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

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7

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52 systems.
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26 ABSTRACT

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

31 **Settings:** The study was conducted based on Asian countries.

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

38 **Results:** The main findings of the study demonstrate that more than half of the sampled countries
39 (57%) in the Asia region are technically inefficient with respect to using their healthcare systems
40 inputs, based on the efficiency frontier generated from the countries studied. We found three high
41 income-countries (Japan, Singapore, and Oman) and eight lower-middle-income countries (Sri Lanka,
42 Pakistan, Timor-Leste, Cambodia, India, Syria, Yemen and Bangladesh) were efficiently using their
43 healthcare resources. In Asia, through efficiency gain, the high-, upper middle-, lower middle-, and
44 low-income countries can improve output indicators of health systems by 2%, 5%, 2% and 7%
45 respectively using the same amount of inputs.

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

50 **Strengths and limitations of this study:**

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

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

58 **BACKGROUND**

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

66 It is important that the healthcare resources in Asia are used efficiently. Overall, government spending
67 on healthcare is low compared to total health expenditure and furthermore it is often not focused on
68 those who need it most. For example, in the South Asia region governments spend 31% of total health
69 expenditure, which is more than one percent of gross domestic product (3,4). For many countries in
70 the Asia region, personal health expenses or out-of-pocket payments are a major cause of poverty
71 (1,5). From a study of 11 Asian countries, it was found that high levels of out-of-pocket healthcare
72 spending have pushed 78 million people into poverty annually (6). Aging populations and non-
73 communicable diseases that are often preventable but expensive to treat (e.g. diabetes and cancers
74 linked to tobacco) impose and will continue to impose heavy costs on households and public health
75 budgets. Moreover, a major challenge for Asian countries is the control and prevention of different
76 communicable diseases (e.g. HIV/AIDS, tuberculosis, and polio) due to the movement of people
77 across borders and the exchange of goods (7).

78 The World Health Organization (WHO) has estimated that about 20% to 40% of total healthcare
79 resources are being wasted per year among the WHO member countries due to inefficiency. Further,
80 this rate is higher in low-and-middle income countries (LMICs) (8). In Asia, the variation in

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3 81 efficiency across income settings can perhaps lead to lessons learned in addressing it. In order to
4
5 82 address inefficiency, Asia's health systems can look toward different dimensions of performance such
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7 83 as their effectiveness, efficiency, access, equity, and quality(9). A great deal of practitioner and
8
9 84 academic literature has analyzed the relationship between the efficient production of health services
10
11 85 and universal health coverage (UHC) as well as the widespread importance of measuring overall
12
13 86 health system performance (8,10).

14
15 87 Assessing the efficiency of healthcare systems is a difficult process as analyses often encounter
16
17 88 methodological problems, particularly due to the need for appropriate and valid outcome indicators
18
19 89 (11). Despite the empirical difficulties in applying efficiency concepts to health systems, inefficiency
20
21 90 can be measured on both micro and macro level (12). Measuring health system efficiency at a macro-
22
23 91 level is particularly important in order to understand health system performance across the globe and
24
25 92 take required action (10,13).

26
27 93 In an international study of efficiency in 170 countries, it was observed that Asian countries were
28
29 94 comparatively in the middle with respect to health system efficiency scores (14). Although this is
30
31 95 perhaps encouraging, a few studies have analyzed health systems efficiency across Asian countries
32
33 96 specifically (15). Asian countries are not homogenous in terms of area, population, and economic
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35 97 conditions, however, they have public health functions and a number of their health system outcomes
36
37 98 in common (16). Many of the countries share similar health systems problems, including inadequate
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39 99 resources for healthcare and a high burden of diseases due to the geographical contiguity, disease
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41 100 patterns, and social conditions. Understanding health systems efficiency in different Asian countries
42
43 101 could promote shared learning and highlight key areas of best practice, as well as areas where
44
45 102 improvement is needed.

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47 103 This paper evaluates the technical efficiency of the healthcare systems of selected Asian countries
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49 104 using data from the World Development Indicators.

50 105 **METHODS**

51
52 106 Data envelopment analysis (DEA) was used for estimating technical and scale efficiency of the health
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54 107 systems of Asian countries.
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108 Input and output variables

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

127 Data

128 According to the list of United Nation Statistics Division, there are 50 Asian countries and territories.
129 Among these , 46 were used for this study (27). Four countries and territories (Hong Kong, North
130 Korea, Macao, and West bank and Gaza) were excluded due to missing data of selected variables in
131 the WDI database (4). However, selected variables for the study countries were not reported in WDI
132 for every year. This problem is unavoidable in studies based on WDI data (17,28,29). Earlier studies
133 adapted two approaches to deal with such problem. Firstly, used a value from a slightly earlier year as
134 in Anderson et al. (28) and secondly, used a smaller number of countries in the model as in Fare et
135 al.(29) and Grubaugh and Santerre (17). Given the importance of including as many countries as

1
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3 136 possible to study technical efficiency using data envelope analysis, we opted for the first approach.
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5 137 We captured most of the variables from the World Development Indicators-2014 (WDI). However, to
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7 138 avoid missing variable we used slightly earlier WDI statistics. Gathering data from a single source
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9 139 ensures the accuracy and comparability of the data which are important requirements for DEA
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11 140 models.

13 141 **Data envelopment analysis**

14 142 DEA is one of the most widely used methods to assess the technical efficiency and scale efficiency of
15
16 143 a set of decision-making units (DMUs) (In the case of this analysis, DMUs are the 46 different Asian
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18 144 countries). DEA is a non-parametric method which identifies an efficiency frontier on which only the
19
20 145 efficient DMUs are placed, by using linear programming techniques. One type of DEA model,
21
22 146 developed by Charnes, Cooper, and Rhodes (CCR), assumes that production has constant returns to
23
24 147 scale (CRS) meaning any change in the input will result in a proportionate change in the output (30).
25
26 148 Another model proposed by Banker, Charnes, and Cooper (BCC), assumes that production has
27
28 149 variable returns to scale (VRS) implying an increase in the input will result in either an increase or a
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30 150 decrease in the output. The latter methodology is particularly useful for this study since it aims to
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32 151 measure the efficiency related to organizational units (i.e. the health systems of the different
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34 152 countries), which use numerous resources to produce multiple outputs and accommodate a more
35
36 153 flexible assumption of VRS (14,31). This is more realistic and reflective of changes in the real world
37
38 154 (32).

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41 155 Scale efficiency scores provide information on the optimality of the DMUs size. If a healthcare
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43 156 system is scale efficient any modifications to its size will result in less efficient production. Scale
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45 157 efficiency is measured as the ratio of CRS technical efficiency scores and VRS technical efficiency
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47 158 scores (33).

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49 159 When it comes to DEA studies comparing countries, both the input and output oriented models have
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51 160 been adopted for this type of analysis. An output-oriented DEA model aims to maximize the outputs
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53 161 obtained by the DMUs, while keeping the inputs constant. The input-oriented models focus on
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55 162 minimizing the inputs used for processing given amounts of outputs. Several studies have been carried
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163 out using DEA to assess the efficiency of healthcare systems using different methods in both high-
 164 income and low-income countries (34–37).

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

167 **Output oriented model**

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

172 The output-oriented DEA model is specified as follows.

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

173 Subject to constraints

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

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

174 $O_r, V_i \geq 0$

175 $O_0 > 0, \text{ or } O_0 = 0 \text{ or } O_0 < 0$

176 Where,

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

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

179 O_r = weight given to output r ,

180 V_i = weight given to input i ,

181 n = number of hospitals,

182 s = number of outputs,

183 m = number of inputs.

184 $O_0 > 0$ defines increasing returns to scale, $O_0 = 0$ defines constant returns to scale, and $O_0 < 0$ defines
 185 decreasing returns to scale.

186 The technical efficiency scores is defined by ϕ and it ranges between 0.00 and 1.00, If it is equal to
 187 1.00, then the production from the DMU is efficient; while if it is less than 1.00, the DMU is
 188 inefficient.

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191 RESULTS

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

200 Table 1. Descriptive statistics of input and output variables

Characteristics/ description	Mean	Median	SD*	Minimum	Maximum
Input variables					
<i>Health systems inputs</i>					
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
<i>Environmental factors</i>					
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

201 *Standard deviation

202 Among the countries analyzed, life expectancy at birth was a minimum of 60.4 years in Afghanistan
 203 and a maximum of 83.6 years in Japan. The infant mortality rate ranged from 2.1 deaths per 1,000 live
 204 births in Japan to 68.1 deaths per 1,000 live births in Afghanistan. On average, there were 21.1 deaths
 205 per 1,000 live births in the studied countries. The scatter matrix of the input and output variables

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3 206 shows that inputs, for instance, per-capita healthcare expenditure was associated with improved health
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5 207 outcomes (e.g. life expectancy and infant mortality) (Figure1). The higher prevalence of smoking has
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7 208 a negative impact on life expectancy. However, life expectancy and infant mortality were inversely
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9 209 associated.

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13 211 (Figure 1. will be inserted here)

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17 213 The mean CRS and VRS technical efficiency scores were 0.925 and 0.969 respectively (Table 2).
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19 214 Whereas, the mean scale efficiency score was 0.954. In terms of both CRS and VRS technical
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21 215 efficiency, Kazakhstan and Afghanistan have the lowest score of 0.766 and 0.850 respectively.

22
23 216 Out of 460 countries studied, 20 (43%) and 16 (35%) countries showed the maximum level of
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25 217 (efficiency score 1.00) VRS and CRS technical efficiency respectively. In total, 17 (37%) countries
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27 218 showed scale efficiency of 1.00 implying these countries created the best practice frontier in this
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29 219 study, based on their input and output combinations. We found that equal number of countries
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31 220 observed increasing returns to scale and constant returns to scale (17 countries), followed by
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33 221 decreasing returns to scale (12 countries).

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36 222 (Table 2. will be inserted here)

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40 224 Among the inefficient countries, 26 (57%), 30 (65%), and 29 (63%) countries had VRS technical
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42 225 efficiency, CRS technical efficiency and scale efficiency score respectively less than one (Figure 2).

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44 226 (Figure 2. will be inserted here)

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48 228 In Table 3, mean efficiency scores are presented by the income categories of the countries. The
49
50 229 highest mean CRS technical efficiency were observed for LMICs (0.95), followed by high-income
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52 230 (0.94), upper-middle-income (0.88) and low-income countries (0.92). The high-income countries and
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54 231 LMICs had the highest average VRS technical efficiency (0.98), followed by upper-middle-income
55
56 232 countries (0.95) and low-income countries (0.93). Maintaining the existing input levels, the high,

233 upper middle-, lower middle-, and low-income countries could improve their outcome by 2%, 5%, 2%
234 and 7% respectively.

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236

237 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%

238

239 DISCUSSION

240 The main findings of this paper demonstrated that more than half (57%) of the studied countries in the
241 Asia region are technically inefficient with respect to using the inputs in their healthcare systems. The
242 study findings showed that the most efficient countries belonged to the lower-middle-income group
243 (Sri Lanka, Pakistan, Timor-Leste, Cambodia, India, Syria, Yemen and Bangladesh). Additionally,
244 three high-income countries (Japan, Singapore, and Oman), one low-income country (Nepal), and
245 three upper-middle income countries (Lebanon, Iran, Iraq, and Thailand) in Asia were also efficient
246 (Technical efficiency =1.00). Among the 46 countries studied, 17 countries (Bangladesh, Sri Lanka,
247 Japan, Oman, Thailand, Iraq, Timor-Leste, Yemen, Singapore, India, Iran, Lebanon, Pakistan, Nepal,
248 Syrian, Cambodia, and Cyprus) showed constant returns to scale efficiency, indicating that they were
249 operating at their most efficient level. Another 17 countries (Malaysia, Bhutan, Myanmar, Tajikistan,
250 Mongolia, Philippines, Indonesia, Uzbekistan, Saudi Arabia, Afghanistan, Kyrgyz Republic,
251 Kazakhstan, Lao PDR, Azerbaijan, Kuwait, and Brunei Darussalam) demonstrated increasing returns
252 to scale suggesting that they should increase inputs into their health systems to be more scale
253 efficient. The remaining 12 countries showed decreasing returns to scale, meaning that their health
254 systems has more inputs compared to their operating size. Therefore, they should scale down if they

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3 255 were to become scale efficient given the existing system. The average scale efficiency score was 0.95
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5 256 which indicates that there was little difference between CRS and VRS production of healthcare
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7 257 services among the countries studied.

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9 258 An important policy implication of this study is that the technically inefficient low-income countries
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11 259 on average can improve their health systems outcome by 7% while maintaining constant levels of per-
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13 260 capita health expenditure and levels of access to hospital beds and availability of physicians. It was
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15 261 observed that the efficiency scores increased from the low-income country groups to high-income
16
17 262 country groups, with a few exceptions. An international study found a similar conclusion that health
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19 263 systems performance is most efficient in the developed countries, according to simple efficiency
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21 264 scores (38).

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24 265 The overall healthcare efficiency in different countries varied considerably (39,40). Among the
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26 266 LMICs studied, eight countries demonstrated to have the most efficient health systems. These
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28 267 countries have both technical and scale efficient health systems, like the high-income countries
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30 268 (Japan, Singapore, and Oman). A possible reason for the high efficiency of these LMICs could be a
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32 269 focus on infant mortality and child health as prioritized in past Millennium Development Goals and in
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34 270 current Sustainable Development Goals agendas, which relates to the output variables used in this
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36 271 study.

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38 272 The DEA showed that many of the LMICs produce good health at low cost and therefore make good
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40 273 use of their inputs (41). This result implies that it is possible for countries to have a high-efficiency
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42 274 score with poor health outcomes because of their low expenditure on resources. In other words, given
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44 275 their moderate consumption of inputs and challenging social environments, these countries can
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46 276 achieve good health outcomes, relative to the other countries. Similar findings were observed for
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48 277 Mexico and Turkey relative to other countries in a study of the OECD countries (25). It should be
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50 278 noted that this study only used per-capita health expenditure and two health systems indicators
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52 279 (number of physicians and beds per 1,000 people) given the data limitation, and there are other factors
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54 280 that influence health outcomes as well. For example differences in life expectancy and infant
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56 281 mortality between populations can be due to lifestyles, preferences (42,43,20) social class,

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3 282 occupation (44) and environmental factors (45,46). On a more macroscopic level, the results could
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5 283 also be impacted by a variety of contextual factors among countries such as different political
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7 284 institutions, economic landscapes, health-seeking behaviour patterns and burden of diseases among
8
9 285 other things. However, in this study, we accommodated two available social and lifestyle factors
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11 286 namely primary completion rate of relevant age group and smoking prevalence among the adult male
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13 287 population to take into consideration some of this variation.

14
15 288 A limitation of DEA methodology is that it works in a deterministic way, meaning that the results
16
17 289 entirely depend on the numeric values in the dataset. As the DEA approach compares DMUs, the
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19 290 number and nature of DMUs in the data set can noticeably change the results. For example, if a more
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21 291 efficient country is added to the dataset, it would move the frontier, causing some of the efficiency
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23 292 scores of other countries to fall. This is a key aspect of the methodology used.

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25 293 Additionally, input and output variable selection were influenced by data availability because the
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27 294 WDI dataset contains many variables with missing values and DEA strictly requires a complete data
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29 295 set. Additional input and output variables were not used in this analysis because of missing data and a
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31 296 primary aim was to include the highest number of countries as possible in the analysis. Additionally,
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33 297 it is important to note that the use of a different set of variables might have generated different
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35 298 conclusions. In the future, if additional data become available for a larger number of countries of the
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37 299 region, the number of variables analyzed could be increased to include an understanding with a
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39 300 greater degree of complexity in health system efficiency.

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42 301 Another data limitation is the comparability of health expenditures among the Asian countries. While
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44 302 recognizing that it is not possible to solve the inherent issues, we made an attempt to minimize it.
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46 303 Since the actual amount of healthcare expenditure across different countries is not comparable due to
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48 304 the difference in purchasing power parity across countries, we used health expenditures as constant of
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50 305 2011 in PPP as an input in the health production model (25).

51 52 53 306 **CONCLUSIONS**

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3 307 This study provides an empirical picture of the technical efficiency of the healthcare systems of 46
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5 308 Asian countries. It found that inefficiency exists in the healthcare systems of most of the countries
6
7 309 studied, however, the results point to three high-income and eight lower-middle-income countries
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9 310 which efficiently used the inputs in their healthcare systems. The interpretation of the inefficient
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11 311 countries identified through this study is that they can improve health outcomes using the current level
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13 312 of per-capita health expenditure and the number of physicians and beds per 1,000 people. These
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15 313 countries could use these results to direct their attention to benchmarking their health systems within
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17 314 their regional or another comparative group in order to understand their health system performance in
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19 315 a more detailed way. This study addresses the need to understand issues of efficiency, as well as
20
21 316 potentially identify good examples of countries which efficiently allocate and use resources to make
22
23 317 their healthcare systems more technically efficient. It narrows a gap in the literature as there are few
24
25 318 countries studying healthcare efficiency in Asia and none looking comparatively in this manner.

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323 **Contributors**

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

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330 **Competing interest**

331 None declared.

332 **Data sharing statement**

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

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17 440 mortality in Ontario. *Soc Sci Med*. 1998;47(1):33–49.
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21
22 442 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

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444 **Figures**

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

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

447

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

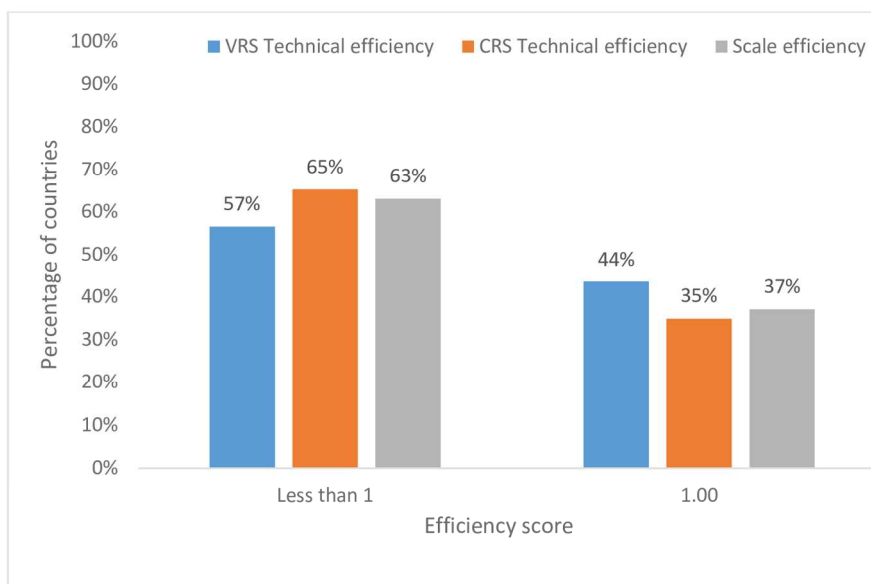


Figure 1. Distribution of efficiency scores in the health systems of Asia

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

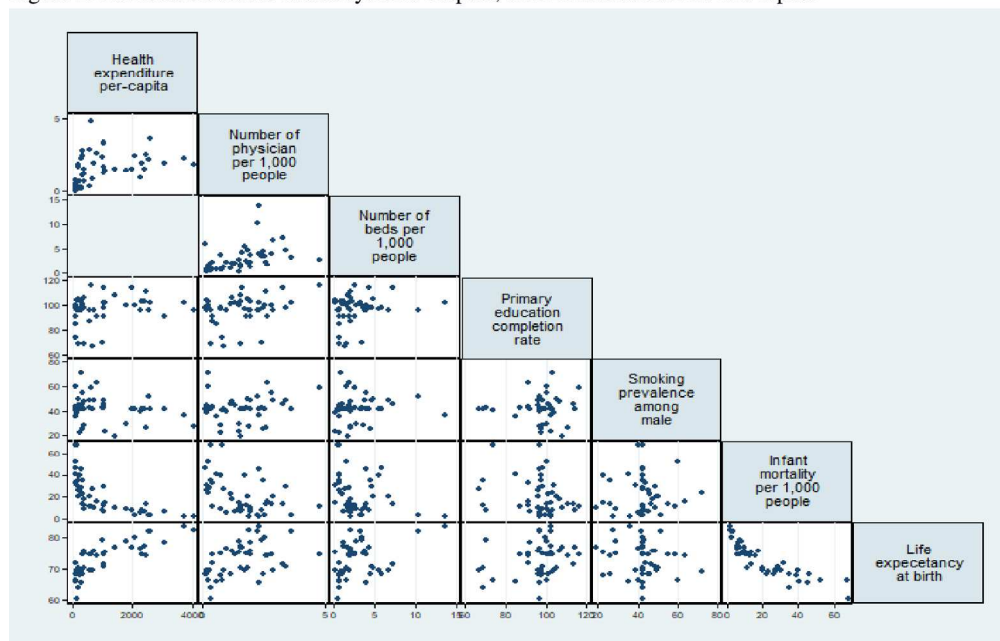


Figure 2. Association across health systems outputs, environmental factors and inputs

165x109mm (300 x 300 DPI)

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

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3 1 **Title.** Measuring the efficiency of health systems in Asia: A data envelopment analysis
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6 2 **Short title.** Measuring the efficiency of health systems in Asia
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26 ABSTRACT

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

28 **Settings:** The study was conducted based on Asian countries.

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

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

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

47 **Strengths and limitations of this study:**

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

54

55 **BACKGROUND**

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

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

75 In light of this, it is very important that the health systems of these countries are efficient in making
76 use of their resources. The World Health Organization (WHO) has estimated that about 20% to 40%
77 of total healthcare resources are being wasted per year among the WHO member countries due to
78 inefficiency. Further, this rate is high in low-and-middle income countries (LMICs) (9). In Asia, the
79 variation in efficiency across income settings can perhaps lead to lessons learned in addressing it. In
80 order to address inefficiency, Asia's health systems can look toward different dimensions of

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3 81 performance such as their effectiveness, efficiency, access, equity, and quality (10). A great deal of
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5 82 practitioner and academic literature has analyzed the relationship between the efficient production of
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7 83 health services and universal health coverage (UHC) as well as the widespread importance of
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9 84 measuring overall health system performance (9,11).

10
11 85 Assessing the efficiency of healthcare systems is a difficult process as analyses often encounter
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13 86 methodological problems, particularly due to the need for appropriate and valid outcome indicators
14
15 87 (12). Despite the empirical difficulties in applying efficiency concepts to health systems, efficiency
16
17 88 can be measured on both micro and macro levels (13). Measuring health system efficiency at a macro-
18
19 89 level is particularly important in order to understand health system performance across the globe and
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21 90 take required action to minimize inefficiency (11,14).

22
23 91 A number of studies have addressed healthcare efficiency in Americas (15,16), Western Europe
24
25 92 (17,18) and Asia (19,20) to shed light on the efficiency of different national health systems. A
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27 93 systematic review on measuring efficiency related to several aspects of healthcare was performed by
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29 94 Hollingsworth et al. (21). Dimas et al. evaluated the productivity of Greek public hospitals and found
30
31 95 that productivity changes were dominated by technical change (22). Zere et al. measured the technical
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33 96 efficiency and productivity of hospitals in South Africa, and examined the impact of hospital
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35 97 characteristics on efficiency and productivity (23).

36
37 98 In an international study of efficiency in 170 countries, it was observed that Asian countries were
38
39 99 comparatively in the middle with respect to health system efficiency scores (24). This indicates that
40
41 100 there is room for improvement to optimize health benefits from the available health sector resources.
42
43 101 In this region, there are a number of studies at the country level to address health systems efficiency
44
45 102 (25,26), but cross country comparison of the health system efficiency is limited (27).

46
47 103 Asian countries are not homogenous in terms of area, population, and economic conditions, however,
48
49 104 they have public health functions and a number of their health system outcomes in common (28).
50
51 105 Many of the countries share similar health systems problems, including inadequate resources for
52
53 106 healthcare and a high burden of diseases due to the geographical contiguity, disease patterns, and
54
55 107 social conditions. Understanding health systems efficiency in different Asian countries could promote
56
57 108 shared learning and highlight key areas of best practice, as well as areas where improvement is

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3 109 needed. Furthermore, given geographical proximity and many strong relationships experienced with
4
5 110 near-by countries, there is likely to be relative ease in the ability to practically understand, learn and
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7 111 apply nuance about healthcare systems from one country to another.

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9 112 A study of the efficiency of health systems in this region will help to provide lessons through
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11 113 comparison across countries. This paper aims to achieve this goal through evaluating the technical
12
13 114 efficiency and scale efficiency of the healthcare systems of selected Asian countries.

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16 116 **METHODS**

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19 117 This study employed Data Envelope Analysis (DEA) which is a commonly used non-parametric
20
21 118 method for efficiency analysis. It was used for estimating technical and scale efficiency scores of the
22
23 119 health systems of Asian countries.

24 120 **Input and output variables**

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26
27 121 A main assumption of the DEA model used in our analysis was that in Asian countries, the selected
28
29 122 health outcomes were dependent on the inputs of healthcare resources. We selected the input variables
30
31 123 as proxies for the quantity of inputs that a country devotes to healthcare (i.e. health expenditure per
32
33 124 capita); and outcome variables of the healthy life expectancy at birth (HALE) and infant mortality
34
35 125 (per 1,000 live births). The relationship between health expenditure and outcomes considered here is
36
37 126 consistent with the view that health expenditure has diminishing returns, or additional expenditure
38
39 127 beyond a certain level has relatively smaller incremental effect on life expectancy or infant mortality
40
41 128 (29). To be clear, reduction in infant mortality and increase in life expectancy signify improvement in
42
43 129 the health outcomes of a country. Some studies have included life expectancy at birth as an outcome
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45 130 variable (31–33), however, it is argued that quality of life matters as much as, if not more than,
46
47 131 quantity of life, and therefore life expectancy should be a weighted health quality measure. As a
48
49 132 result, HALE has been incorporated as a proxy of health quality as the outcome of health systems.
50
51 133 Also, it is important to note that instead of using the infant mortality directly in the DEA model, we
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53 134 used the inverse of infant mortality as the model assumes that inputs and outputs are isotonic (i.e.
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55 135 increased input reduces efficiency as well as increased output increases efficiency) (34). Without this

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3 136 correction, a higher infant mortality figure would have been said to incorrectly contribute to a better
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5 137 health system outcome.

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8 139 **Data sources**

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10 140 We used two main data sources: The World Health Organization data repository and World
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12 141 Development Indicators-2015 (WDI). According to the list of United Nation Statistics Division, there
13
14 142 are 50 Asian countries and territories. Among these , 46 were used for this study (35). Four countries
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16 143 and territories (Hong Kong, North Korea, Macao, and West bank and Gaza) were excluded due to
17
18 144 missing data of selected variables in the WDI database (5). However, selected variables for the study
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20 145 countries were not reported in WDI for every year. This problem is unavoidable in studies based on
21
22 146 WDI data (36–38). Earlier studies adapted two approaches to deal with such problem. Firstly, they
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24 147 used a value from a slightly earlier year as in Anderson et al. (36) and secondly, they used a smaller
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26 148 number of countries in the model as in Fare et al. (37) and Grubaugh and Santerre (38). Given the
27
28 149 importance of including as many countries as possible to study technical efficiency using Data
29
30 150 Envelope Analysis, we opted for the first approach. However, to avoid missing variable we used
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32 151 slightly earlier WDI statistics.

33 34 152 **Data envelopment analysis**

35
36 153 DEA is one of the most widely used methods to assess the technical efficiency and scale efficiency of
37
38 154 a set of decision-making units (DMUs) (In the case of this analysis, DMUs are the 46 different Asian
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40 155 countries). DEA is a non-parametric method which identifies an efficiency frontier on which only the
41
42 156 efficient DMUs are placed, by using linear programming techniques. One type of DEA model,
43
44 157 developed by Charnes, Cooper, and Rhodes (CCR), assumes that production has constant returns to
45
46 158 scale (CRS) meaning any change in the input will result in a proportionate change in the output (39).
47
48 159 Another model proposed by Banker, Charnes, and Cooper (BCC), assumes that production has
49
50 160 variable returns to scale (VRS) implying an increase in the input will result in either an increase or a
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52 161 decrease in the output. The latter methodology is particularly useful for this study since it aims to
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54 162 measure the efficiency related to organizational units (i.e. the health systems of the different
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56 163 countries), which use numerous resources to produce multiple outputs and accommodate a more

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3 164 flexible assumption of VRS (24,40). This is more realistic and reflective of changes in the real world
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5 165 (25).

6
7 166 Scale efficiency scores provide information on the optimality of the DMUs size. When a production
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9 167 unit (DMU) operates at CRS, technical efficiency is equal to scale efficiency. However, when DMUs
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11 168 are not operating at optimum scale, technical efficiency measured with the CCR model may be altered
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13 169 by scale efficiency. The BCC model, which defines production through VRS, can incorporate the
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15 170 impact of scale efficiency in the measurement of technical efficiency. This is measured as the ratio of
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17 171 CRS technical efficiency scores and VRS technical efficiency scores (41).

18
19 172 When it comes to DEA studies comparing countries, both the input and output oriented models have
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21 173 been adopted for this type of analysis. An output-oriented DEA model aims to maximize the outputs
22
23 174 with a given amount of inputs; while input-oriented models focus on minimizing the inputs used to
24
25 175 obtain a certain amount of output. Many studies have been carried out using DEA to assess the
26
27 176 efficiency of healthcare systems using the two approaches in both high-income and low-income
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29 177 countries (42–45). In this study, an output-oriented DEA model was deemed more appropriate based
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31 178 on the premise that the input per capita expenditure is likely to be less flexible. In other words, health
32
33 179 system stewards are likely to have more leverage in controlling outputs through innovative
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35 180 programming and improvements in healthcare provided, rather than by increasing spending and
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37 181 resources.

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40 41 42 183 **Output oriented model**

43
44 184 The output-oriented technical efficiency model focuses on increasing output without changing the
45
46 185 quantity of inputs used. The objective of the model for solving each particular DMU (country) is to
47
48 186 maximize the efficiency score (denoted by ϕ) meaning the amount by which all outputs can be
49
50 187 improved for each country under consideration while holding input constant.

51
52
53 188 The output-oriented DEA model is specified as follows.

$$54
55
56 \text{Max } \phi = \sum O_r Y_{rj_0} + O_0$$

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 $O_0 > 0, \text{ or } O_0 = 0 \text{ or } O_0 < 0$

192 Where,

193 Y_{ij} = 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
201 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
203 1.00, then the production from the DMU is efficient; while if it is less than 1.00, the DMU is
204 inefficient.

205 **Tobit regression analysis**

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

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

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

230 The Tobit regression models were specified as follows,

$$Ineff_i = \beta_0 + \beta_1 P \square y_i + \beta_2 Beds_i + \beta_3 Primay_edu_i + \beta_4 Smoking_i + \beta_5 Inc_i + \beta_5 Pop_density_i + \varepsilon_i$$

231 Where,

232 Ineff = the technical inefficiency score; continues variable.

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

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

237 Inc= Income group of the country; categorical variable (1=Low income, 2=Lower-middle income,
 238 3=Upper-middle-income, 4=High-income)

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

241 Finally, ε_i was the stochastic error term.

242 **Sensitivity analysis**

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

248 **Patient and Public Involvement**

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

252 .

253 **RESULTS**

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

262

263 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

264 *Standard deviation

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

271

272 (Figure 1. will be inserted here)

273

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

279 Out of 46 countries studied, only 4 (8.7%) countries showed the maximum level of (efficiency score
 280 1.00) in VRS and CRS technical efficiency scale. All of these four countries showed scale efficiency
 281 of 1.00 implying that these countries created the best practice frontier based on their input and output

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2
3 282 combinations. 39.1% (18) countries showed increasing returns to scale, 52.2% (24) countries
4
5 283 decreasing returns to scale, and the 4 efficient countries constant returns to scale production function
6
7 284 of their health systems.

8
9
10 285

11
12 286 (Table 2. will be inserted here)

13
14 287

15
16 288 More than half of the countries (30 countries) had VRS efficiency and five countries CRS efficiency
17
18 289 greater than 90% (supplementary figure 1).

19 20 290 **Tobit regression analysis of associated factors with inefficiency**

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22 291 Tobit regression was employed to relate the VRS inefficiency scores to two health service production
23
24 292 variables and four environmental variables. Physician density, income status of countries, and
25
26 293 smoking prevalence among males exhibited a statistically insignificant positive association with the
27
28 294 inefficiency scores. The density of bed (>3 and <=5) had a significantly negative association with the
29
30 295 inefficiency scores compared to less than 1 beds category. Countries having more than 5 beds density
31
32 296 had no significant association with the inefficiency scores. After the bootstrapping more than 5 beds
33
34 297 density showed significant association with inefficiency score (supplementary table 2). However, the
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36 298 coefficient was highest for (>3 and <=5) beds density. This indicates that sample countries with less
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38 299 than 1 bed have lower technical efficiency of its health systems. Furthermore, the primary education
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40 300 completion rate was significantly negatively associated with the inefficiency score which indicates
41
42 301 that countries with higher percentage of primary education completion rate have higher health system
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44 302 efficiency. Population density had a significantly negative association with the inefficiency score.
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46 303 Countries having less than 200 population per square kilometre were found to have lower efficiency.

47 48 304 **Sensitivity of the efficiency scores**

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50 305 We conducted sensitivity analysis using various combinations of input and output variables. In all of
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52 306 these cases the average of the efficiency scores varied from 0.812 to 0.936. The most sensitive
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54 307 combination was found while using the HALE at age 60 as the input variable. The efficiency score
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56 308 changed from 0.919 (main model) to 0.812 (considering input as HALE at age 60) (Figure 2).

309 (Figure 2. will be inserted here)

310

311 In Table 3, mean efficiency scores are presented by the income categories of the countries. The
 312 highest mean VRS technical efficiency were observed for high income countries (0.934; 95% CI
 313 0.905-0.963), followed by upper-middle-income (0.914; 95% CI: 0.894-0.935), and low and lower-
 314 middle income countries (0.913; 95% CI: 0.891-0.935). With the existing input levels, the high-,
 315 upper middle-, low- and lower-middle income countries could improve their health system outcome
 316 by 6.6%, 8.7%, and 8.7% respectively.

317 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%

318

319 DISCUSSION

320 The main findings of this paper demonstrated that about (86.9 %) of the studied Asian countries are
 321 technically inefficient with respect to using healthcare systems resources, (using a proxy of per capita
 322 health expenditure). The study findings showed that the most efficient countries belonged to the high-
 323 income group (Cyprus, Japan, and Singapore). Only one country belonged to the low- and lower
 324 middle income group (Bangladesh). Among the 46 countries studied, only four countries (Bangladesh,
 325 Japan, Singapore, and Cyprus) showed constant returns to scale efficiency, indicating that they were
 326 operating at their most efficient level. Of the 14 high-income countries studied, 9 countries (75.0%)
 327 had health system production at decreasing returns to scale. This implies that although the highest
 328 number of efficient countries belonged to the high-income group, a large number of these countries
 329 health system production requires more resources than the ideal situation. A similar situation was
 330 observed for the upper-middle-income countries. Of the 13 countries, 10 (76.9%) had decreasing

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3 331 returns to scale. Only 5 (23.8%) out of 21 low – and lower-middle-income countries were producing
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5 332 at decreasing returns to scale. Although these low- and lower-middle-income countries are not
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7 333 efficient, most of their production follows increasing returns to scale.

8
9 334 It was observed that the average of the efficiency scores increased from the low and lower-middle-
10
11 335 income countries to high-income countries. An important policy implication of this study could be
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13 336 that the technically inefficient low-income countries on average can improve their health systems
14
15 337 outcome by 8.7%, middle income country by 8.6%, and high income country by 6.6% using the
16
17 338 existing levels of per-capita health expenditure. An international study found a similar conclusion that
18
19 339 health systems performance is most efficient in the developed countries, according to simple
20
21 340 efficiency scores (52).

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23
24 341 The overall healthcare efficiency in different countries varied considerably (53,54). Among the low-
25
26 342 and lower-middle income studied, one country demonstrated the most efficient health systems
27
28 343 (Bangladesh). This county has both technical and scale efficient health systems, like the high-income
29
30 344 countries (Japan, Singapore, and Cyprus) (55). A possible reason for the high efficiency of these
31
32 345 LMICs could be a focus on infant mortality and child health as prioritized in past Millennium
33
34 346 Development Goals and in current Sustainable Development Goals agendas, which relates to the
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36 347 outcome variables used in this study.

37
38 348 The DEA result showed that more than 60% of the low- and lower middle income countries had
39
40 349 health system efficiency greater than 90%. This result implies that these countries produce good
41
42 350 health at low cost and therefore make good use of health systems resources (56). This result suggests
43
44 351 that it is possible for countries to have a high-efficiency score with poor health outcomes because of
45
46 352 their low expenditure on resources and increasing returns to scale production function. In other words,
47
48 353 given their moderate consumption of inputs and challenging social environments, these countries can
49
50 354 achieve good health outcomes, relative to the other countries. Similar findings were observed for
51
52 355 Mexico and Turkey relative to other countries in a study of the OECD countries (33). It should be
53
54 356 noted that this study only used per-capita health expenditure and there are other factors that influence
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56 357 health outcomes as well. For example differences in life expectancy and infant mortality between

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2
3 358 populations can be due to lifestyles, preferences (49,57,58) social class, occupation (59) and
4
5 359 environmental factors (60,61). On a more macroscopic level, the results could also be impacted by a
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7 360 variety of contextual factors among countries such as different political institutions, economic
8
9 361 landscapes, health-seeking behaviour patterns and burden of diseases among other things. However, in
10
11 362 this study, we attempted to address by including variables addressing the number of physicians,
12
13 363 number of inpatient beds, and population density, along with two environmental factors namely
14
15 364 primary completion rate of relevant age group and smoking prevalence among the adult male
16
17 365 population to take into consideration some of this variation. The results showed that more than three
18
19 366 and less than five beds per 1000 population significantly influenced the efficiency score. A low
20
21 367 number of beds cannot serve a large proportion of the population and therefore the systems may be
22
23 368 inefficient. Similarly, a high number of beds may often be left unused and make the health systems
24
25 369 inefficient The countries having more than 200 people living per square kilometre had a higher level
26
27 370 of efficiency in their health systems.

28
29 371
30
31 372 A limitation of DEA methodology is that it works in a deterministic way, meaning that the results
32
33 373 entirely depend on the numeric values in the dataset. As the DEA approach compares DMUs, the
34
35 374 number and nature of DMUs in the data set can noticeably change the results. For example, if a more
36
37 375 efficient country is added to the dataset, it would move the frontier, causing some of the efficiency
38
39 376 scores of other countries to fall. This is a key aspect of the methodology used.

40
41 377 Additionally, it is important to note that the use of a different set of variables might have generated
42
43 378 different conclusions. In the future, if additional data become available for a larger number of
44
45 379 countries in the region, the number of variables analyzed could be increased to include an
46
47 380 understanding with a greater degree of complexity in health system efficiency.

48
49
50 381 Another data limitation is the comparability of health expenditures among the Asian countries. While
51
52 382 recognizing that it is not possible to solve the inherent issues, we made an attempt to minimize it.
53
54 383 Since the actual amount of healthcare expenditure across different countries may not be comparable
55
56 384 due to the difference in purchasing power parity across countries, we used health expenditures as

1
2
3 385 constant of 2011 in PPP as an input in the DEA model (33). Also, when we included health
4 386 expenditure at current USD per capita as an input in the DEA model we found that the efficiency
5
6 387 score did not change significantly.

8
9 388 We applied sensitivity analysis to in an attempt overcome these limitations (Figure 2.) Our results
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11 389 were consistent while using several combinations of inputs and outputs variables which is reassuring
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13 390 and strengthens the findings from this study.

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17 18 19 392 **CONCLUSIONS**

20
21 393 This study provides an empirical picture of the technical efficiency of the healthcare systems of 46
22
23 394 Asian countries. It found that inefficiency exists in the healthcare systems of most of the countries
24
25 395 studied, however, the results point to three high-income and one low- and lower-middle-income
26
27 396 country which efficiently used healthcare systems resources. The interpretation of the inefficient
28
29 397 countries identified through this study is that they can improve health outcomes using the current level
30
31 398 of per-capita health expenditure. These countries could use these results to direct their attention to
32
33 399 benchmarking their health systems within their regional or another comparative group in order to
34
35 400 understand their health system performance in a more detailed way. This study addresses the need to
36
37 401 understand issues of efficiency, as well as potentially identify good examples of countries which
38
39 402 efficiently allocate and use resources to make their healthcare systems more technically efficient. It
40
41 403 narrows a gap in the literature as there are few countries studying healthcare efficiency in Asia and
42
43 404 looking comparatively in this manner.

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1
2
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4
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15
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20
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22
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24
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26
27 423 <https://data.worldbank.org/> and <http://www.who.int/gho/en/>.

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27 564 mortality in Ontario. *Soc Sci Med.* 1998;47(1):33–49.
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31 566 **Tables**

32
33 567 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

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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	0.919	0.847	-
	(0.752-0.808)	(0.905-0.933)	(0.824-0.87)	-
Median	0.772	0.913	0.834	-
Minimum	0.624	0.812	0.716	-
Maximum	1	1	1	-

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570 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

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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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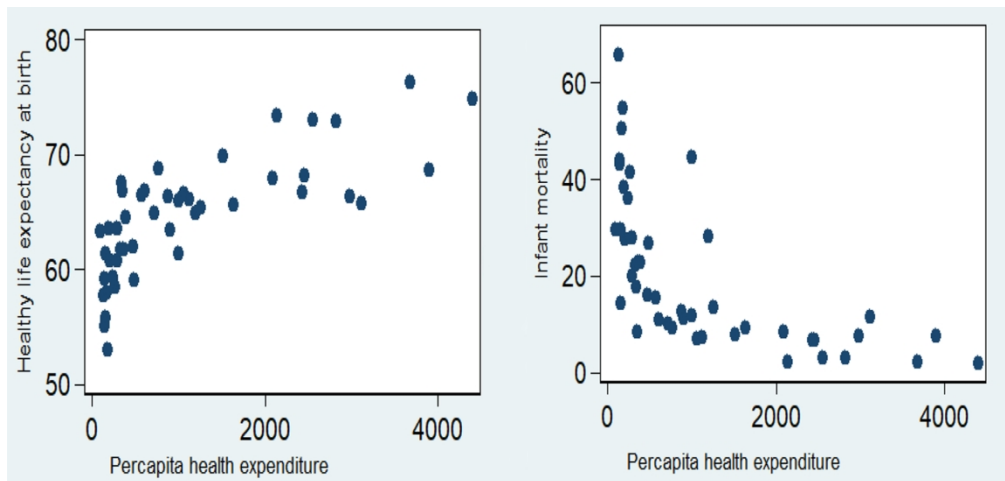


Figure 1. Association across health systems input and outcome
189x91mm (300 x 300 DPI)

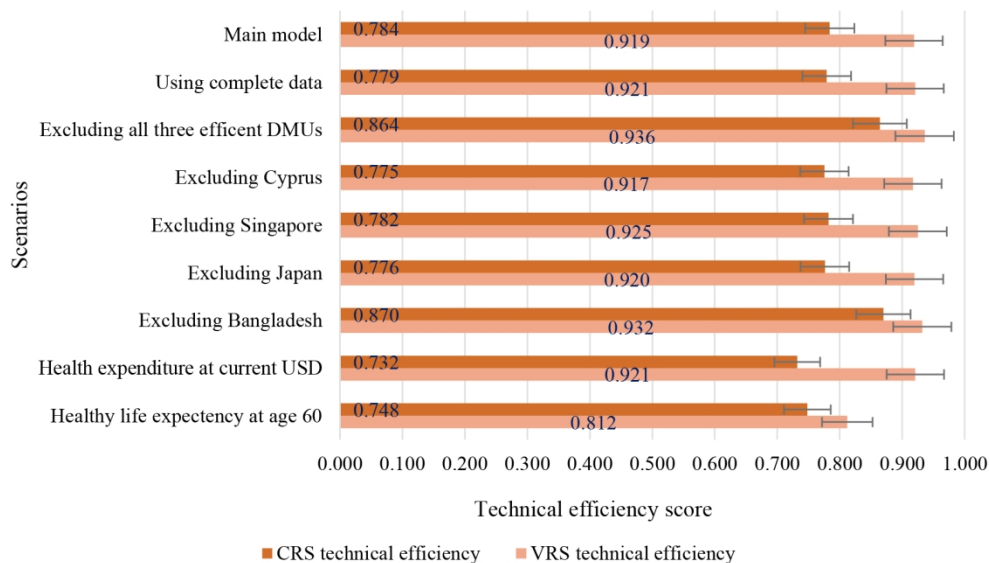


Figure 2. Results from the sensitivity analysis of efficiency scores

155x91mm (300 x 300 DPI)

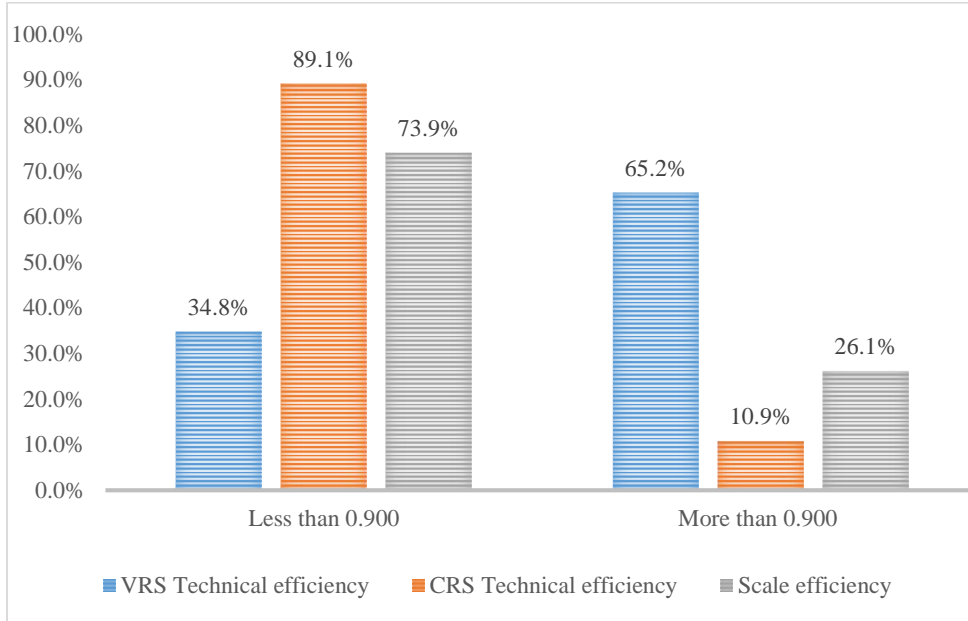
Supplementary Table 1. Correlation among technical efficiency, input, and output variables

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



Peer review only

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.

BMJ Open

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

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Primary Subject Heading:	Health economics
Secondary Subject Heading:	Health policy, Health services research
Keywords:	Technical efficiency, Data envelopment analysis, Asian countries, Health systems efficiency

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3 1 **Title.** Measuring the efficiency of health systems in Asia: A data envelopment analysis
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6 2 **Short title.** Measuring the efficiency of health systems in Asia
7

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51
52 22 **Word count:** 3,331
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54 23 **Keywords:** Technical efficiency, Data envelopment analysis, Asian countries, Health
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56 24 systems.
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26 ABSTRACT

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

28 **Settings:** The study was conducted in Asian countries.

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

36 **Results:** The main findings of this paper demonstrate that about 87% of the studied Asian countries
37 were inefficient with respect to using healthcare system resources. Most of the efficient countries
38 belonged to the high-income group (Cyprus, Japan, and Singapore) and only one country belonged to
39 the lower-middle-income group (Bangladesh). In Asia, through efficiency gains, the high-, upper
40 middle-, lower-, and lower- middle-income countries can improve health system outcomes by 6.6%,
41 8.6%, and 8.7% respectively using the existing level of resources. Population density, bed density, and
42 primary education completion rate significantly influenced the efficiency score.

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

47 **Strengths and limitations of this study:**

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

54 BACKGROUND

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

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

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

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3 82 health services and universal health coverage as well as the widespread importance of measuring
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5 83 overall health system performance (9,11).
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7 84 Assessing the efficiency of healthcare systems is a difficult process as analyses often encounter
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9 85 methodological problems, particularly due to the need for appropriate and valid outcome indicators
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11 86 (12). Despite the empirical difficulties in applying efficiency concepts to health systems, efficiency can
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13 87 be measured on both micro and macro levels (13). Measuring health system efficiency at a macro-level
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15 88 is particularly important in order to understand health system performance across the globe and take
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17 89 required action to minimize inefficiency (11,14).
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20 90 A number of studies have analyzed the healthcare efficiency in the Americas (15,16), Western Europe
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22 91 (17,18) and Asia (19,20) to shed light on the efficiency of different national healthcare systems. A
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24 92 systematic review on measuring efficiency related to several aspects of healthcare performed by
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26 93 Hollingsworth et al. (21). Dimas et al. evaluated the productivity of Greek public hospitals and found
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28 94 that productivity changes were dominated by technical change (22). Additionally, Zere et al. 2005
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30 95 measured the technical efficiency and productivity of hospitals in South Africa, and examined the
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32 96 impact of hospital characteristics on efficiency and productivity (23).
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35 97 Several studies have reported on different determinants of health system efficiency. For example, a
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37 98 study conducted in China reported that GDP per capita, proportion of primary health worker, and
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39 99 population density were the key determinants of the efficiency in Chinese health system (24). Another
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41 100 study in the Canadian context reported that re-admission, obesity and smoking, and average income of
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43 101 the population are key determinants of health system efficiency (25).
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45 102 In an international study of efficiency in 170 Asian and non-Asian countries, it was observed that Asian
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47 103 countries were comparatively in the middle with respect to health system efficiency scores (26). This
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49 104 indicates that there is room for improvement to optimize health benefits from the available health sector
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51 105 resources. In this region, there are a number of studies at the country level to address health systems
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53 106 efficiency (27,28), but cross country comparison of the health system efficiency is limited (29).
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56 107 Asian countries are not homogenous in terms of area, population, and economic conditions, however,
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58 108 they have public health functions and a number of their health system outcomes in common (30). Many
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60 109 of the countries share similar health systems problems, including and a high burden of diseases due to

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2
3 110 the geographical contiguity, disease patterns, and social conditions and inadequate resources for
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5 111 healthcare. Understanding health systems efficiency in different Asian countries could promote shared
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7 112 learning and highlight key areas of best practice, as well as areas where improvement is needed.
8
9 113 Furthermore, given geographical proximity and many strong relationships experienced with near-by
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11 114 countries, there is likely to be relative ease in the ability to practically understand, learn, and apply
12
13 115 nuance about healthcare systems from one country to another.
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15 116 A study of the efficiency of health systems in this region will help to provide lessons through
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17 117 comparison across countries. This paper aims to achieve this goal through evaluating the technical
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19 118 efficiency and scale efficiency of the healthcare systems of selected Asian countries.
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119

120 **METHODS**

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

125

126 **Data sources**

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

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2
3 137 we opted for the first approach. However, to avoid missing variable we used slightly earlier WDI
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5 138 statistics.

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9 **140 Input and output variables**

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11 141 A main assumption of the DEA model used in our analysis was that in Asian countries, the selected
12
13 142 health outcomes are dependent on the inputs of healthcare resources. We selected the input variables as
14
15 143 proxies for the quantity of inputs that a country devotes to healthcare (i.e. health expenditure per capita);
16
17 144 and outcome variables as the healthy life expectancy at birth (HALE) and infant mortality (per 1,000
18
19 145 live births). The health expenditure per capita was extracted from the Global Health Expenditure
20
21 146 database managed by the WHO. In this database there are national health expenditure statistics for more
22
23 147 than 190 WHO Member States in line with the new System of Health Accounts 2011 (SHA 2011)
24
25 148 framework. The SHA 2011 framework was developed by Organisation for Economic Co-operation and
26
27 149 Development (OECD) to rigorously track health expenditure (e.g. by all financial sources, by all
28
29 150 services) at the national level and to enable comparability across countries. The capital expenditure (e.g.
30
31 151 infrastructure) was included in the total health expenditure estimation (31). The relationship between
32
33 152 health expenditure and outcomes considered here is consistent with the view that health expenditure
34
35 153 has diminishing returns, or additional expenditure beyond a certain level has relatively smaller
36
37 154 incremental effect on life expectancy or infant mortality (36). To be clear, reduction in infant mortality
38
39 155 and increase in life expectancy signify improvement in the health outcomes of a country. Some studies
40
41 156 have included life expectancy at birth as an outcome variable (37–39), however, it is argued that quality
42
43 157 of life matters as much as, if not more than, quantity of life, and therefore life expectancy should be a
44
45 158 weighted health quality measure. As a result, HALE has been incorporated as a proxy of health quality
46
47 159 as the outcome of health systems. Also, it is important to note that instead of using the infant mortality
48
49 160 directly in the DEA model, we used the inverse of infant mortality as the model assumes that inputs and
50
51 161 outputs are isotonic (i.e. increased input reduces efficiency as well as increased output increases
52
53 162 efficiency) (40). Without this correction, a higher infant mortality figure would have been said to
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55 163 incorrectly contribute to a better health system outcome.
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165 **Data envelopment analysis**

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

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

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

190 When it comes to DEA studies comparing countries, both the input- and output-oriented models have
191 been adopted for this type of analysis. An output-oriented DEA model aims to maximize the outputs

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2
3 192 with a given amount of inputs; while input-oriented models focus on minimizing the inputs used to
4
5 193 obtain a certain amount of output. Many studies have been carried out using DEA to assess the
6
7 194 efficiency of healthcare systems using the two approaches in both high-income and low-income
8
9 195 countries (28,46–48). In this study, an output-oriented DEA model was deemed more appropriate based
10
11 196 on the premise that the input per capita expenditure is likely to be less flexible. In other words, health
12
13 197 system stewards are likely to have more leverage in controlling outputs through innovative
14
15 198 programming and improvements in healthcare provided, rather than by increasing spending and
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17 199 resources.

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201 **Output oriented model**

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

206 The output-oriented DEA model is specified as follows.

$$207 \quad \text{Max } \phi = \sum O_r Y_{rj_0} + O_0$$

208 Subject to constraints

$$209 \quad \sum_{i=1}^m V_i + X_{ij_0} = 1$$

$$210 \quad \sum_{r=1}^s O_r + Y_{rj} - \sum V_r X_{ij} + O_0 \leq 0, \quad j = 1, \dots, n$$

$$211 \quad O_r, V_i \geq 0$$

$$212 \quad O_0 > 0, \text{ or } O_0 = 0 \text{ or } O_0 < 0$$

213 Where,

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

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

216 O_r = weight given to output r,

1
2
3 217 V_i = weight given to input i ,

4 218 n = number of countries,

5 219 s = number of outputs,

6 220 m = number of inputs.

7
8 221 $O_0 > 0$ defines increasing returns to scale, $O_0 = 0$ defines constant returns to scale, and $O_0 < 0$ defines
9 222 decreasing returns to scale.

10 223 The technical efficiency scores is defined by ϕ and it ranges between 0.00 and 1.00, If it is equal to
11 224 1.00, then the production from the DMU is efficient; while if it is less than 1.00, the DMU is inefficient.

12 225

13 226 **Explaining efficiency through regression analysis**

14 227 One of the limitation of the DEA approach is the serial correlation of the efficiency scores generated
15 228 through this approach. In other words, the correlation between inputs and outputs, and consequently
16 229 with the estimated efficiency scores resulted in this serial correlation. Thus, the scores of one DMU is
17 230 not independent on that of the other DMUs. To handle this limitation, scholars such as Ramalho et al.
18 231 2010 (49) and McDonald 2009 (50) have argued that econometric models like probit, logit, and
19 232 truncated regression (Tobit) can be used for second- stage analysis for identifying impact of
20 233 environmental variables on efficiency. However, scholars such as Simar and Wilson 2007 have argued
21 234 that the conventional statistical inferences are inappropriate in the second-stage regression due to the
22 235 bias of the DEA score and recommend using bootstrap methods (51). Afonso and Aubyn 2011 (52)
23 236 show in their empirical study that the censored normal Tobit regression and bootstrap algorithms yield
24 237 very similar results. However, we have adopted both the Tobit model and smoothed bootstrap model in
25 238 explaining the association with health system efficiency to be comprehensive.

26 239 The VRS efficiency scores computed using the DEA model were regressed against a few health
27 240 service productions (e.g. physician and beds density per 1000 population) and some environmental
28 241 factors (Table 1). Since, by definition, the DEA scores range between zero and one, and some of the
29 242 data tend to concentrate on these boundary values (i.e. censored for the DMUs with a value at one),
30 243 ordinary least squares cannot estimate the regression. Therefore, a Tobit model is suitable for such
31 244 regression. For the convenience of calculation, we assumed a censoring point at zero in this model. As
32 245 a result, the efficient DMUs will have a score of zero and the inefficient DMUs will have score

greater than zero. Following Zere et al. (53), we applied this method by transforming VRS technical efficiency scores into VRS inefficiency scores and leaving censoring at zero as follows.

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

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 (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,

$$\text{Ineff}_i = \beta_0 + \beta_1 \text{Phy}_i + \beta_2 \text{Beds}_i + \beta_3 \text{Primay_edu}_i + \beta_4 \text{Smoking}_i + \beta_5 \text{Inc}_i + \beta_5 \text{Pop_density}_i + \varepsilon_i$$

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)

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2
3 271 Beds =Beds density; categorical variable (1= Fewer than 1 beds 3= More than 1 and less than or equal
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5 272 to 3 beds, 3= More than 3 and less or equal to 5 beds, 4= More than 5 beds)
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7 273 Inc= Income group of the country; categorical variable (1=Low income, 2=Lower-middle income,
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9 274 3=Upper-middle-income, 4=High-income)
10
11 275 Pop_density= Population density; categorical variable (1= Fewer than or equal to 50, 2= More than 50
12
13 276 to fewer than or equal to 100, 3= More than 100 to fewer than or equal 200, 4= More than 200)
14
15 277 Finally, ε_i was the stochastic error term.

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17
18 278 We submitted the initial DEA scores in a smoothed bootstrap method design by Simar and Wilson
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20 279 (51) to estimate the robust efficiency score from the bootstrapped regression analysis to identify
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22 280 factors associated with these scores. The simarwilson command in STATA 13 was applied in the
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24 281 analysis using externally estimated DEA scores (algorithm #1) (58).

25 26 282 **Sensitivity analysis**

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28 283 The efficiency scores can be affected by the number of inputs and outputs used in DEA in relation with
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30 284 the number of DMUs. The scores can be overestimated if the number of DMUs is relatively small
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32 285 compared to the number of inputs, or very large compared to the number of inputs and outputs (59,60).
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34 286 It is suggested that the number of DMUs should be at least three times of the inputs and outputs variables
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36 287 (61,62). In our model, the number of DMUs (46) is more than three times of the number of inputs and
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38 288 outputs (9) and this is not a binding constraint for this study.

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41 289 There is the possibility that choosing different variables in the DEA model may produce inconsistent
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43 290 results such as inconsistent efficiency estimate. There is no test to assess the suitability of a particular
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45 291 model specification in DEA (63). Therefore, we carried out a sensitivity analysis of the efficiency scores
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47 292 by running the DEA model several times using different combinations of input and outcome variables.
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49 293 Different specifications of the DEA models were considered (e.g. dropping the efficient countries, using
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51 294 HALE at age 60, current health expenditure per capita (current US\$) as inputs and using the complete
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53 295 set of data for the year 2015 (excluding countries with any missing variable) for testing the sensitivity
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56 296 of our main model.

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298 Patient and Public Involvement

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

302 RESULTS

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

311 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

312 *Standard deviation

313 Among the countries analyzed, HALE at birth was a minimum of 53.2 years in Afghanistan and a
314 maximum of 75.9 years in Singapore. The infant mortality rate ranged from 2.1 deaths per 1,000 live
315 births in Japan to 68.1 deaths per 1,000 live births in Afghanistan. On average, there were 21.1 deaths

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3 316 per 1,000 live births in the studied countries. The scatter matrix of the input and output variables shows
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5 317 that inputs, for instance, increase in per-capita healthcare expenditure was associated with improved
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7 318 health outcomes (e.g. HALE at birth and reduced infant mortality) (Figure 1).
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11 320 (Figure 1. will be inserted here)
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15
16 322 The mean CRS and VRS technical efficiency scores were 0.780 and 0.921 respectively (Table 2).
17
18 323 Whereas, the mean scale efficiency score was 0.874. Considering VRS efficiency, Afghanistan has the
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20 324 lowest score of 0.812. Both VRS and CRS technical efficiency score were positively correlated with
21
22 325 per capita health expenditure, HALE at birth, and negatively correlated with infant mortality
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24 326 (supplementary table 1).
25

26
27 327 Out of 46 countries studied, only 4 (8.7%) countries showed the maximum level of (efficiency score
28
29 328 1.00) in VRS and CRS technical efficiency scale. All of these four countries showed scale efficiency of
30
31 329 1.00 implying that these countries created the best practice frontier based on their input and output
32
33 330 combinations. 39.1% (18) countries showed increasing returns to scale, 52.2% (24) countries decreasing
34
35 331 returns to scale, and the 4 efficient countries constant returns to scale production function of their health
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37 332 systems.
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43 334 (Table 2. will be inserted here)
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48 336 More than half of the countries (30 countries) had VRS efficiency and five countries CRS efficiency
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50 337 greater than 90% (supplementary figure 1).
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53 54 339 **Result from Tobit regression and bootstrap analysis for associated factors with the inefficiency**

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56 340 Tobit regression and smoothed bootstrap were used to relate VRS efficiency scores to two health service
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58 341 production variables and four environmental variables in two separate models (Table 3). Negative
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3 342 associations with the inefficiency scores in the Tobit model represent positive relation of health system
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5 343 efficiency with the explanatory variables. On the other hand, positive associations with the explanatory
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7 344 variables in the smoothed bootstrap model represent positive relations of the health system efficiency
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9 345 with the explanatory variables.
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14 347 (Table 3. will be inserted here)
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18 349 Physician density, income status of countries, and smoking prevalence among males exhibited
19
20 350 statistically insignificant associations with the health system efficiency in the both models. The density
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22 351 of bed (>3 and ≤ 5) had a significantly negative association with the inefficiency scores (i.e. positive
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24 352 association with the efficiency) compared to less than 1 bed density category. Countries having more
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26 353 than 1 and less than or equal to 3 beds density had no significant association with the inefficiency scores.
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28 354 However, after the bootstrapping, this category become significant and the significance level increased
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30 355 for the rest two categories (i.e. more than 3 and less than or equal to 5 bed density and more than 5 bed
31
32 356 density). The association of beds density in the both models indicates that sample countries with less
33
34 357 than 1 bed density have lower technical efficiency of its health systems. Furthermore, the primary
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36 358 education completion rate was significantly negatively associated with the inefficiency score in the
37
38 359 Tobit model which indicates that countries with higher percentage of primary education completion rate
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40 360 have higher health system efficiency. Similar association was observed in the bootstrap model. In case
41
42 361 of population density, we found in the both models that countries having more than 200 population per
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44 362 square kilometre were more efficient in their health system efficiency compared to the countries with
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46 363 less than or equal to 100 population per square kilometre.
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51 365 **Sensitivity of the efficiency scores**

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53 366 We conducted sensitivity analysis using various combinations of input and output variables. In all of
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55 367 these cases the average of the efficiency scores varied from 0.812 to 0.936. The most sensitive
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57 368 combination was found while using the HALE at age 60 as the outcome variable. The efficiency score
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59 369 changed from 0.919 (main model) to 0.812 (considering input as HALE at age 60) (Figure 2).
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(Figure 2. will be inserted here)

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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; 95% 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.

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381 DISCUSSION

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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.

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3 396 It was observed that the average of the efficiency scores increased from the low and lower-middle-
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5 397 income countries to high-income countries. An important policy implication of this study could be that
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7 398 the technically inefficient low-income countries on average can improve their health systems outcome
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9 399 by 8.7%, middle income country by 8.6%, and high income country by 6.6% using the existing levels
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11 400 of per-capita health expenditure. An international study found a similar conclusion that health systems
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13 401 performance is most efficient in the developed countries, according to simple efficiency scores (64).
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16 402 The overall healthcare efficiency in different countries varied considerably (65,66). Among the low-
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18 403 and lower-middle income studied, one country demonstrated the most efficient health systems
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20 404 (Bangladesh). This county has both technical and scale efficient health systems, like the high-income
21
22 405 countries (Japan, Singapore, and Cyprus) (67). A possible reason for the high efficiency of these LMICs
23
24 406 could be a focus on infant mortality and child health as prioritized in past Millennium Development
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26 407 Goals and in current Sustainable Development Goals agendas, which relates to the outcome variables
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28 408 used in this study.
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31 409 The DEA result showed that more than 60% of the low- and lower middle income countries had health
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33 410 system efficiency greater than 90%. This result implies that these countries produce good health at low
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35 411 cost and therefore make good use of health systems resources (68). This result suggests that it is possible
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37 412 for countries to have a high-efficiency score with poor health outcomes because of their low expenditure
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39 413 on resources and increasing returns to scale production function. In other words, given their moderate
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41 414 consumption of inputs and challenging social environments, these countries can achieve good health
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43 415 outcomes, relative to the other countries. Similar findings were observed for Mexico and Turkey relative
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45 416 to other countries in a study of the OECD countries (39). It should be noted that this study only used
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47 417 per-capita health expenditure and there are other factors that influence health outcomes as well. For
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49 418 example differences in life expectancy and infant mortality between populations can be due to lifestyles,
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51 419 preferences (56,69,70) social class, occupation (71) and environmental factors (72,73). On a more
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53 420 macroscopic level, the results could also be impacted by a variety of contextual factors among countries
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55 421 such as different political institutions, economic landscapes, health-seeking behaviour patterns and
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57 422 burden of diseases among other things. However, in this study, we attempted to address by including
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3 423 variables addressing the number of physicians, number of inpatient beds, and population density, along
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5 424 with two environmental factors namely primary completion rate of relevant age group and smoking
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7 425 prevalence among the adult male population to take into consideration some of this variation. The
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9 426 results showed that more than three and less than five beds per 1000 population significantly influenced
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11 427 the efficiency score. A low number of beds cannot serve a large proportion of the population and
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13 428 therefore the systems may be inefficient. Similarly, a high number of beds may often be left unused and
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15 429 make the health systems inefficient. The countries having more than 200 people living per square
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17 430 kilometre had a higher level of efficiency in their health systems.
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22 432 A limitation of DEA methodology is that it works in a deterministic way, meaning that the results
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24 433 entirely depend on the numeric values in the dataset. As the DEA approach compares DMUs, the
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26 434 number and nature of DMUs in the data set can noticeably change the results. For example, if a more
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28 435 efficient country is added to the dataset, it would move the frontier, causing some of the efficiency
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30 436 scores of other countries to fall. This is a key aspect of the methodology used.
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33 437 Additionally, it is important to note that the use of a different set of variables might have generated
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35 438 different conclusions. In the future, if additional data become available for a larger number of countries
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37 439 in the region, the number of variables analyzed could be increased to include an understanding with a
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39 440 greater degree of complexity in health system efficiency.
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43 441 Another data limitation is the comparability of health expenditures among the Asian countries. While
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45 442 recognizing that it is not possible to solve the inherent issues, we made an attempt to minimize it. Since
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47 443 the actual amount of healthcare expenditure across different countries may not be comparable due to
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49 444 the difference in purchasing power parity across countries, we used health expenditures as constant of
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51 445 2011 in PPP as an input in the DEA model (39). Also, when we included health expenditure at current
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53 446 USD per capita as an input in the DEA model we found that the efficiency score did not change
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55 447 significantly.
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3 448 We applied sensitivity analysis in an attempt to overcome these limitations (Figure 2.) Our results were
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5 449 consistent while using several combinations of inputs and outputs variables which is reassuring and
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7 450 strengthens the findings from this study.
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13 452 **CONCLUSIONS**

15 453 This study provides an empirical picture of the technical efficiency of the healthcare systems of 46
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17 454 Asian countries. It found that inefficiency exists in the healthcare systems of most of the countries
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19 455 studied, however, the results point to three high-income and one lower-middle-income country which
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21 456 efficiently used healthcare systems resources. The interpretation of the inefficient countries identified
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23 457 through this study is that they can improve health outcomes using the current level of per-capita health
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25 458 expenditure. These countries could use these results to direct their attention to benchmarking their
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27 459 health systems within their regional or another comparative group in order to understand their health
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29 460 system performance in a more detailed way. This study addresses the need to understand efficiency
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31 461 issues, as well as potentially identify good examples of countries which efficiently allocate and use
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33 462 resources to make their healthcare systems more technically efficient. It narrows a gap in the literature
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35 463 as there are few countries studying healthcare efficiency in Asia and looking comparatively in this
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37 464 manner.
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56 472 **Contributors**

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648 Tables

649 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

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3	Kazakhstan	0.695	0.882	0.788	1
4	South Korea	0.886	0.972	0.911	-1
5	Kuwait	0.674	0.885	0.762	-1
6	Kyrgyz Republic	0.806	0.941	0.856	1
7	Laos	0.818	0.889	0.920	1
8	Lebanon	0.746	0.910	0.820	1
9	Malaysia	0.778	0.927	0.839	1
10	Maldives	0.730	0.944	0.773	-1
11	Mongolia	0.737	0.896	0.823	1
12	Myanmar	0.743	0.872	0.852	1
13	Nepal	0.861	0.932	0.924	1
14	Oman	0.692	0.896	0.772	-1
15	Pakistan	0.827	0.889	0.930	1
16	Philippines	0.779	0.916	0.850	1
17	Qatar	0.677	0.903	0.749	-1
18	Saudi Arabia	0.624	0.871	0.716	-1
19	Singapore	1.000	1.000	1.000	0
20	Sri Lanka	0.904	0.985	0.917	-1
21	Syria	0.818	0.848	0.964	1
22	Tajikistan	0.856	0.964	0.888	-1
23	Thailand	0.791	0.956	0.828	-1
24	Timor-Leste	0.823	0.903	0.912	1
25	Turkey	0.710	0.916	0.776	-1
26	Turkmenistan	0.639	0.859	0.743	1
27	United Arab Emirates	0.691	0.889	0.777	1
28	Uzbekistan	0.784	0.947	0.828	-1
29	Vietnam	0.845	0.996	0.849	-1
30	Yemen	0.727	0.826	0.881	1
31	Mean (95% CI)	0.780	0.919	0.847	
32		(0.752-0.808)	(0.905-0.933)	(0.824-0.87)	-
33	Median	0.772	0.913	0.834	-
34	Minimum	0.624	0.812	0.716	-
35	Maximum	1	1	1	-

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

Variable	Tobit regression		Bootstrap analysis	
	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)	-
Considering inefficiency <=0.				
Observations summary	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	

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653 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%

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656 **Figures**

657 Figure 1. Association across health systems input and outcome

658 Figure 2. Results from the sensitivity analysis of efficiency scores

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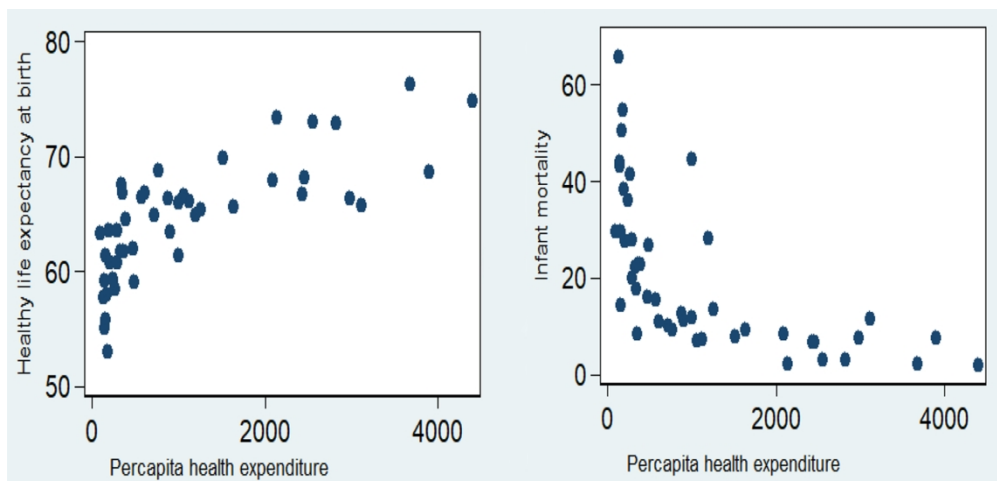


Figure 1. Association across health systems input and outcome

189x91mm (300 x 300 DPI)

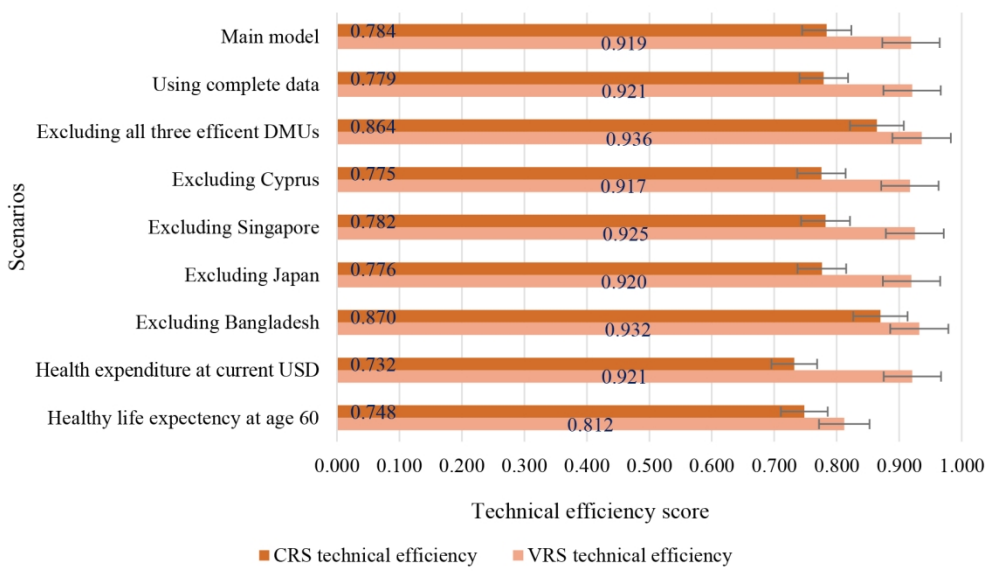


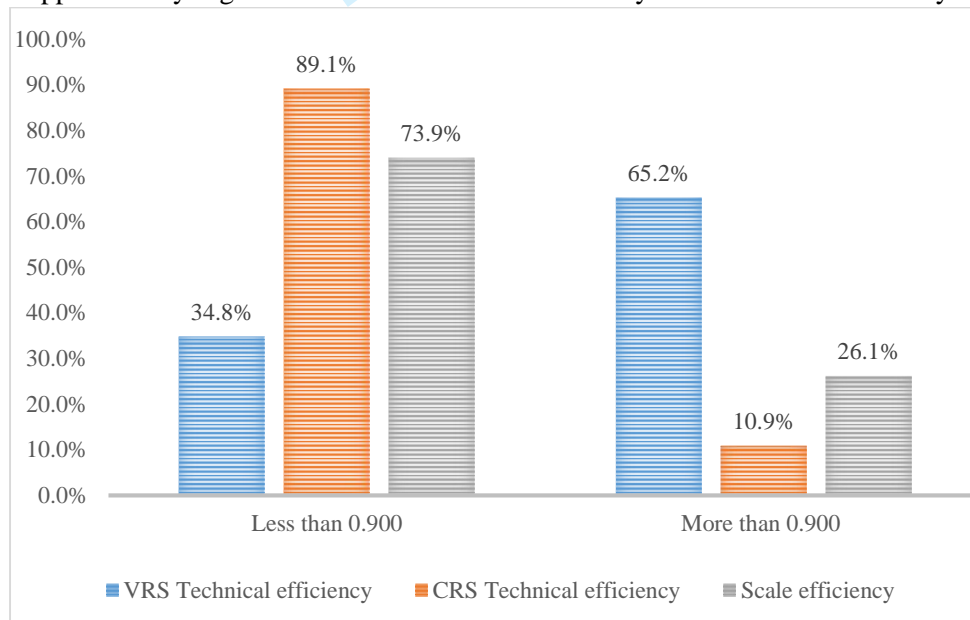
Figure 2. Results from the sensitivity analysis of efficiency scores

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



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60STROBE 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.