Measuring efficiency of nations in Multi Sport Events: A case of Commonwealth Games XIX

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Abstract

This paper used a data envelopment analysis (DEA) to measure the performance of the nations participating in the Commonwealth Games. To increase the consistency of the research, multiple models were employed to validate the result, but the nature of the input and output remained same throughout the paper. The objective of this study was to establish some realistic targets in terms of number of players for all participant countries and evaluations of their performance as well as benchmarks against the most efficient country. This study would help the nations optimize the size of their players to maximize the outcome in terms of the number of medals won in sporting events.

Key words: Performance measurement, data envelopment analysis, efficiency, Commonwealth Games.

1 Introduction

The XIX Commonwealth Games 2010 (CWG 2010), held in Delhi on October 2 through 14, were a major success. The games attracted the participation of 71 nations who are part of the Commonwealth Games Associations (CGAs), representing one-third of the world's population. Approximately 6,500 athletes and team officials competed in 17 sports and four para-sports in 290 sessions. In the end, two new world records (power lifting and athletics) and 108 new Commonwealth records were established.

In general, athletes compete on behalf of the nation, and ranking is based on the total number of gold medals won by each country. Usually the gold medals are worth more than silver ones, which are worth more than bronze ones. At the end of the games, the sum of the medals is computed and used for ranking the participating countries.

2 The Commonwealth Games

The Commonwealth is an alliance of 53 nations across the globe. Although there are 53 Commonwealth nations, presently 71 CGAs can enter a team in the

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Commonwealth Games, as one nation can have multiple CGAs. For example, the United Kingdom is a single Commonwealth nation that consists of seven CGAs: Scotland, Wales, England, Guernsey, Isle of Man, Jersey, and Northern Ireland. The Commonwealth Games are also known as the Friendly Games as they are held between a family of nations that share a common history. Her Majesty Queen Elizabeth II is the head of the Commonwealth and patron of the Commonwealth Games Federation (CGF). Prince Edward, HRH the Earl of Wessex KCVO, is the vice patron.

The first edition of these prestigious games took place in Hamilton, Canada, in 1930, with 11 countries and 400 athletes competing six sports. Since then, 19 games have been held, being scheduled every four years (except for 1942 and 1946 due to World War II). From 1930 to 1950, the games were known as the British Empire Games, from 1954 to 1966 they were the British Empire and Commonwealth Games, and in 1970 and 1974 they were known as the British Commonwealth Games. Finally, in 1978, in Edmonton (Canada), the name of the games were changed to the Commonwealth Games, a name that remains to today (http://www.thecgf.com/games/story.asp)

The number of teams competing in the Commonwealth Games depends on the number of nations in the Commonwealth itself as, from year to year, nations are admitted and suspended for various reasons. Since 2002, there has been an increase in attendance as all Commonwealth nations have been represented in all editions of these prestigious games. As the number of nations taking part has increased, so too have the number of athletes participating, sports included, and events held.

Although various multi-sport events are held globally, the Commonwealth Games are a unique, world-class, multi-sport events held once every four years. Table 1 summarizes a few of the most popular multi-sport events along with their descriptions.

There is still great diversity in the relative performance of athletes, as indicated by nations' rankings, which makes it difficult to understand how and where to improve. This article employs a data envelopment analysis (DEA) to compare the relative efficiency of the utilization of resources (i.e., players) by nations who have won medals in the XIX Commonwealth Games 2010 in Delhi. In an attempt to find new ways to establish alternative performance rankings, this paper uses the DEA model with an output orientation. The total number of players from each country is used as an input, whereas the outputs are the total number of medals (gold, silver, and bronze). The unit of analysis is all countries that won at least one medal.

The objective of the paper is twofold. In the first stage, the paper ranks the nations in terms of all medals won and gold medals won by calculating their relative efficiency. In the second stage, the paper decides the optimal number of players to be sent to win medals in the CWG. To achieve the second objective, a DEA model with input orientation is used.

The paper is organized as follows: Section 2 discusses the DEA models used for evaluating the performance of the participating countries. Section 3 presents an empirical study using different DEA models. Section 4 presents the methodology, while Section presents the findings. Section 6 contains conclusions and discussions.

Table 1 Major International Multi-sporting Events and Descriptions

Event	Description
Summer Olympics	The world's premier multi-sport and multi-country sporting competition, held every four years.
Winter Olympics	The winter sports version of the Olympic Games, held every four years, two years after the Summer Olympics.
Paralympic Games	A major event for athletes with disabilities, now run in conjunction with the Summer Olympic Games, every four years.
Commonwealth Games	Held every four years, most recently held in Glasgow in 2014.
Asian Games	The Asian Games, officially known as Asiad, is a multi-sport event along the lines of the Olympics, though only for Asian countries. They were first held in 1951.
Gay Games	The Gay Games, held every 4 years, is open to all who wish to participate, without regard to sexual orientation.
Military World Games	For military athletes from more than 100 countries.
European Games	A multi-sport event along the lines of the Summer Olympic Games, though limited to athletes from European nations.
Youth Olympics	The Youth Olympic Games is an international multi-sport event, held every four years for athletes aged 14 to 18.

Source: Wood 2010

3 Data Envelopment Analysis

DEA is a non-parametric approach developed by Farrel (1957). Charnes, Cooper and Rhodes (1978) subsequently made a major breakthrough in the same field. Since then, DEA has been widely accepted, particularly in its application to public sector operations, such as education and healthcare, where the policy objectives are vaguely defined as a functional form of input–output relationships. DEA is a non-parametric technique for assessing the relative performance of a set of similar units. Each decision making unit (DMU) has a certain number of inputs and produces a certain number of outputs. In this case, the countries that won at least one medal are considered DMUs. The aim is to identify which country is operating efficiently in converting the inputs into outputs in an optimum way, indicating that it belongs to the efficiency frontier, and which DMUs do not operate efficiently (i.e., not able to convert the inputs to outputs) and therefore should make appropriate adjustments in their input and/or output in order to attain efficiency.

DEA has been applied in a number of different areas, such as hospitality, healthcare (hospitals, doctors), education (schools, universities), banks, manufacturing, benchmarking, management evaluation, energy efficiency, fast food restaurants, and retail stores (Cooper, Seiford, & Tone, 2004; Cooper, Thompson, & Thrall, 1996; Debnath & Shankar, 2009; Debnath & Shankar, 2013; Färe, Grosskopf, & Lovell, 1994; Rhode & Southwick, 1993; Sinauny-Stern, Mehrez, & Barboy, 1994; Thenassoulis & Dunstan, 1994; Tomkins & Green, 1988). Anderson (1995) compiled more than 360 papers on the application of DEA, and there has been a constant increase in the number of DEA applications reported on Portland State University's website. DEA is used to compute a score that defines the relative efficiency of a particular DMU versus all other DMUs observed in the sample. The various inputs and outputs are assigned optimal weights by which the output can be maximized.

The two most frequently applied models used in DEA are the CCR model, named after Charnes et al. (1978), and the BCC model, named after Banker, Charnes, and Cooper (1984). The basic difference between these two models is the returns to scale (RTS). Whereas the latter takes into account the effect of variable RTS (VRTS), the former restricts DMUs to operate with constant RTS (CRTS). Charnes et al. (1978) developed DEA to evaluate the efficiency of public sector non-profit organizations. DEA aims to measure how efficiently a DMU uses the resources available to generate a set of outputs. DMUs can include manufacturing units, departments of big organizations (e.g., universities, schools, bank branches, hospitals, power plants, police stations, tax offices, defense bases), a set of firms, and even practicing individuals like medical practitioners.

Efficiency measurement is a commonly used tool to measure the performance of any DMU and estimate the relative efficiency of the DMUs. Generally speaking, simple efficiency can be calculated using a ratio of outputs to inputs, as given in Equation 1.

$$\text{Efficiency} = \text{Outputs} / \text{Inputs} \qquad (1)$$

However, in DEA, multiple inputs and outputs are linearly aggregated using weights. Therefore, the efficiency is measured as a ratio of:

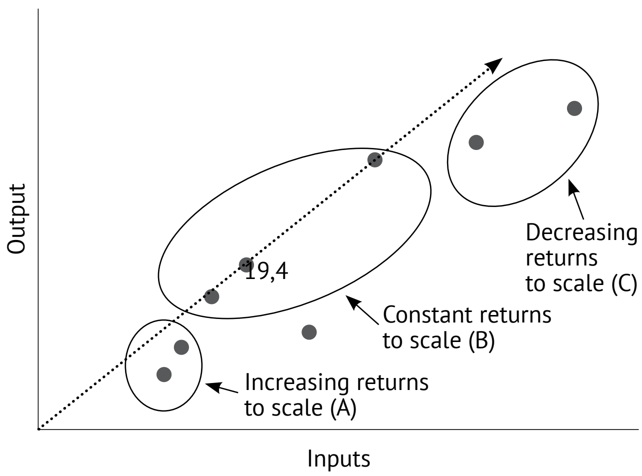
$$\text{Efficiency} = \frac{\text{Weighted Sum of Outputs}}{\text{Weighted Sum of Inputs}} \qquad (2)$$

$$\text{Efficiency} = \frac{\sum_{j=1}^{J} v_j y_j}{\sum_{i=1}^{I} u_i x_i} \qquad (3)$$

where u_i is the weight assigned to input x_i and v_j the weight assigned to output y_j as given in Equation 3.

DEA models assume CRTS and VRTS. In a CRTS, the change in the output is proportionate to the change in the input. However, in a VRTS, the change in output is not proportional to the change in the input. Figure 1 shows various types of RTS.

Figure 1: Various returns to scale in DEA



Point A represents the units present in the region of increasing RTS. If we assume that an increase in inputs will increase outputs above the dashed line that would result in a greater than proportionate increase in outputs. If the units increase their inputs, the ratio of inputs to outputs will change so that the unit moves along the efficiency horizon and the unit will move into the region of CRTS. Point B falls into a CRTS.

Point C falls in the region of decreasing RTS or non-increasing RTS. This implies that increases in inputs will result in a ratio of inputs to outputs that continue to fall along the frontier. If that assumption holds, increases in inputs will result in proportionately smaller increases in output. The only point not identified by any region is an inefficient unit.

4 DEA and Sports

The existing literature shows that researchers have used diverse mathematical models to study the results of multi-sport games. Lozano, Villa, Guerrero, and Cortes (2002) and Estellita Lins, Gomes, Soares de Mello, and Soares de Mello (2003) analyzed the relative efficiency of the participating countries that won at least one medal in Olympic Games in relation to their available resources, where inputs were the country's population and gross domestic product (GDP) and outputs were the numbers of gold, silver, and bronze medals.

Benicio, Bergiante, and Soares (2013) applied the free disposal hull (FDH) model to measure the efficiency of the Winter Olympic Games held in 2010. The authors used the BCC input-oriented model, where the number of athletes was considered as an input and the number of gold, silver and bronze medals was considered as output parameters. Meanwhile, Lozano et al. (2002) measured the performance of the nations at the Summer Olympics Games using DEA, where the gross national product (GNP) and population of the participating countries were input variables while the output variables were the number of gold, silver, and bronze medals. Zhang, Li, Meng, and Liu (2009) used DEA to measure the performance of nations of the Olympic Games. However, the authors used lexicographic preference in the DEA. Churilov and Flitman (2006) used several social economics variables—not only GDP and population, but also the DEL index and IECS index—to evaluate the performance and rank the participating nations in the Sydney Olympics held in 2000. Cesaroni (2011) used the FDH model to analyze the efficiency of Italian drivers and vehicle agencies. Other important European leagues have been investigated using the DEA model as well, such as the Spanish league (Gonzalez-Gomez & Picazo-Tadeo, 2010), the Italian Serie A (Bosca, Liern, Martínez, & Sala, 2009), the German Bundesliga (Haas, Kocher, & Sutter, 2004), and the French Ligue 1 (Jardin, 2009). Sexton and Lewis (2003) applied the two-stage DEA model to baseball and an apportion of the duties of a typical baseball club among the two operating units.

Dawson, Dobson, and Gerrard (2000a, 2000b) applied stochastic frontier analysis to investigate managerial efficiency in English soccer. A similar approach was used by Carmichael, Thomas, and Ward (2001) to investigate the production function in English association football. Haas (2003a, 2003b) used the DEA model to analyze the efficiency of the English Premier League and applied the DEA model to Major League Soccer. Barros and Garcia-del-Barrio (2008) estimated a stochastic frontier latent class model to analyze cost efficiency. Anderson and Sharp (1997) used deterministic non-parametric frontier to create a new measurement to evaluate the batsmen in baseball games. Carmichael, Thomas, and Ward (2000) applied DEA to formulate the production function in rugby games. Fezel and D'Itri (1997) also used deterministic non-parametric frontier to measure coaches' efficiency in basketball. The authors concluded that the results would help replace coaches and enhance teams' performance. Hadley, Poitras, Ruggiero, and Knowles (2000) used DEA in American football to evaluate the team's performance with respect to its potential. Scully (1994) applied stochastic frontier and deterministic frontier in American football and baseball, respectively, to study the relationship between coaches' performance in terms of the team and efficiency of its management.

5 Research Methodology

5.1 Model Selection

As the objective of the study is to optimize the number of players participating in the international games to maximize the efficiency of the team in terms of winning medals, an output-oriented model was selected for the same purpose. The BCC model was chosen as the change in the input does not guarantee a proportionate increase in the output. As previously discussed, the BCC model would have VRTS. The change in the number of medals (output) cannot be proportional to the number of players (input) in our case.

5.2 Data Collection

The data were collected from the CWG office in New Delhi, India. In total, 71 countries participated in the games, representing various region of the world, including the Caribbean, Asia, Oceania, Africa, Europe, and America. Approximately 4400 players participated, including 1700 females. The participating countries won 762 medals, which were nearly equally distributed among gold, silver, and bronze medals. Table 2 shows that, of the 71 participating countries, only 34 (approximately 47%) won medals in international sports events; of these, 23 countries (67%) won gold medals.

6 Findings

This paper performed an independent DEA of the 2010 Commonwealth Games held in India. In the DEA, the DMUs are considered to correspond to the participating nations that won at least one medal. Two models were used to analyze the performance of the medal-winning nations. In the first model, three output variables were considered: he number

Table 2 Highlights of Participating Nations and Medals Won

CODE	COUNTRY	REGION	GOLD	SILVER	BRONZE	TOTAL
AIA	Anguilla	Caribbean				0
ANT	Antigua and Barbuda	Caribbean				0
AUS	Australia	Oceania	74	55	48	177
BAH	Bahamas	Caribbean	1	1	4	6
BAN	Bangladesh	Asia			1	1
BAR	Barbados	Caribbean				0
BER	Bermuda	Americas				0
BIZ	Belize	Americas				0
BOT	Botswana	Africa	1		3	4
BRU	Brunei Darussalam	Asia				0
CAN	Canada	Americas	26	17	33	17
CAY	Cayman Islands	Caribbean	1			1
CMR	Cameroon	Africa		2	4	6
COK	Cook Islands	Oceania				0
CYP	Cyprus	Europe	4	3	5	12
DMA	Dominica	Caribbean				0
ENG	England	Europe	37	60	45	142
FLK	Falkland Islands	Americas				0
GAM	Gambia	Africa				0
GGY	Guernsey	Europe				0
GHA	Ghana	Africa		1	3	4
GIB	Gibraltar	Europe				0
GRN	Grenada	Caribbean				0
GUY	Guyana	Americas		1		1
IND	India	Asia	38	27	36	101
IOM	Isle of Man	Europe			2	2
IVB	British Virgin Islands	Caribbean				0
JAM	Jamaica	Caribbean	2	4	1	7
JEY	Jersey	Europe				0
KEN	Kenya	Africa	12	11	9	32
KIR	Kiribati	Oceania				0
LCA	St. Lucia	Caribbean			1	1
LES	Lesotho	Africa				0
MAS	Malaysia	Asia	12	10	13	35
MAW	Malawi	Africa				0
MDV	Maldives	Asia				0
MLT	Malta	Europe				0
MOZ	Mozambique	Africa				0
MRI	Mauritius	Africa			2	2
MSR	Montserrat	Caribbean				0
NAM	Namibia	Africa		1	2	3
NFK	Norfolk Island	Oceania				0
NGR	Nigeria	Africa	11	8	14	33
NIR	Northern Ireland	Europe	3	3	4	10
NIU	Niue	Oceania				0
NRU	Nauru	Oceania	1	1		2
NZL	New Zealand	Oceania	6	22	8	36
PAK	Pakistan	Asia	2	1	2	5
PNG	Papua New Guinea	Oceania		1		1
RSA	South Africa	Africa	12	11	10	33
RWA	Rwanda	Africa				0
SAM	Samoa	Oceania	3		1	4
SCO	Scotland	Europe	9	10	7	26
SEY	Seychelles	Africa		1	0	1
SHN	St. Helena	Americas				0
SIN	Singapore	Asia	11	11	9	31
SKN	St. Kitts and Nevis	Caribbean				0
SLE	Sierra Leone	Africa				0
SOL	Solomon Islands	Oceania				0
SRI	Sri Lanka	Asia	1	1	1	3
SVG	St.Vincent and The Grenadines	Caribbean				0
SWZ	Swaziland	Africa				0
TAN	Tanzania	Africa				0
TCA	Turks and Caicos Islands	Caribbean				0
TON	Tonga	Oceania			2	2
TRI	Trinidad and Tobago	Caribbean				0
TUV	Tuvalu	Oceania				0
UGA	Uganda	Africa	2			2
VAN	Vanuatu	Oceania				0
WAL	Wales	Europe	2	7	10	19
ZAM	Zambia	Africa				0

of gold, silver, and bronze medals won by a country in the CWG 2010. The DEA output is summarized in Table 3. The input variable was the total number of players representing a country across chosen sports events. In the second model, only one output variable was considered in terms of the number of gold medals won by the nations. The analysis of this model is presented in Table 4. The data set is heterogeneous in terms of the size of the nations and the GDP as the data set represents both poor and rich countries. India is the most populous country that participated in the game, while the Cayman Islands and Nauru are the least populated countries; their GDP is also small compared to India. The analysis primarily computes the relative efficiency of the nations participating in the game, irrespective of their size and economy. Both models are BCC output oriented, where the output (number of medals) is maximized under at most

Table 3 DEA Results Considering Three Outputs

No.	DMU	Score	Rank	Reference set (lambda)							
1	Australia	1	1	Australia	1						
2	Bahamas	1	1	Bahamas	1						
3	Bangladesh	0.175799	31	Bahamas	0.831169	Nigeria	0.168831				
4	Botswana	0.611111	14	Bahamas	0.909091	Nigeria	9.09E-02				
5	Canada	1	1	Canada	1						
6	Cayman Islands	0.430323	19	Australia	1.81E-02	Nauru	0.981865				
7	Cameroon	1	1	Cameroon	1						
8	Cyprus	0.618182	13	Bahamas	0.452941	Nigeria	0.270588	Singapore	0.276471		
9	England	1	1	England	1						
10	Ghana	0.356481	23	Bahamas	0.558442	Nigeria	0.441558				
11	Guyana	0.208633	30	Nauru	0.62069	Singapore	0.37931				
12	India	0.75	10	Australia	1						
13	Isle of Man	0.386935	21	Bahamas	0.883117	Nigeria	0.116883				
14	Jamaica	0.30529	26	England	4.29E-02	Singapore	0.957096				
15	Kenya	0.466896	17	Australia	0.202689	England	7.43E-02	Singapore	0.722994		
16	St. Lucia	1	1	St. Lucia	1						
17	Malaysia	0.501869	16	Australia	9.33E-02	Canada	0.310652	England	9.12E-02	Nigeria	0.504805
18	Mauritius	0.249191	28	Bahamas	0.597403	Nigeria	0.402597				
19	Namibia	0.426952	20	Bahamas	0.865169	Nigeria	2.04E-03	Singapore	0.132789		
20	Nigeria	1	1	Nigeria	1						
21	Northern Ireland	0.358951	22	Bahamas	0.104322	Nigeria	0.533035	Singapore	0.362643		
22	Nauru	1	1	Nauru	1						
23	New Zealand	0.7048	11	England	0.412541	Singapore	0.587459				
24	Pakistan	0.288394	27	Bahamas	0.398374	Nauru	8.13E-03	Singapore	0.593496		
25	Papua New Guinea	7.93E-02	34	England	3.30E-02	Singapore	0.966997				
26	South Africa	0.533079	15	Australia	0.152079	England	7.42E-02	Nigeria	0.231174	Singapore	0.542525
27	Samoa	0.335458	25	Australia	0.108808	Nauru	0.891192				
28	Scotland	0.336404	24	Australia	0.146703	England	0.250434	Singapore	0.602863		
29	Seychelles	0.243697	29	Nauru	0.689655	Singapore	0.310345				
30	Singapore	1	1	Singapore	1						
31	Sri Lanka	8.20E-02	33	Australia	1.31E-03	England	4.29E-02	Nigeria	0.320506	Singapore	0.6353
32	Tonga	0.628571	12	Bahamas	0.727273	St. Lucia	0.272727				
33	Uganda	0.169782	32	Australia	0.147668	Nauru	0.852332				
34	Wales	0.461319	18	Canada	0.249382	England	9.48E-02	Nigeria	0.655821		

the present input (number of players) consumption. Table 3 shows that countries like Australia, Bahamas, Canada, Cameroon, England, St. Lucia, Nigeria, Nauru, and Singapore were fully efficient countries in terms of winning medals, even though these countries differ in terms of their size and economic conditions.

VRTS is assumed to hold. The inputs represent the number of players representing their respective countries, which can be controlled by the countries. As this paper also measures the efficiency of countries in winning medals, the BCC output (O)-oriented model was considered for the analysis.

As Table 3 suggests, very few countries were fully efficient in terms of winning at least one medal in the game. For instance, Australia, Bahamas, Canada, Cameroon, England, Nigeria, Nauru, and Singapore are fully efficient countries (efficiency = 100%).

Table 4 presents the BCC (O)-oriented model, where the number of players are used as the input variable and the only output variable is the number of gold medals won by the participated nations in CWG 2010. Compared to the earlier analysis, a drastic change can be seen as the number of fully efficient countries dropped to three—namely, Australia, India, and Nauru.

Table 5 shows the benchmark of the inefficient countries under the BCC (O)-oriented models. This table summarizes the information from Tables 3 and 4, where Table 3 represents the model (called model 1) with three outputs and Table 4 represents one output (called model 2). In model 1, the numbers of output variables are the number of gold, silver, and bronze medals; model 2 has one output variable—namely, the number of gold medals won in the CWG 2010. The inferences have been drawn heavily from peer group analysis that plays a significant role in DEA modeling. The result is particularly significant for inefficient countries to improve their efficiency by referring to the peer group located on an efficient frontier. For instance, countries like Canada and Singapore are fully efficient countries in model 1 (efficiency = 100%; Table 3), which means these countries

Table 4 DEA Results Considering One Output (Gold Medal)

No.	DMU	Score	Rank	Reference set (lambda)			
1	Australia	1	1	Australia	1		
2	Bahamas	0.274148	14	Australia	3.63E-02	Nauru	0.963731
3	Botswana	0.201146	18	Australia	5.44E-02	Nauru	0.945596
4	Canada	0.549286	5	Australia	0.634715	Nauru	0.365285
5	Cayman Islands	0.430323	9	Australia	1.81E-02	Nauru	0.981865
6	Cyprus	0.404506	11	Australia	0.121762	Nauru	0.878238
7	England	0.534126	6	Australia	0.935233	Nauru	6.48E-02
8	India	0.513514	7	Australia	1		
9	Jamaica	0.138625	21	Australia	0.183938	Nauru	0.816062
10	Kenya	0.416659	10	Australia	0.380829	Nauru	0.619171
11	Malaysia	0.323261	13	Australia	0.494819	Nauru	0.505181
12	Nigeria	0.604069	4	Australia	0.235751	Nauru	0.764249
13	Northern Ireland	0.207937	17	Australia	0.183938	Nauru	0.816062
14	Nauru	1	1	Nauru	1		
15	New Zealand	0.168498	20	Australia	0.474093	Nauru	0.525907
16	Pakistan	0.233515	16	Australia	0.103627	Nauru	0.896373
17	South Africa	0.44283	8	Australia	0.357513	Nauru	0.642487
18	Samoa	0.335458	12	Australia	0.108808	Nauru	0.891192
19	Scotland	0.254096	15	Australia	0.471503	Nauru	0.528497
20	Singapore	0.919048	3	Australia	0.150259	Nauru	0.849741
21	Sri Lanka	6.06E-02	23	Australia	0.212435	Nauru	0.787565
22	Uganda	0.169782	19	Australia	0.147668	Nauru	0.852332
23	Wales	6.60E-02	22	Australia	0.401554	Nauru	0.598446

are able to use their resources (capability of the players) to win at least one medal. However, they are inefficient in model 2, as shown in Table 4, in terms of winning gold medals. Their efficiency scores are 0.549268 and 0.919048, respectively (see Table 4). Furthermore, if these two countries want to improve their performance, they need to refer to their peer group. Although the peers for Canada are Australia and Nauru (5th and 7th column of Table 4), Australia has more weightage (0.634715) than Nauru (0.365285). Hence, the most appropriate peer for Canada would be Australia in terms of improving the efficiency in winning gold medals. Similarly, for Singapore, the peers are Australia (0.150259

Table 5 Benchmarks According to Both Models

Sr. No	Country	Model 1 (Gold+ Silver+Bronze)	Model 2 (Gold Medal)
1.	Anguilla	N/A	N/A
2.	Antigua and Barbuda	N/A	N/A
3.	Australia	Australia	Australia
4.	Bahamas	Bahamas	Nauru
5.	Bangladesh	Bahamas	N/A
6.	Barbados	N/A	N/A
7.	Bermuda	N/A	N/A
8.	Belize	N/A	N/A
9.	Botswana	Bahamas	Nauru
10.	Brunei Darussalam	N/A	N/A
11.	Canada	Canada	Nauru
12.	Cayman Islands	Nauru	Nauru
13.	Cameroon	Cameroon	N/A
14.	Cook Islands	N/A	N/A
15.	Cyprus	Bahamas	Nauru
16.	Dominica		
17.	England	England	Nauru
18.	Falkland Islands	N/A	N/A
19.	Gambia	N/A	N/A
20.	Guernsey	N/A	N/A
21.	Ghana	Bahamas	N/A
22.	Gibraltar	N/A	N/A
23.	Grenada	N/A	N/A
24.	Guyana	Nauru	N/A
25.	India	Australia	Australia
26.	Isle of Man	Bahamas	N/A
27.	British Virgin Islands	N/A	N/A
28.	Jamaica	Singapore	Nauru
29.	Jersey	N/A	N/A
30.	Kenya	Singapore	Nauru
31.	Kiribati	N/A	N/A
32.	St Lucia	St Lucia	N/A
33.	Lesotho	N/A	N/A
34.	Malaysia	Nigeria	Nauru
35.	Malawi	N/A	N/A
36.	Maldives	N/A	N/A
37.	Malta	N/A	N/A
38.	Mozambique	N/A	N/A
39.	Mauritius	Bahamas	N/A
40.	Montserrat	N/A	N/A
41.	Namibia	Bahamas	N/A
42.	Norfolk Island	N/A	N/A
43.	Nigeria	Nigeria	Nauru
44.	Northern Ireland	Nigeria	Nauru
45.	Niue	N/A	N/A
46.	Nauru	Nauru	Nauru
47.	New Zealand	Singapore	Nauru
48.	Pakistan	Singapore	Nauru
49.	Papua New Guinea	Singapore	N/A
50.	South Africa	Singapore	Nauru
51.	Rwanda	N/A	
52.	Samoa	Nauru	Nauru
53.	Scotland	Singapore	Nauru
54.	Seychelles	Nauru	N/A
55.	St. Helena	N/A	N/A
56.	Singapore	Singapore	Nauru
57.	St. Kitts and Nevis	N/A	N/A
58.	Sierra Leone	N/A	N/A
59.	Solomon Islands	N/A	N/A
60.	Sri Lanka	Singapore	Nauru
61.	St.Vincent and The Grenadines	N/A	N/A
62.	Swaziland	N/A	N/A
63.	Tanzania	N/A	N/A
64.	Turks and Caicos Islands	N/A	N/A
65.	Tonga	Bahamas	N/A
66.	Trinidad and Tobago	N/A	N/A
67.	Tuvalu	N/A	N/A
68.	Uganda	Nauru	Nauru
69.	Vanuatu	N/A	N/A
70.	Wales	Nigeria	Nauru
71.	Zambia	N/A	N/A

Table 6 Ideal Number of Players in Two Situations (BCC input-oriented model)

Sr. No.	Country	Actual number of players	Ideal number of players under Model 1 (Gold+Silver+Bronze)	Ideal number of players under Model 2 (Gold Medal)
1.	Anguilla		N/A	N/A
2.	Antigua and Barbuda		N/A	N/A
3.	Australia	396	396*	396*
4.	Bahamas	24	24*	10
5.	Bangladesh	37	13	
6.	Barbados			
7.	Bermuda		N/A	N/A
8.	Belize		N/A	N/A
9.	Botswana	31	21	10
10.	Brunei Darussalam		N/A	N/A
11.	Canada	255	255*	143
12.	Cayman Islands	17	10	10
13.	Cameroon	25	25*	N/A
14.	Cook Islands		N/A	N/A
15.	Cyprus	57	36	25
16.	Dominica			
17.	England	371	371*	201
18.	Falkland Islands		N/A	N/A
19.	Gambia		N/A	N/A
20.	Guernsey		N/A	N/A
21.	Ghana	58	21	N/A
22.	Gibraltar		N/A	N/A
23.	Grenada		N/A	N/A
24.	Guyana	32	10	N/A
25.	India	407	285	206
26.	Isle of Man	33	17	N/A
27.	British Virgin Islands		N/A	N/A
28.	Jamaica	81	28	16
29.	Jersey		N/A	N/A
30.	Kenya	157	72	69
31.	Kiribati		N/A	N/A
32.	St. Lucia	13	13*	N/A
33.	Lesotho		N/A	N/A
34.	Malaysia	201	96	69
35.	Malawi		N/A	N/A
36.	Maldives		N/A	N/A
37.	Malta		N/A	N/A
38.	Mozambique		N/A	N/A
39.	Mauritius	55	17	N/A
40.	Montserrat		N/A	N/A
41.	Namibia	30	17	
42.	Norfolk Island		N/A	N/A
43.	Nigeria	101	101*	63
44.	Northern Ireland	81	30	21
45.	Niue		N/A	N/A
46.	Nauru	10	10*	10*
47.	New Zealand	193	137	37
48.	Pakistan	50	20	16
49.	Papua New Guinea	78	10	N/A
50.	South Africa	148	76	69
51.	Rwanda			
52.	Samoa	52	21	21
53.	Scotland	192	63	53
54.	Seychelles	28	10	N/A
55.	St. Helena		N/A	N/A
56.	Singapore	68	68*	63
57.	St. Kitts and Nevis		N/A	N/A
58.	Sierra Leone		N/A	N/A
59.	Solomon Islands		N/A	N/A
60.	Sri Lanka	92	14	10
61.	St.Vincent and The Grenadines		N/A	N/A
62.	Swaziland		N/A	N/A
63.	Tanzania		N/A	N/A
64.	Turks and Caicos Islands		N/A	N/A
65.	Tonga	21	17	N/A
66.	Trinidad and Tobago		N/A	N/A
67.	Tuvalu		N/A	N/A
68.	Uganda	67	16	16
69.	Vanuatu		N/A	N/A
70.	Wales	165	72	16
71.	Zambia		N/A	N/A

weightage) and Nauru (0.849741 weightage), as depicted in Table 4. Nauru has greater weightage (0.849741 > 0.150259), making it a role model for Singapore to improve its efficiency. Nauru only participated in weight lifting and won medals in that. Similarly, India—being an inefficient DMU in model 1 (Table 3) with only 75% efficiency and 51% efficiency in model 2 (Table 4)—has to follow Australia if it wants to win at least a medal in the game or a gold medal. On a similar note, according to Tables 3 and 4, countries like Sri Lanka, Scotland, and Pakistan should follow Singapore's example to win at least a medal. Surprisingly, when comparing Tables 3 and 4, Nigeria is a fully efficient country in terms of winning at least one medal; however, it needs to follow the strategy adopted by Nauru in order to win a gold medal.

As one of our objectives is to estimate the ideal number of athletes that a country should select to represent in multi-sports events like the CWG in order to win at least a medal or only gold medal, an input-oriented model was also run to analyze the performance of the medal-winning nations. For this purpose, the BCC input-oriented model was selected for both situations—the first for the three output variables (model 1) and the second for one output variable (model 2). In this input-oriented model, which aims to reduce the input amounts by as much as possible while keeping at least the present output levels, the number of athletes was considered as an input variable. Table 6 represents the ideal number of athletes under two different situations: when three outputs (model 1) compared to only one output is considered (model 2). In model 1, the output is the number of gold, silver, and bronze medals won by the nations; in model 2, the number of gold medals won is considered an output variable. Numbers with an asterisk (*)represent an optimum number of players to win at least a medal or a gold medal.

The optimum number of players for a country to win at least a medal is given in the fourth and fifth columns of Table 6. As an explanation, Kenya should be represented by only 72 instead of 157 to win at least a medal, and it requires only 69 to win a gold medal. Similarly, India should represent only 285 and 206 players to win at least a medal and a gold medal, respectively. Scotland was represented by 192 players but it needs only 53 to win a gold medal or 63 players to win at least a medal. South Africa needs only 69 to win a gold medal and 76 to win at least a medal. This analysis is useful for those countries represented by a huge number of players, but not able to compete with the participants of other countries. Therefore, a good strategy could be to select players in such a combination that the players are able to win in the international games. The reputation of a country also depends on success in international games like CWG.

7 Conclusion and Discussion

The present study discussed DEA models with a various combination of input and output variables for the evaluation of the relative efficiency of nations that won medals at CWG held in India in 2010. The findings are interesting and insightful too. In an international sports event, the primary objective of any nation is to show its superiority over other participating nations by winning a maximum number of medals, especially gold medals, in multi-sports events. However, it is also usual practice among many nations to represent the country in multiple sports without any expertise. This leads to a huge participation in terms of the number of players, delegations, and officials without winning any laurels for the country. This is obviously not a desirable situation as it causes embarrassment for the participating nation. Given that one of the contributions of this study is to optimize the number of players to maximize efficiency in terms of medals won in international sports events, DEA modeling has been used. The different DEA models show different results as the number of DMUs (countries in our case) changed when the numbers of output parameters were used as a variable. The result is essentially useful for the policymakers of the international sports events who decide the number of players to represent their country in the international sports arena. The result of the present study would help them strategize the number of players to maximize the probability of winning medals in various sports.

An interesting aspect of this paper was the effort to identify the trend among participating nations in CWG 2010 in terms of representing the ideal number of players. The countries with fewer players were found to be more efficient in terms of their performance than countries with more players in CWG 2010. Indeed, Nauru, with the fewest participating players (only 10), was able to win a gold and silver medal, whereas Sri Lanka won one medal in each category with 92 participating players. Although there is pride in taking part in international sports events and national pride has its own significance, in terms of performance efficiency, the number of medals matter to a great extent.

As per the results, only a handful of nations have been identified as being completely efficient, whether in terms of sending an appropriate number of players to represent the country or to win a medal. Most countries exhibit more of a disappointment and only modest success.

Future research should consider analyzing the same countries for the CWG recently concluded in Glasgow in 2014. As the number of countries remains the same, the efficiency of these countries can be observed with a different number of players in different sports activities.

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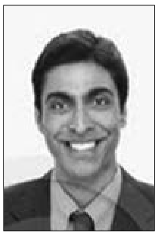

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Merjenje učinkovitosti nacij pri večšportnih dogodkih: primer XIX. iger Commonwealtha

Izvleček

V prispevku je bila za merjenje uspešnosti nacij, sodelujočih na igrah Commonwealtha, uporabljena analiza podatkovne ovojnice. Da bi lahko preiskali veljavnost rezultatov, smo za povečanje doslednosti raziskave uporabili več modelov, vendar je narava vložkov in izložkov ostala nespremenjena.

Namen raziskave je ugotoviti najbolj smiselno število udeleženih športnikov iz vseh sodelujočih držav ter oceniti njihovo uspešnost glede na najučinkovitejšo državo. Raziskava je lahko v pomoč nacijam pri optimizaciji števila udeleženih igralcev, da bi maksimizirali izide, tj. število medalj, dobljenih na športnih dogodkih.

Ključne besede: merjenje uspešnosti, analiza podatkovne ovojnice, učinkovitost, igre Commonwealtha