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Measuring the efficiency of health systems in Asia: A data envelopment analysis

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Title. Measuring the efficiency of health systems in Asia: A data envelopment analysis

Short title. Measuring the efficiency of health systems in Asia

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ABSTRACT

Objective: One of the important objectives of every health systems is to use healthcare resources efficiently. However, such resources are being wasted in many health systems particularly in the low-and-middle income countries of Asia. This study aims to estimate the relative technical efficiency of health systems of Asian countries.

Settings: The study was conducted based on Asian countries.

Methods: We applied an output-oriented data envelopment analysis approach to estimate the technical efficiency of the health systems in Asian countries. As input variables we used per-capita health expenditure, number of physicians and number of beds per 1,000 people, smoking prevalence among adult male, and rate of primary-education completion. Output variables were life expectancy at birth and infant mortality per 1,000 live births. These variables were extracted from the World Development Indicators (WDI).

Results: The main findings of the study demonstrate that more than half of the sampled countries (57%) in the Asia region are technically inefficient with respect to using their healthcare systems inputs, based on the efficiency frontier generated from the countries studied. We found three high income-countries (Japan, Singapore, and Oman) and eight lower-middle-income countries (Sri Lanka, Pakistan, Timor-Leste, Cambodia, India, Syria, Yemen and Bangladesh) were efficiently using their healthcare resources. In Asia, through efficiency gain, the high-, upper middle-, lower middle-, and low-income countries can improve output indicators of health systems by 2%, 5%, 2% and 7% respectively using the same amount of inputs.

Conclusion: The results of this analysis showed inefficiency of the health systems in most of the Asian countries and imply that many countries may improve their health systems efficiency using the current level of resources. The identified inefficient countries could pay attention to benchmarking their health systems within their regional or another type of comparative group.

Strengths and limitations of this study:

- The study estimates the technical efficiency of the health systems in Asia using data envelopment analysis
- We analyzed efficiency of the highest number of health systems in Asia for the first time

- We extracted health systems level indicators from the widely used world development indicators database
- Some environmental factors of health systems were not included in the analysis due to the unavailability of data

BACKGROUND

In Asia, there are approximately 4.4 billion people spread across highly diverse countries, from economic powerhouses like China and Singapore to poorer economies such as Laos, Cambodia, and Myanmar (1). The continent is often cited as the fastest-growing and most dynamic region in the world. Over the past number of years, Asian societies have also made impressive progress in ensuring better healthcare services, especially those targeted towards improving maternal and infant health and increasing life expectancy (2). However, whether economic gains have translated to efficient health systems across the region is still not well studied.

It is important that the healthcare resources in Asia are used efficiently. Overall, government spending on healthcare is low compared to total health expenditure and furthermore it is often not focused on those who need it most. For example, in the South Asia region governments spend 31% of total health expenditure, which is more than one percent of gross domestic product (3,4). For many countries in the Asia region, personal health expenses or out-of-pocket payments are a major cause of poverty (1,5). From a study of 11 Asian countries, it was found that high levels of out-of-pocket healthcare spending have pushed 78 million people into poverty annually (6). Aging populations and non-communicable diseases that are often preventable but expensive to treat (e.g. diabetes and cancers linked to tobacco) impose and will continue to impose heavy costs on households and public health budgets. Moreover, a major challenge for Asian countries is the control and prevention of different communicable diseases (e.g. HIV/AIDS, tuberculosis, and polio) due to the movement of people across borders and the exchange of goods (7).

The World Health Organization (WHO) has estimated that about 20% to 40% of total healthcare resources are being wasted per year among the WHO member countries due to inefficiency. Further, this rate is higher in low-and-middle income countries (LMICs) (8). In Asia, the variation in efficiency across income settings can perhaps lead to lessons learned in addressing it. In order to address inefficiency, Asia's health systems can look toward different dimensions of performance such as their effectiveness, efficiency, access, equity, and quality(9). A great deal of practitioner and academic literature has analyzed the relationship between the efficient production of health services and universal health coverage (UHC) as well as the widespread importance of measuring overall health system performance (8,10).

Assessing the efficiency of healthcare systems is a difficult process as analyses often encounter methodological problems, particularly due to the need for appropriate and valid outcome indicators (11). Despite the empirical difficulties in applying efficiency concepts to health systems, inefficiency can be measured on both micro and macro level (12). Measuring health system efficiency at a macro-level is particularly important in order to understand health system performance across the globe and take required action (10,13).

In an international study of efficiency in 170 countries, it was observed that Asian countries were comparatively in the middle with respect to health system efficiency scores (14). Although this is perhaps encouraging, a few studies have analyzed health systems efficiency across Asian countries specifically (15). Asian countries are not homogenous in terms of area, population, and economic conditions, however, they have public health functions and a number of their health system outcomes in common (16). Many of the countries share similar health systems problems, including inadequate resources for healthcare and a high burden of diseases due to the geographical contiguity, disease patterns, and social conditions. Understanding health systems efficiency in different Asian countries could promote shared learning and highlight key areas of best practice, as well as areas where improvement is needed.

This paper evaluates the technical efficiency of the healthcare systems of selected Asian countries using data from the World Development Indicators**.**

METHODS

Data envelopment analysis (DEA) was used for estimating technical and scale efficiency of the health systems of Asian countries.

Input and output variables

A main assumption of the DEA model used in our analysis was that in Asian countries, the selected health outcomes were dependent on the inputs of healthcare resources. We selected input variables representing access to medical care and the service of physicians as well as per-capita health expenditure. Following similar studies, number of physicians per 1,000 population and number of inpatient beds per 1,000 population were selected as inputs representing access to healthcare (17,18). Noting that in addition to health care, health status of individuals is determined by the lifestyle and behaviors, therefore we also included two environmental factors as input variables, namely smoking prevalence among adult male and primary education completion rate of relevant age group (19). The adverse health effect of smoking consequently affects health outcomes (20,21). Education is also found to one of the important factors in determining individual health status. Higher educational attainment has an association with income which secures healthy living environment and access to healthcare (22). Like similar studies in different context, the health outcomes of this study were life expectancy at birth and infant mortality (per 1,000 live births) (23–25). Declines in infant mortality and increase in life expectancy denotes the improvement in the health status or health outcomes of a country. We used the inverse of infant mortality in the DEA model as the model assumes that inputs and outputs are isotonic (i.e. increased input reduces efficiency as well as increased output increases efficiency) (26). Without this correction, a higher infant mortality figure would have been said to incorrectly contribute to a greater output of health systems.

Data

According to the list of United Nation Statistics Division, there are 50 Asian countries and territories. Among these , 46 were used for this study (27). Four countries and territories (Hong Kong, North Korea, Macao, and West bank and Gaza) were excluded due to missing data of selected variables in the WDI database (4). However, selected variables for the study countries were not reported in WDI for every year. This problem is unavoidable in studies based on WDI data (17,28,29). Earlier studies adapted two approaches to deal with such problem. Firstly, used a value from a slightly earlier year as in Anderson et al. (28) and secondly, used a smaller number of countries in the model as in Fare et al.(29) and Grubaugh and Santerre (17). Given the importance of including as many countries as possible to study technical efficiency using data envelope analysis, we opted for the first approach. We captured most of the variables from the World Development Indicators-2014 (WDI). However, to avoid missing variable we used slightly earlier WDI statistics. Gathering data from a single source ensures the accuracy and comparability of the data which are important requirements for DEA models.

Data envelopment analysis

DEA is one of the most widely used methods to assess the technical efficiency and scale efficiency of a set of decision-making units (DMUs) (In the case of this analysis, DMUs are the 46 different Asian countries). DEA is a non-parametric method which identifies an efficiency frontier on which only the efficient DMUs are placed, by using linear programming techniques. One type of DEA model, developed by Charnes, Cooper, and Rhodes (CCR), assumes that production has constant returns to scale (CRS) meaning any change in the input will result in a proportionate change in the output (30). Another model proposed by Banker, Charnes, and Cooper (BCC), assumes that production has variable returns to scale (VRS) implying an increase in the input will result in either an increase or a decrease in the output. The latter methodology is particularly useful for this study since it aims to measure the efficiency related to organizational units (i.e. the health systems of the different countries), which use numerous resources to produce multiple outputs and accommodate a more flexible assumption of VRS (14,31). This is more realistic and reflective of changes in the real world (32).

Scale efficiency scores provide information on the optimality of the DMUs size. If a healthcare system is scale efficient any modifications to its size will result in less efficient production. Scale efficiency is measured as the ratio of CRS technical efficiency scores and VRS technical efficiency scores (33).

When it comes to DEA studies comparing countries, both the input and output oriented models have been adopted for this type of analysis. An output-oriented DEA model aims to maximize the outputs obtained by the DMUs, while keeping the inputs constant. The input-oriented models focus on minimizing the inputs used for processing given amounts of outputs. Several studies have been carried out using DEA to assess the efficiency of healthcare systems using different methods in both high-income and low-income countries (34–37).

In our analysis, we used the output-oriented BCC and CCR model to estimate both CRS and VRS technical efficiency scores.

Output oriented model

The output-oriented technical efficiency model focuses on increasing output without changing the quantity of inputs used. The objective of the model for solving each particular DMU (country) is to maximize the efficiency score (denoted by ɸ) meaning the amount by which all outputs can be improved for each country under consideration while holding input constant.

The output-oriented DEA model is specified as follows.

$$\text{Max } \phi = \sum O_r Y_{rj_0} + O_0$$

Subject to constraints

$$\sum_{i=1}^{m} V_i + X_{ij_0} = 1$$

$$\sum_{r=1}^{s} O_r + Y_{rj} - \sum V_r X_{ij} + O_0 \leq 0, \quad j = 1, \ldots, n$$

$$O_r, V_i \geq 0$$

$$O_0 > 0, or\ O_0 = 0\ or\ O_0 < 0$$

Where,

Y_{rj} = amount of output r from country j,

X_{ij} = amount of input i to country j,

O_r = weight given to output r,

V_i = weight given to input i,

n = number of hospitals,

s = number of outputs,

m = number of inputs.

$O_0 > 0$ defines increasing returns to scale, $O_0 = 0$ defines constant returns to scale, and $O_0 < 0$ defines decreasing returns to scale.

The technical efficiency scores is defined by ϕ and it ranges between 0.00 and 1.00, If it is equal to 1.00, then the production from the DMU is efficient; while if it is less than 1.00, the DMU is inefficient.

RESULTS

The descriptive statistics of the selected input, output and environmental variables are shown in Table 1. The health expenditure per-capita ranges from a minimum of 88.1 USD (Bangladesh) to a maximum of 4,047.0 USD (Singapore) with a mean, median and standard deviation of 1,041.5, 613.7 and 1,048.4 respectively. The number of physician per 1,000 people ranges from a minimum of 0.1 at Timor-Leste to maximum 4.8 at Georgia. However, the number of inpatient beds per 1,000 people is minimum at Iran (0.1) and maximum at Japan (13.7). The average smoking prevalence of adult male people among the studied countries is 42.2 and average primary education completion rate is 96.5% of the relevant age group.

Table 1. Descriptive statistics of input and output variables

Characteristics/ description	Mean	Median	SD*	Minimum	Maximum
Input variables					
Health systems inputs					
Health expenditure per capita, PPP	1,041.5	613.7	1,048.4	88.1	4,047.0
Physicians (per 1,000 people)	1.6	1.6	1.1	0.1	4.8
Hospital beds (per 1,000 people)	2.9	2.1	2.7	0.1	13.7
Environmental factors					
Smoking prevalence, males (% of adults)	42.2	42.2	10.5	18.9	71.8
Primary completion rate, total (% of relevant age group)	96.5	97.9	11.4	66.7	116.5
Output variables					
Life expectancy at birth (years)	72.9	74.2	5.4	60.4	83.6
Infant mortality (per 1,000 live births)	20.9	13.7	16.8	2.1	68.1

*Standard deviation

Among the countries analyzed, life expectancy at birth was a minimum of 60.4 years in Afghanistan and a maximum of 83.6 years in Japan. The infant mortality rate ranged from 2.1 deaths per 1,000 live births in Japan to 68.1 deaths per 1,000 live births in Afghanistan. On average, there were 21.1 deaths per 1,000 live births in the studied countries. The scatter matrix of the input and output variables shows that inputs, for instance, per-capita healthcare expenditure was associated with improved health outcomes (e.g. life expectancy and infant mortality) (Figure1). The higher prevalence of smoking has a negative impact on life expectancy. However, life expectancy and infant mortality were inversely associated.

(Figure 1. will be inserted here)

The mean CRS and VRS technical efficiency scores were 0.925 and 0.969 respectively (Table 2). Whereas, the mean scale efficiency score was 0.954. In terms of both CRS and VRS technical efficiency, Kazakhstan and Afghanistan have the lowest score of 0.766 and 0.850 respectively.

Out of 460 countries studied, 20 (43%) and 16 (35%) countries showed the maximum level of (efficiency score 1.00) VRS and CRS technical efficiency respectively. In total, 17 (37%) countries showed scale efficiency of 1.00 implying these countries created the best practice frontier in this study, based on their input and output combinations. We found that equal number of countries observed increasing returns to scale and constant returns to scale (17 countries), followed by decreasing returns to scale (12 countries).

(Table 2. will be inserted here)

Among the inefficient countries, 26 (57%), 30 (65%), and 29 (63%) countries had VRS technical efficiency, CRS technical efficiency and scale efficiency score respectively less than one (Figure 2).

(Figure 2. will be inserted here)

In Table 3, mean efficiency scores are presented by the income categories of the countries. The highest mean CRS technical efficiency were observed for LMICs (0.95), followed by high-income (0.94), upper-middle-income (0.88) and low-income countries (0.92). The high-income countries and LMICs had the highest average VRS technical efficiency (0.98), followed by upper-middle-income countries (0.95) and low-income countries (0.93). Maintaining the existing input levels, the high, upper middle-, lower middle-, and low-income countries could improve their outcome by 2%, 5%, 2% and 7% respectively.

Table 3. Mean efficiency scores according to income level of Asian countries

Income groups	**CRS technical efficiency**	**VRS technical efficiency**	**Percentage of output can be improved in CRS technical efficiency**
Low-income	0.92	0.93	7%
Lower middle-income	0.95	0.98	2%
Upper middle-income	0.88	0.95	5%
High -income	0.94	0.98	2%

DISCUSSION

The main findings of this paper demonstrated that more than half (57%) of the studied countries in the Asia region are technically inefficient with respect to using the inputs in their healthcare systems. The study findings showed that the most efficient countries belonged to the lower-middle-income group (Sri Lanka, Pakistan, Timor-Leste, Cambodia, India, Syria, Yemen and Bangladesh). Additionally, three high-income countries (Japan, Singapore, and Oman), one low-income country (Nepal), and three upper-middle income countries (Lebanon, Iran, Iraq, and Thailand) in Asia were also efficient (Technical efficiency =1.00). Among the 46 countries studied, 17 countries (Bangladesh, Sri Lanka, Japan, Oman, Thailand, Iraq, Timor-Leste, Yemen, Singapore, India, Iran, Lebanon, Pakistan, Nepal, Syrian, Cambodia, and Cyprus) showed constant returns to scale efficiency, indicating that they were operating at their most efficient level. Another 17 countries (Malaysia, Bhutan, Myanmar, Tajikistan, Mongolia, Philippines, Indonesia, Uzbekistan, Saudi Arabia, Afghanistan, Kyrgyz Republic, Kazakhstan, Lao PDR, Azerbaijan, Kuwait, and Brunei Darussalam) demonstrated increasing returns to scale suggesting that they should increase inputs into their health systems to be more scale efficient. The remaining 12 countries showed decreasing returns to scale, meaning that their health systems has more inputs compared to their operating size. Therefore, they should scale down if they were to become scale efficient given the existing system. The average scale efficiency score was 0.95 which indicates that there was little difference between CRS and VRS production of healthcare services among the countries studied.

An important policy implication of this study is that the technically inefficient low-income countries on average can improve their health systems outcome by 7% while maintaining constant levels of per-capita health expenditure and levels of access to hospital beds and availability of physicians. It was observed that the efficiency scores increased from the low-income country groups to high-income country groups, with a few exceptions. An international study found a similar conclusion that health systems performance is most efficient in the developed countries, according to simple efficiency scores (38).

The overall healthcare efficiency in different countries varied considerably (39,40). Among the LMICs studied, eight countries demonstrated to have the most efficient health systems. These countries have both technical and scale efficient health systems, like the high-income countries (Japan, Singapore, and Oman). A possible reason for the high efficiency of these LMICs could be a focus on infant mortality and child health as prioritized in past Millennium Development Goals and in current Sustainable Development Goals agendas, which relates to the output variables used in this study.

The DEA showed that many of the LMICs produce good health at low cost and therefore make good use of their inputs (41). This result implies that it is possible for countries to have a high-efficiency score with poor health outcomes because of their low expenditure on resources. In other words, given their moderate consumption of inputs and challenging social environments, these countries can achieve good health outcomes, relative to the other countries. Similar findings were observed for Mexico and Turkey relative to other countries in a study of the OECD countries (25). It should be noted that this study only used per-capita health expenditure and two health systems indicators (number of physicians and beds per 1,000 people) given the data limitation, and there are other factors that influence health outcomes as well. For example differences in life expectancy and infant mortality between populations can be due to lifestyles, preferences (42,43,20) social class, occupation (44) and environmental factors (45,46). On a more macroscopic level, the results could also be impacted by a variety of contextual factors among countries such as different political institutions, economic landscapes, health-seeking behaviour patterns and burden of diseases among other things. However, in this study, we accommodated two available social and lifestyle factors namely primary completion rate of relevant age group and smoking prevalence among the adult male population to take into consideration some of this variation.

A limitation of DEA methodology is that it works in a deterministic way, meaning that the results entirely depend on the numeric values in the dataset. As the DEA approach compares DMUs, the number and nature of DMUs in the data set can noticeably change the results. For example, if a more efficient country is added to the dataset, it would move the frontier, causing some of the efficiency scores of other countries to fall. This is a key aspect of the methodology used.

Additionally, input and output variable selection were influenced by data availability because the WDI dataset contains many variables with missing values and DEA strictly requires a complete data set. Additional input and output variables were not used in this analysis because of missing data and a primary aim was to include the highest number of countries as possible in the analysis. Additionally, it is important to note that the use of a different set of variables might have generated different conclusions. In the future, if additional data become available for a larger number of countries of the region, the number of variables analyzed could be increased to include an understanding with a greater degree of complexity in health system efficiency.

Another data limitation is the comparability of health expenditures among the Asian countries. While recognizing that it is not possible to solve the inherent issues, we made an attempt to minimize it. Since the actual amount of healthcare expenditure across different countries is not comparable due to the difference in purchasing power parity across countries, we used health expenditures as constant of 2011 in PPP as an input in the health production model (25).

CONCLUSIONS

This study provides an empirical picture of the technical efficiency of the healthcare systems of 46 Asian countries. It found that inefficiency exists in the healthcare systems of most of the countries studied, however, the results point to three high-income and eight lower-middle-income countries which efficiently used the inputs in their healthcare systems. The interpretation of the inefficient countries identified through this study is that they can improve health outcomes using the current level of per-capita health expenditure and the number of physicians and beds per 1,000 people. These countries could use these results to direct their attention to benchmarking their health systems within their regional or another comparative group in order to understand their health system performance in a more detailed way. This study addresses the need to understand issues of efficiency, as well as potentially identify good examples of countries which efficiently allocate and use resources to make their healthcare systems more technically efficient. It narrows a gap in the literature as there are few countries studying healthcare efficiency in Asia and none looking comparatively in this manner.

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Contributors

SA, MZH and MM contributed to conceptualizing the research idea, study design, literature search, data extraction and analysis, data interpretation, and writing the manuscript. MWA FD, SMH, MMH, MTI and JAMK contributed to writing, reviewing and revising the manuscript. All authors read and approved the final manuscript

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Competing interest

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Data sharing statement

The data were extracted from the world development indicators which is available online.

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Table 2. Technical and scale efficiency scores of Asian countries

Country Name	**CRS Technical efficiency**	**VRS Technical efficiency**	**Scale efficiency**	**Returns to scale**
Afghanistan	0.836	0.850	0.984	1
Armenia	0.886	0.981	0.904	-1
Azerbaijan	0.786	0.889	0.884	1
Bahrain	0.930	0.991	0.938	-1
Bangladesh	1.000	1.000	1.000	0
Bhutan	0.950	0.968	0.981	1
Brunei Darussalam	0.962	0.987	0.974	1
Cambodia	1.000	1.000	1.000	0
China	0.869	0.967	0.898	-1
Cyprus	0.994	0.994	1.000	0
Georgia	0.797	0.959	0.831	-1
India	1.000	1.000	1.000	0
Indonesia	0.931	0.976	0.954	1
Iran, Islamic Republic	1.000	1.000	1.000	0
Iraq	1.000	1.000	1.000	0
Israel	0.928	1.000	0.928	-1
Japan	1.000	1.000	1.000	0
Jordan	0.858	0.948	0.905	-1
Kazakhstan	0.766	0.899	0.852	1
Korea, Republic	0.962	0.999	0.963	-1
Kuwait	0.819	0.918	0.891	1
Kyrgyz Republic	0.849	0.945	0.898	1
Lao PDR	0.983	1.000	0.983	1
Lebanon	1.000	1.000	1.000	0
Malaysia	0.857	0.953	0.899	1

Maldives	0.808	0.955	0.847	-1
Mongolia	0.806	0.895	0.900	1
Myanmar	0.997	1.000	0.997	1
Nepal	1.000	1.000	1.000	0
Oman	1.000	1.000	1.000	0
Pakistan	1.000	1.000	1.000	0
Philippines	0.831	0.908	0.916	1
Qatar	0.957	1.000	0.957	-1
Saudi Arabia	0.876	0.922	0.950	1
Singapore	1.000	1.000	1.000	0
Sri Lanka	1.000	1.000	1.000	0
Syrian Arab Republic	1.000	1.000	1.000	0
Tajikistan	0.906	0.941	0.963	1
Thailand	1.000	1.000	1.000	0
Timor-Leste	1.000	1.000	1.000	0
Turkey	0.891	0.951	0.936	-1
Turkmenistan	0.822	0.866	0.950	1
United Arab Emirates	0.887	0.985	0.900	-1
Uzbekistan	0.950	0.951	0.998	1
Vietnam	0.878	0.994	0.884	-1
Yemen, Republic	1.000	1.000	1.000	0
Mean	0.925	0.969	0.954	-
Median	0.925	0.969	0.954	-
Median	0.950	0.992	0.969	-
SD	0.076	0.041	0.051	-
Min	0.766	0.850	0.831	-
Max	1.000	1.000	1.000	-

Figures

Figure 1. Distribution of efficiency scores in the health systems of Asia

Figure 2. Association across health systems outputs, environmental factors and inputs

Figure 1. Distribution of efficiency scores in the health systems of Asia

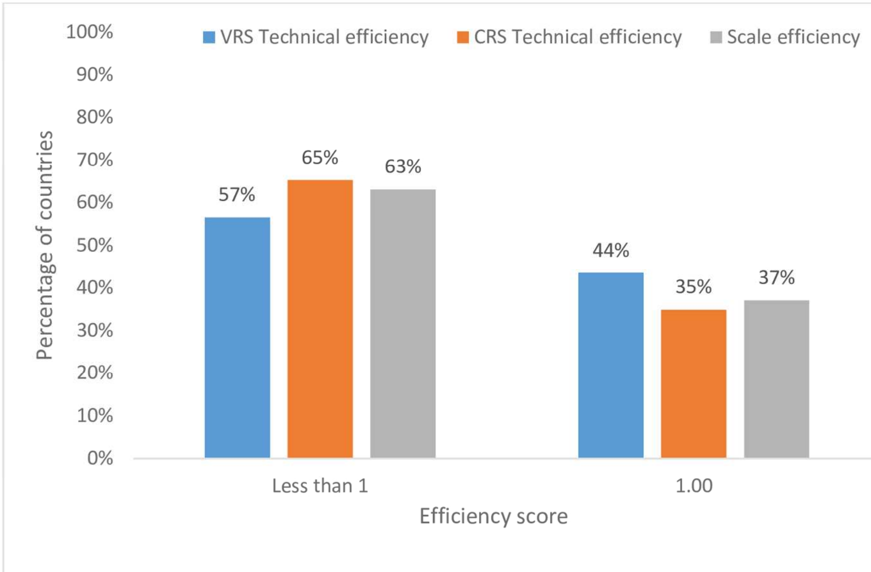

Figure 1. Distribution of efficiency scores in the health systems of Asia

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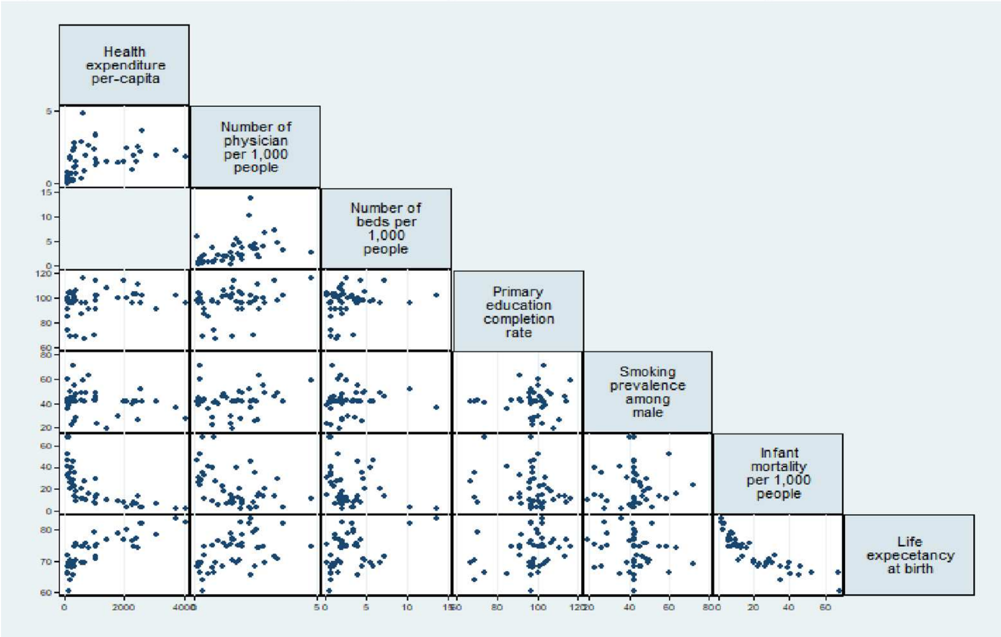
Figure 2. Association across health systems outputs, environmental factors and inputs



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Measuring the efficiency of health systems in Asia: A data envelopment analysis

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Title. Measuring the efficiency of health systems in Asia: A data envelopment analysis

Short title. Measuring the efficiency of health systems in Asia

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ABSTRACT

Objective: This study aims to estimate the technical efficiency of health systems of Asian countries.

Settings: The study was conducted based on Asian countries.

Methods: We applied an output-oriented data envelopment analysis (DEA) approach to estimate the technical efficiency of the health systems in Asian countries. The DEA model used as input per-capita health expenditure (all healthcare resources as a proxy) and as output cross-country comparable health outcome indicators (e.g. HALE at birth and infant mortality per 1,000 live births). A tobit regression model was used to observe the associated factors with the efficiency scores. A sensitivity analysis was performed to assess the consistency of these scores.

Results: The main findings of this paper demonstrated that about (86.9 %) of the studied Asian countries were inefficient with respect to using healthcare systems resources. Most of the efficient countries belonged to the high-income group (Cyprus, Japan, and Singapore) and only one country belonged to the low- and lower middle-income group (Bangladesh). In Asia, through efficiency gain, the high-, upper middle-, lower and lower- middle-income countries can improve health systems outcome by 6.6%, 8.6%, and 8.7% respectively using the existing level of resources. Population density, beds density, and primary education completion rate significantly influenced the efficiency score.

Conclusion: The results of this analysis showed inefficiency of the health systems in most of the Asian countries and imply that many countries may improve their health systems efficiency using the current level of resources. The identified inefficient countries could pay attention to benchmarking their health systems within their income group or other similar type of health system.

Strengths and limitations of this study:

- Data envelopment analysis was used to determine the extent of inefficiency in health systems across Asia.
- We extracted health systems level indicators from the widely used world development indicators database and World Health Organization open data repository
- Due to data availability, we used health system outcomes in addressing the health systems efficiency rather than true health systems output

BACKGROUND

In Asia, there are approximately 4.4 billion people spread across highly diverse countries, from economic powerhouse like China and Singapore to poorer economies such as Laos, Cambodia, and Myanmar (1). The continent is often cited as the fastest-growing and most dynamic region in the world. Over the past number of years, Asian societies have also made impressive progress in ensuring better healthcare services, especially those targeted towards improving maternal and infant health and increasing life expectancy (2). However, whether economic gains have translated to efficient health systems across the region is still not well studied.

It is important that the healthcare resources in Asia are used efficiently. Overall, government spending on healthcare is low compared to total health expenditure and furthermore it is often not focused on those who need it most (3). For example, in the South Asia region governments spend 31% of total health expenditure, which is more than one percent of gross domestic product (4,5). In many Asian countries, personal health expenses or out-of-pocket payments is a major cause of poverty (1,6). From a study of 11 Asian countries, it was found that high levels of out-of-pocket healthcare spending have pushed 78 million people into poverty annually (7). Aging populations and non-communicable diseases that are often preventable but expensive to treat (e.g. diabetes and cancers linked to tobacco) impose and will continue to impose heavy costs on households and public health budgets. Moreover, a major challenge for Asian countries is the control and prevention of different communicable diseases (e.g. HIV/AIDS, tuberculosis, and polio) due to the movement of people across borders and the exchange of goods (8).

In light of this, it is very important that the health systems of these countries are efficient in making use of their resources. The World Health Organization (WHO) has estimated that about 20% to 40% of total healthcare resources are being wasted per year among the WHO member countries due to inefficiency. Further, this rate is high in low-and-middle income countries (LMICs) (9). In Asia, the variation in efficiency across income settings can perhaps lead to lessons learned in addressing it. In order to address inefficiency, Asia's health systems can look toward different dimensions of performance such as their effectiveness, efficiency, access, equity, and quality (10). A great deal of practitioner and academic literature has analyzed the relationship between the efficient production of health services and universal health coverage (UHC) as well as the widespread importance of measuring overall health system performance (9,11).

Assessing the efficiency of healthcare systems is a difficult process as analyses often encounter methodological problems, particularly due to the need for appropriate and valid outcome indicators (12). Despite the empirical difficulties in applying efficiency concepts to health systems, efficiency can be measured on both micro and macro levels (13). Measuring health system efficiency at a macro-level is particularly important in order to understand health system performance across the globe and take required action to minimize inefficiency (11,14).

A number of studies have addressed healthcare efficiency in Americas (15,16), Western Europe (17,18) and Asia (19,20) to shed light on the efficiency of different national health systems. A systematic review on measuring efficiency related to several aspects of healthcare was performed by Hollingsworth et al. (21). Dimas et al. evaluated the productivity of Greek public hospitals and found that productivity changes were dominated by technical change (22). Zere et al. measured the technical efficiency and productivity of hospitals in South Africa, and examined the impact of hospital characteristics on efficiency and productivity (23).

In an international study of efficiency in 170 countries, it was observed that Asian countries were comparatively in the middle with respect to health system efficiency scores (24). This indicates that there is room for improvement to optimize health benefits from the available health sector resources. In this region, there are a number of studies at the country level to address health systems efficiency (25,26), but cross country comparison of the health system efficiency is limited (27).

Asian countries are not homogenous in terms of area, population, and economic conditions, however, they have public health functions and a number of their health system outcomes in common (28). Many of the countries share similar health systems problems, including inadequate resources for healthcare and a high burden of diseases due to the geographical contiguity, disease patterns, and social conditions. Understanding health systems efficiency in different Asian countries could promote shared learning and highlight key areas of best practice, as well as areas where improvement is needed. Furthermore, given geographical proximity and many strong relationships experienced with near-by countries, there is likely to be relative ease in the ability to practically understand, learn and apply nuance about healthcare systems from one country to another.

A study of the efficiency of health systems in this region will help to provide lessons through comparison across countries. This paper aims to achieve this goal through evaluating the technical efficiency and scale efficiency of the healthcare systems of selected Asian countries.

METHODS

This study employed Data Envelope Analysis (DEA) which is a commonly used non-parametric method for efficiency analysis. It was used for estimating technical and scale efficiency scores of the health systems of Asian countries.

Input and output variables

A main assumption of the DEA model used in our analysis was that in Asian countries, the selected health outcomes were dependent on the inputs of healthcare resources. We selected the input variables as proxies for the quantity of inputs that a country devotes to healthcare (i.e. health expenditure per capita); and outcome variables of the healthy life expectancy at birth (HALE) and infant mortality (per 1,000 live births). The relationship between health expenditure and outcomes considered here is consistent with the view that health expenditure has diminishing returns, or additional expenditure beyond a certain level has relatively smaller incremental effect on life expectancy or infant mortality (29). To be clear, reduction in infant mortality and increase in life expectancy signify improvement in the health outcomes of a country. Some studies have included life expectancy at birth as an outcome variable (31–33), however, it is argued that quality of life matters as much as, if not more than, quantity of life, and therefore life expectancy should be a weighted health quality measure. As a result, HALE has been incorporated as a proxy of health quality as the outcome of health systems. Also, it is important to note that instead of using the infant mortality directly in the DEA model, we used the inverse of infant mortality as the model assumes that inputs and outputs are isotonic (i.e. increased input reduces efficiency as well as increased output increases efficiency) (34). Without this correction, a higher infant mortality figure would have been said to incorrectly contribute to a better health system outcome.

Data sources

We used two main data sources: The World Health Organization data repository and World Development Indicators-2015 (WDI). According to the list of United Nation Statistics Division, there are 50 Asian countries and territories. Among these , 46 were used for this study (35). Four countries and territories (Hong Kong, North Korea, Macao, and West bank and Gaza) were excluded due to missing data of selected variables in the WDI database (5). However, selected variables for the study countries were not reported in WDI for every year. This problem is unavoidable in studies based on WDI data (36–38). Earlier studies adapted two approaches to deal with such problem. Firstly, they used a value from a slightly earlier year as in Anderson et al. (36) and secondly, they used a smaller number of countries in the model as in Fare et al. (37) and Grubaugh and Santerre (38). Given the importance of including as many countries as possible to study technical efficiency using Data Envelope Analysis, we opted for the first approach. However, to avoid missing variable we used slightly earlier WDI statistics.

Data envelopment analysis

DEA is one of the most widely used methods to assess the technical efficiency and scale efficiency of a set of decision-making units (DMUs) (In the case of this analysis, DMUs are the 46 different Asian countries). DEA is a non-parametric method which identifies an efficiency frontier on which only the efficient DMUs are placed, by using linear programming techniques. One type of DEA model, developed by Charnes, Cooper, and Rhodes (CCR), assumes that production has constant returns to scale (CRS) meaning any change in the input will result in a proportionate change in the output (39). Another model proposed by Banker, Charnes, and Cooper (BCC), assumes that production has variable returns to scale (VRS) implying an increase in the input will result in either an increase or a decrease in the output. The latter methodology is particularly useful for this study since it aims to measure the efficiency related to organizational units (i.e. the health systems of the different countries), which use numerous resources to produce multiple outputs and accommodate a more flexible assumption of VRS (24,40). This is more realistic and reflective of changes in the real world (25).

Scale efficiency scores provide information on the optimality of the DMUs size. When a production unit (DMU) operates at CRS, technical efficiency is equal to scale efficiency. However, when DMUs are not operating at optimum scale, technical efficiency measured with the CCR model may be altered by scale efficiency. The BCC model, which defines production through VRS, can incorporate the impact of scale efficiency in the measurement of technical efficiency. This is measured as the ratio of CRS technical efficiency scores and VRS technical efficiency scores (41).

When it comes to DEA studies comparing countries, both the input and output oriented models have been adopted for this type of analysis. An output-oriented DEA model aims to maximize the outputs with a given amount of inputs; while input-oriented models focus on minimizing the inputs used to obtain a certain amount of output. Many studies have been carried out using DEA to assess the efficiency of healthcare systems using the two approaches in both high-income and low-income countries (42–45). In this study, an output-oriented DEA model was deemed more appropriate based on the premise that the input per capita expenditure is likely to be less flexible. In other words, health system stewards are likely to have more leverage in controlling outputs through innovative programming and improvements in healthcare provided, rather than by increasing spending and resources.

Output oriented model

The output-oriented technical efficiency model focuses on increasing output without changing the quantity of inputs used. The objective of the model for solving each particular DMU (country) is to maximize the efficiency score (denoted by ϕ) meaning the amount by which all outputs can be improved for each country under consideration while holding input constant.

The output-oriented DEA model is specified as follows.

$$\text{Max}\ \phi = \sum O_r Y_{rj_0} + O_0$$

189 Subject to constraints

$$\sum_{i=1}^{m} V_i + X_{ij_0} = 1$$

$$\sum_{r=1}^{s} O_r + Y_{rj} - \sum V_r X_{ij} + O_0 \leq 0, \quad j = 1, \dots, n$$

190 $O_r, V_i \geq 0$

191 $O_0 > 0, or\ O_0 = 0\ or\ O_0 < 0$

192 Where,

193 Y_{rj} = amount of output r from country j,

194 X_{ij} = amount of input i to country j,

195 O_r = weight given to output r,

196 V_i = weight given to input i,

197 n = number of countries,

198 s = number of outputs,

199 m = number of inputs.

200 $O_0 > 0$ defines increasing returns to scale, $O_0 = 0$ defines constant returns to scale, and $O_0 < 0$ defines decreasing returns to scale.

202 The technical efficiency scores is defined by ϕ and it ranges between 0.00 and 1.00, If it is equal to 1.00, then the production from the DMU is efficient; while if it is less than 1.00, the DMU is inefficient.

205 **Tobit regression analysis**

206 In the second stage, the VRS efficiency scores computed using the DEA model were regressed against some true inputs of the health systems (e.g. physician and beds density per 1000 population) and some environmental factors (Table 1). Since, by definition, the DEA scores range between zero and one, and some of the data tend to concentrate on these boundary values (i.e. censored for the DMUs with a value at one), ordinary least squares can not estimate the regression. Therefore, a tobit model is best for such regression. For the convenience of calculation, we assumed a censoring point at zero in this model. As a result, the efficient DMUs will have a score of zero and the inefficient DMUs will have score greater than zero. Following Zere at et. (46), we applied this method by transforming VRS technical efficiency scores into VRS inefficiency scores and leaving censoring at zero as follows.

$$Inefficiency\ score\ = \left(\frac{1}{VRS\ technical\ efficiency\ score}\right) - 1$$

The Tobit regression model used variables representing access to healthcare and health status. Guided by several similar studies, physician density (the number of physicians per 1,000 population) and bed density (the number of inpatient beds per 1,000 population) were selected as determinants of access to healthcare (38,47). In addition to health care, the health status of individuals is determined by the lifestyle and behaviors, therefore we also included two environmental factors as determinants of efficiency, namely smoking prevalence among adult male (percentage of adults) and primary education completion rate of relevant age group. The relevant age group for the primary completion rate is defined as the number of new entrants (enrolments minus repeaters) in the last grade of primary education (regardless of age); divided by the population at the entrance age for the last grade of primary education of a country (48). The adverse health effect of smoking consequently affects health outcomes (49,50). Education is found to be an important factor in determining individual health status. Higher educational attainment is associated with higher income which in turn secures a healthy living environment and access to healthcare (51). Additionally, we included population density (population living per square kilometre of land area) as the control of efficiency. This is because population density can affect the quality of healthcare services.

The Tobit regression models were specified as follows,

$$Ineff_i = \beta_0 + \beta_1 P\square y_i + \beta_2 Beds_i + \beta_3 \; Primay\_edu_i + \beta_4 Smoking_i + \beta_5 Inc_i + \beta_5 Pop\_density_i + \varepsilon_i$$

Where,

Ineff = the technical inefficiency score; continues variable.

Phy = Physician density; categorical variable (1= Fewer than 1 physician; 2= 1-2 physician, 3= More than 2 physician)

Beds =Beds density; categorical variable (1= Fewer than 1 beds 3= More than 1 and less than or equal to 3 beds, 3= More than 3 and less or equal to 5 beds, 4= More than 5 beds)

Inc= Income group of the country; categorical variable (1=Low income, 2=Lower-middle income, 3=Upper-middle-income, 4=High-income)

Pop_density= Population density; categorical variable (1= Fewer than or equal to 50, 2= More than 50 to fewer than or equal to 100, 3= More than 100 to fewer than or equal 200, 4= More than 200)

Finally, ε_i was the stochastic error term.

Sensitivity analysis

A sensitivity analysis of the efficiency score was conducted by running the DEA model several times using different combinations of input and outcome variables. We considered multiple models (e.g. dropping the efficient countries, using HALE at age 60, current health expenditure per capita (current US$) as inputs. and using the complete set of data for the year 2015 (excluding countries with any missing variable)

Patient and Public Involvement

The study used secondary data from WHO and WDI data base. No patients were involved in this study. Study findings will be shared with the stakeholders, including local community groups in community meetings and at national or regional conferences.

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RESULTS

The descriptive statistics of the selected input, output and environmental variables are shown in Table 1. The health expenditure per-capita ranges from a minimum of 88.03 USD (Bangladesh) to a maximum of 4,405.13 USD (Japan) with a mean, median and standard deviation of 1,133.71, 663.94, and 1,157.72 respectively. The number of physicians per 1,000 people ranges from a minimum of 0.1 at Timor-Leste to maximum 4.8 at Georgia. However, the number of inpatient beds per 1,000 people is smallest in Iran (0.1) and highest in Japan (13.7). The average smoking prevalence of the adult male people among the studied countries is 42.2 and average primary education completion rate is 96.5% of the relevant age group.

Table 1. Descriptive statistics of input and output variables

Characteristics/ description	Mean	Median	SD*	Minimum	Maximum	Source
Input variables						
Health expenditure per capita, PPP	1,133.71	663.94	1,157.72	88.03	4,405.13	WDI
Outcome variables						
Healthy life expectancy at birth (years)	64.29	65.2	5.1	53.2	75.9	WHO
Infant mortality (per 1,000 live births)	19.9	13.9	15.8	2.0	65.7	WDI
Explanatory variables for Tobit model						
Physicians (per 1,000 people)	1.6	1.6	1.1	0.1	4.8	WDI
Hospital beds (per 1,000 people)	2.9	2.1	2.7	0.1	13.7	WDI
Smoking prevalence, males (% of adults)	42.2	42.2	10.5	18.9	71.8	WDI
Primary completion rate, total (% of relevant age group)	96.5	97.9	11.4	66.7	116.5	WDI

*Standard deviation

Among the countries analyzed, HALE at birth was a minimum of 53.2 years in Afghanistan and a maximum of 75.9 years in Singapore. The infant mortality rate ranged from 2.1 deaths per 1,000 live births in Japan to 68.1 deaths per 1,000 live births in Afghanistan. On average, there were 21.1 deaths per 1,000 live births in the studied countries. The scatter matrix of the input and output variables shows that inputs, for instance, increase in per-capita healthcare expenditure was associated with improved health outcomes (e.g. HALE at birth and reduced infant mortality) (Figure 1).

(Figure 1. will be inserted here)

The mean CRS and VRS technical efficiency scores were 0.780 and 0.921 respectively (Table 2). Whereas, the mean scale efficiency score was 0.874. Considering VRS efficiency, Afghanistan has the lowest score of 0.766 and 0.812. Both VRS and CRS technical efficiency score were positively correlated with per capita health expenditure, HALE at birth, and negatively correlated with infant mortality (supplementary table 1).

Out of 46 countries studied, only 4 (8.7%) countries showed the maximum level of (efficiency score 1.00) in VRS and CRS technical efficiency scale. All of these four countries showed scale efficiency of 1.00 implying that these countries created the best practice frontier based on their input and output combinations. 39.1% (18) countries showed increasing returns to scale, 52.2% (24) countries decreasing returns to scale, and the 4 efficient countires constant returns to scale production function of their health systems.

(Table 2. will be inserted here)

More than half of the countries (30 countries) had VRS efficiency and five countries CRS efficiency greater than 90% (supplementary figure 1).

Tobit regression analysis of associated factors with inefficiency

Tobit regression was employed to relate the VRS inefficiency scores to two health service production variables and four environmental variables. Physician density, income status of countries, and smoking prevalence among males exhibited a statistically insignificant positive association with the inefficiency scores. The density of bed (>3 and <=5) had a significantly negative association with the inefficiency scores compared to less than 1 beds category. Countries having more than 5 beds density had no significant association with the inefficiency scores. After the bootstrapping more than 5 beds density showed significant association with inefficiency score (supplementary table 2). However, the coefficient was highest for (>3 and <=5) beds density. This indicates that sample countries with less than 1 bed have lower technical efficiency of its health systems. Furthermore, the primary education completion rate was significantly negatively associated with the inefficiency score which indicates that countries with higher percentage of primary education completion rate have higher health system efficiency. Population density had a significantly negative association with the inefficiency score. Countries having less than 200 population per square kilometre were found to have lower efficiency.

Sensitivity of the efficiency scores

We conducted sensitivity analysis using various combinations of input and output variables. In all of these cases the average of the efficiency scores varied from 0.812 to 0.936. The most sensitive combination was found while using the HALE at age 60 as the input variable. The efficiency score changed from 0.919 (main model) to 0.812 (considering input as HALE at age 60) (Figure 2).

(Figure 2. will be inserted here)

In Table 3, mean efficiency scores are presented by the income categories of the countries. The highest mean VRS technical efficiency were observed for high income countries (0.934; 95% CI 0.905-0.963), followed by upper-middle-income (0.914; 95% CI: 0.894-0.935), and low and lower-middle income countries (0.913; 955% CI: 0.891-0.935). With the existing input levels, the high-, upper middle-, low- and lower-middle income countries could improve their health system outcome by 6.6%, 8.7%, and 8.7% respectively.

Table 4. Mean efficiency scores according to income level of Asian countries

Income groups	**VRS technical efficiency**		**Percentage of output can be improved in CRS technical efficiency**
	Mean	**95% CI**	
Low- and lower middle-income	0.913	(0.891-0.935)	8.7%
Upper middle-income	0.914	(0.894-0.935)	8.6%
High -income	0.934	(0.905-0.963)	6.6%

DISCUSSION

The main findings of this paper demonstrated that about (86.9 %) of the studied Asian countries are technically inefficient with respect to using healthcare systems resources, (using a proxy of per capita health expenditure). The study findings showed that the most efficient countries belonged to the high-income group (Cyprus, Japan, and Singapore). Only one country belonged to the low- and lower middle income group (Bangladesh). Among the 46 countries studied, only four countries (Bangladesh, Japan, Singapore, and Cyprus) showed constant returns to scale efficiency, indicating that they were operating at their most efficient level. Of the 14 high-income countries studied, 9 countries (75.0%) had health system production at decreasing returns to scale. This implies that although the highest number of efficient countries belonged to the high-income group, a large number of these countries health system production requires more resources than the ideal situation. A similar situation was observed for the upper-middle-income countries. Of the 13 countries, 10 (76.9%) had decreasing returns to scale. Only 5 (23.8%) out of 21 low – and lower-middle-income countries were producing at decreasing returns to scale. Although these low- and lower-middle-income countries are not efficient, most of their production follows increasing returns to scale.

It was observed that the average of the efficiency scores increased from the low and lower-middle-income countries to high-income countries. An important policy implication of this study could be that the technically inefficient low-income countries on average can improve their health systems outcome by 8.7%, middle income country by 8.6%, and high income country by 6.6% using the existing levels of per-capita health expenditure. An international study found a similar conclusion that health systems performance is most efficient in the developed countries, according to simple efficiency scores (52).

The overall healthcare efficiency in different countries varied considerably (53,54). Among the low- and lower-middle income studied, one country demonstrated the most efficient health systems (Bangladesh). This county has both technical and scale efficient health systems, like the high-income countries (Japan, Singapore, and Cyprus) (55). A possible reason for the high efficiency of these LMICs could be a focus on infant mortality and child health as prioritized in past Millennium Development Goals and in current Sustainable Development Goals agendas, which relates to the outcome variables used in this study.

The DEA result showed that more than 60% of the low- and lower middle income countries had health system efficiency greater than 90%. This result implies that these countries produce good health at low cost and therefore make good use of health systems resources (56). This result suggests that it is possible for countries to have a high-efficiency score with poor health outcomes because of their low expenditure on resources and increasing returns to scale production function. In other words, given their moderate consumption of inputs and challenging social environments, these countries can achieve good health outcomes, relative to the other countries. Similar findings were observed for Mexico and Turkey relative to other countries in a study of the OECD countries (33). It should be noted that this study only used per-capita health expenditure and there are other factors that influence health outcomes as well. For example differences in life expectancy and infant mortality between populations can be due to lifestyles, preferences (49,57,58) social class, occupation (59) and environmental factors (60,61). On a more macroscopic level, the results could also be impacted by a variety of contextual factors among countries such as different political institutions, economic landscapes, health-seeking behaviour patterns and burden of diseases among other things. However, in this study, we attempted to address by including variables addressing the number of physicians, number of inpatient beds, and population density, along with two environmental factors namely primary completion rate of relevant age group and smoking prevalence among the adult male population to take into consideration some of this variation. The results showed that more than three and less than five beds per 1000 population significantly influenced the efficiency score. A low number of beds cannot serve a large proportion of the population and therefore the systems may be inefficient. Similarly, a high number of beds may often be left unused and make the health systems inefficient The countries having more than 200 people living per square kilometre had a higher level of efficiency in their health systems.

A limitation of DEA methodology is that it works in a deterministic way, meaning that the results entirely depend on the numeric values in the dataset. As the DEA approach compares DMUs, the number and nature of DMUs in the data set can noticeably change the results. For example, if a more efficient country is added to the dataset, it would move the frontier, causing some of the efficiency scores of other countries to fall. This is a key aspect of the methodology used.

Additionally, it is important to note that the use of a different set of variables might have generated different conclusions. In the future, if additional data become available for a larger number of countries in the region, the number of variables analyzed could be increased to include an understanding with a greater degree of complexity in health system efficiency.

Another data limitation is the comparability of health expenditures among the Asian countries. While recognizing that it is not possible to solve the inherent issues, we made an attempt to minimize it. Since the actual amount of healthcare expenditure across different countries may not be comparable due to the difference in purchasing power parity across countries, we used health expenditures as constant of 2011 in PPP as an input in the DEA model (33). Also, when we included health expenditure at current USD per capita as an input in the DEA model we found that the efficiency score did not change significantly.

We applied sensitivity analysis to in an attempt overcome these limitations (Figure 2.) Our results were consistent while using several combinations of inputs and outputs variables which is reassuring and strengthens the findings from this study.

CONCLUSIONS

This study provides an empirical picture of the technical efficiency of the healthcare systems of 46 Asian countries. It found that inefficiency exists in the healthcare systems of most of the countries studied, however, the results point to three high-income and one low- and lower-middle-income country which efficiently used healthcare systems resources. The interpretation of the inefficient countries identified through this study is that they can improve health outcomes using the current level of per-capita health expenditure. These countries could use these results to direct their attention to benchmarking their health systems within their regional or another comparative group in order to understand their health system performance in a more detailed way. This study addresses the need to understand issues of efficiency, as well as potentially identify good examples of countries which efficiently allocate and use resources to make their healthcare systems more technically efficient. It narrows a gap in the literature as there are few countries studying healthcare efficiency in Asia and looking comparatively in this manner.

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Contributors

SA, MZH and MM contributed to conceptualizing the research idea, study design, literature search, data extraction and analysis, data interpretation, and writing the manuscript. MWA FD, SMH, MMH, MTI and JAMK contributed to writing, reviewing and revising the manuscript. All authors read and approved the final manuscript.

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Competing interest

None declared**.**

Data sharing statement

Data were extracted from the World Bank Open Data repository for the "World Development Indicators' and from World Health Organization Global Health Observatory data. The following links was used to extract the excel format of the indicators: https://data.worldbank.org/ and http://www.who.int/gho/en/.

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Tables

Table 2. Technical and scale efficiency score of the health systems in Asian countries

Country name	CRS Technical efficiency	VRS Technical efficiency	Scale efficiency	Returns to scale
Afghanistan	0.724	0.812	0.891	1
Armenia	0.769	0.946	0.813	-1
Azerbaijan	0.660	0.902	0.732	-1
Bahrain	0.714	0.910	0.784	-1
Bangladesh	1.000	1.000	1.000	0
Bhutan	0.775	0.903	0.858	1
Brunei Darussalam	0.708	0.920	0.769	-1
Cambodia	0.805	0.916	0.879	1
China	0.806	0.975	0.826	-1
Cyprus	1.000	1.000	1.000	1
Georgia	0.751	0.923	0.813	-1
India	0.778	0.892	0.872	1
Indonesia	0.746	0.904	0.826	1
Iran	0.678	0.900	0.754	-1
Iraq	0.683	0.850	0.803	1
Israel	0.874	0.967	0.904	-1
Japan	1.000	1.000	1.000	0

Jordan	0.743	0.943	0.789	-1
Kazakhstan	0.695	0.882	0.788	1
South Korea	0.886	0.972	0.911	-1
Kuwait	0.674	0.885	0.762	-1
Kyrgyz Republic	0.806	0.941	0.856	1
Laos	0.818	0.889	0.920	1
Lebanon	0.746	0.910	0.820	1
Malaysia	0.778	0.927	0.839	1
Maldives	0.730	0.944	0.773	-1
Mongolia	0.737	0.896	0.823	1
Myanmar	0.743	0.872	0.852	1
Nepal	0.861	0.932	0.924	1
Oman	0.692	0.896	0.772	-1
Pakistan	0.827	0.889	0.930	1
Philippines	0.779	0.916	0.850	1
Qatar	0.677	0.903	0.749	-1
Saudi Arabia	0.624	0.871	0.716	-1
Singapore	1.000	1.000	1.000	0
Sri Lanka	0.904	0.985	0.917	-1
Syria	0.818	0.848	0.964	1
Tajikistan	0.856	0.964	0.888	-1
Thailand	0.791	0.956	0.828	-1
Timor-Leste	0.823	0.903	0.912	1
Turkey	0.710	0.916	0.776	-1
Turkmenistan	0.639	0.859	0.743	1
United Arab Emirates	0.691	0.889	0.777	1
Uzbekistan	0.784	0.947	0.828	-1
Vietnam	0.845	0.996	0.849	-1
Yemen	0.727	0.826	0.881	1
Mean (95% CI)	**0.780 (0.752-0.808)**	**0.919 (0.905-0.933)**	**0.847 (0.824-0.87)**	-
Median	0.772	0.913	0.834	-
Minimum	0.624	0.812	0.716	-
Maximum	1	1	1	-

Table 3. Result from tobit regression analysis

Variable	Coefficient (95% CI)	P-value
Physician density (per 1,000 population)		
Fewer than 1 physician		
1-2 physician	-0.0005 (-0.0363,0.0353)	0.9780
More than 2 physician	-0.0003 (-0.0445,0.044)	0.9900
Bed density (per 1,000 population)		
Fewer than 1 beds	1.000	
More than 1 and less than or equal to 3 beds	-0.0146 (-0.0558,0.0267)	0.4770

More than 3 and less or equal to 5 beds	-0.0398 (-0.0852,0.0055)	0.0830
More than 5 beds	-0.0412 (-0.0917,0.0092)	0.1060
Primary completion rate, total (% of relevant age group)	-0.0018 (-0.003--0.0007)	0.0030
Smoking prevalence, males (% of adults)	0.0002 (-0.0012-0.0016)	0.7470
Income group		
Low income	1.00	
Lower-middle income	-0.0367 (-0.1041-0.0306)	0.2750
Upper-middle-income	-0.0240 (-0.0986-0.0506)	0.5170
High-income	-0.0279 (-0.107-0.0513)	0.4790
Population live per square kilometre of land area		
less than or equal to 50	1.000	
>50 to <=100	-0.053 (-0.0892--0.0168)	0.0050
>100 to <=200	-0.0678 (-0.1071--0.0285)	0.0010
More than 200	-0.0867 (-0.1224--0.0509)	0.0000
Constant	0.3623 (0.2233-0.5014)	0.0000
Sigma	0.0394(0.0305-0.0484)	-
Observations summary	4 left-censored observations 42 uncensored observations 0 right-censored observations	
Number of observation	46	-
Log likelihood	71.4	-
Prob. > chi2	0.000	-

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574 **Figures**

575 Figure 1. Association across health systems input and outcome
576 Figure 2. Results from the sensitivity analysis of efficiency scores

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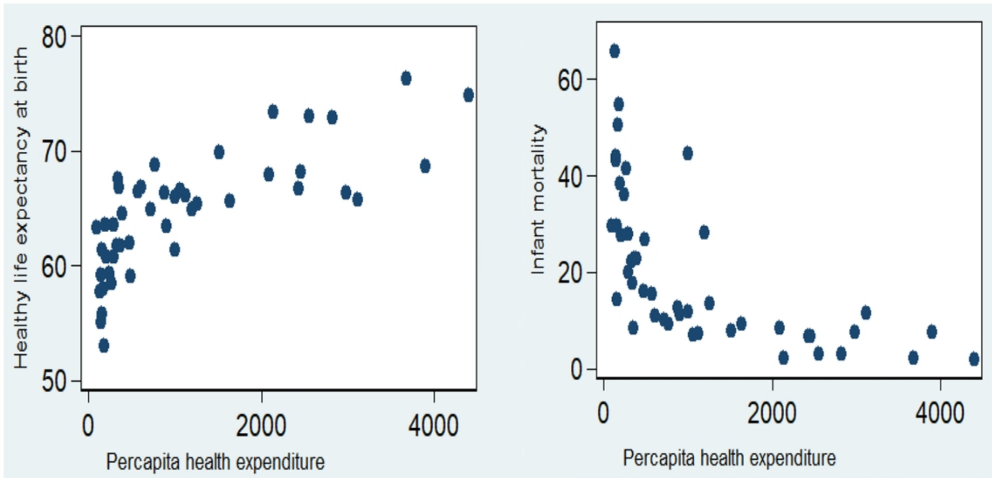


Figure 1. Association across health systems input and outcome

189x91mm (300 x 300 DPI)

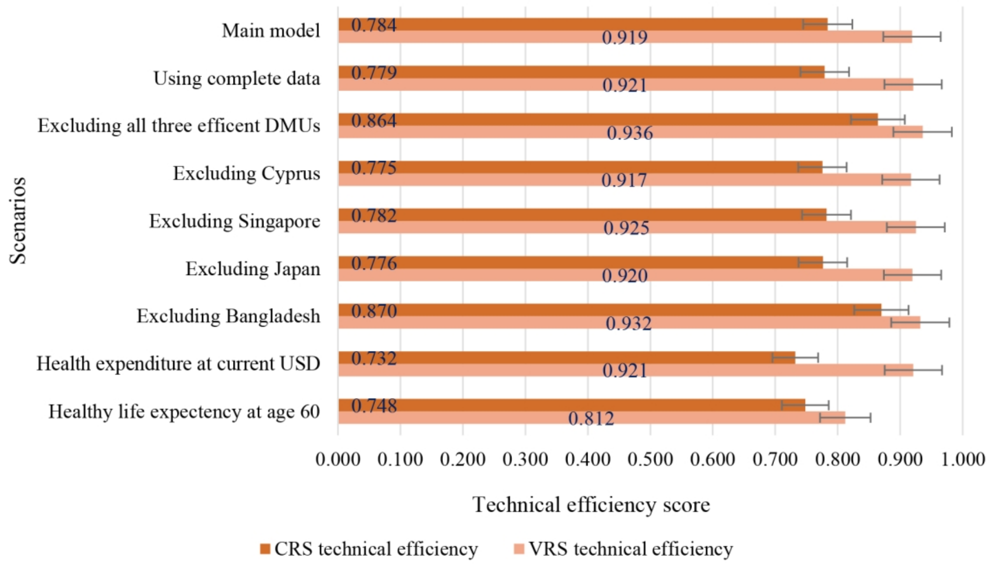


Figure 2. Results from the sensitivity analysis of efficiency scores

155x91mm (300 x 300 DPI)

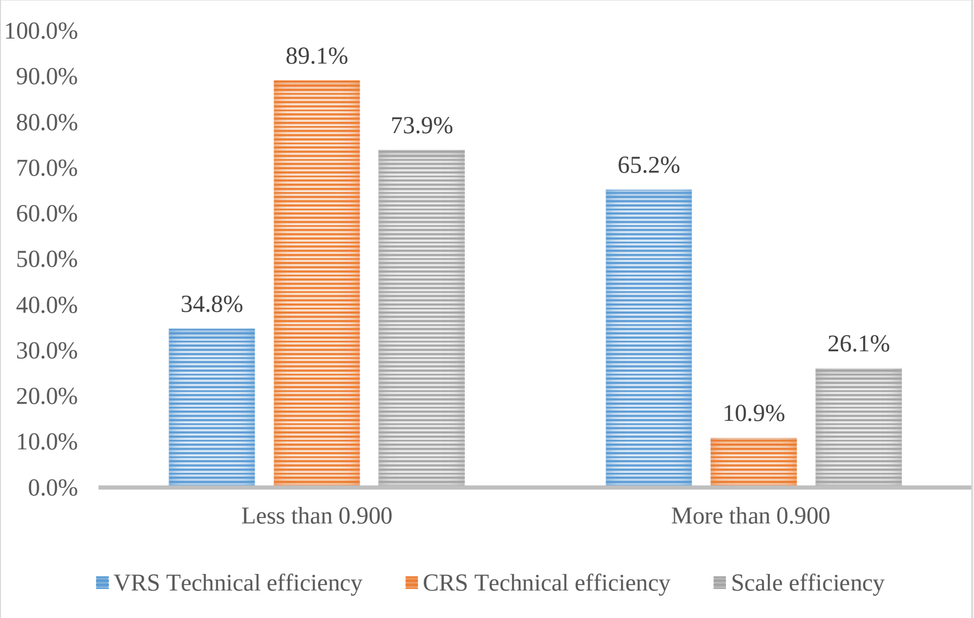
Supplementary Table 1. Correlation among technical efficiency, input, and output variables

Variables	CRS technical efficiency	VRS technical efficiency	Per capita health expenditure	Healthy life expectancy at birth	Infant mortality
CRS technical efficiency	1.000				
VRS technical efficiency	0.739	1.000			
Per capita health expenditure	0.089	0.277	1.000		
Healthy life expectancy	0.343	0.755	0.774	1.000	
Infant mortality	-0.092	-0.485	-0.651	-0.811	1.000

Supplementary Table 2. Result from bootstrap method

Variable	Coefficient	Bootstrap standard error	p-value	95% CI
Physician density (per 1,000 population)				
Fewer than 1 physician	1.000	-	-	-
1-2 physician	0.007	0.014	0.622	(-0.02,0.0346)
More than 2 physician	-0.009	0.018	0.631	(-0.0424,0.026)
Bed density (per 1,000 population)				
Fewer than 1 beds	1.000	-	-	-
> 1 to <=3 beds	0.032	0.016	0.047	(-0.0003,0.0639)
> 3 to <=5 beds	0.052	0.018	0.004	(0.016,0.0851)
More than 5 beds	0.047	0.021	0.024	(0.0058,0.0874)
Primary completion rate, total (% of relevant age group)	0.001	0.000	0.002	(0.0005,0.0022)
Smoking prevalence, males (% of adults)	0.000	0.001	0.735	(-0.0008,0.0012)
Income group				
Low- and lower-middle income	1.000	-	-	-
Upper-middle-income	-0.007	0.014	0.637	(-0.0357,0.0201)
High-income	-0.026	0.017	0.130	(-0.0619,0.0094)
Population live per square meter of land				
less than or equal to 100	1.000	-	-	-
>100 to <=200	0.021	0.014	0.000	(-0.004,0.0493)
More than 200	0.044	0.013	0.000	(0.0173,0.0684)
Constant	0.737	0.046	0.000	(0.6431,0.8262)
Sigma	0.030	0.003	0.000	(0.0197,0.0324)
Number of observation				42
Number of efficient DMUs				4
Number of bootstrap (reps)				1000
Prob. > chi2				0.0000

Supplementary Figure 1. Distribution of the efficiency scores of Asian health systems



STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

		Item No	Recommendation
×	**Title and abstract**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
			(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction			
×	Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
×	Objectives	3	State specific objectives, including any prespecified hypotheses
Methods			
×	Study design	4	Present key elements of study design early in the paper
×	Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
	Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
×	Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
×	Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
	Bias	9	Describe any efforts to address potential sources of bias
×	Study size	10	Explain how the study size was arrived at
×	Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
×	Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
			(*b*) Describe any methods used to examine subgroups and interactions
×			(*c*) Explain how missing data were addressed
			(*d*) If applicable, describe analytical methods taking account of sampling strategy
×			(*e*) Describe any sensitivity analyses
Results			
×	Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
			(b) Give reasons for non-participation at each stage
			(c) Consider use of a flow diagram
×	Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
			(b) Indicate number of participants with missing data for each variable of interest
	Outcome data	15*	Report numbers of outcome events or summary measures
×	Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included

			(*b*) Report category boundaries when continuous variables were categorized
			(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
×	Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
	Discussion		
×	Key results	18	Summarise key results with reference to study objectives
×	Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
×	Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
×	Generalisability	21	Discuss the generalisability (external validity) of the study results
	Other information		
×	Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Measuring the efficiency of health systems in Asia: A data envelopment analysis

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Title. Measuring the efficiency of health systems in Asia: A data envelopment analysis

Short title. Measuring the efficiency of health systems in Asia

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ABSTRACT

Objective: This study aims to estimate the technical efficiency of health systems in Asia.

Settings: The study was conducted in Asian countries.

Methods: We applied an output-oriented data envelopment analysis (DEA) approach to estimate the technical efficiency of the health systems in Asian countries. The DEA model used as input variable per-capita health expenditure (all healthcare resources as a proxy) and as output variables cross-country comparable health outcome indicators (e.g. HALE at birth and infant mortality per 1,000 live births). Censored Tobit regression and smoothed bootstrap models were used to observe the associated factors with the efficiency scores. A sensitivity analysis was performed to assess the consistency of these scores.

Results: The main findings of this paper demonstrate that about 87% of the studied Asian countries were inefficient with respect to using healthcare system resources. Most of the efficient countries belonged to the high-income group (Cyprus, Japan, and Singapore) and only one country belonged to the lower-middle-income group (Bangladesh). In Asia, through efficiency gains, the high-, upper middle-, lower-, and lower- middle-income countries can improve health system outcomes by 6.6%, 8.6%, and 8.7% respectively using the existing level of resources. Population density, bed density, and primary education completion rate significantly influenced the efficiency score.

Conclusion: The results of this analysis show inefficiency of the health systems in most of the Asian countries and imply that many countries may improve their health system efficiency using the current level of resources. The identified inefficient countries could pay attention to benchmarking their health systems within their income group or other similar types of health systems.

Strengths and limitations of this study:

- Data envelopment analysis was used to determine the extent of inefficiency in health systems across Asia.
- We extracted health systems level indicators from the widely used World Bank World Development Indicators database and the World Health Organization Open Data Repository.
- Due to data unavailability, we used health system outcomes in addressing the health systems efficiency rather than true health system output.

BACKGROUND

In Asia, there are approximately 4.4 billion people spread across highly diverse countries, from economic powerhouses like China and Singapore to poorer economies such as Laos, Cambodia, and Myanmar (1). Overall, the continent is often cited as the fastest-growing and most dynamic region in the world. Over the past number of years, Asian societies have also made impressive progress in ensuring better healthcare services, especially those targeted towards improving maternal and infant health and increasing life expectancy (2). However, whether economic gains have translated to efficient health systems across the region is still not well studied.

It is important that the healthcare resources in Asia are used efficiently. In Asia, generally government spending on healthcare is low compared to total health expenditure and it is often not focused on those who need it most (3). For example, in the South Asia region governments spend 31% of total health expenditure, which is about one percent of gross domestic product (GDP) (4,5). In many Asian countries, personal health expenses or out-of-pocket payments are a major cause of poverty (1,6). For instance, from a study of 11 Asian countries, it was found that high levels of out-of-pocket healthcare spending have pushed 78 million people into poverty annually (7). Aging populations and non-communicable diseases that are often preventable but expensive to treat (e.g. diabetes and cancers linked to tobacco) impose and will continue to impose heavy costs on households and public health budgets. Moreover, a major challenge for Asian countries is the control and prevention of different communicable diseases (e.g. HIV/AIDS, tuberculosis, and polio) due to the movement of people across borders and the exchange of goods (8).

In light of this, it is very important that the health systems of these countries are efficient in using their resources. The World Health Organization (WHO) has estimated that about 20% to 40% of total healthcare resources are being wasted per year among the WHO member countries due to inefficiency. Furthermore, this rate is higher in low-and-middle income countries (LMICs) (9). In Asia, the variation in efficiency across income groups, and contexts can perhaps lead to lessons learned in addressing it. In order to address inefficiency, Asia's health systems can look toward different dimensions of performance such as their effectiveness, efficiency, access, equity, and quality (10). A great deal of practitioner and academic literature have analyzed the relationship between the efficient production of health services and universal health coverage as well as the widespread importance of measuring overall health system performance (9,11).

Assessing the efficiency of healthcare systems is a difficult process as analyses often encounter methodological problems, particularly due to the need for appropriate and valid outcome indicators (12). Despite the empirical difficulties in applying efficiency concepts to health systems, efficiency can be measured on both micro and macro levels (13). Measuring health system efficiency at a macro-level is particularly important in order to understand health system performance across the globe and take required action to minimize inefficiency (11,14).

A number of studies have analyzed the healthcare efficiency in the Americas (15,16), Western Europe (17,18) and Asia (19,20) to shed light on the efficiency of different national healthcare systems. A systematic review on measuring efficiency related to several aspects of healthcare performed by Hollingsworth et al. (21). Dimas et al. evaluated the productivity of Greek public hospitals and found that productivity changes were dominated by technical change (22). Additionally, Zere et al. 2005 measured the technical efficiency and productivity of hospitals in South Africa, and examined the impact of hospital characteristics on efficiency and productivity (23).

Several studies have reported on different determinants of health system efficiency. For example, a study conducted in China reported that GDP per capita, proportion of primary health worker, and population density were the key determinants of the efficiency in Chinese health system (24). Another study in the Canadian context reported that re-admission, obesity and smoking, and average income of the population are key determinants of health system efficiency (25).

In an international study of efficiency in 170 Asian and non-Asian countries, it was observed that Asian countries were comparatively in the middle with respect to health system efficiency scores (26). This indicates that there is room for improvement to optimize health benefits from the available health sector resources. In this region, there are a number of studies at the country level to address health systems efficiency (27,28), but cross country comparison of the health system efficiency is limited (29).

Asian countries are not homogenous in terms of area, population, and economic conditions, however, they have public health functions and a number of their health system outcomes in common (30). Many of the countries share similar health systems problems, including and a high burden of diseases due to the geographical contiguity, disease patterns, and social conditions and inadequate resources for healthcare. Understanding health systems efficiency in different Asian countries could promote shared learning and highlight key areas of best practice, as well as areas where improvement is needed. Furthermore, given geographical proximity and many strong relationships experienced with near-by countries, there is likely to be relative ease in the ability to practically understand, learn, and apply nuance about healthcare systems from one country to another.

A study of the efficiency of health systems in this region will help to provide lessons through comparison across countries. This paper aims to achieve this goal through evaluating the technical efficiency and scale efficiency of the healthcare systems of selected Asian countries.

METHODS

This study employed two stages of efficiency analysis using cross sectional data. In the first stage, Data Envelopment Analysis (DEA) was used to estimate the country efficiency scores. In the second stage, a regression analysis and a bootstrap method were employed to identify the factors associated with the health system efficiency. The software package STATA 13 was used for all of the analyses.

Data sources

We used two main data sources: The World Health Organization data repository (31) and World Development Indicators-2015 (WDI). According to the list of United Nation Statistics Division, there are 50 Asian countries and territories. Among these , 46 were used for this study (32). Four countries and territories (Hong Kong, North Korea, Macao, and West bank and Gaza) were excluded due to missing data of selected variables in the WDI database (5). However, selected variables for the study countries were not reported in WDI for every year. This problem is unavoidable in studies based on WDI data (33–35). Earlier studies adapted two approaches to deal with such problem. Firstly, they used a value from a slightly earlier year as in Anderson et al. (33) and secondly, they used a smaller number of countries in the model as in Fare et al. (34) and Grubaugh and Santerre (35). Given the importance of including as many countries as possible to study technical efficiency using Data Envelope Analysis, we opted for the first approach. However, to avoid missing variable we used slightly earlier WDI statistics.

Input and output variables

A main assumption of the DEA model used in our analysis was that in Asian countries, the selected health outcomes are dependent on the inputs of healthcare resources. We selected the input variables as proxies for the quantity of inputs that a country devotes to healthcare (i.e. health expenditure per capita); and outcome variables as the healthy life expectancy at birth (HALE) and infant mortality (per 1,000 live births). The health expenditure per capita was extracted from the Global Health Expenditure database managed by the WHO. In this database there are national health expenditure statistics for more than 190 WHO Member States in line with the new System of Health Accounts 2011 (SHA 2011) framework. The SHA 2011 framework was developed by Organisation for Economic Co-operation and Development (OECD) to rigorously track health expenditure (e.g. by all financial sources, by all services) at the national level and to enable comparability across countries. The capital expenditure (e.g. infrastructure) was included in the total health expenditure estimation (31). The relationship between health expenditure and outcomes considered here is consistent with the view that health expenditure has diminishing returns, or additional expenditure beyond a certain level has relatively smaller incremental effect on life expectancy or infant mortality (36). To be clear, reduction in infant mortality and increase in life expectancy signify improvement in the health outcomes of a country. Some studies have included life expectancy at birth as an outcome variable (37–39), however, it is argued that quality of life matters as much as, if not more than, quantity of life, and therefore life expectancy should be a weighted health quality measure. As a result, HALE has been incorporated as a proxy of health quality as the outcome of health systems. Also, it is important to note that instead of using the infant mortality directly in the DEA model, we used the inverse of infant mortality as the model assumes that inputs and outputs are isotonic (i.e. increased input reduces efficiency as well as increased output increases efficiency) (40). Without this correction, a higher infant mortality figure would have been said to incorrectly contribute to a better health system outcome.

Data envelopment analysis

DEA is a widely used non-parametric method that identifies an efficiency frontier by using linear programming techniques and the distance of each decision-making unit (DMUs) to the frontier. Of the two types of efficiency analysis approach namely DEA and Stochastic Frontier Analysis (SFA) we choose DEA. The key advantage of the DEA approach in this analysis is that it can incorporate multiple inputs and outputs which are measured in different units.

One type of DEA model, developed by Charnes, Cooper, and Rhodes (CCR), assumes that production has constant returns to scale (CRS), meaning any change in the input will result in a proportionate change in the output (41). Another model proposed by Banker, Charnes, and Cooper (BCC), assumes that production has variable returns to scale (VRS) implying an increase in the input will result in either an increase or a decrease in the output. The latter methodology is particularly useful for this study since it aims to measure the efficiency related to organizational units (i.e. the health systems of the different countries), which use numerous resources to produce multiple outputs and accommodate a more flexible assumption of VRS (26,42). This is more realistic and reflective of changes in the real world (27).

We measured scale efficiency to see whether the health systems of Asian countries are operating at their optimal sizes or not (43). The size of health systems is a major political decision in Asian countries. To some extent, it depends on how the policymakers or government are prioritizing health among other competing public services (e.g. education, military, electricity) (44). Scale efficiency scores provide information on the optimality of a DMU size, in this case the health system of a country. When a production unit (DMU) operates at CRS, technical efficiency is equal to scale efficiency. However, when DMUs are not operating at optimum scale, technical efficiency measured with the CCR model may be altered by scale efficiency. The BCC model, which defines production through VRS, can incorporate the impact of scale efficiency in the measurement of technical efficiency. The scale efficiency is measured as the ratio of CRS technical efficiency scores and VRS technical efficiency scores (45).

When it comes to DEA studies comparing countries, both the input- and output-oriented models have been adopted for this type of analysis. An output-oriented DEA model aims to maximize the outputs with a given amount of inputs; while input-oriented models focus on minimizing the inputs used to obtain a certain amount of output. Many studies have been carried out using DEA to assess the efficiency of healthcare systems using the two approaches in both high-income and low-income countries (28,46–48). In this study, an output-oriented DEA model was deemed more appropriate based on the premise that the input per capita expenditure is likely to be less flexible. In other words, health system stewards are likely to have more leverage in controlling outputs through innovative programming and improvements in healthcare provided, rather than by increasing spending and resources.

Output oriented model

The output-oriented technical efficiency model focuses on increasing output without changing the quantity of inputs used. The objective of the model for solving each particular DMU (health system) is to maximize the efficiency score (denoted by ϕ) meaning the amount by which all outputs can be improved for each country's health system under consideration while holding input constant.

The output-oriented DEA model is specified as follows.

$$\text{Max } \phi = \sum O_r Y_{rj_0} + O_0$$

Subject to constraints

$$\sum_{i=1}^{m} V_i + X_{ij_0} = 1$$

$$\sum_{r=1}^{s} O_r + Y_{rj} - \sum V_r X_{ij} + O_0 \leq 0, \quad j = 1,\ldots,n$$

$$O_r, V_i \geq 0$$

$$O_0 > 0, or\ O_0 = 0\ or\ O_0 < 0$$

Where,

Y_{rj} = amount of output r from country j,

X_{ij} = amount of input i to country j,

O_r = weight given to output r,

V_i = weight given to input i,
n = number of countries,
s = number of outputs,
m = number of inputs.

$O_0 > 0$ defines increasing returns to scale, $O_0 = 0$ defines constant returns to scale, and $O_0 < 0$ defines decreasing returns to scale.

The technical efficiency scores is defined by ϕ and it ranges between 0.00 and 1.00, If it is equal to 1.00, then the production from the DMU is efficient; while if it is less than 1.00, the DMU is inefficient.

Explaining efficiency through regression analysis

One of the limitation of the DEA approach is the serial correlation of the efficiency scores generated through this approach. In other words, the correlation between inputs and outputs, and consequently with the estimated efficiency scores resulted in this serial correlation. Thus, the scores of one DMU is not independent on that of the other DMUs. To handle this limitation, scholars such as Ramalho et al. 2010 (49) and McDonald 2009 (50) have argued that econometric models like probit, logit, and truncated regression (Tobit) can be used for second- stage analysis for identifying impact of environmental variables on efficiency. However, scholars such as Simar and Wilson 2007 have argued that the conventional statistical inferences are inappropriate in the second-stage regression due to the bias of the DEA score and recommend using bootstrap methods (51). Afonso and Aubyn 2011 (52) show in their empirical study that the censored normal Tobit regression and bootstrap algorithms yield very similar results. However, we have adopted both the Tobit model and smoothed bootstrap model in explaining the association with health system efficiency to be comprehensive.

The VRS efficiency scores computed using the DEA model were regressed against a few health service productions (e.g. physician and beds density per 1000 population) and some environmental factors (Table 1). Since, by definition, the DEA scores range between zero and one, and some of the data tend to concentrate on these boundary values (i.e. censored for the DMUs with a value at one), ordinary least squares cannot estimate the regression. Therefore, a Tobit model is suitable for such regression. For the convenience of calculation, we assumed a censoring point at zero in this model. As a result, the efficient DMUs will have a score of zero and the inefficient DMUs will have score greater than zero. Following Zere at et. (53), we applied this method by transforming VRS technical efficiency scores into VRS inefficiency scores and leaving censoring at zero as follows.

$$Inefficiency\ score\ =\ (\frac{1}{VRS\ technical\ efficiency\ score})\ -\ 1$$

The Tobit regression model used variables representing access to healthcare and health status. Guided by several similar studies, physician density (the number of physicians per 1,000 population) and bed density (the number of inpatient beds per 1,000 population) were selected as determinants of access to healthcare (35,54). In addition to health care, the health status of individuals is determined by the lifestyle and behaviors, therefore we also included two environmental factors as determinants of efficiency, namely smoking prevalence among adult male (percentage of adults) and primary education completion rate of relevant age group. The relevant age group for the primary completion rate is defined as the number of new entrants (enrolments minus repeaters) in the last grade of primary education (regardless of age); divided by the population at the entrance age for the last grade of primary education of a country (55). The adverse health effect of smoking consequently affects health outcomes and also the health system efficiency (25,52,56). Education is found to be an important factor in determining individual health status. Higher educational attainment is associated with higher income which in turn secures a healthy living environment and access to healthcare (57). Additionally, we included population density (population living per square kilometre of land area) as the control of efficiency. This is because population density can affect the quality of healthcare services.

The Tobit regression models were specified as follows,

$$Ineff_i = \beta_0 + \beta_1\ Phy_i + \beta_2\ Beds_i + \beta_3\ \ Primay\_edu_i + \beta_4\ Smoking_i + \beta_5\ Inc_i + \beta_5\ Pop\_density_i + \varepsilon_i$$

Where,

Ineff = the technical inefficiency score; continues variable.

Phy = Physician density; categorical variable (1= Fewer than 1 physician; 2= 1-2 physician, 3= More than 2 physician)

Beds =Beds density; categorical variable (1= Fewer than 1 beds 3= More than 1 and less than or equal to 3 beds, 3= More than 3 and less or equal to 5 beds, 4= More than 5 beds)

Inc= Income group of the country; categorical variable (1=Low income, 2=Lower-middle income, 3=Upper-middle-income, 4=High-income)

Pop_density= Population density; categorical variable (1= Fewer than or equal to 50, 2= More than 50 to fewer than or equal to 100, 3= More than 100 to fewer than or equal 200, 4= More than 200)

Finally, ε_i was the stochastic error term.

We submitted the initial DEA scores in a smoothed bootstrap method design by Simar and Wilson (51) to estimate the robust efficiency score from the bootstrapped regression analysis to identify factors associated with these scores. The simarwilson command in STATA 13 was applied in the analysis using externally estimated DEA scores (algorithm #1) (58).

Sensitivity analysis

The efficiency scores can be affected by the number of inputs and outputs used in DEA in relation with the number of DMUs. The scores can be overestimated if the number of DMUs is relatively small compared to the number of inputs, or very large compared to the number of inputs and outputs (59,60). It is suggested that the number of DMUs should be at least three times of the inputs and outputs variables (61,62). In our model, the number of DMUs (46) is more than three times of the number of inputs and outputs (9) and this is not a binding constraint for this study.

There is the possibility that choosing different variables in the DEA model may produce inconsistent results such as inconsistent efficiency estimate. There is no test to assess the suitability of a particular model specification in DEA (63). Therefore, we carried out a sensitivity analysis of the efficiency scores by running the DEA model several times using different combinations of input and outcome variables. Different specifications of the DEA models were considered (e.g. dropping the efficient countries, using HALE at age 60, current health expenditure per capita (current US$) as inputs and using the complete set of data for the year 2015 (excluding countries with any missing variable) for testing the sensitivity of our main model.

Patient and Public Involvement

The study used secondary data from WHO and WDI databases. No patients were involved in this study. Study findings will be shared with the stakeholders, including local community groups in community meetings and at national or regional conferences.

RESULTS

The descriptive statistics of the selected input, outcome, and environmental variables are shown in Table 1. The health expenditure per-capita ranges from a minimum of 88.03 USD (Bangladesh) to a maximum of 4,405.13 USD (Japan) with a mean, median, and standard deviation of 1,133.71, 663.94, and 1,157.72 respectively. The number of physicians per 1,000 people ranges from a minimum of 0.1 at Timor-Leste to maximum 4.8 at Georgia. However, the number of inpatient beds per 1,000 people is the smallest in Iran (0.1) and the highest in Japan (13.7). The average smoking prevalence of the adult male people among the studied countries is 42.2 and average primary education completion rate is 96.5% of the relevant age group.

Table 1. Descriptive statistics of input and output variables

Characteristics/ description	Mean	Median	SD*	Minimum	Maximum	Source
Input variable						
Health expenditure per capita, PPP	1,133.71	663.94	1,157.72	88.03	4,405.13	WDI
Outcome variables						
Healthy life expectancy at birth (years)	64.29	65.2	5.1	53.2	75.9	WHO
Infant mortality (per 1,000 live births)	19.9	13.9	15.8	2.0	65.7	WDI
Explanatory variables for Tobit model						
Physicians (per 1,000 people)	1.6	1.6	1.1	0.1	4.8	WDI
Hospital beds (per 1,000 people)	2.9	2.1	2.7	0.1	13.7	WDI
Smoking prevalence, males (% of adults)	42.2	42.2	10.5	18.9	71.8	WDI
Primary completion rate, total (% of relevant age group)	96.5	97.9	11.4	66.7	116.5	WDI

*Standard deviation

Among the countries analyzed, HALE at birth was a minimum of 53.2 years in Afghanistan and a maximum of 75.9 years in Singapore. The infant mortality rate ranged from 2.1 deaths per 1,000 live births in Japan to 68.1 deaths per 1,000 live births in Afghanistan. On average, there were 21.1 deaths per 1,000 live births in the studied countries. The scatter matrix of the input and output variables shows that inputs, for instance, increase in per-capita healthcare expenditure was associated with improved health outcomes (e.g. HALE at birth and reduced infant mortality) (Figure 1).

(Figure 1. will be inserted here)

The mean CRS and VRS technical efficiency scores were 0.780 and 0.921 respectively (Table 2). Whereas, the mean scale efficiency score was 0.874. Considering VRS efficiency, Afghanistan has the lowest score of 0.812. Both VRS and CRS technical efficiency score were positively correlated with per capita health expenditure, HALE at birth, and negatively correlated with infant mortality (supplementary table 1).

Out of 46 countries studied, only 4 (8.7%) countries showed the maximum level of (efficiency score 1.00) in VRS and CRS technical efficiency scale. All of these four countries showed scale efficiency of 1.00 implying that these countries created the best practice frontier based on their input and output combinations. 39.1% (18) countries showed increasing returns to scale, 52.2% (24) countries decreasing returns to scale, and the 4 efficient countires constant returns to scale production function of their health systems.

(Table 2. will be inserted here)

More than half of the countries (30 countries) had VRS efficiency and five countries CRS efficiency greater than 90% (supplementary figure 1).

Result from Tobit regression and bootstrap analysis for associated factors with the inefficiency

Tobit regression and smoothed bootstrap were used to relate VRS efficiency scores to two health service production variables and four environmental variables in two separate models (Table 3). Negative associations with the inefficiency scores in the Tobit model represent positive relation of health system efficiency with the explanatory variables. On the other hand, positive associations with the explanatory variables in the smoothed bootstrap model represent positive relations of the health system efficiency with the explanatory variables.

(Table 3. will be inserted here)

Physician density, income status of countries, and smoking prevalence among males exhibited statistically insignificant associations with the health system efficiency in the both models. The density of bed (>3 and <=5) had a significantly negative association with the inefficiency scores (i.e. positive association with the efficiency) compared to less than 1 bed density category. Countries having more than 1 and less than or equal to 3 beds density had no significant association with the inefficiency scores. However, after the bootstrapping, this category become significant and the significance level increased for the rest two categories (i.e. more than 3 and less than or equal to 5 bed density and more than 5 bed density). The association of beds density in the both models indicates that sample countries with less than 1 bed density have lower technical efficiency of its health systems. Furthermore, the primary education completion rate was significantly negatively associated with the inefficiency score in the Tobit model which indicates that countries with higher percentage of primary education completion rate have higher health system efficiency. Similar association was observed in the bootstrap model. In case of population density, we found in the both models that countries having more than 200 population per square kilometre were more efficient in their health system efficiency compared to the countries with less than or equal to 100 population per square kilometre.

Sensitivity of the efficiency scores

We conducted sensitivity analysis using various combinations of input and output variables. In all of these cases the average of the efficiency scores varied from 0.812 to 0.936. The most sensitive combination was found while using the HALE at age 60 as the outcome variable. The efficiency score changed from 0.919 (main model) to 0.812 (considering input as HALE at age 60) (Figure 2).

(Figure 2. will be inserted here)

In Table 4, mean efficiency scores are presented by the income categories of the countries. The highest mean VRS technical efficiency were observed for high income countries (0.934; 95% CI 0.905-0.963), followed by upper-middle-income (0.914; 95% CI: 0.894-0.935), and low and lower-middle income countries (0.913; 955% CI: 0.891-0.935). If all the health systems operated at maximum efficiency at their given input level, the high-, upper middle-, low- and lower-middle income countries could improve their health system outcome (e.g. HALE at birth and reduce infant mortality) by 6.6%, 8.7%, and 8.7% respectively.

DISCUSSION

The main findings of this paper demonstrated that about (86.9 %) of the studied Asian countries are technically inefficient with respect to using healthcare systems resources, (using a proxy of per capita health expenditure). The study findings showed that the most efficient countries belonged to the high-income group (Cyprus, Japan, and Singapore). Only one country belonged to the low- and lower middle income group (Bangladesh). Among the 46 countries studied, only four countries (Bangladesh, Japan, Singapore, and Cyprus) showed constant returns to scale efficiency, indicating that they were operating at their most efficient level. Of the 14 high-income countries studied, 9 countries (75.0%) had health system production at decreasing returns to scale. This implies that although the highest number of efficient countries belonged to the high-income group, a large number of these countries health system production had more resources than the ideal situation. A similar situation was observed for the upper-middle-income countries. Of the 13 countries, 10 (76.9%) had decreasing returns to scale. Only 5 (23.8%) out of 21 low – and lower-middle-income countries were producing at decreasing returns to scale. Although these low- and lower-middle-income countries are not efficient, most of their production follows increasing returns to scale.

It was observed that the average of the efficiency scores increased from the low and lower-middle-income countries to high-income countries. An important policy implication of this study could be that the technically inefficient low-income countries on average can improve their health systems outcome by 8.7%, middle income country by 8.6%, and high income country by 6.6% using the existing levels of per-capita health expenditure. An international study found a similar conclusion that health systems performance is most efficient in the developed countries, according to simple efficiency scores (64).

The overall healthcare efficiency in different countries varied considerably (65,66). Among the low- and lower-middle income studied, one country demonstrated the most efficient health systems (Bangladesh). This county has both technical and scale efficient health systems, like the high-income countries (Japan, Singapore, and Cyprus) (67). A possible reason for the high efficiency of these LMICs could be a focus on infant mortality and child health as prioritized in past Millennium Development Goals and in current Sustainable Development Goals agendas, which relates to the outcome variables used in this study.

The DEA result showed that more than 60% of the low- and lower middle income countries had health system efficiency greater than 90%. This result implies that these countries produce good health at low cost and therefore make good use of health systems resources (68). This result suggests that it is possible for countries to have a high-efficiency score with poor health outcomes because of their low expenditure on resources and increasing returns to scale production function. In other words, given their moderate consumption of inputs and challenging social environments, these countries can achieve good health outcomes, relative to the other countries. Similar findings were observed for Mexico and Turkey relative to other countries in a study of the OECD countries (39). It should be noted that this study only used per-capita health expenditure and there are other factors that influence health outcomes as well. For example differences in life expectancy and infant mortality between populations can be due to lifestyles, preferences (56,69,70) social class, occupation (71) and environmental factors (72,73). On a more macroscopic level, the results could also be impacted by a variety of contextual factors among countries such as different political institutions, economic landscapes, health-seeking behavour patterns and burden of diseases among other things. However, in this study, we attempted to address by including variables addressing the number of physicians, number of inpatient beds, and population density, along with two environmental factors namely primary completion rate of relevant age group and smoking prevalence among the adult male population to take into consideration some of this variation. The results showed that more than three and less than five beds per 1000 population significantly influenced the efficiency score. A low number of beds cannot serve a large proportion of the population and therefore the systems may be inefficient. Similarly, a high number of beds may often be left unused and make the health systems inefficient. The countries having more than 200 people living per square kilometre had a higher level of efficiency in their health systems.

A limitation of DEA methodology is that it works in a deterministic way, meaning that the results entirely depend on the numeric values in the dataset. As the DEA approach compares DMUs, the number and nature of DMUs in the data set can noticeably change the results. For example, if a more efficient country is added to the dataset, it would move the frontier, causing some of the efficiency scores of other countries to fall. This is a key aspect of the methodology used.

Additionally, it is important to note that the use of a different set of variables might have generated different conclusions. In the future, if additional data become available for a larger number of countries in the region, the number of variables analyzed could be increased to include an understanding with a greater degree of complexity in health system efficiency.

Another data limitation is the comparability of health expenditures among the Asian countries. While recognizing that it is not possible to solve the inherent issues, we made an attempt to minimize it. Since the actual amount of healthcare expenditure across different countries may not be comparable due to the difference in purchasing power parity across countries, we used health expenditures as constant of 2011 in PPP as an input in the DEA model (39). Also, when we included health expenditure at current USD per capita as an input in the DEA model we found that the efficiency score did not change significantly.

We applied sensitivity analysis in an attempt to overcome these limitations (Figure 2.) Our results were consistent while using several combinations of inputs and outputs variables which is reassuring and strengthens the findings from this study.

CONCLUSIONS

This study provides an empirical picture of the technical efficiency of the healthcare systems of 46 Asian countries. It found that inefficiency exists in the healthcare systems of most of the countries studied, however, the results point to three high-income and one lower-middle-income country which efficiently used healthcare systems resources. The interpretation of the inefficient countries identified through this study is that they can improve health outcomes using the current level of per-capita health expenditure. These countries could use these results to direct their attention to benchmarking their health systems within their regional or another comparative group in order to understand their health system performance in a more detailed way. This study addresses the need to understand efficiency issues, as well as potentially identify good examples of countries which efficiently allocate and use resources to make their healthcare systems more technically efficient. It narrows a gap in the literature as there are few countries studying healthcare efficiency in Asia and looking comparatively in this manner.

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Contributors

SA, MZH and MM contributed to conceptualizing the research idea, study design, literature search, data extraction and analysis, data interpretation, and writing the manuscript. MWA FD, SMH, MMH, MTI and JAMK contributed to writing, reviewing and revising the manuscript. All authors read and approved the final manuscript.

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Competing interest

None declared**.**

Data sharing statement

Data were extracted from the World Bank Open Data repository for the "World Development Indicators' and from World Health Organization Global Health Observatory data. The following links was used to extract the excel format of the indicators: https://data.worldbank.org/ and http://www.who.int/gho/en/.

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Tables

Table 2. Technical and scale efficiency scores of the health systems in Asian countries

Country name	CRS Technical efficiency	VRS Technical efficiency	Scale efficiency	Returns to scale
Afghanistan	0.724	0.812	0.891	1
Armenia	0.769	0.946	0.813	-1
Azerbaijan	0.660	0.902	0.732	-1
Bahrain	0.714	0.910	0.784	-1
Bangladesh	1.000	1.000	1.000	0
Bhutan	0.775	0.903	0.858	1
Brunei Darussalam	0.708	0.920	0.769	-1
Cambodia	0.805	0.916	0.879	1
China	0.806	0.975	0.826	-1
Cyprus	1.000	1.000	1.000	1
Georgia	0.751	0.923	0.813	-1
India	0.778	0.892	0.872	1
Indonesia	0.746	0.904	0.826	1
Iran	0.678	0.900	0.754	-1
Iraq	0.683	0.850	0.803	1
Israel	0.874	0.967	0.904	-1
Japan	1.000	1.000	1.000	0
Jordan	0.743	0.943	0.789	-1

Kazakhstan	0.695	0.882	0.788	1
South Korea	0.886	0.972	0.911	-1
Kuwait	0.674	0.885	0.762	-1
Kyrgyz Republic	0.806	0.941	0.856	1
Laos	0.818	0.889	0.920	1
Lebanon	0.746	0.910	0.820	1
Malaysia	0.778	0.927	0.839	1
Maldives	0.730	0.944	0.773	-1
Mongolia	0.737	0.896	0.823	1
Myanmar	0.743	0.872	0.852	1
Nepal	0.861	0.932	0.924	1
Oman	0.692	0.896	0.772	-1
Pakistan	0.827	0.889	0.930	1
Philippines	0.779	0.916	0.850	1
Qatar	0.677	0.903	0.749	-1
Saudi Arabia	0.624	0.871	0.716	-1
Singapore	1.000	1.000	1.000	0
Sri Lanka	0.904	0.985	0.917	-1
Syria	0.818	0.848	0.964	1
Tajikistan	0.856	0.964	0.888	-1
Thailand	0.791	0.956	0.828	-1
Timor-Leste	0.823	0.903	0.912	1
Turkey	0.710	0.916	0.776	-1
Turkmenistan	0.639	0.859	0.743	1
United Arab Emirates	0.691	0.889	0.777	1
Uzbekistan	0.784	0.947	0.828	-1
Vietnam	0.845	0.996	0.849	-1
Yemen	0.727	0.826	0.881	1
Mean (95% CI)	**0.780 (0.752-0.808)**	**0.919 (0.905-0.933)**	**0.847 (0.824-0.87)**	-
Median	0.772	0.913	0.834	-
Minimum	0.624	0.812	0.716	-
Maximum	1	1	1	-

650

651 Table 3. Result from Tobit regression and smooth bootstrap analysis

	Tobit regression		Bootstrap analysis	
Variable	**Co-efficient (95% CI)**	**P-value**	**Co-efficient (95% CI)**	**P-value**
Physician density (per 1,000 population)				
1-2 physician (Ref=Fewer than 1 physician)	-0.0041 (-0.0437,0.0355)	0.8360	0.0069 (-0.02,0.0346)	0.6220
More than 2 physician (Ref=Fewer than 1 physician)	0.0001 (-0.0495,0.0495)	0.9990	-0.0086 (-0.0424,0.026)	0.6310
Bed density (per 1,000 population)				
More than 1 and less than or equal to 3 beds (Ref= Fewer than 1 beds)	-0.025 (-0.0698,0.0198)	0.2660	0.032 (-0.0003,0.0639)	0.0470
More than 3 and less or equal to 5 beds (Ref= Fewer than 1 beds)	-0.0469 (-0.0964,0.0026)	0.0620	0.0519 (0.016,0.0851)	0.0040

More than 5 beds (Ref= Fewer than 1 beds)	-0.0524 (-0.1079,0.0032)	0.0640	0.0467 (0.0058,0.0874)	0.0240
Primary completion rate, total (% of relevant age group)	-0.0015 (-0.0028--0.0002)	0.0260	0.0013 (0.0005,0.0022)	0.0020
Smoking prevalence, males (% of adults)	0.0000 (-0.0015-0.0016)	0.9930	0.0002 (-0.0008,0.0012)	0.7350
Income group				
Upper-middle-income (Ref=Low and Lower middle income)	0.0088 (-0.0296-0.0472)	0.6450	-0.0067 (-0.0357,0.0201)	0.6370
High-income (Ref=Low and Lower middle income)	0.0087 (-0.0403-0.0577)	0.7200	-0.0264 (-0.0619,0.0094)	0.1300
Population live per square meter of land				
>100 to <=200 (Ref=less than or equal to 100)	-0.0385 (-0.0775-0.0005)	0.0010	0.0212 (-0.004,0.0493)	0.1150
More than 200 (Ref=less than or equal to 100)	-0.0654 (-0.1009--0.0299)	0.0000	0.0435 (0.0173,0.0684)	0.0010
Constant	0.2859 (0.1534-0.4185)	0.0000	0.7368 (0.6431,0.8262)	0.0000
Sigma	0.0444 (0.0343-0.0545)	-	0.0304 (0.0197,0.0324)	-
Observations summary	Considering inefficiency <=0. left-censored (4) Uncensored (42) right-censored (0)			
Number of observation	46		42	
Log likelihood/number of efficient DMUs	66.5		4	
degrees of freedom/Number of bootstrap reps	11		1000	
Prob. > chi2	0.000		0.000	

Table 4. Mean efficiency scores according to income level of Asian countries

Income groups	**VRS technical efficiency**		**Percentage of output can be improved in VRS technical efficiency**
	Mean	**95% CI**	
Low- and lower middle-income	0.913	(0.891-0.935)	8.7%
Upper middle-income	0.914	(0.894-0.935)	8.6%
High -income	0.934	(0.905-0.963)	6.6%

Figures

Figure 1. Association across health systems input and outcome
Figure 2. Results from the sensitivity analysis of efficiency scores

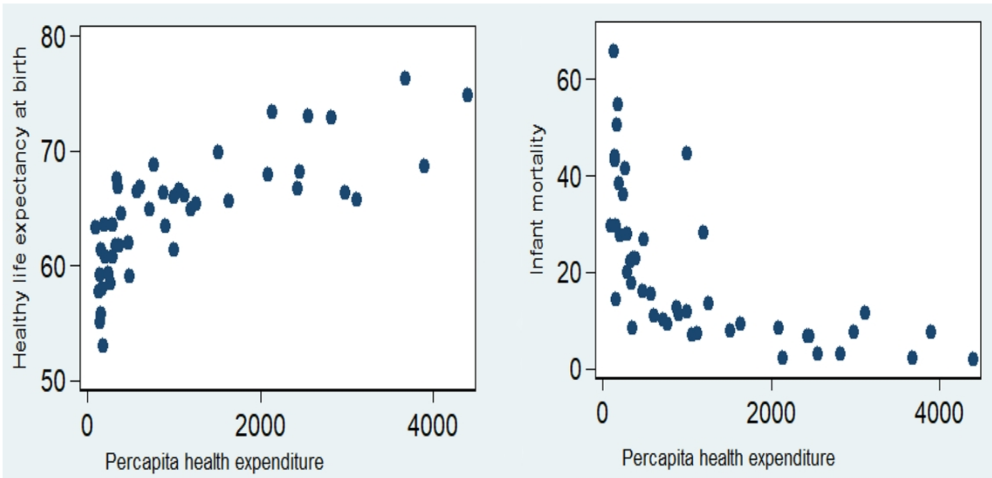


Figure 1. Association across health systems input and outcome

189x91mm (300 x 300 DPI)

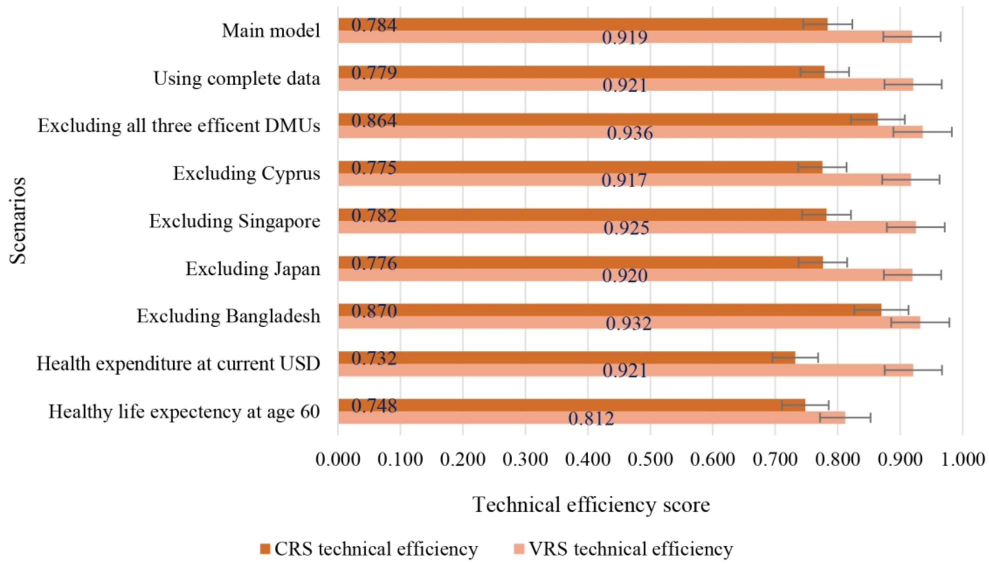


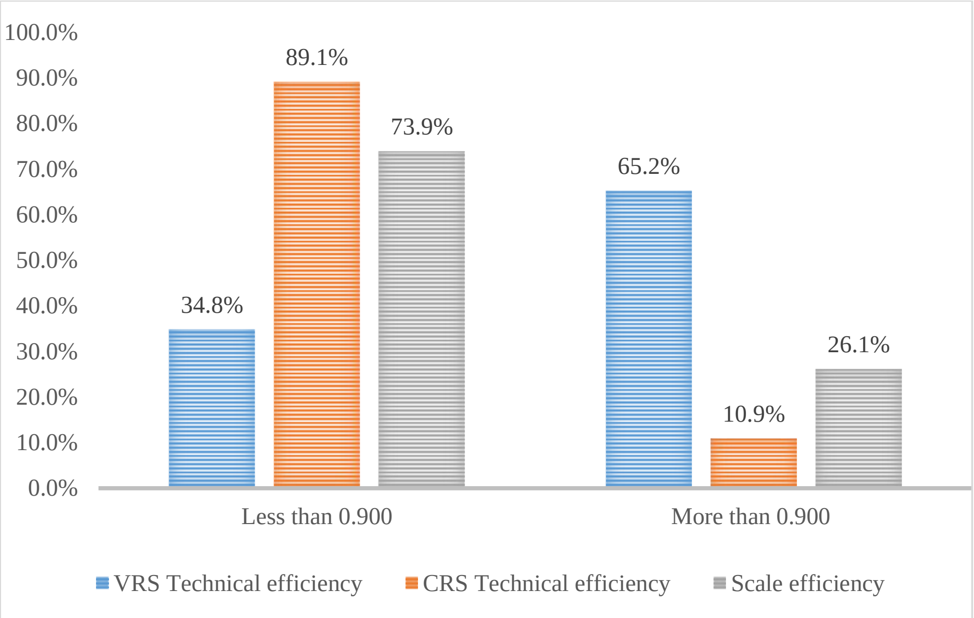
Figure 2. Results from the sensitivity analysis of efficiency scores

155x91mm (300 x 300 DPI)

Supplementary Table 1. Correlation among technical efficiency, input, and output variables

Variables	CRS technical efficiency	VRS technical efficiency	Per capita health expenditure	Healthy life expectancy at birth	Infant mortality
CRS technical efficiency	1.000				
VRS technical efficiency	0.739	1.000			
Per capita health expenditure	0.089	0.277	1.000		
Healthy life expectancy	0.343	0.755	0.774	1.000	
Infant mortality	-0.092	-0.485	-0.651	-0.811	1.000

Supplementary Figure 1. Distribution of the efficiency scores of Asian health systems



STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Page no	Item No	Recommendation
Title and abstract	0	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
	1		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction			
Background/rationale	2	2	Explain the scientific background and rationale for the investigation being reported
Objectives	4	3	State specific objectives, including any prespecified hypotheses
Methods			
Study design	4	4	Present key elements of study design early in the paper
Setting	4	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	"n/a"	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants
Variables	5	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	5	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	"n/a"	9	Describe any efforts to address potential sources of bias
Study size	"n/a"	10	Explain how the study size was arrived at
Quantitative variables	"6"	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	6	12	(*a*) Describe all statistical methods, including those used to control for confounding
	8		(*b*) Describe any methods used to examine subgroups and interactions
	4		(*c*) Explain how missing data were addressed
	"na"		(*d*) If applicable, describe analytical methods taking account of sampling strategy
	10		(*e*) Describe any sensitivity analyses
Results			
Participants	"na"	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
	"na"		(b) Give reasons for non-participation at each stage
	"na"		(c) Consider use of a flow diagram
Descriptive data	11	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
	4		(b) Indicate number of participants with missing data for each variable of interest
Outcome data	"na"	15*	Report numbers of outcome events or summary measures
Main results	12	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included

	13		(*b*) Report category boundaries when continuous variables were categorized
	"n/a"		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	13	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
	Discussion		
Key results	14	18	Summarise key results with reference to study objectives
Limitations	16	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	14,15	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	15	21	Discuss the generalisability (external validity) of the study results
	Other information		
Funding	18	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.