Assessing the Efficiency of Taiwan's Health Care Systems by Using the Network DEA

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Abstract

A high-quality health care system requires substantial financial resources. The question of how to efficiently use the health care system's financial and medical resources has attracted the attention of researchers. The purpose of this study is to develop a network data envelopment analysis (DEA). Previous studies used the radial measure to assess efficiency in the network DEA model, but the radial measure might not satisfy the principles of unit invariance, translation invariance, and monotonicity. The developed model applied the non-radial measure to evaluate performance and suggested several modifications to the assessment of health care system efficiency. First, we redefine the relationships among financial resources, medical resources, medical care outcomes, and national health as a value-added process. Second, we build an optimal degree measure for medical resources to investigate resource wastage and shortages. Third, we internalize variable transformation and external factors into a single DEA model. The empirical evaluation applies sample data from 21 regions to examine the proposed model, which results in several practical implications for Taiwan's health care system.

Keywords: data envelopment analysis, health care system, network model, medical care, disease prevention

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1. Introduction

Health care is indispensable for the preservation of national health and influences both the productivity of a nation and its economic growth (Asandului et al. [1]; Popescu et al. [2]). However, the quality of health care systems relies on the support from substantial financial resources. However, in recent years, Taiwan's national health insurance system has gradually exhibited increasing signs of potential financial crisis due to its imbalanced distribution and wastage of financial and medical resources. Improving the efficiency of the health care system has been widely discussed by international practitioners and academic researchers (Kocisova et al. [3]). With the aging trend of Taiwan's population, the annual increase in patients with chronic disease and cancer has increased the pressure on health care expenditures. Assessing the efficiency of Taiwan's health care system is thus a crucial topic of concern for the sustainability of the health care system and the preservation of national health (Zuckerman et al. [4]).

National health care systems are typically financed by public budgets, and the resulting stress created by health care spending thus beleaguers governments. The efficient use of public financial resources in health care systems has attracted considerable research attention (Androniceanu & Ohanyan [5]). Grausova and Huzvar [6] defined health care system efficiency as being based on effectiveness and economics. According toHeller and Hauner [7], increased cost efficiency appears to be the only method of overcoming the pressure of health care system expenditures in countries that are both well developed and at the middle-level stage of development. Djerdjouri et al. [8] and Kirigia and Asbu [9] both argued that improving efficiency is among the most critical goals of health care systems amid rising costs. Chandra et al. [10] and Gearhart and Michieka [11] verified that assessing the efficiency of health care systems can help control the use of both financial resources and medical resources. In this regard, data envelopment analysis (DEA) has been considered by numerous researchers to be a favored methodology for assessing the efficiency of health care systems.

The main purpose of this study is to develop a network DEA in which a health care system is structured by four sectors. Previous studies, such as Kalhor and Matin [12], Maghbouli et al. [13], and Michali et al. [14], used the radial measure to assess efficiency in the network DEA model, but the radial measure might not satisfy the principles of unit invariance, translation invariance, and monotonicity (Chu et al. [15]; Lovell & Pastor [16]; Tone [17]). The developed network DEA applied the non-radial measure (i.e. the slacks-based measure) to evaluate performance for health care system, and it provides several modifications that have not been considered in prior studies on health care system efficiency. The first modification is to redefine the relationships among financial resources, medical resources, medical care outcomes, and national health as a three-stage, value-added process. Efficiency reflects the relationship between health care system inputs and outputs (Krot [18]), but our assumptions for inputs and outputs diverge from those of other studies that have assessed health care system efficiency. For example, medical resources (e.g., physicians, nurses, and hospital beds) were defined to be health care system inputs in the studies of Asandului et al. [1], Grausova et al. [19], and Sun et al. [20]; conversely, they were defined to be outputs in the studies of Dlouhy [21] and Grausova and Huzvar [6]. In the first stage, this study redefines financial resources as initial inputs used to produce medical resources. In the second stage, this study investigates whether medical resources are efficiently used in medical care services. Whether medical services influence national health outcomes is assessed in the third stage.

Second, this study proposes a developed network DEA model based on an optimal degree measure to explore the gap between optimal degree and actual degree for a specific resource and to definitively determine how to reallocate medical resources to address excesses and deficits. Researchers have studied the optimal allocation of health care resources (Lai et al. [22]). In investigating the source of wastage, Kocisova et al. [3] and Mohamadi et al. [23] have calculated input slack values for medical resources. However, based on the assumption of nonradial DEA, their slack values must have positive values, which only reveals the amounts of excess medical resource utilization but does not reveal the amounts of deficits. In the allocation of medical resources, wastage is certainly a concern, but shortages might also occur, especially in developing regions (Naicker et al. [24]). This study assumes medical resources to be discretionary factors, and the gaps between actual and optimal levels allow researchers to explore medical resource wastages and shortages and how to redistribute such resources to improve efficiency.

Third, this study internalizes variable transformation and external factors into a single DEA implementation. Previous studies have used various variable transformations to treat the undesirable output in their DEA models. For example, Ibrahim and Daneshvar [25] converted the highest mortality rate to the lowest mortality rate; Kujawska [26] and Grausova and Huzvar [6] both adopted a modified mortality rate instead of the original mortality rate. Shakouri and Salahi [27] incorporated the undesirable outputs into the radial network DEA. To satisfy the unit invariance property in the DEA, this study modifies several mathematical constraints of the previous network DEA, which allows us to measure undesirable final outputs without any prior variable transformation. The effects of external factors such as environmental quality (Gearhart and Michieka [11, 28]) and food safety (Li et al. [29]) on the health care system have been discussed in previous studies, which have mostly used regressions to estimate the relation between efficiency and external factors. This conventional approach can detect whether the external factors are positive or negative on an entire system, but it cannot be used to compare the effects of external factors on different regions. This study develops factor effect indices to address this defect in the traditional approach.

The study investigates data from 21 regions in Taiwan to examine the developed network DEA in an empirical evaluation. The remainder of this paper is organized as follows. Section 2 presents a review of the literature on health care system efficiency. Section 3 illustrates the modified network DEA. Section 4 presents a discussion of the results of the empirical evaluation. Section 5 presents the conclusions of the study.

2. Literature Review

Medical care has been identified as a significant element of health care systems (Al-Refaie et al. [30]), and numerous studies have applied hospital sample data to analyze the performance of the medical care sector. Viola and Benvenuto [31] defined medical resources as inputs and patients as outputs to measure the efficiency of health care organizations. Akkan et al. [32], who investigated the efficiency of emergency departments, applied different assumptions of returns to scale on the technological frontier. Du et al. [33] used revenues as one of their outputs. Mitropoulos et al. [34] added medical services such as medical exams and laboratory tests as outputs. Otay et al. [35] defined patient satisfaction to be an output in their efficiency assessment, in addition to the number of patients. Duchoslav and Cecchi [36] incorporated disease prevention activities such as antenatal care and immunization into their assessment of health care system outcomes. Sun et al. [20] added surgery as an output and used a DEA game to measure medical care efficiency. Darabi et al. [37] utilized birth outcomes as outputs of health care system.

An increasing number of studies have focused on the performance of overall health care systems across regions. National health outcomes, including both positive and negative indices, have thus been defined to be outputs. Asandului et al. [1], Grausova et al. [19], and Mourad et al. [38] used physicians, hospital beds, medical tests, and health care expenditures as inputs and life expectancy and mortality rates as outputs. Ibrahim and Daneshvar [25] applied similar assumptions for inputs and outputs, and they also included disease infections as a negative output. Mohamadi et al. [23] transformed infant mortality as a desirable indicator by using the gap between the optimal value and actual value. Abolghasem et al. [39] suggested the use of population, birthrate, and fertility rate, in addition to medical resources, as inputs to assess health care system efficiency.

Health care systems have been studied from the perspective of the interaction between national health policy and medical care in studies by Woolf and Aron [40] and Ozcan and Khushalani [41], which investigated performance by using multiple efficiency indices. Grausova and Huzvar [6] investigated whether health expenditures effectively generate national health outcomes and used infant mortality and life expectancy as outputs to assess health care system efficiency. Kujawska [42], which defined health care systems as including the public health and medical care sectors, used financial resources as inputs and life expectancy as the output; the medical care sector was measured using medical resources as inputs and the death rate as the output. Gavurova et al. [43], Miszczynska and Miszczyński [44], and Singh et al. [45] extended the framework to be an intertemporal assessment.

Some studies have applied a framework of sequent processes to assess the efficiency of the medical care sector and health care systems. For example, Mirmozaffari and Alinezhad [46, 47] structured a two-stage DEA to estimate hospital efficiency. Khushalani and Ozcan [48] assessed medical care efficiency and quality efficiency. In their study, and the number of patients was defined as the intermediary linking the two sectors. Dlouhy [21] defined health care resources as the initial input, health care services as an intermediary, and national health outcomes as the final output in a two-stage framework.

Researchers have used slacks measured using the DEA to gauge the internal effects on inefficiency. For instance, Harrison and Ogniewski [49] calculated excessive utilization of medical and financial resources, and Dharmapala [50] and Kujawska [42] established several adjustment indices to improve resource utilization. Kocisova et al. [3] and Mousa and Aldehayyat [51] computed the optimal value of inputs and outputs to discover potential room for improving health care systems. A few studies such as those of Nistor et al. [52], Top et al. [53], and Konca and Top [54] have applied a regression model to estimate the internal effect. In addition, regression analysis has frequently been applied to estimate the external effect on inefficiency. For example, Halkos and Tzeremes [55] estimated the effects of environmental factors, economic performance, and population density on the efficiency. Chowdhury and Zelenyuk [56] used a truncated regression to analyze the effect of environmental variables. De Nicola et al. [57] defined patient flow, percentage of caesarean operations, and bed utilization rates as external factors to measure their effects on efficiency. In addition, Gearhart and Michieka [11, 28] defined preventive physical examination and environmental quality as external factors.

3. Methodology

Charnes et al. [58] and Banker et al. [59] developed the primary DEA model to measure the efficiency of decision-making units. The methodology has been modified and improved by subsequent researchers for multiple purposes. The network DEA has generally been defined as having multiple divisions and multiple processes. Seiford and Zhu [60], Chen and Zhu [61], and Kao and Hwang [62] used this methodology to investigate value-added chains in business processes. Huang et al. [63], Sigala [64], Yilmaz and Bititci [65], and Huang [66] evaluated supply chain efficiency by using the network DEA.

The modified network DEA developed in this study structures a health care system as a network framework (illustrated in Figure 1) that includes three stages and four sectors. The first stage assesses public expenditure efficiency. Financial resources, including government expenditure on health care and national health insurance expenses, are defined as initial inputs, which follows the assumptions of Kujawska [26] and Shetty and Pakkala [67]. The outputs of the first stage, which are also intermediaries that link to the second stage, consist of medical resources and disease prevention services. This study examines medical institutions, doctors, nurses, and hospital beds as the variables in an empirical evaluation of medical resources and disease preventive physical examinations and vaccinations as the variables for prevention services. A critical difference from previous studies (Chowdhury & Zelenyuk [56]; Otay et al. [35]) is that we assume medical resources to be discretionary factors, which allows us to measure the optimal degree of resource utilization and explore excessive use or deficits of medical resources. The discretionary factors were defined as that inputs or outputs are controllable by firms in some previous studies, such as, Galagedera [68], Heesche and Bogetoft [69], Henriques et al. [70], Shakouri and Salahi [71], and Wu et al. [72]. Tone and Tsutsui [73, 74] further defined discretionary intermediate as the linking activities which can be handled freely by firms.

The second stage evaluates the efficiency of the medical care and disease prevention sectors. The medical care sector is examined using medical resources as inputs and inpatients and outpatients as outcomes, which follows the approach adopted by numerous previous studies (De Nicola et al. [57]; Akkan et al. [32]). Considering the importance of pharmaceutical supplies (Bhakoo & Choi [75]; Hsiao & Chen [76]), this study incorporates the number of pharmacies as an intermediate input. In evaluating the disease prevention sector, this study examines disease prevention services as inputs and notifiable patients and the incidence rate of malignant neoplasms as outcomes. Li et al. [29] defined food hygiene monitoring as an intermediate input to reflect the influence of food safety on disease prevention and control. The outcomes generated from the two sectors are also employed as intermediates that link to the third stage.

The third stage evaluates the national health sector. The medical care and disease prevention outcomes are used as inputs. Following the relevant literature, (Mohamadi et al. [23]; Top et al. [53]), this study defines life expectancy as a positive output and the mortality rate and number of cancer deaths as negative outputs. The evaluation of the national health sector also includes environmental quality control (Nevalainen & Pekkanen [77]; Parker et al. [78]) as an intermediate input in the efficiency assessment, with the number of pollution inspections as the relevant variable.

[Insert Figure 1 here]

Based on the aforementioned framework, our proposed network DEA for measuring health care system performance is modeled as follows. Public expenditure efficiency is assessed in the first stage, and the observations are assumed to be an *N*-dimension set of decision-making units (DMUs). The DMU under evaluation is labeled as DMU_o and is subject to $DMU_o \in N$. The initial inputs are labeled as $x_i \in R_+^I$. The intermediates between the first and second stages are assumed to be of different types. The intermediates between public expenditure and medical care are assumed to be discretionary factors and are labeled as $z_j^1 \in R_+^J$. The intermediates between public expenditure and disease prevention are assumed to be desirable factors and are labeled as $z_k^2 \in R_+^K$. The intensity variable λ_n is defined for mathematical programming.

The technology set for the public expenditure process is defined as follows:

$$T^{PE}=\left\{(x_i\ ,z_j^1,z_k^2):x_i\ \geq \sum\nolimits_{n=1}^{N} x_{ni}\bullet\lambda_n\left(\forall i\right),z_j^1\geq,=,\leq \sum\nolimits_{n=1}^{N} z_{nj}^1\cdot\lambda_n\left(\forall j\right),z_k^2\leq \sum\nolimits_{n=1}^{N} z_{nk}^2\cdot\lambda_n\left(\forall k\right),\sum\nolimits_{n=1}^{N}\lambda_n\ =1\right.$$
$$\left.\lambda_n\geq 0\right\}. \tag{1}$$

The second stage is separated into two divisions: medical care and disease prevention. In the medical care efficiency assessment, the inputs are assumed to be discretionary intermediates, $z_j^1\in R_+^J$. The outputs, which are assumed to be intermediates that link to the third stage, are represented as $m_p^1\in R_+^P$. The intermediate input, which is assumed to measure the pharmaceutical service, is labeled as $w_g^1\in R_+^G$. The intensity variable δ_n^1 is also defined for mathematical programming. The technology set for the medical care sector is defined as follows:

$$T^{MC}=\left\{(z_j^1,m_p^1,w_g^1):z_j^1\geq,=,\leq \sum\nolimits_{n=1}^{N} z_{nj}^1\cdot\delta_n^1\left(\forall j\right),w_g^1\geq \sum\nolimits_{n=1}^{N} w_{ng}^1\cdot\delta_n^1\left(\forall g\right),m_p^1\leq \sum\nolimits_{n=1}^{N} m_{np}^1\cdot\delta_n^1\left(\forall p\right),\sum\nolimits_{n=1}^{N}\delta_n^1=1,\right.$$
$$\left.\delta_n^1\geq 0\right\}. \tag{2}$$

The other division assessed in the second stage is the disease prevention sector. The inputs used to assess the efficiency of disease prevention are assumed to be desirable intermediates, $z_k^2\in R_+^K$. The outputs, which are assumed to be undesirable intermediates that link to the third stage, are represented by $m_q^2\in R_+^q$. The intermediate input, which is assumed to measure food hygiene, is labeled $w_h^2\in R_+^H$. The intensity variable δ_n^2 is also defined for mathematical programming. The technology set for disease prevention sector is defined as follows:

$$T^{DP}=\left\{(z_k^2,w_h^2,m_q^2):z_k^2\geq \sum\nolimits_{n=1}^{N} z_{nk}^2\cdot\delta_n^2\left(\forall k\right),w_h^2\geq \sum\nolimits_{n=1}^{N} w_{nh}^2\cdot\delta_n^2\left(\forall h\right),m_q^2\geq \sum\nolimits_{n=1}^{N} m_{nq}^2\cdot\delta_n^2\left(\forall q\right),\sum\nolimits_{n=1}^{N}\delta_n^2=1,\right.$$
$$\left.\delta_n^2\geq 0\right\}. \tag{3}$$

National health efficiency is evaluated in the final stage. The inputs use the desirable intermediates $m_p^1\in R_+^P$ and the undesirable intermediates $m_q^2\in R_+^q$ generated during the second stage. The final outputs include desirable factors and undesirable factors, which are labeled as $y_u^1\in R_+^U$ and $y_v^2\in R_+^V$, respectively. The intermediate input, which is assumed to measure environmental quality control, is labeled as $w_l^3\in R_+^L$. The intensity variable μ_n is also defined for mathematical programming. The technology set for national health efficiency is defined as follows:

$$T^{NH}=\{(m_p^1,m_q^2,w_l^3,y_u^1,y_v^2):m_p^1\geq\sum_{n=1}^N m_{np}^1\cdot\mu_n\,(\forall p),m_q^2\leq\sum_{n=1}^N m_{nq}^2\cdot\mu_n\,(\forall q),w_l^3\geq\sum_{n=1}^N w_{nl}^3\cdot\mu_n\,(\forall l),$$
$$y_u^1\leq\sum_{n=1}^N y_{nu}^1\cdot\mu_n\,(\forall u),y_v^2\geq\sum_{n=1}^N y_{nv}^2\cdot\mu_n\,(\forall v),\sum_{n=1}^N\mu_n=1,\mu_n\geq 0\} \quad (4)$$

The technology set for the overall health care system, which is structured by the four sectors, is defined as follows:

$$\begin{aligned}
T^{Overall}=\{&(x_i\ ,z_j^1,z_k^2,m_p^1,m_q^2,w_g^1,w_h^2,w_l^3,y_u^1,y_v^2):\\
&x_i\geq\sum_{n=1}^N x_{ni}\cdot\lambda_n\,(\forall i),z_j^1\geq,=,\leq\sum_{n=1}^N z_{nj}^1\cdot\lambda_n\,(\forall j),z_k^2\leq\sum_{n=1}^N z_{nk}^2\cdot\lambda_n\,(\forall k),\\
&z_j^1\geq,=,\leq\sum_{n=1}^N z_{nj}^1\cdot\delta_n^1(\forall j),w_g^1\geq\sum_{n=1}^N w_{ng}^1\cdot\delta_n^1(\forall g),m_p^1\leq\sum_{n=1}^N m_{np}^1\cdot\delta_n^1(\forall p),\\
&z_k^2\geq\sum_{n=1}^N z_{nk}^2\cdot\delta_n^2\,(\forall k),w_h^2\geq\sum_{n=1}^N w_{nh}^2\cdot\delta_n^2\,(\forall h),m_q^2\geq\sum_{n=1}^N m_{nq}^2\cdot\delta_n^2\,(\forall q),\\
&m_p^1\geq\sum_{n=1}^N m_{np}^1\cdot\mu_n\,(\forall p),m_q^2\leq\sum_{n=1}^N m_{nq}^2\cdot\mu_n\,(\forall q),w_l^3\geq\sum_{n=1}^N w_{nl}^3\cdot\mu_n\,(\forall l),\\
&y_u^1\leq\sum_{n=1}^N y_{nu}^1\cdot\mu_n\,(\forall u),y_v^2\geq\sum_{n=1}^N y_{nv}^2\cdot\mu_n\,(\forall v),\\
&\sum_{n=1}^N\lambda_n=1,\sum_{n=1}^N\delta_n^1=1,\sum_{n=1}^N\delta_n^2=1,\sum_{n=1}^N\mu_n=1,\\
&\lambda_n\geq 0,\delta_n^1\geq 0,\delta_n^2\geq 0,\mu_n\geq 0\}
\end{aligned} \quad (5)$$

In accordance with the technology set for the overall health care system, the nonradial mathematical programming for the network DEA model is presented as follows:

$$\underset{\theta,\lambda,\delta^1,\delta^2,\mu,s}{Min}\ =\theta$$

$$\begin{aligned}
s.t.\quad & x_i=\sum_{n=1}^N x_{ni}\cdot\lambda_n+s_i^x\ (\forall i) && \text{(financial resources)}\\
& z_j^1=\sum_{n=1}^N z_{nj}^1\cdot\lambda_n+s_j^{z1}(\forall j), && \text{(medical resources)}\\
& \sum_{n=1}^N z_{nj}^1\cdot\lambda_n=\sum_{n=1}^N z_{nj}^1\cdot\delta_n^1(\forall j) &&\\
& z_k^2=\sum_{n=1}^N z_{nk}^2\cdot\lambda_n-s_k^{z2}(\forall k), && \text{(disease prevention service)}\\
& w_g^1=\sum_{n=1}^N w_{ng}^1\cdot\delta_n^1+s_g^{w1}(\forall g), && \text{(pharmaceutical service)}\\
& m_p^1=\sum_{n=1}^N m_{np}^1\cdot\delta_n^1-s_p^{m1}(\forall p), && \text{(medical care outcomes)}\\
& w_h^2=\sum_{n=1}^N w_{nh}^2\cdot\delta_n^2+s_h^{w2}(\forall h), && \text{(food hygiene)}\\
& m_q^2=\sum_{n=1}^N m_{nq}^2\cdot\mu_n+s_q^{m2}(\forall q), && \text{(disease prevention outcomes)}\\
& w_l^3=\sum_{n=1}^N w_{nl}^3\cdot\mu_n+s_l^{w3}(\forall l), && \text{(environmental quality control)}\\
& y_u^1=\sum_{n=1}^N y_{nu}^1\cdot\mu_n-s_u^{y1}(\forall u), && \text{(national health outcomes)}\\
& y_v^2=\sum_{n=1}^N y_{nv}^2\cdot\mu_n+s_v^{y2}(\forall v), && \text{(national health outcomes)}\\
& \sum_{n=1}^N\lambda_n=1,\sum_{n=1}^N\delta_n^2=1,\sum_{n=1}^N\delta_n^1=1,\sum_{n=1}^N\mu_n=1,\\
& \lambda_n\geq 0,\delta_n^1\geq 0,\delta_n^2\geq 0,\mu_n\geq 0(\forall n),\\
& s_i^x,s_k^{z2},s_p^{m1},s_q^{m2},s_g^{w1},\ s_h^{w2},\ s_l^{w3},s_u^{y1},s_v^{y2}\geq 0,\\
& s_j^{z1}\quad \text{is unrestricted in sign.}
\end{aligned} \quad (6)$$

In function (6), the slack $s_j^{z1}(\forall j)$ represents the gap between the optimal degree and actual degree of discretionary intermediate utilization. If $s_j^{z1} > 0$, then the actual degree is higher than the optimal degree; if $s_j^{z1} < 0$, then the actual degree is lower than the optimal degree; and if $s_j^{1} = 0$, then the actual degree is equal to the optimal degree. This study defines the slacks $s_j^{z1+}(\forall j)$ and $s_j^{z1-}(\forall j)$, by applying a nonnegative transformation for $s_j^{1}(\forall j)$ and the following functions:

$$s_j^{z1-}\left(R_+^J\right) = Max\left\{0, s_j^{z1}\right\}\left(\forall j\right). \tag{7}$$

$$s_j^{z1+}\left(R_+^J\right) = -Min\left\{0, s_j^{z1}\right\}\left(\forall j\right). \tag{8}$$

In functions (7) and (8), s_i^x represents the input slack and s_k^{z2} represents the slack of the disease prevention service. The symbols s_p^{m1} and s_q^{m2} represent the slacks of the medical care outcome and disease prevention outcome, respectively. The symbols s_u^{y1} and s_v^{y2} represent the slacks of the desirable and undesirable final outputs, respectively. s_g^{w1} is defined as the slack of pharmaceutical service; s_h^{w2} is the slack of food hygiene; and s_l^{w3} is the slack of environmental quality control. The objective value θ is measured as the sum of the slacks by referring to the additive slacks-based measure proposed by Asanimoghadam et al. [79], Charnes et al. [80], and Torabi Golsefid and Salahi [81]. The efficiencies of the four sectors, which follow the assumptions of Tone and Tsutsui [73, 74] to measure undesirables, for the n^{th} DMU are defined using the solved slacks and are formulated as follows.

Public expenditure:

$$eff_n^{PE} = \left[1 - \frac{1}{I+J}\left(\sum_{i=1}^{I}\frac{s_i^x}{x_i} + \sum_{j=1}^{J}\frac{s_j^{z1-}}{z_j^1}\right)\right] \cdot \left[1 + \frac{1}{K+J}\left(\sum_{k=1}^{K}\frac{s_k^{z2}}{z_k^2} + \sum_{j=1}^{J}\frac{s_j^{z1+}}{z_j^1}\right)\right]^{-1} \tag{9}$$

Medical care:

$$eff_n^{MC} = \left[1 - \frac{1}{G}\left(\sum_{g=1}^{G}\frac{s_g^{w1}}{w_g^1}\right)\right] \cdot \left[1 + \frac{1}{P}\left(\sum_{p=1}^{P}\frac{s_p^{m1}}{m_p^1}\right)\right]^{-1} \tag{10}$$

Disease prevention:

$$eff_n^{DP} = \left[1 - \frac{1}{Q+H}\left(\sum_{q=1}^{Q}\frac{s_q^{m2}}{m_q^2} + \sum_{h=1}^{H}\frac{s_h^{w2}}{w_h^2}\right)\right] \cdot [1]^{-1}$$

(11)

National health:

$$eff_n^{NH} = \left[1 - \frac{1}{L+V}\left(\sum_{l=1}^{L}\frac{s_l^{w3}}{w_l^3} + \sum_{v=1}^{V}\frac{s_v^{y1}}{y_v^2}\right)\right] \cdot \left[1 + \frac{1}{U}\left(\sum_{u=1}^{U}\frac{s_u^{y2}}{y_u^1}\right)\right]^{-1}$$

(12)

The overall efficiency of the health care system is described as follows:

$$eff_n = \frac{\left[1-\frac{1}{I+J}\left(\sum_{i=1}^{I}\frac{s_i^x}{x_i}+\sum_{j=1}^{J}\frac{s_j^{z1-}}{z_j^1}\right)\right]+\left[1-\frac{1}{G}\left(\sum_{g=1}^{G}\frac{s_g^{w1}}{w_g^1}\right)\right]+\left[1-\frac{1}{Q+H}\left(\sum_{q=1}^{Q}\frac{s_q^{m2}}{m_q^2}+\sum_{h=1}^{H}\frac{s_h^{w2}}{w_h^2}\right)\right]+\left[1-\frac{1}{L+V}\left(\sum_{l=1}^{L}\frac{s_l^{w3}}{w_l^3}+\sum_{v=1}^{V}\frac{s_v^{y1}}{y_v^2}\right)\right]}{\left[1+\frac{1}{K+J}\left(\sum_{k=1}^{K}\frac{s_k^{z2}}{z_k^2}+\sum_{j=1}^{J}\frac{s_j^{z1+}}{z_j^1}\right)\right]+\left[1+\frac{1}{P}\left(\sum_{p=1}^{P}\frac{s_p^{m1}}{m_p^1}\right)\right]+[1]+\left[1+\frac{1}{U}\left(\sum_{u=1}^{U}\frac{s_u^{y2}}{y_u^1}\right)\right]} \quad (13)$$

This study uses the slacks calculated using function (6) and the observations to define the factor effect indices to explore the internal effects on efficiency. To determine whether wastage of health care financial resources exists, the factor effect indices of government health care expenditure and national health insurance expense are formulated as follows:

$$\rho_i^x = \frac{x_i - s_i^-}{x_i}(\forall i). \quad (14)$$

A high ρ_i^x value indicates that the respective region's financial resources are efficiently used in the health care system; conversely, a low ρ_i^x value indicates the existence of health care resource waste.

Then, the factor effect indices of medical resources are measured by using the arbitrary slacks s_j^{z1-} and s_j^{z1+}, which can have a result that is positive, negative, or zero, and is defined as follows:

$$\rho_j^{z1} = \frac{z_j^1 + s_j^{z1-}}{z_j^1} \; or \; \frac{z_j^1 - s_j^{z1+}}{z_j^1}(\forall j). \quad (15)$$

If $\rho_j^{z1} > 1$, then excessive utilization of the medical resources exists in the relevant region; if $\rho_j^{z1} < 1$, then there is a shortage of medical resources; and if $\rho_j^{z1} = 1$, then medical resources utilization is at the optimal level.

The factor effect index of disease prevention service is used to verify whether local governments provide adequate preventive physical examination and vaccination services, and it is defined as follows:

$$\rho_k^{z2} = \frac{z_k^2 - s_k^{z2}}{z_k^2}(\forall k).$$

(16)

The slack s_k^z is a nonnegative value, and ρ_k^{z2} is measured as a ratio. If $\rho_k^{z2} = 1$, it implies that the provision of disease prevention services is adequate in the relevant region. If $\rho_k^{z2} < 1$, it implies that disease prevention services are insufficient.

The medical care outcome is defined as a desirable intermediate linking the medical care sector and national health. It is measured by the number of outpatients and the number of inpatients, and the factor effect index is described as follows:

$$\rho_p^{m1} = \frac{m_p^1 - s_p^{m1}}{m_p^1} (\forall p).$$

(17)

If $\rho_p^{m1} = 1$, then a region implements best practices in terms of its medical care outcomes; whereas a lower value of ρ_p^{m1} implies inferior performance.

The disease prevention outcome is defined as an undesirable intermediate in the health care system and is measured by the number of notifiable patients and the incidence rate of malignant neoplasms. Its factor effect index is described as follows:

$$\rho_q^{m2} = \frac{m_q^2 - s_q^{m2}}{m_q^2} (\forall q). \quad (18)$$

If $\rho_q^{m2} = 1$, then the relevant region implements best practices in disease prevention; and a lower value of ρ_q^{m2} implies inferior performance.

The desirable and undesirable final outputs represent positive and negative outcomes of national health, respectively. Their factor effect indices are described as follows.

Desirable output: $\rho_u^{y1} = \frac{y_u^1}{y_u^1 + s_u^{y1}} (\forall u).$ (19)

Undesirable output: $\rho_v^{y2} = \frac{y_v^2 - s_v^{y2}}{y_v^2} (\forall v)$ (20)

The indices ρ_u^{y1} and ρ_v^{y2} are measured as nonnegative ratios, and relatively high values imply superior health conditions in the relevant region.

The model also defines the factor effect indices for the three intermediates as follows.

Pharmaceutical service: $\rho_g^{w1} = \frac{w_g - s_g^{w1}}{w_g} (\forall g)$ (21)

Food hygiene: $\rho_h^{w2} = \frac{w_h - s_h^{w2}}{w_h} (\forall h)$

(22)

Environmental quality control: $\rho_l^{w3} = \frac{w_l - s_l^{w3}}{w_l} (\forall l)$ (23)

If $\rho_g^{w1} = 1$, then the number of pharmacies is sufficient in the relevant region; if $\rho_g^{w1} < 1$, there is a shortage of pharmacies in the region. If $\rho_h^{w2} = 1$, then the number of food hygiene inspections is assessed to be sufficient in the relevant region; if $\rho_h^{w2} < 1$, then the local government should increase the number of inspections of food industry firms and restaurants. If $\rho_l^{w3} = 1$, then the relevant region's local government carries out adequate pollution inspections to ensure environmental quality; if $\rho_l^{w3} < 1$, then the number of pollution inspections is insufficient.

4. Empirical Results

This study's empirical evaluation uses data from 21 regions across Taiwan in 2018, , which are collected from the online databases of Taiwan's Ministry of Health and Welfare (https://dep.mohw.gov.tw) and the National Statistics Bureau of the ROC (https://www.stat.gov.tw) to test the proposed model. Table 1 presents the results of the descriptive statistics.

[Insert Table 1 here]

Table 2 presents the health care system efficiency scores as evaluated using the network DEA. The results of overall efficiency (i.e., eff_n) reveal that 10 regions (no. 1, 2, 3, 4, 6, 7, 8, 9, 20, and 21) are assessed to be efficient, achieving the highest possible score of 1.0. Ilan County (0.943) and Tainan City (0.930) rank second and third, respectively. The average score is 0.861.

The results of the government expenditure efficiency (i.e., eff_n^{PE}) reveal that 13 regions (no. 1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 19, 20, and 21) are determined to have achieved optimal performance with a score equal to 1.0. Changhua County (0.912) and Tainan City (0.840) rank second and third, respectively. The results of the medical care efficiency (i.e., eff_n^{MC}) measurement reveal that 12 regions (no. 1, 2, 3, 4, 6, 7, 8, 9, 10, 19, 20, and 21) are assessed to be efficient. Changhua County (0.980) and Taitung County (0.941) rank second and third, respectively. Nantou County ranks last. The results of the disease prevention efficiency (i.e., eff_n^{DP}) measurement reveal that 12 regions (no. 1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 20, and 21) are assessed to have achieved optimal performance. Miaoli County (0.786) and Ilan County (0.772) rank second and third, respectively. The results of national health efficiency (i.e., eff_n^{NH}) reveal that 12 regions (no. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, and 21) are evaluated to be efficient. Hualien County (0.923) and Hsinchu County (0.846) rank second and third, respectively.

To compare the different sectors, medical care is assessed as the division with the highest efficiency, with an average value of 0.927. Public expenditure efficiency and national health efficiency rank second and third, respectively, with average values of 0.860 and 0.855, respectively. Disease prevention ranks as the lowest sector in the health care system, with an average value of 0.802.

[Insert Table 2 here]

The empirical evaluation adopts factor effect indices to explore whether financial and medical resources are efficiently utilized in the health care system, and the results are presented in Table 3. In the analysis of government health care expenditure, seven regions (no. 12–18) are assessed to have an index lower than 1.0, indicating that these regions exhibit excessive utilization of government health care expenditure. In addition, seven regions (no. 5 and no. 12–18) are assessed to have an index lower than 1.0 in terms of national health insurance expenses, indicating that national health insurance expenses collected in these regions are not efficiently used in the health care system. The averages of government health care expenditure and national health insurance expenses are 0.864 and 0.855, respectively, with no significant difference between the two types of financial resource.

The factor effect indices of medical resources (i.e., ρ_j^{z1}) are listed in Table 3. In the use of the four medical resources, 12 regions (no. 1, 2, 3, 4, 6, 7, 8, 9, 10, 19, 20, and 21) are assessed to have a score of 1.0, implying that the quantity of medical resources in these regions have achieved the optimal level. For quantity of medical institutions, three regions (no. 11, 16, and 18) are assessed to have a score lower than 1.0, implying that the quantity of medical institutions in these regions is insufficient. By contrast, six regions (no. 5, 12, 13, 14, 15, and 17) are assessed to have a score higher than 1.0, implying that the quantity of medical institutions in these regions is excessive. In addition, the number of doctors in seven regions (no. 11, 12, 13, 14, 16, 17, and 18) are assessed to have a score lower than 1.0, indicating an insufficient quantity of doctors in these regions. Tainan City and Yunlin County are identified as having an excessive number of doctors and are thus assessed to have a score higher than 1.0. For the quantity of nurses, Hsinchu County, Miaoli County, and Nantou County are assessed a score of lower than 1.0, indicating a shortage. Six regions (no. 5, 13, 15, 16, 17, and 18) are assessed to have a score higher than 1.0, implying that the quantity of nurses is excessive in these regions. In the examination of the number of hospital beds, four regions (no. 11, 12, 16, and 18) are assessed to have a score lower than 1.0, implying a shortage; five regions (no. 5, 13, 14, 15, and 17) are assessed to have a score higher than 1.0, indicating excessive utilization.

In the comparison of medical resources, the average number of doctors is 0.957, and this is the only indicator that is below 1.0. The average number of medical institutions has the highest value at 1.021; the average number of nurses has the second highest value at 1.011; and the average number of beds ranks third at 1.005.

[Insert Table 3 here]

The factor effect indices of disease prevention service, pharmaceutical service, and food hygiene service are evaluated using the proposed model, as illustrated in Table 4. Six regions (no. 11, 12, 15, 16, 17, and 18) have an index lower than 1.0, indicating that these regions do not provide adequate preventive physical examinations for residents. In addition, five regions (no. 13, 14, 16, 17, and 18) are evaluated as having insufficient vaccination services. The indices of pharmaceutical service (i.e., ρ_g^{w1}) are listed under the heading "Pharmaceutical service". The results reveal that nine regions (no. 5 and 11–18) are assessed to have a score lower than 1.0, which implies that these regions do not provide adequate pharmaceutical service. The indices of food hygiene service (i.e., ρ_h^{w2}) are listed in the last column of Table 4. The results reveal that nine regions (no. 10 and 12–19) are assessed to have a score lower than 1.0, implying that these regions' governments do not provide adequate numbers of food hygiene inspections.

The average indices of preventive physical examination and vaccination are 0.960 and 0.966, respectively, which are higher than the indices of the other services. The average index of pharmaceutical service is 0.927, ranking second; the average index of food hygiene service is 0.802, ranking third. By contrast, the influence of inadequate food hygiene service on inefficiency is relatively high, especially in regions where it is inadequate (where the indices are evaluated at below 0.800). This finding indicates that the relevant regional governments should increase the number of inspections that they implement by more than 20% to reach the benchmark.

Table 4

This study uses the factor effect indices of medical care outcomes and disease prevention outcomes to investigate the effects of these two sectors on the health care system. The indices of medical care outcomes (i.e., ρ_p^{m1}) are listed in Table 5. In terms of outpatients, six regions (no. 11, 12, and 15–18) are assessed to have a score lower than 1.0. For inpatients, four regions (no. 11, 12, 14, and 15) are assessed to have an index score lower than 1.0, which indicates that the number of inpatients in these regions is less than their hospital capacity. The averages of outpatients and inpatients are 0.919 and 0.946, respectively, indicating that the utilization of inpatient medical care is slightly more efficient than that of outpatient medical care.

For the number of notifiable patients, six regions (no. 14–19) are identified as not achieving optimal performance, with index values lower than 1.0. The indices of the incidence rate of malignant neoplasms reveal that nine regions (no. 11–19) are assessed to have a value lower than 1.0, indicating relatively poor performance in the prevention of malignant neoplasms. The average indices of notifiable patients and rate of malignant neoplasms are 0.904 and 0.883, respectively. The results reveal that the prevention of notifiable infectious diseases is slightly higher than the prevention of malignant neoplasms is.

[Insert Table 5 here]

The factor effect indices of environmental quality control and final outputs are presented in Table 6. The indices of pollution inspection (i.e., ρ_l^{w3}) reveal that nine regions are assessed to have values lower than 1.0, and the average index is 0.809.

The desirable output (i.e., ρ_u^{y1}), which represents life expectancy, reveals that eight regions are assessed to have a value lower than 1.0, implying that these regions perform poorly relative to the regions that are assessed to have a value of 1.0 in life expectancy. In terms of the undesirable output (i.e., ρ_v^{y2}), the indices of mortality rate reveal that nine regions are assessed to have a value less than 1.0, indicating relatively weak performance; the indices of cancer deaths reveal that nine regions perform relatively poorly.

The averages of mortality rate and cancer deaths are 0.914 and 0.857, respectively, and the average of life expectancy is 0.992. The results also reveal that the indices of life expectancy are higher than 0.950 for all regions, and no significant difference exists between the regions in terms of life expectancy. Cancer deaths are assessed as having the lowest average among all outcomes, which indicates that a high number of cancer deaths is a major cause of inefficiency in regional health care systems. Relative to cancer deaths, the overall mortality rate exerts a weaker effect on health care system efficiency.

[Insert Table 6 here]

To identify differences among regional types, the samples are classified under metropolitan (city), county, and island districts, and the Kruskal–Wallis test is applied to examine the averages of the efficiencies. The results are presented in Table 7. The island type is assessed with highest score in all efficiency indicators, with all averages equal to 1.0. The metropolitan type is assessed to be efficient in disease prevention and national health, but its public expenditure and medical care efficiencies are assessed to have scores less than 1.0. For the county type, medical care efficiency is assessed to have the highest score, at 0.858; public expenditure efficiency scores second highest, at 0.721. Disease prevention is assessed to have the lowest average, at 0.584; national health efficiency in the counties is assessed to be 0.696. These results reveal that the metropolises and islands have superior performance than that of the counties in the overall health care system and individual sectors. Public expenditure, disease prevention, and national health in the county type are evaluated to be significantly lower by approximately 30% than the scores of the metropolitan and island districts.

[Insert Table 7 here]

This study also examines the averages of the factor effect indices in the different regional types, as illustrated in Table 8. For financial resources, government expenditure and national health insurance expenses are used inefficiently in the county type. For medical resources, the four items exhibit excessive utilization in the metropolitan type. Medical institutions, nurses, and beds are assessed to have higher scores than the optimal level in the county type; but the quantity of doctors is assessed to have a lower score than the optimal level. Medical institutions, nurses, and beds are not at optimal levels in either the metropolitan or island types, but the gaps are of a small margin. However, the shortage of doctors is verified to be a significant influence on the inefficiency of medical care in the counties.

The county type is assessed to have scores of 0.917 and 0.928 in preventive physical examinations and vaccinations, respectively, which are unique in failing to achieve optimal performance in disease prevention service at the county level. The metropolitan and county types are assessed to be inefficient in pharmaceutical service. Food hygiene service in the county type has the lowest value, at 0.584.

The indices of medical care and disease prevention are assessed to have an average of 1.0 in the metropolitan and island regions. In the county regions, the averages of outpatients and inpatients are assessed as 0.830 and 0.887, respectively; the notifiable patients and incidence rate of malignant neoplasms are 0.798 and 0.755, respectively.

The metropolitan and island types achieve optimal performance in environmental quality control; however, the county type is assessed to have a lower index than those of the other regional types, at 0.599, and this result is significant. As such, inefficient environmental quality control is observed to be a significant cause of low health care system efficiency in the counties.

The national health outcome indices reveal that the metropolitan and island types are assessed the highest values. In the county type, the index of life expectancy is assessed to be 0.984; the mortality rate is 0.819; and the number of cancer deaths is 0.700. Thus, the study determines that the high number of cancer deaths is a significant factor resulting in low performance of the health care systems in the counties.

[Insert Table 8 here]

5. Conclusion

This study establishes a modified network DEA to measure the efficiency of health care systems. The empirical evaluation applies data from 21 regions as samples to examine the proposed model and provides several practical implications for Taiwan’s health care system. First, the results of the efficiency evaluation reveal that nearly half of the regions examined do not achieve health care system efficiency. The efficiency of medical care is identified to be higher than that of the other factors, and disease prevention is assessed to have the lowest efficiency of all the factors. Health care efficiency in the county regions is determined to be lower than that of the metropolitan and island regions.

Second, the factor effect indices of financial resources indicate the existence of financial waste in nearly one-third of the regions. This result is especially acute in the counties, where the average factor effect index is approximately 30% lower than those of the metropolitan and island regions. The results of the medical resource indices reveal that the number of regions evaluated to have excessive quantities of medical institutions, nurses, and hospital beds is higher than the number of regions evaluated to have deficits in these resources. This finding implies that these medical resources are wasted in most regions, whereas a few regions exhibit shortages. The quantity of doctors is verified to be insufficient in most regions but excessive in two regions. This study's comparison of regional types reveals that the metropolises have an excess of physicians but the counties have a shortage.

Third, the results of the measurements of disease prevention, pharmaceutical, and food hygiene services reveal that the effectiveness of disease prevention service is higher than it is for the other services. Disease prevention service in the metropolitan and island regions is evaluated more highly than it is in the counties. Pharmaceutical service in the island regions is assessed to be higher than it is in the metropolises and the counties. The effectiveness of food hygiene service is assessed to have the lowest index value among all factors; this is especially acute in the counties, the factor effect index of which averages only 0.584. This finding implies that the poor performance of food hygiene service is a significant external cause of health care system inefficiency.

Fourth, the factor effect indices of the medical care and disease prevention outcomes reveal that outpatients and inpatients are assessed higher scores than those of notifiable patients and the rate of malignant neoplasms. This finding indicates that inadequate disease prevention outcomes are major causes of low efficiency in the disease prevention sector.

In summary, this study determines that the medical care sector has the highest efficiency and the disease prevention sector has the lowest efficiency among the health care systems in the regions of Taiwan. Although government expenditure efficiency is not assessed to have the lowest score, this study discovered approximately 15% inefficient utilization of national health insurance funding and the government's health care budget. For medical resources overall, the number of doctors requires increased efficiency. Among the different regional types, the metropolises should decrease the number of doctors and the counties should increase it; this finding indicates the existence of an imbalanced distribution of medical resources within the regions. In addition to food hygiene service and environmental quality control, disease prevention outcomes and financial resource utilization are determined to be weaknesses of the health care system.

This study's empirical results imply that local governments should increase the efficiency of medical care and enhance the effectiveness of disease prevention by increasing their attention on food hygiene and environmental quality control. Such practices could reduce the risk of cancer in the population, and the efficiency of health care system would improve as a result. The empirical results reveal that Taiwan's medical resources are excessive in some regions but insufficient in other regions, suggesting that the central government should coordinate and adjust the allocation of medical resources to address this imbalance.

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Conflict of interest statement

I declare that I have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled, "Assessing the Efficiency of Taiwan's Health Care Systems by Using the Network DEA."

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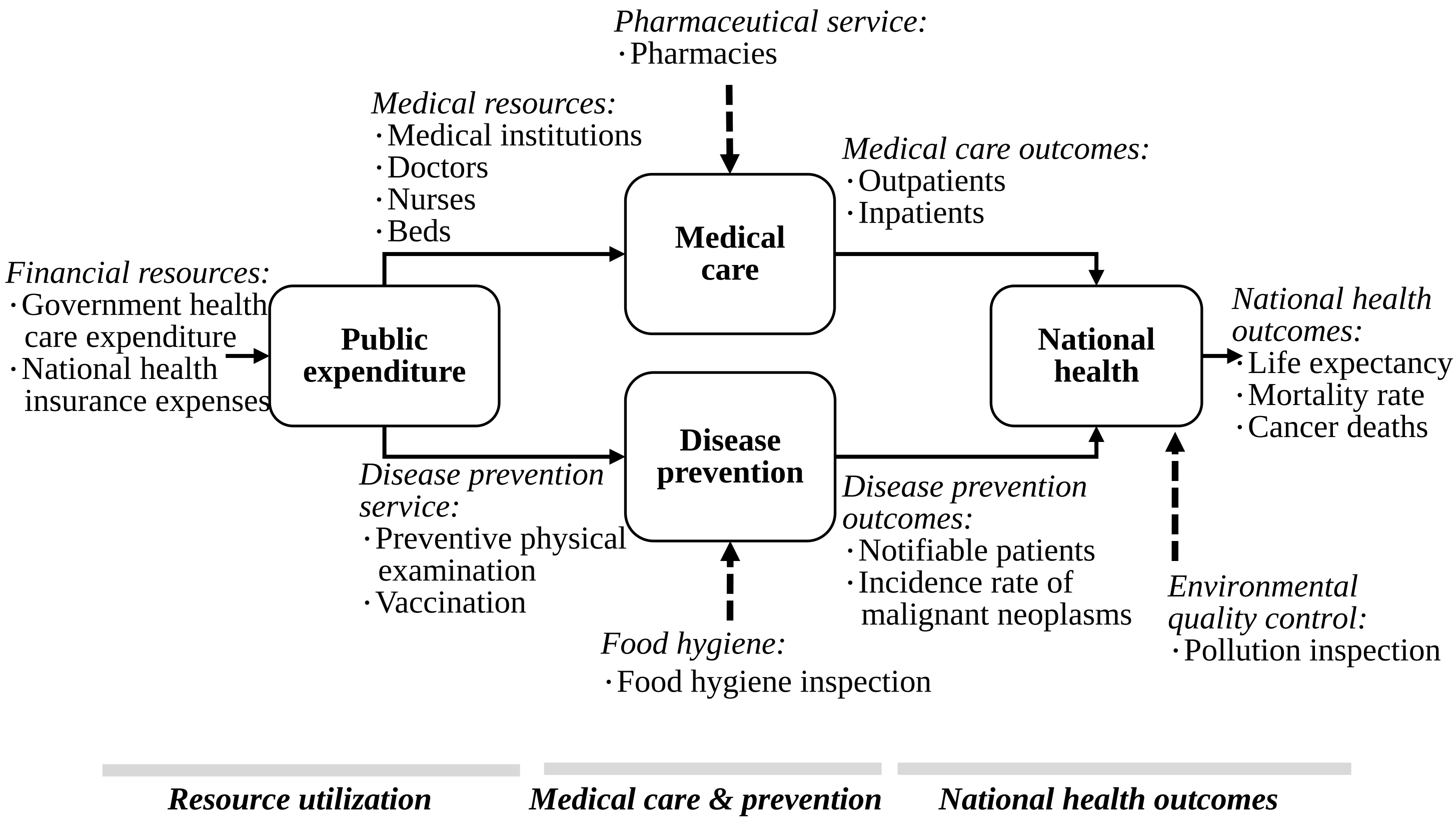

Figure 1. Health care system performance measurement framework

Table 1. Descriptive statistics

	Mean	S.D.	Max	Min
Financial resource				
Government health care expenditure	1,193	1,373	5,347	268
National health insurance expenses	32,917	31,785	111,464	3,363
Medical resource				
Medical institutions	1,086	1,226	3,608	53
Doctors	3,288	4,016	14,359	106
Nurses	7,988	8,364	28,345	288
Beds	7,975	7,974	25,464	343
Disease prevention service				
Preventive physical examination	526	542	1,795	33
Vaccination	169	176	523	10
Pharmaceutical service				
Pharmacies	3,453	3,937	12,178	141
Medical care outcome				
Outpatients	5,399	6,139	23,903	226
Inpatients	159	171	601	4
Food hygiene				
Food hygiene inspection	27,962	25,126	110,541	2,512
Disease prevention outcome				
Notifiable patients	1,427	1,555	5,781	68
Incidence rate of malignant neoplasms	293	44	334	128
Environmental quality control				
Pollution inspection	2,730	2,517	9,740	323
National health outcome				
Mortality rate	351	51	463	258
Cancer deaths	2,322	2,094	7,026	238
Life expectancy	80	2	84	76

Table 2. Results of overall and sector efficiencies

No.	Region	Overall	Public expenditure	Medical care	Disease prevention	National health
1	New Taipei City	1	1	1	1	1
2	Taipei City	1	1	1	1	1
3	Taoyuan City	1	1	1	1	1
4	Taichung City	1	1	1	1	1
5	Tainan City	0.930	0.840	0.885	1	1
6	Kaohsiung City	1	1	1	1	1
7	Keelung City	1	1	1	1	1
8	Hsinchu City	1	1	1	1	1
9	Chiayi City	1	1	1	1	1
10	Ilan County	0.943	1	1	0.772	1
11	Hsinchu County	0.897	1	0.741	1	0.846
12	Miaoli County	0.734	0.611	0.874	0.786	0.664
13	Changhua County	0.750	0.912	0.980	0.497	0.613
14	Nantou County	0.577	0.597	0.609	0.379	0.722
15	Yunlin County	0.523	0.433	0.719	0.469	0.474
16	Chiayi County	0.623	0.513	0.856	0.622	0.503
17	Pingtung County	0.554	0.556	0.864	0.291	0.505
18	Taitung County	0.699	0.591	0.941	0.554	0.709
19	Hualien County	0.849	1	1	0.473	0.923
20	Penghu County	1	1	1	1	1
21	Kinmen County	1	1	1	1	1
	Mean	0.861	0.860	0.927	0.802	0.855
	S.D.	0.174	0.207	0.114	0.257	0.198

Table 3. Factor effect indices of financial and medical resources

No.	Region	Financial resource		Medical resource			
		Government health care expenditure	National health insurance expenses	Medical institutions	Doctors	Nurses	Beds
1	New Taipei City	1	1	1	1	1	1
2	Taipei City	1	1	1	1	1	1
3	Taoyuan City	1	1	1	1	1	1
4	Taichung City	1	1	1	1	1	1
5	Tainan City	1	0.679	1.147	1.049	1.222	1.084
6	Kaohsiung City	1	1	1	1	1	1
7	Keelung City	1	1	1	1	1	1
8	Hsinchu City	1	1	1	1	1	1
9	Chiayi City	1	1	1	1	1	1
10	Ilan County	1	1	1	1	1	1
11	Hsinchu County	1	1	0.950	0.752	0.809	0.823
12	Miaoli County	0.632	0.591	1.008	0.757	0.813	0.931
13	Changhua County	0.903	0.920	1.042	0.953	1.011	1.018
14	Nantou County	0.659	0.535	1.325	0.986	0.922	1.125
15	Yunlin County	0.451	0.415	1.219	1.025	1.107	1.074
16	Chiayi County	0.535	0.492	0.749	0.898	1.035	0.962
17	Pingtung County	0.554	0.559	1.091	0.836	1.148	1.108
18	Taitung County	0.420	0.761	0.905	0.850	1.161	0.981
19	Hualien County	1	1	1	1	1	1
20	Penghu County	1	1	1	1	1	1
21	Kinmen County	1	1	1	1	1	1
	Mean	0.864	0.855	1.021	0.957	1.011	1.005
	S.D.	0.215	0.212	0.112	0.086	0.096	0.062

Table 4. Factor effect indices of disease prevention, pharmaceutical, and food hygiene services

No.	Region	Disease prevention service		Pharmaceutical service	Food hygiene service
		Preventive physical examination	Vaccination	Pharmacies	Inspection
1	New Taipei City	1	1	1	1
2	Taipei City	1	1	1	1
3	Taoyuan City	1	1	1	1
4	Taichung City	1	1	1	1
5	Tainan City	1	1	0.885	1
6	Kaohsiung City	1	1	1	1
7	Keelung City	1	1	1	1
8	Hsinchu City	1	1	1	1
9	Chiayi City	1	1	1	1
10	Ilan County	1	1	1	0.772
11	Hsinchu County	0.814	1	0.741	1
12	Miaoli County	0.862	1	0.874	0.786
13	Changhua County	1	0.960	0.980	0.497
14	Nantou County	1	0.953	0.609	0.379
15	Yunlin County	0.904	1	0.719	0.469
16	Chiayi County	0.723	0.573	0.856	0.622
17	Pingtung County	0.905	0.870	0.864	0.291
18	Taitung County	0.959	0.922	0.941	0.554
19	Hualien County	1	1	1	0.473
20	Penghu County	1	1	1	1
21	Kinmen County	1	1	1	1
	Mean	0.960	0.966	0.927	0.802
	S.D.	0.077	0.096	0.114	0.257

Table 5. Factor effect indices of medical care and disease prevention outcomes

No.	Region	Medical care outcome		Disease prevention outcome	
		Outpatients	Inpatients	Notifiable patients	Incidence rate of malignant neoplasms
1	New Taipei City	1	1	1	1
2	Taipei City	1	1	1	1
3	Taoyuan City	1	1	1	1
4	Taichung City	1	1	1	1
5	Tainan City	1	1	1	1
6	Kaohsiung City	1	1	1	1
7	Keelung City	1	1	1	1
8	Hsinchu City	1	1	1	1
9	Chiayi City	1	1	1	1
10	Ilan County	1	1	1	1
11	Hsinchu County	0.384	0.416	1	0.785
12	Miaoli County	0.746	0.689	1	0.725
13	Changhua County	1	1	1	0.837
14	Nantou County	1	0.867	0.670	0.590
15	Yunlin County	0.838	0.900	0.732	0.578
16	Chiayi County	0.789	1	0.689	0.798
17	Pingtung County	0.825	1	0.617	0.640
18	Taitung County	0.719	1	0.309	0.609
19	Hualien County	1	1	0.961	0.986
20	Penghu County	1	1	1	1
21	Kinmen County	1	1	1	1
	Mean	0.919	0.946	0.904	0.883
	S.D.	0.156	0.142	0.188	0.163

Table 6. Factor effect indices of environmental quality control and final outputs

No	Region	Environmental quality control	Desirable output	Undesirable output	
		Pollution inspection	Life expectancy	Mortality rate	Cancer deaths
1	New Taipei City	1	1	1	1
2	Taipei City	1	1	1	1
3	Taoyuan City	1	1	1	1
4	Taichung City	1	1	1	1
5	Tainan City	1	1	1	1
6	Kaohsiung City	1	1	1	1
7	Keelung City	1	1	1	1
8	Hsinchu City	1	1	1	1
9	Chiayi City	1	1	1	1
10	Ilan County	1	1	1	1
11	Hsinchu County	0.680	1	0.906	0.952
12	Miaoli County	0.568	0.990	0.806	0.638
13	Changhua County	0.301	0.992	0.929	0.623
14	Nantou County	0.820	0.986	0.738	0.639
15	Yunlin County	0.238	0.982	0.734	0.474
16	Chiayi County	0.246	0.985	0.821	0.464
17	Pingtung County	0.321	0.962	0.686	0.568
18	Taitung County	0.965	0.950	0.636	0.639
19	Hualien County	0.852	0.992	0.938	1
20	Penghu County	1	1	1	1
21	Kinmen County	1	1	1	1
	Mean	0.809	0.992	0.914	0.857
	S.D.	0.289	0.014	0.123	0.207

Table 7. Differences in efficiency by regional classification

Efficiency	Average efficiency			Chi-square value	P-value
	City	County	Island		
Overall	0.992	0.715	1	16.219	0.000
Public expenditure	0.982	0.721	1	8.460	0.015
Medical care	0.987	0.858	1	10.283	0.006
Disease prevention	1	0.584	1	14.921	0.001
National health	1	0.696	1	14.921	0.001

Table 8. Difference classification of the factor effect indices

Factor	Average factor effect index			Chi-square value	*P* value
	City	County	Island		
Financial resource					
Government health care expenditure	1	0.715	1	10.432	.005
National health insurance expenses	0.968	0.727	1	8.010	.018
Medical resource					
Medical institutions	1.015	1.029	1	0.357	.837
Doctors	1.005	0.906	1	7.618	.022
Nurses	1.022	1.001	1	0.237	.888
Beds	1.008	1.002	1	0.230	.891
Disease prevention service					
Preventive physical examination	1	0.917	1	8.486	.014
Vaccination	1	0.928	1	6.715	.035
Pharmaceutical service					
Pharmacies	0.987	0.858	1	10.283	.006
Medical care performance					
Outpatients	1	0.830	1	8.486	.014
Inpatients	1	0.887	1	5.105	.078
Food hygiene					
Food hygiene inspection	1	0.584	1	14.921	.001
Disease prevention performance					
Notifiable patients	1	0.798	1	8.486	.014
Incidence rate of malignant neoplasms	1	0.755	1	14.921	.001
Environmental quality control					
Pollution inspection	1	0.599	1	14.921	.001
National health performance					
Life expectancy	1	0.984	1	12.582	.002
Mortality rate	1	0.819	1	14.921	.001
Cancer deaths	1	0.700	1	12.582	.002