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RESEARCH ARTICLE

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Healthcare systems and Covid19: Lessons to be learnt from efficient countries

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Abstract

Background: The novel coronavirus is rapidly spreading over the world and puts the health systems of countries under intense pressure. High hospitalization levels due to the pandemic outbreak have caused the intensive care units to work above capacity.

Purpose: A data envelopment analysis (DEA) based modelling approach was developed to evaluate the effectiveness of regions (i.e. city, country or clinical commissioning groups) against the pandemic outbreak. The objective is to enable related authorities better manage the struggle against the outbreak and put in place the emergency action plans immediately.

Methodology/Approach: DEA method was used to measure the efficiency scores of countries. Super efficiency DEA method was also applied to countries based on the level of efficiencies they have achieved. Sixteen countries were selected that have been facing with Covid19 pandemic outbreak for at least 5 consecutive weeks after their 100th confirmed case.

Results: A total of 80 DEA models were developed, that is, 16 DEA models for each week. The percentage of efficient countries decreased dramatically over time, from 43.75% in the first week to 25% in the fifth week. Unlike most European countries, China and South Korea increased their effectiveness after first week of implementing all the necessary measures.

Conclusion: This study sheds light into better understanding the effectiveness of policies adopted by countries and their management strategy in dealing with Covid19 pandemic. Our model will enable political leaders to identify inadequate policies as quickly as possible and learn from their peers for more effective decisions.

KEYWORDS

Covid19, data envelopment analysis, decision support system, pandemic outbreak, region

1 | INTRODUCTION

Coronaviruses are a large family of viruses that can cause a variety of conditions, from common cold to more severe diseases, such as acute respiratory syndromes.

The first case was reported to the World Health Organization on 31 December 2019, cases of unknown pneumonia in Wuhan, China.[1] Since then, the city of Wuhan has taken unprecedented countermeasures against the outbreak, including closure of schools and business.

Despite these measures, the spread of the disease was not contained, and the beast is spreading very fast, so far effecting 213 countries worldwide. As of 24 April 2020, there are 2,631,839 confirmed Covid19 cases and 182,100 deaths.[2]

The world has experienced and struggled with numerous outbreaks and pandemics in the past, such as cholera, black plague, typhoid and influenza, but nothing like Covid19, disrupting every aspect of our lives. A sudden influx of patients to hospitals within a very short period of time, meant that even the most advanced healthcare systems around the world were unable to cope with the demand, and resources were stretched to its limit (e.g., beds, ventilators, personal protective equipment's, intensive care beds, doctors and nurses), forcing some countries to construct new Covid19 hospitals and departments within days and weeks.

Covid19 has prompted the scientific community to research on a wide range of issues, the most pressing been the search for therapeutics and vaccines; modelling the spread of the disease and expected mortality; capacity planning of hospitals; the impact on supply chain logistics and the economy, and association of meteorological factors and disease spread.[3]

However, no studies have been conducted to determine how efficient and effective countries are in terms of using scarce hospital resources to treat Covid19 patients, in the form of benchmarking, thus the opportunity of healthcare senior decision makers and political leaders to learn from best practices. They will be able to understand where their country and hospitals are heading in such a global disaster in terms of demand-capacity. Political leaders can determine the cities of their country which need to be considered more in terms of emergency action plan, specify how to optimize their limited resources with minimal loss.

Advanced statistical modelling is typically carried out for benchmarking organisations/institutions, e.g., multilevel modelling. However, the main reasons to use DEA method are as follows: (1) 'DEA method enables to compare variables with "the best value" whereas statistical methods analyse the variables based on "average value" using central tendency approach',[4] and (2) There are multiple inputs and outputs, where DEA is the only methodology that is able to deal with such datasets. In this study, we developed a data envelopment analysis (DEA) based modelling to determine the efficiency levels of countries (out of the selected 16 nations) with respect to healthcare systems preparedness (in the form of availability of resources, i.e. number of physicians and hospital beds), demography (i.e. population, elderly people and age) and Covid19 confirmed cases.

We collected weekly number of Covid19 cases for each country after 100th confirmed case, as significant increase is observed after 100th case, where intensive care units have reached intolerable levels. Note that the date that any country reaches the 100th confirmed case is different. A total of 16 countries (See Table 1) is selected that had the outbreak for at least 5 consecutive weeks after their 100th confirmed case (as of 11 April 2020).

DEA is an extremely popular technique applied to a wide range of sectors, including health, education, agriculture, finance and manufacturing services.[5] DEA gives a more meaningful index of comparative performance, establishing both the opportunities of improvement for healthcare services and reliable rankings for countries. DEA replaces multiple efficiency ratios by a single weighted sum of outputs over the weighted sum of inputs. The strength and ease of use of this method has attracted many researchers to develop models that rank hospital departments; compare healthcare services, and establish the efficiencies of clinics (i.e. surgery, gynaecology) in hospitals between countries[6–12]).

Using the DEA-based modelling approach, this study will enable healthcare organizations and governments to develop an effective strategy around resource planning and use (now and in the future) by comparing most effective nations in the fight against Covid19, and the opportunity to learn from those that are highly efficient. Furthermore, assessing weekly changes on efficiency levels of countries and better understanding whether the measures taken and implemented plans are sufficient or not, will enables us to assist organizations and governments to reallocate effectively and efficiently related resources (i.e., staff, beds, budgets), bring the regions struggling with the Covid19 outbreak under control, and allow us to debate the efficiencies of action plans against Covid19.

The DEA and the super efficiency methodology are explained in Section 2; Section 3 presents the DEA-based modelling framework, where results are presented in Section 4, and finally Section 5 concludes the article.

TABLE 1 A summary of confirmed Covid19 cases and dates of the first 100th cases in the selected countries

Decision making units (DMUs)	Countries	Total number of cases	Number of days since the 100th confirmed case (days)	Dates the 100th case was confirmed case
DMU1	United States	501560	39	10.03.2020
DMU2	Spain	157022	39	10.03.2020
DMU3	Italy	147577	47	02.03.2020
DMU4	Germany	117658	41	08.03.2020
DMU5	France	90,676	41	08.03.2020
DMU6	China	83,004	83	26.01.2020
DMU7	United Kingdom	70,272	36	13.03.2020
DMU8	Iran	68,192	44	05.03.2020
DMU9	Belgium	26,667	35	14.03.2020
DMU10	Switzerland	24,228	35	14.03.2020
DMU11	Netherlands	23,097	35	14.03.2020
DMU12	South Korea	10,450	50	28.02.2020
DMU13	Sweden	9685	35	14.03.2020
DMU14	Norway	6244	35	14.03.2020
DMU15	Japan	5347	49	29.02.2020
DMU16	Singapore	1909	41	08.03.2020

Abbreviation: DMU, decision making unit.

2 | METHODS

DEA is a method which is applied to determine the relative efficiencies of decision-making units (DMUs; e.g., hospitals, universities, countries) and has been widely used for a few decades.[13] DEA method with the Charnes-Cooper-Rodes (CCR) model was developed by Charnes et al.[14] and the DEA model with the Banker- Charnes-Cooper (BCC) model by Banker et al.[15] The DEA model is a fractional programming which maximizes a ratio dividing the virtual outputs by virtual inputs. The weights are calculated by means of mathematical programming technique.[13] The fractional programming was converted to linear programming by Charnes et al.[16] The fractional programming of our DEA model for DMU 1 (i.e., United States) is adapted from Cooper et al.[17] by considering 16 DMUs, seven inputs and three outputs shown in Table 2. The formulation of a typical DEA model is in Appendix. The objective function (1) maximizes the ratio dividing output by input. Constraint (Equation (2)) ensures each ratio for every DMU not to exceed 1. Constraints (3) and (4) are positive variables.[17]

The linear programming (adapted from Cooper et al.[17]) obtained from the fractional programming above is for DMU 1 in Appendix. The objective function (5) maximizes the weighted sum of outputs. Constraints (6) ensures the weighted sum of outputs is less than or equals to the weighted sum of inputs for every DMU. Constraints (7) and (8) are positive variables.[17]

DEA determines efficiencies in the range of [0, 1] and maximum efficiency score does not exceed 1. This therefore causes an uncertainty on the relative efficiency scores of each efficient DMU. In other words, the DEA model does not allow to rank efficient DMUs between each other. Andersen and Petersen[18] modified the DEA method by excluding the evaluated DMU in the comparison with all other DMUs. They provided the efficient DMU to have efficiency score greater than 1.

In our study, there exists a total of 16 constraints which compares the evaluated DMU with all DMUs (see Equations (2) and (6)). Several DMUs (e.g., China) are determined as efficient DMU as can be seen in the next

TABLE 2 Descriptive statistics of the input and output variables

Variables		Mean	Standard deviation	Minimum		Maximum	
				Country	Value	Country	Value
Inputs	Number of population ($\tilde{x}_1$)	15047192	341510669.1	Singapore	5850342	China	1439323776
	Median age ($\tilde{x}_2$)	40.84	4.22	Iran	30.3	Japan	47.3
	Percentage of people who is 70 or over ($\tilde{x}_3$)	11.64	3.86	Iran	3.18	Japan	18.49
	Physicians (per 1000 people) ($\tilde{x}_4$)	3.13	0.91	Iran	1.49	Norway	4.39
	Hospital beds (per 100,000) ($\tilde{x}_5$)	4.90	3.34	Iran	1.5	Japan	13.05
	Total confirmed cases of Covid19 ($\tilde{x}_6$)	65,804	87,202.12	Singapore	1189	United States	368196
	Weekly total confirmed cases of Covid19 ($\tilde{x}_7$)	28,250	47,977	Singapore	386	United States	203576
Outputs	Total confirmed deaths ($\tilde{y}_1$)	4036	4337.16	Singapore	6	United States	10,989
	Weekly total confirmed deaths ($\tilde{y}_2$)	2225	2538.43	Singapore	3	United States	7819
	Non-mortality rate of Covid19 ($\tilde{y}_3$)	93.82	4.25	United Kingdom	87.74	Singapore	99.50

section. To rank these DMUs with each other, we used super efficiency DEA method and remove the related constraint from our DEA model. For example, the Constraint (9) in Appendix was removed from the DEA model developed for China in the first week in the study period.

2.1 | Inputs and outputs

Figure 1 illustrates the hierarchy of the developed DEA model. The inputs are categorized into three groups: demography, cases and resources. *Number of populations* is the sum of people living in the country. *Percentage of people who is 70 or over* is a ratio that a specific age group including elderly and risky population in terms of Covid19 over the number of populations. *Median age* is the age that divides the population sorted from the youngest person to the eldest one into two equal parts. *Total confirmed cases of Covid19* is the cumulated number of cases from the time 100th case occurred. *Weekly total confirmed cases of Covid19* is the number of cases occurring in a specific time horizon. *Number of physicians* is the number of consultants per 1000 people. *Hospital beds* is the number of available beds per 100,000 people. The outputs are total confirmed deaths, periodical total confirmed deaths and non-mortality rate of Covid19. *Total confirmed deaths* are the cumulated number of deaths due to Covid19 from the time 100th case occurred. *Weekly total confirmed deaths* are the number of deaths due to Covid19 occurring in a specific time horizon. *Non-mortality rate of Covid19* is a ratio of people who is infected with Covid19 and not died over the total number of confirmed cases.

2.2 | Data

The data for a total of 222 regions (i.e., countries and continents) are recorded and the data we used in this study is from 31st December 2019 to 11th April 2020.

The data were provided in .csv format from (Roser et al.,[19] World Population Review[20]) and imported into Microsoft SQL Server version 12.0. for database programming and analysis purposes. The data period depends on the data of 100th confirmed case within each country. After initial checks, we decided to include 16 countries in our study according to the criterion explained in the next section. Therefore, the starting dates of the first week for each country differ due to the dates of 100th occurring case, that is, 10th of March 2020 for USA and 29th of January for Japan. Table 1 shows the starting dates of the first week and the number of days since the 100th confirmed case.

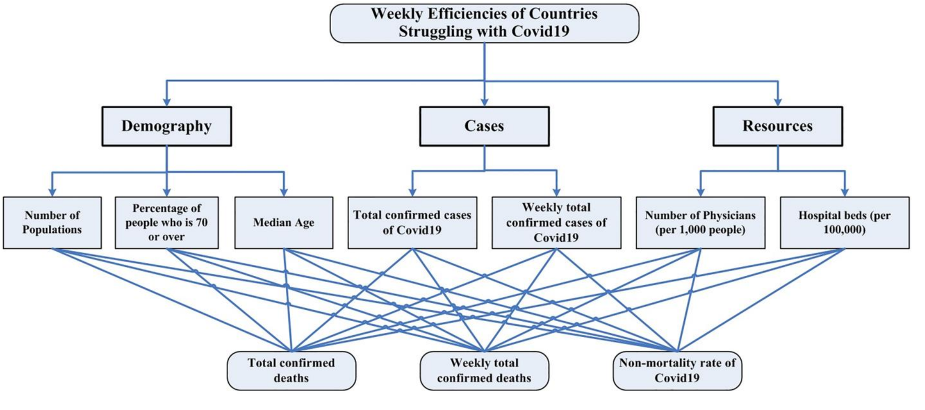

FIGURE 1 The hierarchy of the developed data envelopment analysis model for the Covid19 outbreak [Colour figure can be viewed at wileyonlinelibrary.com]

Table 2 gives the descriptive statistics of the input and output variables used in this study. The percentage of elderly people as well as median age is very high in Japan, whereas in Iran the opposite. There is a huge difference regarding total confirmed cases between the countries having minimum and maximum values, that is, the total confirmed cases in the United States is around six times the average value. The highest number of physicians per 1000 people in Norway and Japan uses around 13 beds per 100,000 people. The lowest values for these two inputs are observed in Iran. The highest number of deaths is observed to be in the United States, whereas UK with the highest mortality rate.

3 | A DEA-BASED MODELLING FRAMEWORK

The DEA-based modelling framework includes the five steps to determine weekly efficiencies of regions struggling with the pandemic outbreak.

1. Determine a study period for a region (i.e. city, country, clinical commissioning groups, provincial directorate of health and so on). The countries are ranked from the highest number of cases to the lowest. Countries are then selected based on the following criterion: to experience with Coronavirus outbreak for at least 5 weeks after their 100th confirmed case. Table 1 illustrates the countries, total number of cases and dates of 100th confirmed case at the end of week 5th[19]
2. Extract weekly data for the inputs and outputs in the study. The inputs are categorized into three groups: (1) demography (i.e., number of populations, percentage of people who are 70 or over and median age), (2) cases (i.e., total and weekly confirmed cases of Covid19) and (3) resources (i.e., number of physicians per 1000 people and hospital beds per 100,000). The outputs are total confirmed deaths, weekly total confirmed deaths and non-mortality rate of Covid19
3. We develop the DEA model by taking into account all the inputs and outputs mentioned in the previous step. A total of 26 constraints related to DMUs (16 constraints) and integer variables (10 constraints) along with the objective function maximizing the output of the model are considered in each model. If any DMU has an efficient score (i.e., 1), the DEA model is modified using the super efficiency method, so that we can rank countries from the most efficient to the least
4. The same process is repeated for the next period after the efficiency scores of all DMUs are calculated. We applied this process for five weeks
5. Rank and compare the determined regions over the selected period

4 | RESULTS AND DISCUSSION

A total of 80 DEA model was developed, that is, 16 DEA models for each week. Table 3 and Figure 2 illustrate the efficiency scores of the DMUs for each week over the study period.

Most countries have lost the ability to cope with Covid19 over time (from week 1 to week 5). While some countries (i.e. USA, UK, Germany and Belgium) in the first week were around the efficient boundary, they experienced a dramatic decrease in the following week. The efficiency scores gradually decreased in subsequent weeks. Countries (i.e. Spain, Italy, Switzerland and Netherlands) having low efficiency scores since the first week failed in the five-week period and their efficiency scores decreased further. Some of those countries with greater than one efficiency score (i.e. France, China, South Korea, Sweden and Norway) in the first week maintained their effectiveness and the rest experienced fluctuations. For example, China has become an efficient country consecutively during the 5-week period. As of May 2020, South Korea was still combatting with the disease and maintained efficiency for the entire study period, whereas Iran and Singapore were super-efficient countries.

TABLE 3 Efficiency and super efficiency scores of the DMUs for each week of the 5 weeks

Decision making units	Countries	1st week	2nd week	3rd week	4th week	5th week
DMU1	United States	0.96	0.86	0.84	0.84	0.82
DMU2	Spain	0.87	0.76	0.74	0.73	0.71
DMU3	Italy	0.76	0.69	0.68	0.67	0.65
DMU4	Germany	0.92	0.72	0.70	0.71	0.69
DMU5	France	1.01	0.79	0.78	0.76	0.72
DMU6	China	1.21	0.84	0.86	0.87	1.07
DMU7	United Kingdom	0.90	0.81	0.79	0.75	0.72
DMU8	Iran	2.11	2.09	2.05	2.01	2.05
DMU9	Belgium	0.93	0.82	0.80	0.77	0.74
DMU10	Switzerland	0.81	0.81	0.81	0.79	0.79
DMU11	Netherlands	0.81	0.78	0.76	0.73	0.72
DMU12	South Korea	1.03	0.85	0.95	0.99	0.99
DMU13	Sweden	1.09	1.05	1.03	1.00	0.97
DMU14	Norway	1.08	1.08	1.08	1.07	1.06
DMU15	Japan	0.96	0.94	0.94	1.33	0.93
DMU16	Singapore	4.52	62.62	54.77	123.67	59.39

Abbreviation: DMU, decision making unit.

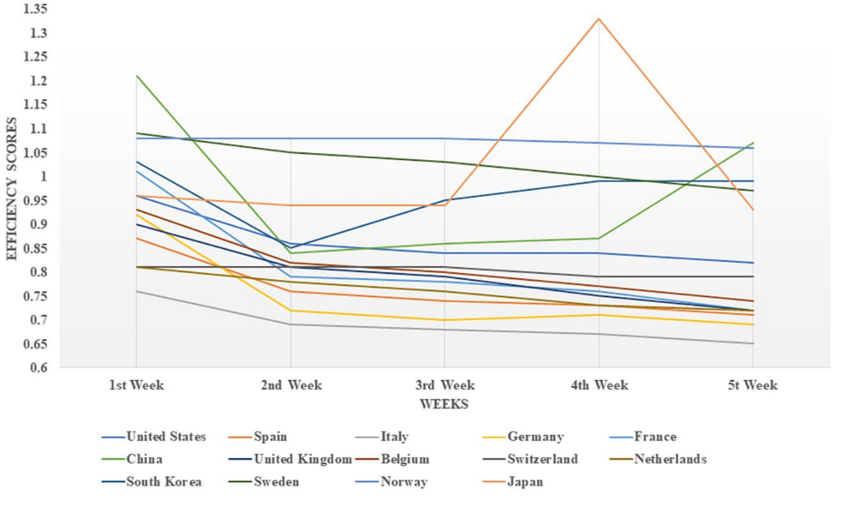

FIGURE 2 The graph for the first 5-week efficiency scores of the countries (Exc. Iran and Singapore) struggling with Covid19 [Colour figure can be viewed at wileyonlinelibrary.com]

Table 4 summaries the DEA-based modelling approach. This study provides a periodical-based DEA modelling framework for healthcare organizations and governments to more proactively manage the Covid19 outbreak process. Thus, in order to overcome this process with less material and moral losses, these institutions and organizations will be provided to update themselves and renew their perspective. For example, the followed paths

TABLE 4 The summary of the DEA-based modelling

	1st week	2nd week	3rd week	4th week	5th week
Maximum efficiency score	1.00	1.00	1.00	1.00	1.00
Minimum efficiency score	0.76	0.69	0.68	0.67	0.65
Number of efficient DMUs	7	4	4	5	4
Total number of DMUs	16	16	16	16	16
% Of efficient DMUs	43.75	25.00	25.00	31.25	25.00

Abbreviations: DEA, data envelopment analysis; DMU, decision making unit.

and the action plans which efficient countries have implemented in combating the pandemic outbreak will shed light on inefficient countries.

It is noteworthy that the number of tests generally performed in countries that can be considered successful in the fight against Covid19 is high. However, this may not be sufficient alone and the filiation teams investigating the source of Covid19 can be required to be established. The filiation teams to be established by the Ministries of Health determine the patients with Covid19 and reach out to those who are in contact with them. In this way, virus carriers have been identified before proceeding to the advanced stages of the disease, but the treatment process is started immediately. These people are also prevented from getting around in the community.

In regions where the Covid19 outbreak is partially or fully controlled, if positive cases are observed, the relevant regions (i.e. town, district and province) can be quarantined in a short time. Thus, mobility is prevented.

There may be reports of new signs about Covid19 in the printed and visual media. As the virus mutates, it may show different characteristics. In this process, countries, which are active in treatment and tracking, constantly update the algorithms in Covid19 Treatment protocols. Thus, they can be successful in reducing mortality rates and minimizing the number of intensive care and intubated patients. Until today, from the beginning of Covid19 outbreak, it has been revealed that herd immunity policy did not work, and this policy could destroy health systems. As a result, the number and percentage of efficient DMUs in Table 4 proved that countries need different policies rather than the current to control the pandemic.

5 | CONCLUSION

With this DEA-based modelling approach, some results have been reached with this study, where the activities of countries in the fight against Covid19 are taken into consideration. For example, when the inputs of the study are examined, it is seen that Iran is disadvantaged in terms of health system preparedness, and despite its disadvantage, it has the highest efficiency. It can be said that the positive effects of the younger population and outbreak management increased the effectiveness.

Although Japan's population average age is high, it has been observed that it is managing well, compared to other countries in terms of strength of its health system and policies they implemented during the pandemic.

While the average number of healthcare workers in countries analysed within the scope of the study is 11.63 per 1000 people, this number in America is 9,73; the average bed capacity is 3.13 per 100,000 people, and 2.57 in USA.

In all low-productivity countries, such as Spain, Italy, Netherlands and Switzerland, the average age of its population is above the average of the remaining countries in the study. However, they are the more developed countries having advanced and modern health systems. These low-efficient countries need to urgently change their outbreak management policies to turn their age disadvantage into an advantage.

As can be seen from our inputs and outputs, the mortality rate and spread of the virus do not depend on a single factor. With the combination of a few negative factors, such as elderly population average, health conditions, and poor management policies, the efficiency decreases gradually.

This study can guide the organizations on outbreak management policies and the analysis of the current situation of the countries. In addition, the results obtained from the study and especially the epidemic management policies of the countries with high effectiveness have been analysed and the basis has been established for the preparation of a guide for combating the Covid19 outbreak.

We considered only 16 countries in this study due to the reasons explained in the previous sections. However, the study can be further extended by including more countries, longitudinal data considering more than 5 weeks, additional inputs (e.g., total number of tests, weekly number of tests, number of intensive care units) and output (e.g., total number of recovered patients and weekly number of recovered patients). We only used seven inputs and three outputs, and additional variables could have been considered, such as the number of tests for Covid19 per week. During the pandemic outbreak, researchers might have difficulties in accessing data, however, organizations such as WHO and/or governments can make relevant data available for research purposes.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENTS

The paper does not require any human/animal subjects to acquire ethics approval.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX

$$Max\ \theta = \frac{u_1 y_{11} + u_2 y_{21} + u_3 y_{31}}{v_1 x_{11} + v_2 x_{21} + v_3 x_{31} + v_4 x_{41} + v_5 x_{51} + v_6 x_{61} + v_7 x_{71}} \tag{1}$$

$$\frac{u_1 y_{1j} + u_2 y_{2j} + u_3 y_{3j}}{v_1 x_{1j} + v_2 x_{2j} + v_3 x_{3j} + v_4 x_{4j} + v_5 x_{5j} + v_6 x_{6j} + v_7 x_{7j}} \leq 1 \tag{2}$$

$$v_1,\ v_2, v_3, v_4, v_5, v_6, v_7 \geq 0 \tag{3}$$

$$u_1, u_2, u_3 \geq 0 \tag{4}$$

$$Max\ \theta = \mu_1 y_{11} + \mu_2 y_{21} + \mu_3 y_{31} \tag{5}$$

$$\mu_1 y_{1j} + \mu_2 y_{2j} + \mu_3 y_{3j} \leq v_1 x_{1j} + v_2 x_{2j} + v_3 x_{3j} + v_4 x_{4j} + v_5 x_{5j} + v_6 x_{6j} + v_7 x_{7j} \tag{6}$$

$$v_1,\ v_2, v_3, v_4, v_5, v_6, v_7 \geq 0 \tag{7}$$

$$\mu_1, \mu_2, \mu_3 \geq 0 \tag{8}$$

where, u_s is the weight of output s, v_i is the weight of input i, y_{sj} is the value of output s for decision making unit (DMU) j, and x_{ij} is the value of input i for DMU j, $j = 1, 2, \ldots, 16$

$$\mu_1 y_{16} + \mu_2 y_{26} + \mu_3 y_{36} \leq v_1 x_{16} + v_2 x_{26} + v_3 x_{36} + v_4 x_{46} + v_5 x_{56} + v_6 x_{66} + v_7 x_{76} \tag{9}$$

where, u_s is the weight of output s, v_i is the weight of input i, y_{s6} is the value of output s for DMU China, x_{i6} is the value of input i for DMU China.