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Models for measuring and benchmarking olympics achievements☆

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Abstract

As demonstrated in several recent studies, data envelopment analysis (DEA) is a useful tool for evaluating and comparing the performance of nations competing in the Olympic Games. Assurance regions (ARs) have been used to further refine the DEA results. These AR DEA models assume that ARs apply uniformly across all nations. Such models can have shortcomings in the sense that different nations may impose different ARs, as nations may value gold, silver, and bronze medals differently. This paper extends previous DEA studies by incorporating multiple sets of nation-specific ARs into the DEA. By doing so, we establish fair models for measuring and benchmarking the performance of nations at six summer Olympic Games.

Keywords: Data envelopment analysis; Olympic; Performance; Assurance region

1. Introduction

The Olympic Games are the most important and most popular sporting event in the world. There are 28 summer Olympic Games, including the upcoming ones in Beijing, China. Although the Olympic Committee has never published an official ranking system, research has been done in an effort to evaluate the performance of nations with respect to the number of gold, silver, and bronze medals won. Several studies that use data envelopment analysis (DEA) have shown how to effectively and fairly rank the Olympic achievements among nations. DEA uses linear programming techniques to provide a relative efficiency measure for peer decision making units (DMUs) with multiple inputs and outputs. To evaluate Olympic achievements, the DMUs are defined as the participating nations and the outputs are usually defined as the number of different types of medals. The inputs are often defined as GDP per capita, population, and other country-specific features, as done by Lozano et al. [1] in their assurance region (AR) DEA model. The AR restrictions are used to reflect the relative importance of gold versus silver versus bronze medals.

Other DEA studies on Olympics include those by Lins et al. [2] and Churilov and Flitman [3]. Lins et al. [2] proposed a Zero Sum Gains DEA model where the sum of outputs (total medals) is kept constant. Churilov and Flitman [3] used self-organizing maps and DEA in a two-stage analysis of the real achievements of various Olympics participants. The main purpose of using

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self-organizing maps is to group countries into clusters that have similar profiles. A single set of AR constraints is used in the DEA.

Existing DEA studies recognize the importance of incorporating AR constraints, to reflect the relative valuation of different medals. However, these studies all assume that the same set of AR constraints is universally applicable across all nations. This assumption may not be tenable, as different nations may impose different valuations of the medal types. Nigeria, for example, with a GDP of $593 per capita and a population of 129 million in 2004, is defined as a low income country by the World Bank, but still won two bronze medals in the 2004 Olympic Games held in Athens, Greece. In contrast, Japan, a well-developed country with a GDP of $36,500 per capita and a population of 127 million in 2004, won 16 gold, 9 silver, and 12 bronze medals. The huge gap between the medals won by the two countries may be due to their differing economic status, as reflected by the per capita GDP. In battling with starvation and poverty, it is hard for the Nigerians to allocate huge expenses to sporting infrastructure and equipment. Indeed, participating in the Athens Olympics was in itself a great success for the Nigerians. Nigeria might care only about the total number of medals won, while Japan may place more value on the number of gold medals. In this case, one would impose two different sets of AR restrictions on the relative importance of gold, silver, and bronze medals. For example, for Nigeria, a gold medal would be at least one time, but not more than two times as important as a silver medal, and for Japan, a gold medal would be at least three times and not more than five times as important as a silver medal.

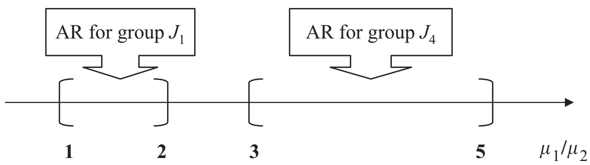

Fig. 1. Two AR ranges for different groups.

Cook and Zhu [4] point out that the situation described above may be related to the homogeneity of DMUs. They elaborate the AR DEA model, and develop a context-dependent AR DEA (CAR-DEA) model that allows multiple sets of AR restrictions to be incorporated into the DEA.

This paper applies the CRA-DEA of Cook and Zhu [4] to six summer Olympic Games, held from 1984 to 2004. Using a system of classification defined by the World Bank, participating nations are grouped into four economic classes: low income, lower middle income, upper middle income, and high income. Low-income and middle-income economies are sometimes referred to as developing economies. This classification is used to reflect the argument that Olympic achievement correlates to the wealth of participating countries. As noted in Bernard and Busse [5], income per capita is a key indicator because wealthier countries are more likely to have organizations with the resources required to properly train and develop Olympic medal contenders.

The rest of this study is organized as follows. Section 2 presents the CAR-DEA model. Section 3 reports the results and findings for the six Olympic Games from 1984 to 2004. Section 4 presents our conclusions.

2. DEA models

In this section, we present the variable returns to scale (VRS) version of the CRA-DEA approach recently developed by Cook and Zhu [4]. We use this model because the population of participating countries varies greatly. Output-orientation is assumed, since Olympic achievement is measured with respect to the medals won.

To introduce the DEA approach, suppose there are n DMUs, each representing a participating nation. Each DMU_j $(j=1,2,\ldots,n)$ contains m inputs, denoted by x_{ij} $(i=1,2,\ldots,m)$ and s outputs, denoted by y_{rj} $(r=1,2,\ldots,s)$. The output-oriented VRS model can be

Table 1
AR ranges

Ratio	Bound	Group 1; $K=1$	Group 2; $K=2$	Group 3; $K=3$	Group 4; $K=4$	Common AR
U_1/U_2	Lower Lim	1	1	2	3	1
	Upper Lim	2	2	4	5	1.6667
U_1/U_3	Lower Lim	1	1	3	4	1
	Upper Lim	2	2	6	8	2

written as

$$
\begin{aligned}
\min \quad & \sum_{i=1}^{m} v_i x_{i0} + \mu_0 \\
\text{s.t.} \quad & \sum_{i=1}^{m} v_i x_{ij} + \mu_0 - \sum_{r=1}^{s} \mu_r y_{rj} \geqslant 0, \quad j=1,2,\ldots,n, \\
& \sum_{r=1}^{s} \mu_r y_{r0} = 1, \\
& c_{r\mathrm{L}} \mu_r \leqslant \mu_1 \leqslant c_{r\mathrm{U}} \mu_r, \quad r = 2, \ldots, s, \\
& \mu_r, v_i \geqslant 0 \quad \forall r, i, \quad \mu_0, \text{free.}
\end{aligned} \tag{1}
$$

Cook and Zhu [4] further assume that all DMUs can be divided into K groups $\{J_k\}_{k=1}^{K}$ and that each group J_k has a set of different AR restrictions of the following form:

$$
\begin{aligned}
& c_{r\mathrm{L}}^{k} \mu_r \leqslant \mu_1 \leqslant c_{r\mathrm{U}}^{k} \mu_r, \\
& \quad r = 2, 3, \ldots, s, \quad k = 1, 2, \ldots, K,
\end{aligned} \tag{2}
$$

where the first output is selected as the numeraire [6]
.

If the first output represents the number of gold medals won, and the second and third outputs are the number of silver and bronze medals won, respectively, then (2) means that a gold medal is at least $c_{r\mathrm{L}}^{k}$, and not more than $c_{r\mathrm{U}}^{k}$ as important as a silver or bronze medal in group J_k.

We require a DEA model that can deal with multiple sets of AR constraints. If one attempts to impose the K sets simultaneously, infeasibility would occur. For example, suppose that in group J_1 the AR restriction on the gold and silver medals is $\mu_2 \leqslant \mu_1 \leqslant 2\mu_2$, and in group J_4 the AR restriction is $3\mu_2 \leqslant \mu_1 \leqslant 5\mu_2$ (see Fig. 1). The intersection of these two ARs is obviously the null set.

Cook and Zhu [4] find a solution to this problem by simultaneously adjusting the magnitude of outputs and AR ranges as follows.

First, noting that the aggregated output for a DMU $j \in J_k$, namely $\sum_{r \in R} \mu_r y_{rj}$, $j \in J_k$, can be expressed as $\sum_{r \in R} \mu_r' (c_{r\mathrm{L}}^{1}/c_{r\mathrm{L}}^{k}) y_{rj}$, $j \in J_k$ if $\mu_r' = (c_{r\mathrm{L}}^{k} \mu_r)/c_{r\mathrm{L}}^{1}$, this means that the constraint $\mu_1 \geqslant c_{r\mathrm{L}}^{k} \mu_r$ can be replaced by $\mu_1 \geqslant c_{r\mathrm{L}}^{1} \mu_r'$, if we replace the expression $\sum_{r \in R} \mu_r y_{rj}$ by $\sum_{r \in R} \mu_r' (c_{r\mathrm{L}}^{1}/c_{r\mathrm{L}}^{k}) y_{rj}$.

Therefore, the AR restrictions $c_{r\mathrm{L}}^{k} \mu_r \leqslant \mu_1 \leqslant c_{r\mathrm{U}}^{k} \mu_r$ can be adjusted as $c_{r\mathrm{L}}^{1} \mu_r' \leqslant \mu_1 \leqslant (c_{r\mathrm{L}}^{1}/c_{r\mathrm{L}}^{k}) c_{r\mathrm{U}}^{k} \mu_r'$, where $\mu_r' = (c_{r\mathrm{L}}^{k}/c_{r\mathrm{L}}^{1}) \mu_r$.

For example, we adjust the AR restriction $3 \leqslant \mu_1/\mu_2 \leqslant 5$ by the factor $c_{r\mathrm{L}}^{2}/c_{r\mathrm{L}}^{1} = 3/1 = 3$ to $1 \leqslant \mu_1/\mu_2 \leqslant 5/3$. The ARs for both groups now have the same lower AR bound.

As demonstrated in Cook and Zhu [4], the common upper AR bound can be determined via $\bar{c}_{r\mathrm{U}} = \min\{\bar{c}_{r\mathrm{U}}^{1}, \bar{c}_{r\mathrm{U}}^{2}, \bar{c}_{r\mathrm{U}}^{3}, \ldots, \bar{c}_{r\mathrm{U}}^{K}\}$ where $\bar{c}_{r\mathrm{U}}^{k} = (c_{r\mathrm{L}}^{1}/c_{r\mathrm{L}}^{k}) c_{r\mathrm{U}}^{k}$.

Let $\bar{c}_{r\mathrm{L}} = c_{r\mathrm{L}}^{1}$, then the multiple ARs in (2) can be replaced by

$$
\bar{c}_{r\mathrm{L}} \mu_r \leqslant \mu_1 \leqslant \bar{c}_{r\mathrm{U}} \mu_r. \tag{3}
$$

When we evaluate a specific DMU $j_{k_0} \in J_k$, we have following CAR-DEA model:

$$
\begin{aligned}
\min \quad & \sum_{i=1}^{m} v_i x_{i j_{k_0}} + \mu_0 \\
\text{s.t.} \quad & \sum_{i=1}^{m} v_i x_{i j_k} + \mu_0 - \sum_{r=1}^{s} \mu_r \frac{c_{r\mathrm{L}}^{1}}{c_{r\mathrm{L}}^{k}} y_{r j_k} \geqslant 0, \\
& \quad j_k \in J_k, \quad k = 1, \ldots, K, \\
& \sum_{r=1}^{3} \mu_r y_{r0} = 1, \\
& \bar{c}_{r\mathrm{L}} \mu_r \leqslant \mu_1 \leqslant \bar{c}_{r\mathrm{U}} \mu_r, \quad r = 2, \ldots, s, \\
& \mu_r, v_i \geqslant 0 \quad \forall r, i, \quad \mu_0, \text{free.}
\end{aligned} \tag{4}
$$

3. Measuring the performance of Olympics participants

In this section, we apply the CAR-DEA model to analyze the performance of participating nations in six summer Olympic Games, held from 1984 to 2004. Based upon previous DEA studies cited in the introduction, we use three outputs, namely, the number of gold, silver, and bronze medals won. We use two inputs, GDP per capita (in US dollars) and population of the country. As noted in Lozano et al. [1], these two input attributes capture the most important factors expressing the economic and demographic power of nations. There are 78 different countries participating in these six summer Olympic Games.

Using the classification from the World Bank, the countries are grouped into four classes: low income, lower middle income, upper middle income, and high income. These groups are presented in Table 2. In particular,

Group 1—low income, \$825 or less, contains low developing countries from Africa and middle-Asia.

Group 2—lower middle income, \$826 to \$3357, contains some developing countries from Eastern Europe, southern Africa and eastern Asia.

Group 3—upper middle income, \$3358 to \$10,461, contains some developing or some low developed countries from middle-Europe, southern Africa, and America.

Table 2
Efficiency and benchmarks in 2004 Athens Olympic Games

Group	DMU	Nation	Model (4)	Rank	Benchmarks			Model (1)	Rank	Diff.
Low income	1	Korea People	1	13				1	11	−2
	2	Uzbekistan	1	10				1	11	1
	3	Kenya	1	13				1	15	2
	4	Ethiopia	1	9				1	6	−3
	5	Nigeria	0.14835	51	4	19	24	0.12368	57	6
	6	India	0.03561	62	4	24		0.03561	62	0
Lower middle income	7	Jamaica	1	6				1	8	2
	8	Georgia	1	7	8			1	5	−2
	9	Bulgaria	0.71119	17	7	13	39	0.71116	19	2
	10	Azerbaijan	1	10				1	8	−2
	11	Belarus	0.78787	16	8	10	13	0.78787	17	1
	12	Yugoslavia	0.14093	52	8	13	19	0.14011	52	0
	13	Cuba	1	1				1	2	1
	14	Kazakhstan	0.32446	32	8	13	19	0.32178	40	8
	15	Cameroon	0.18924	45	2	8	19	0.18924	46	1
	16	Romania	0.68217	18	13	38	53	0.62896	24	6
	17	Morocco	0.1928	44	8	13	19	0.1885	47	3
	18	Colombia	0.082036	57	13	19	38	0.070625	60	3
	19	Ukraine	1	5				1	11	6
	20	Thailand	0.26263	37	13	19	38	0.19705	45	8
	21	Iran	0.18652	47	13	19	38	0.14236	51	4
	22	Brazil	0.22145	40	19	24	38	0.1496	50	10
	23	Indonesia	0.16701	48	4	19	24	0.13666	54	6
	24	China	1	8				1	6	−2
Upper middle income	25	Trinidad and Tobago	0.25504	39	7	26	39	0.37287	37	−2
	26	Estonia	1	10				1	11	1
	27	Latvia	0.53193	22	7	13	39	1	8	−14
	28	Lithuania	0.32621	31	7	13	39	0.47251	33	2
	29	Croatia	0.27304	36	7	13	39	0.45992	35	−1
	30	Slovakia	0.32429	33	7	13	39	0.47659	32	−1
	31	Hungary	0.60957	21	13	39		0.77595	18	−3
	32	Czech Republic	0.16152	49	13	39		0.31972	41	−8
	33	Chile	0.10982	54	13	38	53	0.11597	59	5
	34	Poland	0.18791	46	13	38	53	0.24544	43	−3
	35	South Africa	0.099707	56	13	38	53	0.13839	53	−3
	36	Turkey	0.15641	50	13	38	53	0.17563	48	−2
	37	Mexico	0.042038	60	13	38	53	0.058664	61	1
	38	Russia	1	3				1	2	−1
High income	39	Bahamas	1	2				1	4	2
	40	Slovenia	0.21097	42	13	39		0.67326	21	−21
	41	Israel	0.10018	55	13	39		0.13366	55	0
	42	New Zealand	0.4837	26	13	39		0.56254	27	1
	43	Norway	0.63998	19	13	39		0.63089	23	4
	44	Finland	0.064768	59	13	39		0.1755	49	−10
	45	Denmark	0.29503	34	13	39		0.63785	22	−12
	46	Switzerland	0.12849	53	13	39		0.28188	42	−11
	47	Austria	0.21933	41	13	39		0.3756	36	−5
	48	Sweden	0.29467	35	13	39		0.34662	39	4
	49	Belgium	0.072086	58	13	39		0.13125	56	−2
	50	Portugal	0.03958	61	13	39		0.11811	58	−3
	51	Greece	0.41703	29	13	39		0.61768	25	−4
	52	The Netherlands	0.35139	30	13	53		0.54864	28	−2
	53	Australia	1	4				1	1	−3
	54	Canada	0.20272	43	38	53		0.23809	44	1
	55	Spain	0.25706	38	13	38	53	0.36157	38	0
	56	Korea Republic	0.48873	25	13	38	53	0.60971	26	1

Table 2 *(Continued)*

Group	DMU	Nation	Model (4)	Rank	Benchmarks			Model (1)	Rank	Diff.
	57	Italy	0.48292	27	38	53		0.52131	30	3
	58	Britain	0.43469	28	13	38	53	0.48077	31	3
	59	France	0.50202	23	38	53		0.52771	29	6
	60	Germany	0.61308	20	38	53		0.69257	20	0
	61	Japan	0.49545	24	38	53		0.46723	34	10
	62	USA	1	13				1	15	2

Table 3
Efficiency in six Olympic Games

DMU	Country	Los Angeles 1984	Seoul 1988	Barcelona 1992	Atlanta 1996	Sydney 2000	Athens 2004
1	Algeria	0.04517	–	0.060786	0.14395	0.16144	–
2	Armenia	+	+	+	1	1	–
3	Australia	0.26387	0.17232	0.41247	0.72784	0.98209	1
4	Austria	0.087786	0.051209	0.035807	0.044875	0.14164	0.21933
5	Azerbaijan	+	+	+	0.39853	0.43066	1
6	Bahamas	–	–	1	1	1	1
7	Barbados	–	–	–	–	1	–
8	Belarus	+	+	–	0.84872	1	0.78787
9	Belgium	0.078479	0.016239	0.028671	0.16006	0.05266	0.072086
10	Brazil	0.15523	0.16626	0.055315	0.35211	0.05682	0.22145
11	Britain	0.2257	0.16876	0.20877	0.16431	0.38823	0.43469
12	Bulgaria	+	1	1	1	0.81017	0.71119
13	Cameroon	0.065312	–	–	–	0.1316	0.18924
14	Canada	0.40088	0.11833	0.30998	0.32452	0.17423	0.20272
15	Chile	–	0.019572	–	–	0.0127	0.10982
16	China	1	1	1	1	1	1
17	Colombia	0.021923	0.049251	0.033755	–	0.03565	0.082036
18	Costa Rica	–	0.11468	–	0.17966	0.07831	–
19	Croatia	+	+	0.10268	0.1759	0.14646	0.27304
20	Cuba	+	+	1	1	1	1
21	Czech Republic	+	0.1726	0.21386	0.33121	0.17415	0.16152
22	Denmark	0.13301	0.21511	0.16188	0.51402	0.26043	0.29503
23	Estonia	+	+	1	1	1	1
24	Ethiopia	+	+	1	1	1	1
25	Finland	0.49379	0.14188	0.16328	0.18578	0.22876	0.064768
26	France	0.18817	0.14668	0.31198	0.74563	0.47118	0.50202
27	Georgia	+	+	+	0.48033	1	1
28	Germany	0.44283	1	0.96107	0.98107	0.45668	0.61308
29	Greece	0.02481	0.0080995	0.0895	0.27434	0.30252	0.41703
30	Hungary	+	0.56088	0.73695	0.58753	0.52964	0.60957
31	Iceland	1	–	–	–	0.24572	–
32	India	–	–	–	0.042776	0.03483	0.03561
33	Indonesia	–	0.08546	0.2194	0.13708	0.15336	0.16701
34	Iran	+	0.040879	0.079665	0.104	0.10472	0.18652
35	Ireland	0.041676	–	0.16482	0.54368	0.03644	–
36	Israel	–	–	0.042517	0.02291	0.01825	0.10018
37	Italy	0.35097	0.14332	0.22306	0.68331	0.45775	0.48292
38	Jamaica	1	1	1	1	1	1
39	Japan	0.2106	0.089055	0.12729	0.15328	0.12723	0.49545
40	Kazakhstan	+	+	+	0.6011	0.46177	0.32446
41	Kenya	1	1	1	1	0.79871	1
42	Korea People	+	+	0.66968	0.60685	0.32879	1
43	Korea Republic	0.18833	0.4679	0.45001	0.4884	0.35071	0.48873
44	Kuwait	–	–	–	–	0.04656	–
45	Kyrgyzstan	+	+	+	–	1	+
46	Latvia	+	+	0.27331	0.13655	0.60644	0.53193

Table 3 *(Continued)*

DMU	Country	Los Angeles 1984	Seoul 1988	Barcelona 1992	Atlanta 1996	Sydney 2000	Athens 2004
47	Lithuania	+	+	0.19516	0.052492	0.6686	0.32621
48	Mexico	0.073352	0.019881	0.010073	0.010546	0.04428	0.042038
49	Moldova	+	+	+	1	1	+
50	Morocco	0.15708	0.20818	0.12177	0.10373	0.18952	0.1928
51	Mozambique	–	–	–	1	1	–
52	Netherlands	0.24055	0.11177	0.18121	0.33908	0.6336	0.35139
53	New Zealand	1	0.95927	0.36871	0.60329	0.19879	0.4837
54	Nigeria	0.041274	–	0.3657	0.63019	0.15102	0.14835
55	Norway	0.076227	0.34075	0.34887	0.39717	0.55751	0.63998
56	Poland	+	0.26249	0.23601	0.43463	0.2705	0.18791
57	Portugal	0.075914	0.041057	–	0.068735	0.02943	0.03958
58	Qatar	–	–	0.28569	–	0.13447	–
59	Romania	1	0.71746	0.937	0.89289	0.98314	0.68217
60	Russia	+	1	1	1	1	1
61	Saudi Arabia	–	–	–	–	0.02487	–
62	Slovakia	+	+	+	0.17076	0.21882	0.32429
63	Slovenia	+	+	0.131	0.1724	0.52807	0.21097
64	South Africa	+	+	0.029129	0.15815	0.11358	0.099707
65	Spain	0.03911	0.036168	0.47145	0.31919	0.13985	0.25706
66	Sri Lanka	–	–	–	–	0.06361	–
67	Sweden	0.3554	0.093439	0.18602	0.21227	0.31677	0.29467
68	Switzerland	0.1435	0.048196	0.067654	0.40457	0.19503	0.12849
69	TFYR of Macedonia	+	+	+	–	1	+
70	Thailand	0.035894	0.052287	0.025032	0.072739	0.07046	0.26263
71	Trinidad and Tobago	–	–	–	0.70357	0.294	0.25504
72	Turkey	0.021635	0.062677	0.081745	0.18248	0.10727	0.15641
73	Ukraine	+	+	+	1	0.94801	1
74	Uruguay	–	–	–	–	0.06586	–
75	USA	1	0.64741	0.80298	1	0.77906	1
76	Uzbekistan	+	+	+	0.18719	0.27422	1
77	Vietnam	+	–	–	–	0.05576	–
78	Yugoslavia	0.36121	0.3158	–	0.22648	0.21259	0.14093

"–" no medals won; "+" not participated.

Group 4—high income, \$10,462 or more, contains well-developed countries from western Europe and northern America.

This classification is used to account for the different countries' wealth. Consequently, nations in each classification may value gold, silver, and bronze medals differently, and therefore different AR restrictions should be imposed.

Table 1 shows the four separate AR ranges for the four groups. Based on the values in Table 1, common AR restrictions for all nations are obtained and shown in the last column of Table 1.

Based upon model (4) and using the common AR restrictions in Table 1, the efficiency of each participant in the 2004 Athens Olympics is reported in the fourth column of Table 2.These efficiency scores are the inverses of the optimal values to model (4). It can be seen that out of 62 countries, only 15 are efficient or best practices. These countries are Korea People, Uzbekistan, Kenya, Ethiopia, Jamaica, Georgia, Azerbaijan, Cuba, Ukraine, China, Estonia, Russia, Bahamas, Australia, and the USA. The majority of these 15 efficient countries are in low income and lower middle income groups. The sixth column of Table 2 reports which countries are used as benchmarks when a country is not DEA efficient. This information is available via the binding constraints in model (4). Among the 15 best-practice participants, the one that acts most frequently as benchmark is Cuba (36 times), followed by Bahamas (20 times), and Russia (18 times). The majority of nations served more frequently as benchmark are small countries with respect to both population and GDP per capital. The USA was not used as a benchmark in any of the non-best-practice nations.

Table 2 also reports the rankings based upon models (1) and (4). The rankings of efficient nations are based upon the benchmark ranking method described in Torgersen et al. [7] and Sinuany-Stern et al. [8]. The

Table 4
Number of times a nation served as a benchmark

DMU	Country	Los Angeles 1984	Seoul 1988	Barcelona 1992	Atlanta 1996	Sydney 2000	Athens 2004
2	Armenia	+	+	+	4	1	–
3	Australia						15
6	Bahamas	–	–	17	18	23	20
7	Barbados	–	–	–	–	2	–
8	Belarus	+	+	–		13	
12	Bulgaria	+	31	1	9		
16	China	4	2	8	5	3	4
20	Cuba	+	+	39	41	46	36
23	Estonia	+	+	2	3	2	1
24	Ethiopia	+	+		3	6	3
27	Georgia	+	+	+			5
28	Germany		16				
38	Jamaica	4	8	3	10	8	6
41	Kenya	4	11	6	4		
49	Moldova	+	+	+	5	10	+
53	New Zealand	14					
59	Romania	30					
60	Russia	+	15	23	10	36	18
73	Ukraine	+	+	+	12		10
75	USA	11			16		

"–" no medals won; "+" not participated.

efficiency scores from model (1) are reported in column 9. The ranking difference is reported in the last column of Table 2. Both models yield the same rank for a DMU in only 8.06% of the time. Our application confirms the statement made in Cook and Zhu [4]. That is, *purely on the basis of observation*, *one can generally declare that quite different results occur using the two DEA methods*. *Therefore*, *there appears to be no decisive argument in favor of substituting the group-specific analysis in place of that using model* (4).

Table 3 reports the efficiency scores obtained from model (4) for the last six Olympic Games. A "+" sign indicates that a nation did not participate in a specific Olympic Game, while a "–" sign indicates that a nation did not win any medals. Some countries, such as Bahamas, Mozambique, are efficient if they won medals, while others, such as Belarus, People's Korea, Germany, Hungary, and Romania, exhibit a consistently high level of efficiency. Some countries, such as Australia, Norway, North Korea, and Azerbaijan, show very positive trends in terms of performance improvement. On the other hand, countries such as New Zealand and Finland show negative trends. The performance of countries, such as USA, Romania, and Germany, has its ups and downs.

Table 4 shows the evolution of the frequency of the efficient nations acting as benchmarks for the six summer Olympics. Jamaica and China served as benchmarks with extremely high frequency in all six games, followed by Bahamas and Russia (five games), Cuba, Estonia, and Kenya (four games), and Ethiopia and Bulgaria (three games). Note that the USA never served as a benchmark except during the 1984 and 1996 Olympics held in its own cities, Los Angeles and Atlanta. To some extent, it proves that host nations have an advantage in improving their Olympic performances.

4. Conclusions

Conventional DEA models of performance in the Olympic Games do not take into consideration the variability in the economic status of participating nations. In this paper, a context-dependent AR DEA model is used to analyze the achievements of nations during six summer Olympic Games. Multiple sets of AR restrictions can be incorporated into the DEA. As a result, a fair comparison of different nations is achieved. It is shown that by scaling up or down the outputs, multiple AR restrictions of different groups of nations can be transformed into a common set of AR restriction that is applicable to all nations. Further studies can use the recent approaches of Seiford and Zhu [9] and Cook, Seiford and Zhu [10] to benchmark the nations.

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