Advances in Management & Applied Economics, vol. 7, no. 4, 2017, 17-31
ISSN: 1792-7544 (print version), 1792-7552(online)
Scienpress Ltd, 2017

Changes in total factor productivity in National Health Insurance system of Taiwan between 2005 and 2014

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Abstract

In this study, we evaluated changes inefficiency in the medical service industry of Taiwan at the level of decision-making units as well as at the industry level. The efficiency, technology, and total factor productivity of the National Health insurance system has changed considerably since it was first developed in 1995. We employed the data envelopment analysis (DEA) and Malmquist index methodology using two input and two output indicators in assessing the total factor productivity of22 counties/cities over the period 2005~2014. Decomposing the Malmquist index into "catch-up" and "frontier shift" components revealed a decrease in the quality of care during the study period.

JEL classification numbers: I13, I18, O32
Keywords: data envelopment analysis, Malmquist index, medical service industry, total factor productivity.

1 Introduction

In this study, we sought to measure productivity in the medical service industry of Taiwan over the last decade. We also examined the impact of health policy and resource allocation in various areas of the country. Measuring the efficiency of medical services presents a number of difficulties. Previous researchers [1-3] have reported that investment in medical institutions can be categorized as medical

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Article Info: *Received*: March 7, 2017. *Revised:* April 9, 2017.
Published online: July 1, 2017

manpower, the number of beds, and operating expenses. Personnel costs generally account for at least 50 percent of the total costs [4, 5]; i.e., collinearity exists between the number of medical personnel and operating expenses[6]. We adopted the following medical service outputs: revenue, number of patients, number of outpatient and emergency department visits, and number of surgical procedures. This diversity of outputs hinders assessment, due to the fact that most of these factors are statistically collinear. In other words, the number of outpatients and emergency department visits are related to revenue as well as to the number of patients treated.

Previous researchers investigated changes in medical care at the industry level. This has left unanswered the question of whether productivity can be improved through innovations in medical technology, the development of new drugs, increasing manpower, or the adoption of new technologies for the management of medical institution. Globally, the productivity efficiency of medical services appears to be in decline. [7-9]. In this study, we sought to determine whether output efficiency in the medical service industry of Taiwan has been increasing or decreasing over the last decade.

We employed data envelopment analysis (DEA) to analyse the efficiency of medical service output[10, 11]. DEA is a nonparametric method that measures the relative efficiency of an object referred to as a decision-making unit (DMU) using multiple inputs and outputs. The fact that DEA can be used to deal with multiple outputs makes it possible to implement novel DMU sets in the measurement of relative efficiency. To the best of our knowledge, no previous research has used DEA analysis to examine the efficiency of the medical service industry in Taiwan over time (time-transection).

In this study, we introduce the DEA/Malmquist index [12, 13] to measure the time-longitudinal changes in the efficiency boundary of medical services at the industry level. The Malmquist index measures differences in DEA efficiency during two time intervals. It can be decomposed into 1) catch-up, which measures how close the DMU moves toward the frontier, and 2) frontier shift, which moves the efficiency boundary. The efficiency boundary is composed of DMUs related to DEA efficiency in all DMUs during a given period. The movement of the frontier indicates changes at the industry level. In this study, we used the frontier shift to indicate changes in the productivity of the medical service industry throughout the period of study.

2 Data and methodology

2.1 Inputs and outputs for measurement of efficiency in provision of medical services

Taiwan implemented National Health Insurance (NHI) in 1995, and has increased this budget on a yearly basis. Over the last two decades, the NHI has been suffering dramatic losses. This has prompted the government to formulate policies

to remedy this situation. Between 2004 and 2015, the annual expenditures of the NHI have increased an average of 3.43%. Nonetheless, issues pertaining to the efficiency of the system have been largely overlooked. Using DEA to analyse productivity in the provision of medical services is based on the selection of DEA inputs and outputs. DEA determines how DMUs convert multiple inputs into multiple outputs [14]. In other words, any DMU with an input lower than the output is considered efficient. The inputs used in this study were the total number of medical staff and the total number of beds in all hospitals and clinics. The number of outpatient visits and inpatient visits were adopted as outputs. Ozcan (2008) treated operating costs as an input indicator; however, we were unable to do the same due to a lack of data related to operating costs in the National Health Insurance database. Furthermore, we observed considerable collinearity between the number of medical staff and operating costs. The outputs in this study were the total number of outpatients and the number of emergency visits/hospitalizations.
We initially formulated four data panels, each of which included 22 counties × 10 years (2005 to 2014). The cities and counties included the following: New Taipei City, Taipei City, Taichung City, Tainan City, Kaohsiung City, Ilan County, Taoyuan City, Hsinchu County, Miaoli County, Changhua County, Nantou County, Yunlin County, Chiayi County, Pingtung County, Taitung County, Hualien County, Penghu County, Keelung City, Hsinchu City, Chiayi City, Kinmen County, and Lianjiang County. These cities/counties cover all of the administrative regions of Taiwan, which should be sufficient to examine the impact of government policy at the industry level. One advantage of using a longitudinal database for cross-year analysis is the fact that DEA analysis of outputs often involves the deferral of inputs from medical personnel and beds invested over the preceding years. In practice, if a new hospital is opened (new medical staff and hospital beds are put into operation), then it generally takes2-3 years before a steady state is reached. We adopted the Malmquist index (MI) known as total factor productivity (TFP) to resolve this discrepancy. The MI can be decomposed into changes in technical efficiency, scale efficiency, and technology. When applied to the medical industry, MI refers to changes in the efficiency of management, changes in the efficiency of hospitals of various scale, and changes in medical technology. These types of data are unsuitable for input and output data from the same year. To assess the suitability of four-panel data for DEA models, we analyze 220 data items from three perspectives, returning to the Malmquist index for further analysis.

2.2 DEA analysis of efficiency in the provision of medical services

We analyzed medical service production efficiency in 22 counties/cities in Taiwan using DEA for the period 2005~2014. We adopted the *BCC* model of DEA [15], assuming the variable return-to-scale. The BCC model in its weak efficiency, input-oriented and envelopment form to measure DEA efficiency of medical service production of target DMU is formulated as the following linear program (LP) (1):

$$\textit{Max} \quad g_k = \sum_{i=1}^{s} \mu_r Y_{rk} - u_0$$

$$\textit{s.t.} \quad \sum_{i=1}^{m} \upsilon_i X_{ik} = 1 \qquad (1)$$

$$\sum_{i=1}^{s} \mu_r Y_{rk} - \sum_{i=1}^{m} \upsilon_i X_{ik} - u_0 \le 0, \quad j = 1, \ldots\ldots, n$$

$$\mu_r, \upsilon_i \ge \varepsilon > 0, \quad i = 1, \ldots\ldots, m; \quad r = 1, \ldots\ldots, s$$

Tables 1-3 present three sets of DEA analysis of 22 counties/cities in Taiwan during 2005-2014.

Table 1: 10 DEA cross-sectional analysis by year (DMU=22counties and cities)

Counties/cities	**Medical treatment input by year**									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Kaohsiung city	1.00	0.68	0.68	0.70	0.70	0.69	0.68	0.69	0.69	0.70
Hualien county	0.44	0.45	0.50	0.55	0.58	0.58	0.59	0.57	0.58	0.57
Keelung city	0.56	0.55	0.60	0.63	0.64	0.66	0.66	0.62	0.61	0.61
Chiayi city	0.29	0.28	0.30	0.30	0.30	0.31	0.30	0.29	0.28	0.31
Chiayi county	0.70	0.71	0.79	0.87	0.83	0.88	0.91	0.85	0.85	0.87
Kinmen county	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Lianjiang county	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Miaoli county	0.83	0.83	0.91	0.96	0.98	1.00	1.00	1.00	1.00	1.00
Nantou county	0.80	0.80	0.88	0.94	0.94	0.94	0.92	0.89	0.90	0.94
Penghu county	1.00	0.99	0.96	0.97	0.90	0.88	0.85	0.78	0.68	0.85
Pingtung county	0.86	0.88	0.91	0.94	0.98	1.00	0.95	0.99	0.98	1.00
Taipei city	0.45	0.46	0.46	0.49	0.51	0.52	0.52	0.52	0.52	0.52
Taitung county	0.77	0.76	0.80	0.82	0.88	0.90	0.88	0.81	0.82	0.87
Tainan city	0.64	0.66	0.68	0.72	0.73	0.74	0.74	0.73	0.73	0.74
Taichung city	0.63	0.62	0.62	0.67	0.66	0.66	0.66	0.66	0.66	0.67
Taoyuan city	0.50	0.56	0.56	0.58	0.59	0.61	0.62	0.61	0.60	0.61

New Taipei City	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Hsinchu City	0.54	0.57	0.57	0.62	0.63	0.62	0.61	0.58	0.54	0.58
Hsinchu County	0.73	0.78	0.85	0.93	0.96	1.00	1.00	1.00	1.00	1.00
Ilan County	0.74	0.77	0.81	0.87	0.90	0.92	0.96	0.93	0.90	0.91
Yunlin County	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Changhua County	0.76	0.74	0.80	0.84	0.84	0.83	0.82	0.83	0.83	0.86

Table 2: 10 DEA time series analysis by year(DMU=10 years)

Counties/cities	**Medical treatment input by year**									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Kaohsiung city	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.99	1.00
Hualien county	1.00	0.99	0.98	0.99	1.00	1.00	1.00	1.00	1.00	1.00
Keelung city	1.00	1.00	0.96	0.92	0.97	1.00	0.86	0.85	0.97	1.00
Chiayi city	1.00	1.00	0.98	0.96	1.00	1.00	0.96	0.97	1.00	1.00
Chiayi county	1.00	0.97	0.94	0.97	0.96	0.96	0.98	0.99	1.00	1.00
Kinmen county	1.00	0.95	0.99	1.00	1.00	0.97	0.94	0.89	0.97	1.00
Lianjiang county	1.00	0.97	0.97	1.00	0.98	1.00	1.00	0.99	0.99	1.00
Miaoli county	1.00	0.96	0.94	0.96	1.00	0.99	0.95	0.95	0.98	1.00
Nantou county	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00
Penghu county	1.00	1.00	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
Pingtung county	1.00	0.96	0.96	0.92	0.98	0.97	0.94	0.93	1.00	1.00
Taipei city	1.00	0.97	0.90	0.86	0.87	1.00	0.77	0.77	0.90	1.00
Taitung county	1.00	0.96	1.00	1.00	1.00	0.87	0.88	0.87	1.00	1.00
Tainan city	1.00	0.97	1.00	0.98	1.00	1.00	1.00	0.96	0.97	1.00
Taichung city	1.00	0.99	0.99	1.00	0.98	0.97	0.98	0.99	1.00	1.00
Taoyuan city	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
New Taipei City	1.00	1.00	0.99	0.94	0.95	0.96	0.99	0.98	1.00	1.00
Hsinchu City	1.00	0.99	0.99	1.00	1.00	1.00	0.96	0.95	0.97	1.00
Hsinchu County	1.00	0.98	0.96	1.00	1.00	1.00	0.95	0.94	0.98	1.00
Ilan County	0.94	1.00	0.98	0.94	1.00	0.98	0.99	0.99	1.00	1.00

Yunlin County	1.00	0.99	0.99	1.00	1.00	1.00	0.98	0.99	1.00	1.00
Changhua County	1.00	0.97	0.94	0.98	1.00	1.00	0.92	0.93	0.97	1.00

Table 3: Panel DEA by year(DMU=22counties and cities)

Counties/cities	**Medical treatment input by year**									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Kaohsiung city	0.36	0.34	0.33	0.32	0.32	0.32	0.31	0.31	0.34	0.34
Hualien county	0.37	0.35	0.36	0.37	0.38	0.38	0.34	0.34	0.36	0.35
Keelung city	0.41	0.40	0.40	0.40	0.40	0.41	0.38	0.34	0.37	0.36
Chiayi city	0.21	0.19	0.19	0.19	0.18	0.18	0.17	0.16	0.17	0.18
Chiayi county	0.58	0.55	0.56	0.59	0.55	0.55	0.51	0.48	0.51	0.50
Kinmen county	0.94	1.00	0.90	0.86	0.84	0.85	0.90	0.94	1.00	0.99
Lianjiang county	0.63	0.52	0.62	0.67	0.67	0.47	0.50	0.45	0.52	0.51
Miaoli county	0.69	0.64	0.64	0.64	0.64	0.64	0.57	0.57	0.61	0.61
Nantou county	0.67	0.62	0.62	0.63	0.61	0.60	0.52	0.50	0.54	0.55
Penghu county	0.65	0.61	0.62	0.60	0.60	0.61	0.61	0.61	0.59	0.60
Pingtung county	0.60	0.57	0.56	0.55	0.55	0.55	0.47	0.48	0.51	0.51
Taipei city	0.25	0.25	0.25	0.24	0.25	0.25	0.24	0.24	0.26	0.26
Taitung county	0.64	0.59	0.59	0.58	0.60	0.59	0.53	0.50	0.54	0.54
Tainan city	0.38	0.36	0.36	0.36	0.36	0.36	0.34	0.34	0.37	0.37
Taichung city	0.34	0.31	0.31	0.32	0.32	0.32	0.30	0.30	0.32	0.32
Taoyuan city	0.31	0.31	0.30	0.30	0.29	0.29	0.27	0.26	0.28	0.29
New Taipei City	0.55	0.53	0.52	0.49	0.49	0.48	0.46	0.46	0.50	0.49
Hsinchu City	0.35	0.33	0.32	0.34	0.34	0.33	0.31	0.31	0.32	0.31
Hsinchu County	0.61	0.60	0.59	0.59	0.59	0.60	0.54	0.53	0.57	0.56
Ilan County	0.62	0.60	0.57	0.58	0.58	0.58	0.54	0.52	0.54	0.53
Yunlin County	0.84	0.78	0.71	0.67	0.65	0.63	0.55	0.55	0.58	0.57
Changhua County	0.48	0.45	0.46	0.45	0.44	0.43	0.39	0.40	0.44	0.45

2.3 Changes in medical service efficiency for the study decade (Malmquist index)

We used DEA/Malmquist index with data from the NHI database to quantify changes in technical efficiency in the medical service industry. The MI [16] can be used to measure changes in total factor productivity across periods by multiplying technical efficiency with technique change. We multiplied the distance function of technical efficiency change and technique change to obtain the distance function of the Malmquist index as follows:

$$\textbf{Malmquist index (MI)} = \frac{d_i^t(x_t, y_t)}{d_i^s(x_s, y_s)} \left[\frac{d_i^s(x_s, y_s)}{d_i^t(x_s, y_s)} \times \frac{d_i^s(x_t, y_t)}{d_i^t(x_t, y_t)} \right]^{1/2} \quad (2)$$

$$= \left[\frac{d_i^s(x_t, y_t)}{d_i^s(x_s, y_s)} \times \frac{d_i^t(x_t, y_t)}{d_i^t(x_s, y_s)} \right]^{1/2}$$

Technical efficiency change (also referred to as catch-up effect) indicates the extent to which the technical efficiency of a decision-making unit (DMU) improves or declines. Technique change (also known as a frontier-shift effect or innovation effect), indicates changes in the frontier between two periods. From (2), we can see that the MI comprises four distance functions: dis (xs, ys), dit (xt, yt), dit (xs, ys), dis (xt, yt). dis (xs, ys) and dit (xt, yt) measure the distance from the observations (DMU) to the efficiency boundary. dit (xs, ys) and dis (xt, yt) are measures of the intertemporal efficiency index (IEI). When the Malmquist index > 1, it represents an increase in total factor productivity from S to T. When the Malmquist index = 1, the total factor productivity is constant. When the Malmquist index < 1, the total factor productivity is declining.

Tables4-6 respectively show MI_{jo} [2005, β], CU_{jo} [2005, β] and FS_{jo} [2005, β], compared with all previous years except 2005. The index values are 1 when β=2005. We employ geometric means (rather than arithmetic ones) as averages of MI, CU and FS indices due to their multiplicative nature.

Table 4: Malmquist index (MI)

Counties/cities	**Year β of medical service MI_{io} [2005, β], β=2005...,2014**										**Annual change**
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Kaohsiung City	1	0.653	0.978	0.974	0.99	0.969	0.919	0.991	1.085	1.005	0.944
Hualien County	1	0.954	1.004	1.054	1.011	0.995	0.905	0.979	1.081	0.983	0.995
Keelung City	1	0.911	0.989	0.969	1.018	0.985	0.979	0.951	0.994	0.987	0.976
Chiayi City	1	0.908	0.998	0.961	1.009	0.984	0.999	0.985	1.013	1.045	0.988
Chiayi County	1	0.942	1.02	1.059	0.92	1.019	0.947	0.935	1.068	1.008	0.989
Kinmen County	1	1.104	0.986	0.998	1.148	1.02	1.086	1.099	1.147	0.836	1.043
Lianjiang County	1	0.941	1.009	1.139	0.923	0.838	0.977	0.916	0.974	1.062	0.972
Miaoli County	1	0.923	1.004	1	0.994	1.003	0.905	1.001	1.059	1.002	0.987
Nantou County	1	0.926	1.006	1.013	0.967	0.975	0.894	0.967	1.069	1.024	0.981
Penghu County	1	0.939	1.02	1.003	1.043	0.968	1.039	1.008	0.978	1.024	1.002
Pingtung County	1	0.933	0.975	0.975	1.032	0.998	0.822	1.017	1.092	1.009	0.981
Taipei City	1	0.994	0.984	0.991	1.043	1.007	0.935	0.995	1.108	0.994	1.005
Taitung County	1	0.932	0.982	0.982	1.038	0.995	0.887	0.937	1.108	1.008	0.984
Tainan City	1	0.916	0.997	0.986	1.006	0.972	0.975	0.978	1.071	1.004	0.989
Taichung City	1	0.909	0.991	1.013	0.983	0.974	0.962	0.992	1.044	1.016	0.986
Taoyuan City	1	1.016	0.975	0.974	1.01	0.996	0.97	0.966	1.036	1.002	0.994
New Taipei City	1	0.979	0.99	0.956	0.993	0.986	1	0.984	1	0.991	0.986
Hsinchu City	1	0.973	0.97	1.056	1.045	0.987	0.991	0.972	1.016	0.981	0.999
Hsinchu County	1	0.97	0.996	1.011	1.035	1.021	0.993	1.008	0.986	0.993	1.001
Ilan County	1	0.962	0.952	1.026	1.002	0.992	0.92	0.961	1.044	1.004	0.984
Yunlin County	1	0.916	0.921	0.948	0.971	0.957	0.918	0.995	1.046	0.985	0.961
Changhua County	1	0.896	1.036	0.998	0.991	0.967	0.934	0.996	1.076	1.025	0.99
Average	1	0.936	0.990	1.004	1.008	0.982	0.953	0.983	1.050	0.999	0.988

Table 5: Catch-up index (CU)

Counties/cities	**Year β of medical service CU_{io} [2005, β], β=2005...,2014**										**Annual change**
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Kaohsiung City	1	0.681	0.991	1.04	0.99	0.995	0.985	1.015	1.001	1.008	0.961
Hualien County	1	1.022	1.104	1.108	1.044	1.006	1.01	0.975	1.014	0.981	1.028
Keelung City	1	0.978	1.086	1.043	1.015	1.036	0.997	0.938	0.984	1.002	1.008
Chiayi City	1	0.976	1.036	1.019	0.99	1.027	0.973	0.961	0.962	1.134	1.007
Chiayi County	1	1.014	1.12	1.101	0.957	1.053	1.037	0.939	1.001	1.024	1.026
Kinmen County	1	1	1	1	1	1	1	1	1	1	1
Lianjiang County	1	1	1	1	1	1	1	1	1	1	1
Miaoli County	1	0.995	1.102	1.053	1.029	1.016	1	1	1	1	1.021
Nantou County	1	0.997	1.104	1.067	1	1	0.978	0.966	1.017	1.044	1.018
Penghu County	1	0.993	0.97	1.008	0.931	0.972	0.965	0.919	0.876	1.251	0.983
Pingtung County	1	1.026	1.027	1.03	1.047	1.021	0.954	1.038	0.994	1.017	1.017
Taipei City	1	1.04	1	1.045	1.053	1.018	1.005	1.004	0.991	1.009	1.018
Taitung County	1	0.991	1.05	1.029	1.07	1.016	0.984	0.921	1.009	1.063	1.014
Tainan City	1	1.029	1.033	1.064	1.015	1.009	0.999	0.989	0.993	1.016	1.016
Taichung City	1	0.99	1.006	1.081	0.984	1.002	0.987	1.01	1	1.009	1.007
Taoyuan City	1	1.111	1.006	1.034	1.018	1.036	1.009	0.985	0.998	1.006	1.022
New Taipei City	1	1	1	1	1	1	1	1	1	1	1
Hsinchu City	1	1.052	0.99	1.099	1.006	0.99	0.984	0.95	0.927	1.071	1.006
Hsinchu County	1	1.055	1.096	1.09	1.036	1.042	1	1	1	1	1.035
Ilan County	1	1.037	1.045	1.081	1.036	1.014	1.048	0.965	0.974	1.013	1.023
Yunlin County	1	1	1	1	1	1	1	1	1	1	1
Changhua County	1	0.975	1.075	1.051	1	0.988	0.99	1.012	1	1.031	1.013
Average	1	0.998	1.038	1.047	1.010	1.011	0.996	0.981	0.988	1.031	1.010

Table 6. Frontier shift index (FS)

Counties/cities	**Year β of medical service FS_{io} [2005, β], β=2005...,2014**										**Annual change**
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Kaohsiung City	1	0.958	0.987	0.937	1	0.973	0.934	0.977	1.084	0.996	0.982
Hualien County	1	0.934	0.91	0.951	0.968	0.989	0.896	1.004	1.065	1.002	0.967
Keelung City	1	0.932	0.911	0.929	1.002	0.951	0.983	1.013	1.01	0.985	0.968
Chiayi City	1	0.93	0.963	0.943	1.019	0.958	1.026	1.025	1.054	0.922	0.981
Chiayi County	1	0.929	0.911	0.962	0.962	0.968	0.913	0.996	1.067	0.985	0.965
Kinmen County	1	1.104	0.986	0.998	1.148	1.02	1.086	1.099	1.147	0.836	1.043
Lianjiang County	1	0.941	1.009	1.139	0.923	0.838	0.977	0.916	0.974	1.062	0.972
Miaoli County	1	0.928	0.911	0.95	0.967	0.987	0.905	1.001	1.059	1.002	0.967
Nantou County	1	0.928	0.911	0.95	0.967	0.974	0.913	1	1.052	0.982	0.963
Penghu County	1	0.946	1.051	0.995	1.12	0.996	1.077	1.097	1.116	0.819	1.02
Pingtung County	1	0.91	0.949	0.947	0.986	0.978	0.862	0.98	1.099	0.992	0.965
Taipei City	1	0.956	0.984	0.948	0.991	0.989	0.931	0.991	1.118	0.985	0.987
Taitung County	1	0.941	0.935	0.954	0.97	0.98	0.901	1.017	1.098	0.949	0.97
Tainan City	1	0.89	0.965	0.927	0.991	0.963	0.976	0.989	1.078	0.988	0.973
Taichung City	1	0.918	0.985	0.938	0.999	0.972	0.974	0.982	1.044	1.007	0.979
Taoyuan City	1	0.914	0.969	0.942	0.992	0.961	0.961	0.981	1.038	0.996	0.972
New Taipei City	1	0.979	0.99	0.956	0.993	0.986	1	0.984	1	0.991	0.986
Hsinchu City	1	0.925	0.98	0.961	1.039	0.997	1.008	1.024	1.095	0.915	0.992
Hsinchu County	1	0.919	0.908	0.928	0.998	0.98	0.993	1.008	0.986	0.993	0.968
Ilan County	1	0.928	0.911	0.95	0.967	0.978	0.878	0.996	1.071	0.991	0.962
Yunlin County	1	0.916	0.921	0.948	0.971	0.957	0.918	0.995	1.046	0.985	0.961
Changhua County	1	0.919	0.963	0.95	0.991	0.979	0.944	0.985	1.075	0.994	0.977
Average	1	0.938	0.955	0.959	0.998	0.972	0.957	1.003	1.063	0.972	0.978

3 Results

3.1 DEA analysis

As shown in Table 1, we solve the DEA model using two inputs and two outputs in order to determine the DEA efficiency (value 1 means DMU efficient). From the perspective of the number of inpatient cases, New Taipei City is the largest city and Lianjiang County is the smallest. Both of these cities are considered DEA-efficient during the 10-year study period; however, the extreme difference in size means that they are located at the border. Kinmen County (the 2nd smallest DMU) is also close to the border. Table 2 presents the DMUs located at the border of the frontier in the first and last years. The fluctuations in this study are significantly smaller (efficiency score 0.77~1) than those observed in time series analysis[17]. Table 3 presents the results of DEA panel analysis using220 DMUs (n=22 counties and cities x 10 years=220). There were only 2 efficient DMUs (Kinmen County: 2006 and Kinmen County: 2013). The average DEA efficiency among the 110 DMUs in the first half of the decade was 0.50 and 0.46 in the latter half. The difference is not significant. As shown in Tables 2 and 3, medical service production efficiency appears not to have improved at all during the past decade. Thus, we must go beyond traditional DEA analysis using CCR and BCC models in order to determine how medical service changed.

3.2 Changes in medical service production efficiency at the DMU level

The MI indicates changes in the total productivity over time for use by decision-makers. The measurement of DEA efficiency is based on the efficiency frontier comprising the most efficient units for a given year, the efficiency value of which is 1. The MI takes into account shifts in the frontier. As shown in Table 4, the efficiency of medical service production in Taiwan decreased at a rate of 1.2% per year between 2005 and 2014. During the same period, health expenditures increased at an average rate of 3.43%. The scale effect on the MI was 1.0047, presenting an average annual increase of 0.47%. It should be noted that only four of the cities/counties presented a rise in total factor productivity; i.e., all of the others presented a drop. Kinmen County presented the best performance during the study period with an annual change rate of 1.043.Kaohsiung presented the worst performance with an annual change rate of 0.944%, indicating an average yearly drop of 5.6%. Four cities/counties presented a growth trend: Kinmen County, Taipei City, Penghu County and Hsinchu County. Taipei City and the remaining three counties/cities are considered deficient in medical facilities. As a growing metropolitan area, the growth in efficiency in Taipei was unexpected. Nonetheless, the annual catch-up index of Taipei City was 1.018 and the frontier shift index was 0.987. However, the scale effect on efficiency change was 0.983%. This is an indication that policy-makers have good control over the growth of the city in meeting the growing demand for medical services.

The catch-up index measures how close a DMU moves to the efficiency boundary as well as the rate of change in efficiency when compared to the previous year. Table 5 shows that Kinmen County, Lianjiang County, New Taipei City and Yunlin County remained at the efficiency boundary from 2005 to 2014. Chiayi City and Penghu County were not on the frontier in 2005, but have since caught up with the frontier. In 2014, they presented the highest catch-up index. Table 5 shows that the 22 cities/counties grew at an average annual rate of 1% per year to catch the frontier. The highest catch-up index was in Hsinchu County (3.5%), followed by Ilan County, Hualien County, Chiayi County, Miaoli County, Taoyuan City and Ilan County at more than 2%.

3.3 Changes in medical service production efficiency according to industry and innovation

The catch-up index and the MI indicate movement of the DMU relative to the frontier, where as the frontier-shift index represents the movement of the efficiency frontier itself. This is determined by the most efficient DMUs in the study. The frontier of changes in technical efficiency is "industry", rather than every DMU. Taiwan's administrative region comprises 22 cities/counties, covering all of the variables in the medical service industry. The efficiency frontier refers to the efficiency of medical service provision at the industry level. In other words, the average frontier shift index of all counties/cities is an appropriate indicator by which to evaluate changes in efficiency at the industry level. A frontier shift index > 1 indicates (forward) movement in the direction of fewer medical service inputs and more outputs. It is also indicative of industry innovation or significant changes in technique. As shown in Table 6, we found that an annual change of 0.978 in the frontier shift index means changes in the efficiency of medical service provision deteriorated at an annual rate of 2.2% during the study period (2005-2014). In other words, the medical service efficiency boundary at the industry level moved backward.

From Tables 4-6, we can plot the three indices for each county. Take Hsinchu County as an example (Figure 1). Hsinchu County is the only county with a catch-up index > 1. This means that Hsinchu County has been able to catch up with the efficiency frontier since 2005. Since2011, the catch-up index has not changed. The Malmquist index moved synchronously with the efficiency frontier. In the medical service industry, changes in technical efficiency are correlated with input and output factors. In our study, the inputs include the number of medical staff and the number of beds. The output items are the number of outpatient visits and the number of hospitalizations. As a result, changes in technical efficiency are due to the effectiveness with which medical staff and beds are managed, including downsizing the number of the medical staff and beds, improving allocation, and/or increasing turnover in the use of beds. Technique change (frontier-shift effect) is indicative of innovations in medical technology. This makes it possible to use time-varying indices to provide a quantitative illustration of the means by which medical service productivity changes.

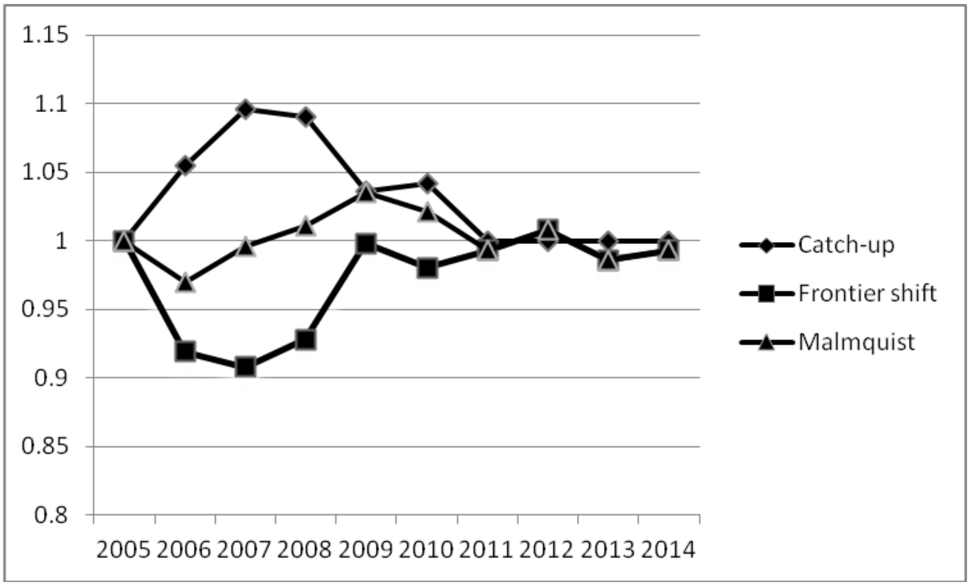

Figure 1: Three indices for Hsinchu County

Figure2 is a graph illustrating the average frontier shift index in Table 6. The results show that technique change increased initially but eventually fell to 0.978. It should be noted that productivity was declining throughout the entire decade; i.e., the average frontier-shift index has been dropping for nearly ten years. The FS index of Kinmen County (1.043%) presented the best annual rate of change. Nonetheless, there were still 3 years of negative growth during that period. It is also noteworthy that Kinmen County lacks medical resources, which means that additional output must be generated despite limited manpower and hospital beds.

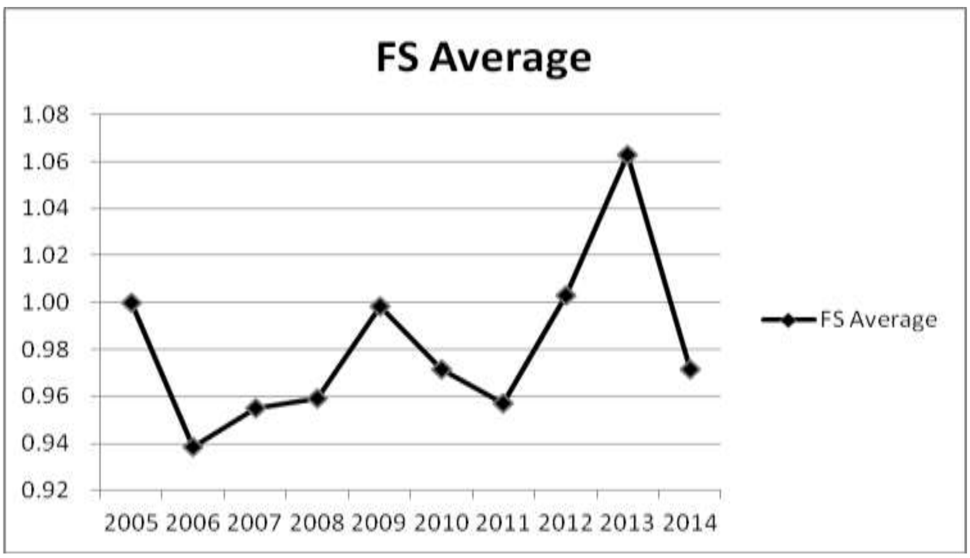

Figure 2: Changes in medical service production efficiency at industry level

4 Conclusion

This study uses a DEA/MI method to measure change in total factor productivity in the medical service industry of Taiwan. Decomposing the MI into changes in technical efficiency and technique revealed a gradual improvement in technical efficiency and a gradual drop in technique change (or innovation). TFP was also shown to decline during that period. Based on the frontier shift, we quantitatively show time-series changes in production efficiency at the industry level. Among the 22 counties/cities in this study, only Kinmen County and Penghu County presented an annual increase in the frontier shift, due to a lack of medical resources. Following cross-validation using scale effect, we determined that most of the expansion was implemented by foundation hospitals and chain group hospitals. The frontier shift index remained positive only in the outer islands of Taiwan (Kinmen County and Penghu County). Furthermore, most metropolitan areas presented significant scale expansion. The average annual rate of increase in national health expenditures (NHE) was 3.43%, far exceeding the average TFP of -1.2%. In other words, expenditures for medical services increased but efficiency did not. Of course, advances in preventive medical care and average life expectancy cannot be assessed by the number of medical staff or the number of beds. The method proposed in this study is able to measure only the efficiency of medical service production and the efficiency changes at the industry level. Nonetheless, this provides useful information for public health policy and the allocation of medical resources.

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