401</td>
<td>0.591</td>
<td>0.547</td>
</tr>
<tr>
<td>AIC</td>
<td>-177.584</td>
<td>-411.724</td>
<td>-1048.966</td>
<td>-938.886</td>
</tr>
<tr>
<td>BIC</td>
<td>-161.239</td>
<td>-384.482</td>
<td>-983.586</td>
<td>-900.747</td>
</tr>
<tr>
<td>Fixed effect</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note: Monetary indicators were taken as natural logarithms; Standardized regression coefficient, with standard errors in parentheses; #p < 0.1; *p < 0.05; **p < 0.01; ***p < 0.001

### 4.4 Regression analysis of efficiency and the COVID-19 pandemic

The difference in efficiency between public and private hospitals from 2019 to 2021 respectively shown in Table 3. As we can find that the difference is significant in 2019 (m5, $\beta=-0.077$, $p < 0.001$) and 2021 (m6, $\beta=-0.089$, $p < 0.001$), while it (m6) is not significant in 2020 ($\beta=-0.032$, $p > 0.05$). This suggests that the epidemic has further widened the efficiency gap between public and private hospitals. (see Table 3)
Table 3  
Relationship between efficiency scores and the period

<table>
<thead>
<tr>
<th></th>
<th>(m5)</th>
<th>(m6)</th>
<th>(m7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2019</td>
<td>2020</td>
<td>2021</td>
</tr>
<tr>
<td>Ownership (ref: Public hospitals)</td>
<td>-0.077*** (0.018)</td>
<td>-0.032 (0.017)</td>
<td>-0.089*** (0.018)</td>
</tr>
<tr>
<td>N</td>
<td>559</td>
<td>559</td>
<td>599</td>
</tr>
<tr>
<td>AIC</td>
<td>-234.685</td>
<td>-325.458</td>
<td>-197.503</td>
</tr>
<tr>
<td>BIC</td>
<td>-187.097</td>
<td>-277.870</td>
<td>-149.155</td>
</tr>
<tr>
<td>R²</td>
<td>0.617</td>
<td>0.435</td>
<td>0.438</td>
</tr>
<tr>
<td>Control variables</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fixed effect</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note: Monetary indicators were taken as natural logarithms; Standardized regression coefficient, with standard errors in parentheses; The control variables are the same as regressions (m2) *p < 0.05; **p < 0.01; ***p < 0.001

Table 4 shows the impact of the COVID-19 pandemic on the efficiency of public and private hospitals independently. (m8) shows a decrease in the efficiency of public hospitals in 2020 (β=-0.086, p < 0.001) and 2021 (β=-0.051, p < 0.001) compared to 2019, while (m9) shows that the efficiency of private hospitals was not significantly affected by the pandemic.
Table 4
Relationship between efficiency scores of different ownership hospitals and the pandemic

<table>
<thead>
<tr>
<th>Year (ref 2019)</th>
<th>Public hospitals</th>
<th>Private hospitals</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>-0.086***</td>
<td>-0.015</td>
</tr>
<tr>
<td></td>
<td>(0.016)</td>
<td>(0.011)</td>
</tr>
<tr>
<td>2021</td>
<td>-0.051***</td>
<td>-0.020</td>
</tr>
<tr>
<td></td>
<td>(0.015)</td>
<td>(0.011)</td>
</tr>
<tr>
<td>N</td>
<td>729</td>
<td>988</td>
</tr>
<tr>
<td>AIC</td>
<td>-364.918</td>
<td>-863.337</td>
</tr>
<tr>
<td>BIC</td>
<td>-309.818</td>
<td>-804.589</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.606</td>
<td>0.528</td>
</tr>
<tr>
<td>Control variables</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fixed effect</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note: Monetary indicators were taken as natural logarithms; Standardized regression coefficient, with standard errors in parentheses; The control variables are the same as regressions (m2) *p < 0.05; **p < 0.01; ***p < 0.001

4.5 Robustness tests

Table 5 demonstrates the values of the average treatment effect (ATT) for the matched treatment groups. This study used nearest-neighbor matching while the caliper value was set to 0.5. The matching variable was the same as the (m3) control variable. The results were found to be significant in line with Table 3.

Table 5
Result of PSM

<table>
<thead>
<tr>
<th></th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>0.384</td>
<td>0.265</td>
<td>0.310</td>
</tr>
<tr>
<td>private</td>
<td>0.289</td>
<td>0.246</td>
<td>0.249</td>
</tr>
<tr>
<td>ATT</td>
<td>0.095**</td>
<td>0.019</td>
<td>0.061*</td>
</tr>
</tbody>
</table>

Note: *p < 0.05; **p < 0.01; ***p < 0.001; ATT, Average treatment on treated, means the average difference of efficiency score.

Finally, we measure efficiency using the BCC-DEA model and perform regression analysis, finding that the correlation between economic type and efficiency is still significant ($\beta = -0.078$, $p < 0.001$). The results are also consistent using Tobit regression ($\beta = -0.052$, $p < 0.001$). It is demonstrated that our results are robust. For space reasons, we do not show the detailed results of the regression.

5 Discussion
Throughout this fierce battle against Covid-19, public and private hospitals have played their respective roles in protecting the health and safety of the people to the greatest extent possible, despite the differences in efficiency between them.

In general, the mean efficiency score of private hospitals in Hubei Province was much lower than that of public hospitals before and after the COVID-19 pandemic. There has been no change in the policy direction of public hospitals being the mainstay and private hospitals being a supplement in China. During the pandemic, the ratio of public and private hospitals in the designated hospitals is 9:1[28]. This leads to a large flow of resources to public hospitals. Meanwhile, the outbreak has caused disruptions to the healthcare supply chain[56, 57]. Under the red line of hospitalization and stricter anti-epidemic policies around the world, private hospitals, as a strong complement to public hospitals, may see a positive outpatient volume. However, because of the butterfly effect of the pandemic, it was difficult for patients to seek medical treatment in sealed and controlled areas, and both public and private hospitals saw a sharp decline in outpatient volume. And whenever hospitals had confirmed patients, they had to be temporarily shut down. Some hospitals (especially public hospitals) were able to open immediately after the danger was lifted, while some took longer[58, 59]. In the post-epidemic era, patient demand for care declined. At the same time, it has also spawned a shift in access to care. Internet hospitals and telemedicine have been able to flourish[60, 61]. Even if patients need to go offline, they tend to choose public hospitals, which have a higher level of social trust and reputation[62]. There is no domestic literature on this topic. Before the epidemic, this is consistent with the view of Beijing’s case[26]. According to Tiemann et al, the evidence from Germany also supports that private ownership is not necessarily associated with higher efficiency than public ownership[63].

A stratified regression analysis was performed to distinguish the impacts of ownership from other confounding factors when comparing the technical efficiency of hospitals with different types of ownership[64]. We arrive at consistent results when the region, period and institutional variables are controlled. The difference in efficiency between public and private hospitals is significant in 2019 and 2021, but not in 2020. After PSM, the results are consistent. The possible reason for this is that in 2020, the epidemic is so severe in Hubei province that all public and private hospitals, except for the designated ones, stop operating. To some extent, the outbreak has even widened this gap. For public hospitals, efficiency decreases significantly during the outbreak period (2020) compared to the pre-outbreak period (2019). Their efficiency picks up in 2021 but does not yet return to pre-outbreak levels. Dan et al evaluated the efficiency of health systems in Europe against COVID-19 and reach the same result[65]. According to the L.E.K. 2022 Asia Pacific Hospital Survey, most hospitals are recovering from the pandemic and elective surgery volumes are rebounding to pre-COVID-19 outbreak levels. However, these results are still relatively fragile, with about 20% of large private hospitals facing losses[66]. In general, private hospitals have had a harder time recovering from the outbreak than public hospitals.

The optimal balance between public and private healthcare provision is a common concern in all healthcare systems. In terms of efficiency, private hospitals should perform better than public hospitals, according to several important theoretical contributions (public choice and property rights theory)[14, 22, 67, 68]. However, Administrative operations in the public sector tend to make it more efficient during public health emergencies[69]. The "Main force" role of public hospitals in fighting COVID-19 has been proven. It is important to strengthen the construction of public medical and health institutions. We should also be aware of the occurrence of widening the overall gap between public and private hospitals in the wake of the pandemic. Hospitals are complicated institutions that include high- and low-specificity services. According to asset specificity theory, this adds uncertainty to the benefits and efficiency of privatization in comparison to the competition and ownership argument[14]. In the post-epidemic era, private hospitals may have to prioritize finding the right positioning and offering highly specific medical services to expand.
With the promotion of high-quality development of public hospitals in China, their main position has been consolidated. Now public hospitals have shifted from "quantitative accumulation" to "qualitative improvement", with quality and efficiency as their main focus. In this way, public hospitals developed from an expansion phase to a refinement phase, from crude management to refined management, from a focus on material elements to a focus on talent and technology, to improve the quality and efficiency of medical and health services, prevent and resolve major pandemics and public health risks, and create a healthy China as a source of strong support[70]. At the same time, the tone of China's policy supporting the private operation of hospitals has never changed. By combing through the past 10 years, we found that the state has been positioning private hospitals as a complement to public hospitals, which should provide multi-level, differentiated and characteristic medical services[71, 72]. With the decentralisation of the public healthcare system, quality medical resources are gradually becoming available at the primary. Without the support of highly specific medical services and strong physician resources, small and medium-sized private hospitals are more likely to be squeezed for survival. Such a squeeze is not due to a small market, but rather to the inability of medical services to keep up with development requirements and to form an effective complement to public hospitals. During the reform process, utilizing the innovations, efficiency, and responsiveness of the private sector will be a challenge, as well as enhancing the capacity to regulate and monitor to ensure equitable access[73]. For decades to come, China's response to this challenge will determine its equity and efficiency in the healthcare system.

6 Conclusion

In this paper, we combine the SBM model with the two-way fixed effects model to explore the efficiency of public and private hospitals in Hubei Province, China, before and after the outbreak. The results were then tested for robustness using the BCC-DEA model, Tobit regression and the PSM model. Hubei Province is a representative province in China that is both hardest hit by the epidemic and extremely rich in medical resources. We found that the efficiency of public hospitals in Hubei province was much higher than that of private hospitals before and after the epidemic. In the face of the epidemic outbreak, they also showed a faster recovery rate. Public hospitals played a major role in the fight against the epidemic. The country's public health protection network should be fortified and efforts should be made to promote the high-quality development of public hospitals. Private hospitals have also played their part in the epidemic. Only with their long-established brand strength, strong teams of doctors, refined management capabilities, highly specific medical services offerings and other core competencies will quality private hospitals be able to gain a foothold at a time of reform. In this way, they will be able to move forward alongside public hospitals in the future and meet the demand for multi-level healthcare services.

Despite the empirical contribution of this paper, the following limitations exist. We lack data beyond Hubei province, and the national representativeness of the results is relatively weak. We lack more detailed operational data (e.g. surgery volume, etc.) and data on the quality of care in healthcare institutions, so it cannot provide insight into hospital quality or patient satisfaction. Reputation can also influence efficiency. We are currently unable to measure the differences between public and private healthcare institutions in these areas. We do not distinguish between private non-profits (PNFPs) and private for-profits (PFPs) due to data availability. A more detailed analysis will be conducted if required data are available in the future.

Declarations

Ethics approval and consent to participate

Not applicable.
Consent for publication

Not applicable.

Availability of data and materials

Publicly available datasets were analyzed in this study. This data can be found here: http://www.nhc.gov.cn/mohwsbwstjxxzx/tjztjcx/tjsj_list.shtml and http://tjj.hubei.gov.cn/tjsj/sjkscx/tjnj/qstjnj/

Competing interests

The authors declare that they have no competing interests.

Funding

None.

Authors’ contributions

SY, CJ and QW designed the study. SY, CJ, SA, YW and CY collected data. CJ analyzed and interpreted data. SY drafted the manuscript. SY, CJ, CY, ZM, DC and QW revised the manuscript. All authors have read and agreed to the published version of the manuscript. The author(s) read and approved the final manuscript.

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References


**Figures**

**Figure 1**

Change in the number of public and private hospitals

**Figure 2**

Change in the number of public and private hospitals
Hospital efficiency score of public hospitals and private hospitals

Figure 3
Mean efficiency score changes of public hospitals (blue) and private hospitals (green) by district or county

Figure 4
Kdensity distribution of propensity score (a) Before PSM; (b) After PSM