Has the medical reform improved the cost efficiency of Chinese hospitals?

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ARTICLE INFO

ABSTRACT

After three decades of reform, the medical care system in China has experienced significant changes. However, the present research has not made a tentative evaluation of it to justify further reform. This paper analyses the cost efficiency of Chinese hospitals in 31 provinces during the period from 2002 to 2011 and adopts a Bayesian stochastic frontier model taking account of the identified heterogeneity according to the background of Chinese medical system reform, including the coastal location, 3A class hospital proportion, public subsidies and medical insurance reforms. It finds that the public subsidies and medical insurance reforms have improved the cost efficiency of Chinese hospitals, while the coastal location and 3A class hospital proportion have decreased the cost efficiency of Chinese hospitals. Therefore, these results imply that it will be beneficial for Chinese medical system to optimize the fiscal subsidies of public hospitals, encourage the entrance of private hospitals, improve the medical insurance coverage and set up the pre-triage system.

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1. Introduction

As the aging society is approaching for the most populated country in the world, the medical services and public health become a more important issue for China. Due to the miracle of economic development after the reform and open-up policy since 1978, the health status and outcome has already been improved in China. According to the World Development Indicators (WDI), life expectancy in China increased from 66.5 years in 1978 to 73.5 years in 2011, and infant mortality rate decreased from 5.3% to 1.3% during the same period (World Bank, 2013). However, the development of health care has long been lagging in

China (Eggleston, 2012; Li, Dong, & Liu, 2014). With the increasing demand on high-quality medical services, the medical care sector of China has still been blamed for the high fee and low accessibility of medical services after the market-orientated reform started from 1985 in this sector. It even has been regarded as a failure by some researchers in China (Eggleston, Ling, Qingyue, Lindelow, & Wagstaff, 2008; State Council DRC Research Project, 2005; Wagstaff, Yip, Lindelow, & Hsiao, 2009). At present, despite there is broad agreement on that the system needs reform, there is less agreement on the causes of the system's failure and the reforms necessary to improve it (Eggleston et al., 2008). Therefore, it is urgent and necessary to make an overall evaluation for the passing reform and search for solutions to present challenges.

Hospitals are the main medical institutions that deliver medical service to people in China. Therefore, the research on whether have the Chinese hospitals efficiently delivered enough medical service to people is one of the vitally

important topics, which rarely has been paid attention to in the literature before (Eggleston et al., 2008; Ng, 2011). Meanwhile, monitoring the efficiency performance of Chinese hospitals can provide useful information for assessing the effectiveness of health policies and measures, and also as a way to achieve sustainable development in the most cost-effective way. Moreover, the Chinese hospitals were always the first priority in the medical reform, which have undergone series of reform and deregulation in last three decades. More details are present in the contextual setting part. Therefore, it is worthwhile to investigate the reform's effects on cost efficiency of Chinese hospitals.

For the important role that the hospitals have played in the medical sector, greater attention has been given to hospital efficiency and a growing number of studies have employed SFA to analyze cost-inefficiency in hospitals (Barros, de Menezes, & Vieira, 2013; Hollingsworth, 2008; Hsu, 2013; Hwang & Akdede, 2011; Jacobs, 2001). However, focus on efficiency of Chinese hospitals has not been well discussed until recent years. Eggleston et al. (2008) and Wagstaff, Yip, et al. (2009) have identified dozens of issues in the medical sector of China and concluded that Chines hospitals were quite inefficient through literature review. Recently, several researches have analyzed the productive efficiency of Chinese hospitals in the post reform period with empirical method (Audibert, Mathonnat, Pelissier, Huang, & Ma, 2013; Hu, Qi, & Yang, 2012; Ng, 2011). According to these researches, the efficiency of Chinese hospitals varies from different provinces and different year. And the overall efficiency had slightly increased before 2008. However, all of them only use the non-parametric method, i.e. Data Envelop Analysis (DEA) to analyze the efficiency of Chinese hospitals. However, this method cannot handle the noise and outliers in the data, which may strongly influence the shape of the frontier. It also suffers from the inability to test statistically for goodness of fit or significance of variables included in the functions. Meanwhile, the Stochastic Frontier Analysis (SFA) can overcome these limitations, despite being criticized for requiring a predefined functional form in the estimation of the frontier. And Coelli, Prasada Rao, and Battese (1998) argue that SFA is more powerful than DEA in panel data applications as it can be used to measure the efficiency and technical change over time. Therefore, we use the SFA to overcome the inherent drawbacks of DEA and make a robust check. To improve the methodological accuracies, recent studies have extended the use of the SFA methodology through introducing Bayesian stochastic frontier (SF) methodology (Assaf, Gillen, & Barros, 2012).[2] The Bayesian SF model incorporates informative priors and use prior knowledge to inform the current model. And small sample inference is carried out in the same way as if one had access to a large sample. The estimation is unbiased with respect to the sample size. However, quite a little literature on the

hospital efficiency uses the Bayesian stochastic frontier (SF) model, except Koop, Osiewalski, and Steel (1997). Following Tsionas (2002) and Assaf (2011), we adopt the Bayesian SF model with random coefficients in this paper. Comparing with traditional SFA and DEA, the Bayesian SF model with random coefficients that capture the unobserved heterogeneity and is more close to the reality, which will assure the efficiency is correctly estimated for separating technical inefficiency from technological differences across hospitals. And Pereira de Souza, Diallo, Castro Souza, and Baidya (2010) analyze the 60 Brazilian electricity distribution utilities with DEA and Bayesian SF and conclude that the DEA results are vulnerable to outlier while the results under Bayesian SF are more credible. Therefore, we are motivated to adopt Bayesian SF model to analyze the efficiency of Chinese hospitals.

Moreover, this paper aims to analyze all the hospitals across all the provinces of China, i.e. 5 autonomous regions, 4 municipalities and 22 normal provinces (it is called 31 provinces below for short). Although these provinces basically are in equal status in administration of government, there are plenty of differences among them, including different economic development, different strategies of local governments to develop the hospital sector and etc. (Jian, Sachs, & Warner, 1996; Xu et al., 2013). It also justifies using the Bayesian SF model with random coefficients in the research to allow for the heterogeneity and acquire more robust results or conclusion (Koop et al., 1997).

With respect to the medical care reform and its influences on the efficiency of Chinese hospitals, Eggleston et al. (2008) and Wagstaff, Yip, et al. (2009) have concluded that the Chinese hospital is quite inefficient after a comprehensive review of Chinese health care system. Hu et al. (2012) use the Tobit model to analyze the effects of some factors on the efficiency of Chinese hospitals, including the coastal location, public subsidies, the social medical insurance reform, the ratio of third-class hospitals to total hospitals and etc. And they conclude that the former two have insignificant effect on improving the technical efficiency, while the latter two significantly promote the technical efficiency. However, they use the traditional DEA to estimate the efficiency score in the first step. Moreover, McDonald (2009) argues that the use of Tobit regression was considered inappropriate in the second stage of DEA. This was because technical efficiency is fraction data and not generated by a censoring process. Therefore, it still needs more rigorous research to act as robust check.

Despite the majority of Chinese hospitals is non-profit, the medical care industry of China had undergone the market-orientated reform. The hospitals had been entitled more autonomy to personnel management and charging of medical service, which had meanwhile triggered the upsurge of medical service price. More details can be learned from the contextual setting part of this paper. Therefore, we focus on the cost efficiency of Chinese hospitals, which had been overlooked in the literature.

The remainder of this paper is organized as follows: section 2 briefly introduces the contextual setting of this paper. Then the methodology, variable selection and data

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[2] It is different from the traditional estimation method, i.e. maximum likelihood (ML). Moreover, other Partial frontier approaches, like the order-m (Cazals, Florens, & Simar, 2002) and alpha-frontiers (Aragon, Daouia, & Thomas-Agnan, 2005), and StoNED-stochastic Non-Smooth Envelopment of Data (Kuosmanen, 2012) are also developed to cope with the limitations of DEA.

specification are presented in section 3. In section 4, we examine the results of Bayesian SF model estimation and comparing it with results of traditional SFA and Hu et al. (2012) with further discussion, the Section 5 concludes and provides some policy implications.

2. Contextual setting

Before the reform and open up in 1978, China had a planned economy. The medical care system of China was characterized by "prevention first", community organization and cooperative financing (Hsiao, 1995). Medical service was delivered through a three-tier organization system, the street (sub-district), district and municipal level hospitals in urban areas as well as the village health stations, township health centers and county hospitals in rural areas. There was also a three-tier health insurance system that consisted of publicly-funded medical care, labor insurance medical care and cooperative medical care schemes (Dong, 2001, 2009). The publicly-funded medical care, which was also called Government Insurance Schemes, covers civil servant, employees of public enterprises, military offices and university students. And the labor insurance medical care covers workers in state-owned and collective companies. Moreover, the cooperative medical care schemes cover the rural population and collapsed in 1990s (Audibert et al., 2013). In this period, the price of medical service was kept low by the Central Price Commission. People's needs for basic medical service had been satisfied, which helped to improve their health status (Hsiao, 1995). However, the 10 years' Culture Revolution began in 1966. This undermined the medical care system. As the economic reform moved forward, the government put first priority on economic development when the local government was given more autonomy and competed for economic growth, rather than public services like medical care (Audibert et al., 2013; Dong, 2001). As a result, the development of the medical care system was challenged by limited public funds and the rapid expansion of medical expenditures (Dong, 2009).

Reform in the medical care system was not implemented until 1985, when the State Council approved the plan proposed by the Ministry of Health (MOH) of China, which intended to encourage the establishment of more hospitals in urban and rural areas. This gave existing hospitals more autonomy and raised the price of medical service, reducing the restrictions on the supply of medical service (Yip & Hsiao, 2009). Meanwhile, the MOH of China also strengthened the quality of medical service through stipulating a regulation on hospital grading in late of 1989, namely certificating hospitals in China every three year in different grade according to their capacity to supply high-quality medical service. Later in 1992, the MOH of China granted further substantial financial autonomy to hospitals, encouraging the hospitals to increase their revenue by offering higher quality service and allowing hospitals to transform to modern companies and set joint ventures. After these reforms, new hospitals began to spring up and the supply of medical service largely increased (World Bank, 2010). As the regulation and entry barriers, the number of private hospitals had not increased a lot until 2001 when the government abolished some limitations. And up to March 2013, there are 10166 private hospitals in China.[3] However, the public hospitals still maintain the dominant position in the healthcare sector of China (Gu & Zhang, 2006). At the same time, China began market and commercialization reform in the medical care system. Negative externalities quickly began to emerge, including the poor access and high costs of medical service (Audibert et al., 2013; Eggleston et al., 2008).

Responding to the rapid increase of costs and the reduction of medical care affordability, the government launched a series of reforms in 1994. The State Council implemented the pilot reform of basic social medical insurance scheme (BSMIS) for urban employees in Jiangsu and Jiangxi province. This was applied to the whole country in 1998. In 2003, the new rural cooperative medical system (NRCMS) was implemented in the four provinces by the State Council. Both BSMIS and NRCMS are different from the traditional medical care insurance before 1978. And there are individual responsibility of premium contribution and individual accounts in the new schemes. For more details, see Dong (2009). In 2000, the State Council announced different policies for both for-profit and non-profit hospitals, lifting restrictions on public hospitals, separating pharmacies from medical practices. Before this reform, the hospitals always sold patients medicine at high price, so that to increase the revenue of hospitals and relieve the limits of low fiscal budgets on hospitals. This situation was also described as "medicine-supported-hospitals" in China. With the outbreak of SARS (Severe Acute Respiratory Syndromes) in 2003 and the scandal of expenses in medical service, the MOH finally made a prudent review on the medical care system in China and admitted the low coverage of the medical insurance and the failure of market-orientation reform in medical care industry.

After 2005, the government took measures to increase the coverage of medical insurance. The government became aware of the importance of medical service to public welfare. They planned to raise the fiscal budget for the medical care system. However, reform will never cease until people can access to more affordable, accessible and equal medical service in this first largest populated country. And the milestone in this period is the publication of new scheme for medical care reform in 2009. The government promised to increase the fiscal subsidies rather than rely on market to sufficiently satisfy people's needs for basic medical services. Meanwhile, it would investment 850 million yuan in the next two years to deepen the reform, including accelerating the establishment of basic medical care insurance system and essential drug system, improving the community-level medical service system, increasing the equalization in the public medical services and the pilot experiments on public hospital reforms.

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[3] The statistics is obtained from "Private Hospital Blue Books: The Report of Chinese Private Hospital development" (in Chinese) that published by Chinese Hiospital Association.

3. Methodology, variable selection and data

3.1. Methodology

Hospital efficiency analysis is an important issue within the field of health economics. There are two contemporary approaches to measure cost efficiency of hospitals: the parametric approach and the non-parametric approach. The most used parametric method is SFA, while the popular non-parametric approach is DEA (Barros, de Menezes, Peypoch, Solonandrasana, & Vieira, 2008; Wei, Ni, & Sheng, 2011; Yu, Choi, & Zhang, 2013; Zhang & Choi, 2013; Zhu, Wang, & Wu, 2014). However, Tsionas (2002) and Assaf (2011) argue that these traditional methods have inherent limitations that assume that all hospitals operate under the same production or cost technology in the estimation of efficiency, while in practice this is not true and might lead to incorrect efficiency estimates. Battese and Rao (2002) have begun to use the metafrontier approach to take account of the different production technology when estimating the efficiency and productivity. And it has brought out a large strand of literature. However, this metafrontier approach has inherent deficiency that requires prior knowledge of different groups of the DMUs (Kumbhakar, Wang, & Horncastle, 2015). Therefore, we adopt the Bayesian SF model with random coefficients that was introduced by Tsionas (2002). It assumes that each hospital is allowed different intercepts as well as slope coefficients. The main purpose of the model is to improve the accuracy in the efficiency estimation by separating the cost-efficiency estimates from heterogeneity among hospitals. This model is different from the Bayesian fixed frontier model, introduced by Koop et al. (1997), which assumes that all hospitals share exactly the same production possibilities (i.e. no heterogeneity between hospitals).

The Bayesian SF model with random coefficients is estimate through Bayesian method, which has an additional key advantage, in that the technique incorporates informative priors, so that prior knowledge, or results of a previous model, can be used to inform the current model (Greene, 2005; Orea & Kumbhakar, 2004). In other words, it obeys the likelihood principle. And small sample inference is carried out in the same way as if one had access to a large sample, and all inferences follow logically from Bayes' theorem. Therefore, any sample size can be accommodated, no matter how small. The estimation is unbiased with respect to sample size. Moreover, Bayesian inference is consistent with much of the philosophy of science regarding epistemology, where knowledge cannot be built entirely through experimentation, but requires prior knowledge (Griffin & Steel, 2007; Koop et al., 1997).

To illustrate the general setup of cost function in SFA and the model of Tsionas (2002) with random coefficients, we consider the following cost equation:

$$C_{it} = a + X_{it}\beta_i + v_{it} + \mu_{it}; \quad i = 1, 2, \ldots, N, \ t = 1, 2, \ldots, T \tag{1}$$

where C_{it} is a vector of the dependent variable for the ith observation of year t (typically logs of production or cost), X_{it} is vector of explanatory variables (typically logs of inputs), v_{it} is a random error identically and independently distributed as $N(0,\sigma^2{}_n)$, μ_{it} is a non-negative random error which captures the level of cost inefficiency and ensures that each hospital's cost-efficiency lies on or below the frontier model, β_i is a vector of random coefficients and α is a non-random intercept. In the Bayesian context, it is common to assume that the inefficiency term μ_{it} is exponentially distributed (Other distributions such as truncated and gamma are also possible, but the exponential distribution is generally the most common in the Bayesian framework. More details can be referred to Koop (2003)) with a parameter θ, and which can be expressed as follows:

$$f(\mu_{it}) = \theta \ \exp(-\theta\mu_{it}) \tag{2}$$

To complete the model assumptions, the parameters β_i follows a multivariate normal distribution, where $\bar{\beta}$ is a vector of parameter means, Ω is a positive-definite covariance matrix.

$$\beta_i \sim N(\bar{\beta}, \Omega) \tag{3}$$

This makes the model hierarchical with two levels of latent variables, β_i and μ_{it}. Specifically, each hospital under consideration has its own cost function with parameters β_i which account for heterogeneity or technological differences between hospitals. The restriction of $\Omega = 0$ will make the model in Eq. (1) converge to the traditional or fixed stochastic frontier model, which is commonly used in the literature. Some additional assumptions of the model are that β_i is independently distributed, and e_{it} as well as μ_{it} are independent of X_{it}, where $e_{it} = C_{it} - \alpha - X_{it}\beta_i$. For details about the likelihood and the conditional posteriors of the model refer to Appendix A.

3.2. Variable selection and model setting

3.2.1. Variable selection

In this section, the selection of explanatory variables X_{it} in the formula (1) is introduced. According to the cost function in SFA models, the explanatory variables adopted in the Bayesian SF model include the input and output variables, which will be selected based on a large strand of literature on efficiency analysis of hospitals and the available data in China. Referring to Hu et al. (2012), we choose several measures that describe the reform undergone by the medical system of China in several dimensions to analyze their influences on the hospital efficiency of China, so that to provide some policy implications for the medical system of China. And the details are presented as follows:

3.2.1.1. Input and output variables. The model adopts the costs function with three inputs (price of labour (*PL*), number of beds (*Beds*) and asset value (*Assets*)) and two outputs (number of surgeries (*Surgery*) and revenue (*Revenue*)). They are adopted according to the previous research on hospital efficiency, which include Koop et al. (1997), Jacobs (2001), Rosko and Mutter (2008), Barros et al. (2013) and etc., and the accessibility of the data of Chinese hospitals. Because the research on Chinese hospital efficiency is rare, we mainly refer to the literature on hospital of other countries. The price of labour is determined by dividing

Table 1
Descriptive statistics of the data.

Variable	Description	Minimum	Maximum	Mean	SD
$\ln C_{it}$	Logarithm of operational cost of hospitals in Yuan (RMB), 2008 = 100	17.332	22.386	19.630	0.962
T	Trend variable from 1 = 2002 to 10 = 2011	1	10	5.5	2.876
T^2	Squared value of the trend variable	1	100	38.5	32.472
$\ln PL_{it}$	Logarithm of price of workers, measured by dividing total wages by the number of workers	9.275	11.870	10.322	0.524
$\ln Beds_{it}$	Logarithm of beds as a proxy for hospital capital	8.351	13.843	11.151	0.852
$\ln Assets_{it}$	Logarithm of total assets in Yuan (RMB), 2008 = 100	29.89	36.222	33.224	1.247
$\ln Surgery_{it}$	Number of surgery undertaken	8.737	16.588	12.826	1.097
$\ln Revenue_{it}$	Logarithm of total revenue in Yuan (RMB), 2008 = 100	20.192	25.797	23.568	1.046
Coastal	Dummy variable which is one for coastal hospitals and zero elsewhere	0	1	0.354	
Best	The proportion of 3A class hospitals (%)	0.791	13.142	4.077	2.457
$\ln Subsidy$	Logarithm of public subsidy allocated to hospital at in 1000 Yuan (RMB), 2008 = 100	12.241	16.643	14.627	0.896
reform 1	Dummy variable which is one for year after 2003	0	1	0.800	
reform 2	Dummy variable which is one for year after 2007	0	1	0.400	

Sources: China's Health Statistical Yearbook 2003–2012.

the total salary expenditure by total staff of the hospitals. The number of beds and asset value is a quasi-fixed factor (Caves, Christensen, & Swanson, 1981; Kaparakis, Miller, & Noulas, 1994). The units analyzed are provincial hospitals, which include a bunch of different hospitals in each province of China.

3.2.1.2. Reform variables. Except for the general input and output variables, the SFA models also allow for other explanatory variables. Based on the literature survey and contextual setting of China, we further try to detect the influence of reform in the medical care system on hospital efficiency in different dimensions, i.e. we will examine the relationship between hospital technical efficiency and the following covariates: coastal location (*Coastal*), 3A class (San Ji Jia Deng) hospital proportion (*Best*), public subsidies (*Subsidy*), medical insurance reforms (*Reform*1) and (*Reform*2). The justification for the selection of these covariates is provided in the following subsections.

Coastal location is a dummy variable that indicates whether the hospitals are located in a coastal province or a non-coastal province.[4] Costal location may have an effect on hospital efficiency. For example, Hu et al. (2012) found that there is no apparent efficiency difference between coastal and non-coastal provinces. However, Ng (2011) concludes that the hospitals in coastal provinces suffer from more productivity decline than the non-coastal provinces in China from 2002 to 2005. Reform was first initiated in coastal provinces of China, which may enhance the management and incentives in the medical care industry through deregulation. Moreover, the eastern area, i.e. coastal provinces, is richer and more developed than western and central area of China (Jian et al., 1996). The more favorable environment and diversified medical demand of people will drive the hospitals to be more efficient.

The 3A class hospital proportion in the total number of public hospitals indicates the supervision as well as the medical services quality. In China, the hospitals have been divided into three grades according to their capability to supply high-quality medical service. There are three sub-classes in each grade. The top is labeled as 3A hospital. They could offer specialized medical service, medical research and tertiary medical education. However, the technological advantage and accumulation of human resources is costly to improve the medical services of hospitals (Li et al., 2014).

The public subsidy is the amount of funds transferred to the hospitals, which could increase the hospitals' budget for more professional personnel and advanced equipment, as well as induce moral hazard or shirking behavior. The net effects of public subsidy are not clear. Public hospitals in China always hold the major share of the medical market despite flourishing private hospitals since 2001. Furthermore, price regulation on medical service makes the public subsidies very significant to cover expenses for public hospitals.

The social medical insurance reform is measured with two dummy variables. As the contextual setting part indicates, China initiated the NRCMS in 2003. The government launched the basic social medical insurance for urban residents program (BSMIP) in 2007, which is different from BSMIS and covers the elderly, students, children and unemployed. Then the three-tier social medical insurance schemes finally established and increase the affordability of medical service. Follow the research of Hu et al. (2012), we also examine whether the introduction of NRCMS and BSMIP have increased the efficiency of hospitals. And we define that these binary dummy variables equal 1 for post-reform period after 2003 and 2007, respectively.

Table 1 summarizes the input and output variables and the reform variables. And the input and output variables and the *Subsidy* are all taken the logarithm according to cost function under SFA models. Meanwhile, the variable *Revenues*, *Assets* and *Subsidy* have been corrected for price changes.

4. Model setting

The specification of the cost function follows microeconomic theory (Varian, 1987), which is also in line with most literature on production function and cost efficiency

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[4] The coastal provinces in China are as follows: Liaoning, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, Hainan.

(Kumbhakar et al., 2015). Based on the selected variables and Bayesian SF model with random coefficients, the final model is obtained:

$$
\ln\left(C_{it}/PK_{it}\right) = \alpha_{it} + \kappa_t T + \frac{1}{2}\kappa_{tt}T^2 + \beta_1 \ln Surgery_{it}
$$

$$
+ \beta_2 \ln Revenue_{it} + \beta_3 \ln \frac{PL_{it}}{PK_{it}} + \beta_4 \ln \frac{Beds_{it}}{PK_{it}}
$$

$$
+ \beta_5 \ln \frac{Assets_{it}}{PK_{it}} + \frac{1}{2}\beta_6(\ln Surgery_{it})^2
$$

$$
+ \frac{1}{2}\beta_7(\ln Revenue_{it})^2 + \frac{1}{2}\beta_8\left(\ln \frac{PL_{it}}{PK_{it}}\right)^2
$$

$$
+ \frac{1}{2}\beta_9\left(\ln \frac{Beds_{it}}{PK_{it}}\right)^2 + \frac{1}{2}\beta_{10}\left(\ln \frac{Assets_{it}}{PK_{it}}\right)^2
$$

$$
+ \beta_{11} \ln Surgery_{it} * \ln Revenue
$$

$$
+ \beta_{12} \ln Surgery_{it} * \ln \frac{PL_{it}}{PK_{it}}
$$

$$
+ \beta_{13} \ln Sugery * \ln \frac{Beds_{it}}{PK_{it}}
$$

$$
+ \beta_{14} \ln Sugery * \ln \frac{Assets_{it}}{PK_{it}}
$$

$$
+ \beta_{15} \ln Revenue_{it} * \ln \frac{PL_{it}}{PK_{it}}
$$

$$
+ \beta_{16} \ln Revenue_{it} * \ln \frac{Beds_{it}}{PK_{it}}
$$

$$
+ \beta_{17} \ln Revenue_{it} * \ln \frac{Assets_{it}}{PK_{it}}
$$

$$
+ \beta_{18} \ln \frac{PL_{it}}{PK_{it}} * \ln \frac{Beds_{it}}{PK_{it}} + \beta_{19} \ln \frac{PL_{it}}{PK_{it}} *
$$

$$
\ln \frac{Assets_{it}}{PK_{it}} + \beta_{20} \ln \frac{Beds_{it}}{PK_{it}} * \ln \frac{Assets_{it}}{PK_{it}}
$$

$$
+ \rho_1 Coastal + \rho_2 Best + \rho_3 \ln Subsidy
$$

$$
+ \rho_4 reform1 + \rho_5 reform2 + \upsilon_{it} + \mu_{it} \qquad (4)
$$

where C_{it} is the total operational cost of hospitals, which is chosen according to literature of cost efficiency analysis. PK_{it} is the price of capital premised calculated by dividing the total depreciation by total assets. And we divided the total cost (C_{it}), price of labour (PL_{it}), number of beds (Bed_{it}) and asset value ($Assets_{it}$) by the PK_{it}, to ensure homogeneity (normalization) in price for the cost function. T is time trend to capture the missing dynamics. With parameters in this model being estimated, the efficiency of hospitals in different province of China can be calculated.

4.1. Data

Our analysis includes the province-level data of Chinese hospitals available over the period 2002–2011 (310 observations), which cover much longer period than previous research on China, like Hu et al. (2012), Ng (2011) and etc. This province-level data was obtained from China's Health Statistical Yearbook that published by MOH of China during 2003–2012. It covers all the hospitals in 31 different provinces of China. According to the data of China's Health Statistical Yearbook, the overwhelming majority of Chinese hospitals are public hospitals. The scale and number of private hospitals is relatively small when comparing the public hospitals.[5]

5. Results and discussion

5.1. Parameters estimation

To proceed with the Bayesian estimation, we estimate the formula (4) with Winbugs software applying the Gibbs sampling with data augmentation for the above data using 100,000 iterations (first 10,000 iterations are dropped to avoid sensitivity of starting values). The value r_i^* was set at 0.875 following other studies in the literature (Tsionas, 2002; Van den Broeck, Koop, Osiewalski, & Steel, 1994). The posterior estimates of mean parameters and posterior standard error are reported in column (1) of Table 2.

From the results of column (1) in Table 2, it is verified that costs increase with the time trend but the square trend declares that it increases at decreasing rates. The cost increase as theoretically expected with the inputs (*PL*, *Beds* and *Assets*) as well as with the outputs (Surgery and Revenue), signifying that it is costly to produce surgeries and hospital revenue. Relative to the equation square terms, the costs increase with some and decrease with others.

The analysis of the variables concerned with the reform in the medical care system in China is explained as follows:

Since the parameter of binary dummy variable "*Coastal*" is significant and positive (see column (1) in Table 2), it means that the coastal location has increased costs of Chinese hospitals. Ng (2008) also finds the same results for Chinese hospitals. But she does not explain the reason in details. As the reform and opening up began in the coastal area of China and it is more developed than other area of China. Most private hospitals in China were also set up there for deregulation.[6] Therefore, the cost efficiency of hospitals[7] may be lowered down mainly for the market share nibbled away by the private hospitals. It implies the plausibility to motivate the private investments or private hospitals into medical care industry, despite the results still need further research and tests.

According to the column (1) in Table 2, the coefficient of the 3A class hospital proportion is significantly positive at 1 percent level, implying that it has increased the operational cost of hospitals when there are more 3A hospitals in the whole public hospitals. Rosko (2001), Rosko and Mutter (2008) also find that the same situation in the United State. However, our result is the contrary to the findings of Hu et al. (2012). The supervising authorities will grade the hospitals according to several standards every

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[5] According to the data of China's Health Statistical Yearbook, the proportion of total assets of private hospitals just reached 4.02% at end of 2011 in China.

[6] The statistics is obtained from "Private Hospital Blue Books: The Report of Chinese Private Hospital development" (in Chinese) that published by Chinese Hospital Association.

[7] It does not include the private hospital in the sample of this article.

Table 2
Bayesian Stochastic Frontier Analysis Parameters Estimation.

Variables	Parameters	(1) Tsionas (2002) Bayesian stochastic frontier model		(2) Battese and Coelli (1995) standard stochastic frontier model	
		Coefficient	SE	coefficients	SE
Constant	cons	−4.348	4.692	−3.127	2.123
T	κt	**0.018**	0.00003	**0.017**	0.002
½T²	κtt	**−0.003**	0.0044	**−0.0012**	0.001
ln *Surgery$_{it}$*	$\beta 1$	**0.803**	0.004	**0.912**	0.003
ln *Revenue$_{it}$*	$\beta 2$	**1.854**	0.0027	**1.213**	0.004
ln *PL$_{it}$*	$\beta 3$	**1.461**	0.0087	**1.027**	0.0021
ln *Beds$_{it}$*	$\beta 4$	**1.756**	0.0032	**1.219**	0.0011
ln *Assets$_{it}$*	$\beta 5$	**0.716**	0.0008	**0.813**	0.0013
½(ln Surgery$_{it}$)²	$\beta 6$	0.027	0.229	0.017	2.131
½(ln Revenue$_{it}$)²	$\beta 7$	0.807	1.527	0.813	2.128
½(ln PL$_{it}$)²	$\beta 8$	−0.401	0.349	−0.217	1.289
½ (ln Beds$_{it}$)²	$\beta 9$	**0.118**	0.0035	**0.115**	0.0012
½(ln Assets$_{it}$)²	$\beta 10$	**−0.318**	0.0059	**−0.319**	0.0018
ln *Surgery$_{it}$*ln Revenue$_{it}$*	$\beta 11$	**−0.887**	0.007	**−0.873**	0.0014
ln *Surgery$_{it}$*ln PL$_{it}$*	$\beta 12$	**−0.086**	0.0032	**−0.073**	0.0021
ln *Surgery$_{it}$*ln Beds$_{it}$*	$\beta 13$	−0.388	1.614	−0.318	1.542
ln *Surgery$_{it}$*ln Assets$_{it}$*	$\beta 14$	**−0.028**	0.0027	**−0.017**	0.0003
ln *Revenue$_{it}$*ln PL$_{it}$*	$\beta 15$	−0.495	0.491	−0.518	1.341
ln *Revenue$_{it}$ * ln Beds$_{it}$*	$\beta 16$	**−1.234**	0.0092	−1.147	3.218
ln *Revenue$_{it}$ * ln Assets$_{it}$*	$\beta 17$	**1.887**	0.0017	**1.716**	0.0021
ln *PL$_{it}$*ln Beds$_{it}$*	$\beta 18$	**−0.518**	0.0091	**−0.543**	0.0025
ln *PL$_{it}$ * ln Assets$_{it}$*	$\beta 19$	**1.218**	0.0055	**1.167**	0.0022
ln *Beds$_{it}$*ln Assets$_{it}$*	$\beta 20$	1.563	1.505	1.428	2.312
Coastal	$\rho 1$	**0.027**	0.004	**0.032**	0.0011
Best	$\rho 2$	**0.0013**	0.001	**0.0025**	0.0024
ln Subsidy	$\rho 3$	**−0.0238**	0.0090	**−0.0315**	0.0018
***reform* 1**	$\rho 4$	**−0.058**	0.0071	**−0.048**	0.0011
***reform* 2**	$\rho 5$	**−0.0012**	0.0061	**−0.0022**	0.0015
Error term	ν	**0.01**	0.007	**0.08**	0.0012
non-negative random error	μ	**0.218**	0.006	**0.312**	0.004
Number of observations	*Nobs*	310		310	
Number of iterations	*iterations*	10,000			

Notes: Statistical significant parameters at 1% level are in bold.
The denominator PK_{it} of each variable is not wrote out for short.

three years. Hence, the 3A hospital rating is also a signal for great technology advantage and high quality of medical service. Without a sound pre-triage system, the 3A hospitals just attract crowded patients for signals and take advantage of the monopoly power in the medical market. And this will increase the costs and distortions of the whole society.

As the column (1) in Table 2 shows, the coefficient of public subsidies is negative at 1-percent significant level, which means that the subsidies make positive impact on the Chinese hospitals to reduce hospital's cost efficiency. This is evidence that subsidies are an incentive to reduce cost efficiency rather than inducing moral hazards. On the contrary, Hu et al. (2012) argued that the government subsidy has ambiguous and insignificant effects on the Chinese hospital efficiency. And Chen, Yamauchi, Kato, Nishimura, and Ito (2006) claimed that the government subsidy of public hospitals in China was very low and the survival pressure from market competition was higher. And it would not lead to the moral risks and inefficiency when increasing the government subsidy. As the contextual setting part and World Bank (2010) show, public hospitals still control the majority of the market share in medical industry. And they are very popular among people and preferred to private

hospitals for more talented doctors, better medical equipment, higher guarantee for medical negligence and etc. Therefore, it favors increasing the cost efficiency of Chinese hospitals when raising the government fiscal budgets on medical care system.

As the definition in Table 1, the binary dummy variables *Reform*1 and *Reform*2 are designed to analyze the effects when introducing the social medical insurance reform in 2003 and 2007. Referring to the column (1) in Table 2, both coefficients of *Reform*1 and *Reform*2 are significantly negative at 1 percent level. In other words, the social medical insurance reform has a positive influence on the efficiency of Chinese hospitals decreasing costs, which is consistent with the empirical results of Hu et al. (2012). The medical insurance reform of the NRCMS and BSMIP has increase the opportunity of the poor to acquire the medical service, namely the government subsidy people to get the basic medical service and therefore increasing the demand for medical service as well as the output of the hospitals. Wagstaff and Lindelow (2008) and Wagstaff, Lindelow, Jun, Ling, and Juncheng (2009a) also witnessed the increase in the medical service utilization after the reform. Moreover, as the column (1) in Table 2 indicates, the absolute value of the coefficients of *Reform*1 is much larger than the *Reform*2.

Table 3
Efficiency scores.

Provinces	(1)	(2)
	Mean efficiency ranks in Tsionas (2002) Bayesian stochastic frontier	Mean efficiency ranks in Battese and Coelli (1995) standard stochastic frontier model
Beijing	0.949	0.912
Tianjin	0.978	0.932
Hebei	0.915	0.910
Shanxi	0.883	0.871
Inner Mongolia	0.960	0.952
Liaoning	0.867	0.843
Jilin	0.937	0.912
Heilongjiang	0.964	0.957
Shanghai	0.935	0.831
Jiangsu	0.939	0.912
Zhejiang	0.963	0.915
Anhui	0.960	0.943
Fujian	0.945	0.927
Jiangxi	0.955	0.939
Shandong	0.952	0.946
Henan	0.969	0.927
Hubei	0.968	0.972
Hunan	0.976	0.985
Guangdong	0.951	0.943
Guangxi	0.972	0.962
Hainan	0.970	0.937
Chongqing	0.964	0.912
Sichuan	0.980	0.969
Guizhou	0.972	0.958
Yunnan	0.929	0.918
Tibet	0.962	0.942
Shaanxi	0.960	0.928
Gansu	0.933	0.919
Qinghai	0.965	0.943
Ningxia	0.970	0.959
Xinjiang	0.974	0.963
Mean	0.952	0.932
Median	0.961	0.937
SD	0.026	0.034

It implies that the coverage of social medical insurance in the rural is more effectively lower the cost of Chinese hospitals than that in the urban.

Relative to the SF parameters, the error term is statistically significant and the non-negative random error is also statistically significant meaning that this data is adequately described by a SF model.

5.2. Efficiency score

Cost efficiency is defined as the ratio between the minimum cost and the actual cost, and takes values of between 0 and 1. According to this definition, the closer the efficiency measure is to 1, the more efficient the hospitals can be considered to be. Given that the dependent variable is expressed in logarithms, it was calculated as:

$$EC = \exp(-\hat{\mu}) \tag{5}$$

where the estimated value of the inefficiency ($\hat{\mu}$) is separated from the random error term ($\hat{v}$) using the Jondrow, Lovell, Materov, and Schmidt (1982) formula.

The hospital efficiency scores are present in Table 3. The column (1) reports the efficiency score under the

Bayesian stochastic frontier model. From the scores it is verified that the mean efficiency is 0.952, signifying that the average waste is of $1 - 0.952 = 0.048$. In other words, there is a potential to reduce the cost by 4.8%. This small waste varies among the hospitals analyzed. The hospitals in Sichuan province are the most efficient with an average value of 0.980 and the hospitals in Liaoning province the least efficient with an average value of 0.867. Therefore, the differences are small signifying that there is similar hospital behavior in a Chinese context. The reason behind this phenomenon may lie in they are public hospitals in different provinces but with similar management system. In other words, the Chinese hospitals have not yet entitle more autonomy to improve the management as well as innovation, which was one of most important objectives in the New Medical Care Reform launched in 2009.

5.3. Robust check

As the Bayesian stochastic frontier analysis model is clearly not comparable to homogenous hospital studies, like Hu et al. (2012) and Ng (2011), since those studies do not take into consideration the aforementioned heterogeneity (Assaf, 2011; Tsionas, 2002). Moreover, the study of Hu et al. (2008) and Ng (2011) estimate a production function in which the dependent variable is the output rather than the cost with DEA. However, we still check the robustness (i.e. correctness) of the Bayesian results following the Battese and Coelli (1995) stochastic frontier model, which is a traditional SFA mode for panel data and assumes the coefficients of β are fixed for all the hospitals. The results are reported in the column (2) of Table 2.

These results reveal that the parameter estimation is in line with the Bayesian frontier model estimated with the same signs, despite the values are different. The Battese and Coelli (1995) stochastic frontier model has less statistical significant parameters. Moreover, the Error term v of the Bayesian stochastic frontier model is 0.01 while it is 0.08 under the standard stochastic frontier model. Differences in v can be attributed to the heteroscedastic nature of the stochastic frontier model. Moreover, the efficiency rank among the Chinese hospitals in 31 different provinces basically changed, except for the two provinces, i.e. Xinjiang and Qinghai, which are both minority autonomy areas that located at the northwest region of China.

The column (2) of Table 3 reports the efficiency score under the standard stochastic frontier model. The mean and median of the efficient scores for the Battese and Coelli (1995) stochastic frontier model is lower than the one for Bayesian stochastic frontier models, despite the efficiency ranking does not significantly change.

6. Conclusion

This study is the first to compare the efficiency of province-level of Chinese hospitals in the period 2002–2011 using a Bayesian SF model with random coefficients. The results reveal that efficiency varies among Chinese hospitals in different regions but this variability is small signifying that the hospitals have a homogenous

efficiency behavior, which highlights the necessary to promote the reform of public hospitals, so that to be entitled more autonomy to realize robust management and diversified innovations in technology.

Based on the analysis of hospital efficiency, we further check the influence of reform in the medical care system on the efficiency of Chinese hospitals, which also shed lights on the effects and effectiveness of reforms undergone, i.e. some reforms have improved the cost efficiency while others have not. And this is different from the viewpoints of some scholars that negated the positive effects of the medical reform in the last thirty years (State Council DRC Research Project, 2005). Meanwhile, it does not flatter that the past medical reform is totally a big success for the negative influences on the cost efficiency of Chinese hospitals. It concludes that raising the subsidy to the hospital and increasing the coverage of social medical insurance both will promote the cost efficiency, while the coastal location and raising the proportion of 3A hospitals both have positive influence on increasing the costs. Based on the analysis and discussion in Part IV, the policy implications are derived as follows:

First, it justifies the new scheme for medical care reform in 2009 to increase the fiscal budgets on the medical system and switch from relying on the market to government. However, the government subsidies have decreased as a share of total hospital revenues for more than 20 years and now account for about 10 percent of total revenues (World Bank, 2010). Hence, it is reasonable to encourage the development of private hospitals to ease the pressure of decreasing fiscal subsidies in public hospitals. The result for the variable "Coastal" also indicates the significance to deregulate the private hospitals.

Secondly, according to the statistics of Ministry of Health, the coverage of medical insurance in China had already reached over 95% of the total population since 2011. However, the coverage of medical services should be also enlarged, especially for the treatment of critical diseases as well as the essential drugs. Meanwhile, the medical insurance for the rural and urban should be unified an integrated to offer people equal insurance for basic medical service. According to the results, the introduction of the new rural cooperative medical system (NRCMS) has brought out more significant improvement in efficiency of Chinese hospitals than the basic social medical insurance scheme (BSMIS) for urban employees. The present medical insurance in China is in a high degree of fragmentation for different provinces or counties.

Finally, a sound pre-triage system is necessary when the pushing the reform of big public hospitals and community-level hospitals. When 3A hospital is labelled without it, the effects of this monitoring mechanism will be negative and derive excessive demand for the high-quality medical services, which mismatch with their needs for basic medical services.

As this present empirical research just uses the Chinese hospitals with province-level data, the future research could move to collect and utilize the hospital-level data located at different provinces of China when the data can be accessed, so that to check convince the conclusions as well as provide more insightful policy implications.

Appendix A. Appendix

The likelihood of the model in Equation (1) can be expressed as

$$L(\alpha, \bar{\beta}, \sigma, \theta; C, X) = NT \ln \theta + (\frac{\theta^2}{2}) \sum_{t=1}^{T} \sum_{i=1}^{N} W_{it} + \sum_{t=1}^{T} \sum_{i=1}^{N}$$

$$\left[\ln \Phi(\frac{-\varepsilon_{it} - \theta W_{it}}{W_{it}^{1/2}}) + \theta \varepsilon_{it} \right] \quad (A1)$$

where $\varepsilon_{it} \equiv C_{it} - \alpha - X'_{it}\bar{\beta}$; $w_{it} \equiv \sigma^2 + X'_{it}\Omega X_{it}$; $\Phi(\cdot)$ denotes the standard normal distribution function, and X is a matrix of explanatory variables.

Along with this likelihood, the Bayesian estimation of the model requires prior information about the parameters. The general priors for the model can be summarized as follows:

$$\rho(\sigma^2, \theta, \Omega) \propto \sigma^{-(\underline{N}_1+1)} \exp\left(-\frac{q_1}{2\sigma^2}\right) \theta^{\underline{N}_2 - 1}$$

$$\exp(-\underline{q}_2 \theta)|\Omega|^{-(K+\underline{v}+1)/2} \exp(\frac{-1}{2tr\Omega^{-1}\underline{S}}) \quad (A2)$$

where $\underline{N}_1$, $\underline{N}_2$, $\underline{q}_1$ and $\underline{q}_2$ are small positive numbers, and S is a positive definite matrix.

A common practice is to choose the priors for α and β as flat (i.e. imposing no prior information about the parameter mean). A gamma prior is selected for θ, an inverted gamma prior is selected for σ.

Having information about the likelihood and the priors, the conditional posterior of each of the model parameters can then be estimated. The conditional posteriors of the model parameters can be summarized as follows: for σ^2.

$$\frac{q_1 + \sum_{t=1}^{N} \sum_{i=1}^{N} (C_{it} + u_{it} - \alpha - X'_{it}\beta_i)^2}{\sigma^2} \sim \chi^2(NT + N_1) \quad (A3)$$

For $\bar{\beta}$

$$p(\bar{\beta}|\alpha, \beta_i, \sigma, \Omega, \theta, C, X) \propto$$

$$\times \exp\left[-\frac{1}{2} \sum_{i=1}^{N} (\beta_i - \bar{\beta})' \Omega^{-1} (\beta_i - \bar{\beta}) \right] \quad (A4)$$

for μ_{it}:

$$\mu_{it}|\alpha, \bar{\beta}, \beta_i, \sigma, \Omega, \theta, C, X \sim N(\alpha + X'_{it}\bar{\beta}$$

$$- C_{it} - \theta W_{it}, W_{it}) \cdot 1(u_{it}) \geq 0 \quad (A5)$$

Where 1(A) is indicator function and it is equal to one if event A is true, otherwise it is zero.

And the conditional posterior for θ is gamma,

$$\theta | \alpha, \bar{\beta}_i, \sigma, \Omega, \mu, C, X \sim G(NT + \underline{N}_2, \sum_{t=1}^{T} \sum_{i=1}^{T} \mu_{it} - \ln r_*) \quad (A6)$$

where r_i^* is a measure of cost-efficiency of the ith hospital.

More details could be referred to Tsionas (2002).

Using these conditional densities the Gibbs sampler follows. When the iterations approach to infinity, the Gibbs sampling methods converges to the actual joint posterior density function. In this paper, we generate 100,000 parameter vectors and drop the first 10,000 to avoid sensitivity of starting values.

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