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A two-stage DEA model to evaluate the efficiency of countries at the Rio 2016 Olympic Games

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Abstract

This study uses a two-stage DEA model to evaluate the efficiency of countries that participated in the Rio 2016 Olympic Games. In the first stage, we calculated the efficiency scores using the number of athletes as the input, and the numbers of gold, silver, and bronze medals earned by each country as the outputs. In the second stage, we analyzed the effects of economic, demographic, and political factors on the efficiency scores. We show that GDP and low levels of democracy are also positively associated with efficiency scores, especially in the less efficient countries.

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1. Introduction

The Data Envelopment Analysis (DEA) is a technique widely used to measure the efficiency of different decision-making units (DMUs) when converting resources (inputs) into results (outputs). From the seminal research of Charnes, Cooper & Rhodes (1978), the literature has continued to grow in the form of new models, estimation techniques and application fields (Emrouznejad & Yang, 2017; Aldamak & Zolfaghari, 2017; Liu et al., 2013). One of the evolutionary lines of these models that Liu, Lu & Lu (2016) considers the more active DEA subarea is the "two-stage contextual factor evaluation." A two-stage analysis is a useful tool for decision makers who are looking for improving performance while coping with environmental factors (Silva et al., 2019; Zhu, 2016).

Recently, evaluating the performance of participating countries in the Olympic Games is a relevant application of DEA (Lei et al., 2015). Previous studies have used DEA models to measure the efficiency of participating countries in Los Angeles 1984, Seoul 1988, Barcelona 1992, Atlanta 1996 and Sydney 2000 (Lozano et al., 2002), Sydney 2000 (Lins et al., 2003; Churilov & Flitman, 2006), Athens 2004 (Mello, Angulo-Meza & Silva, 2009; Zhang et al., 2009; Azizi & Wang, 2013), Beijing 2008 (Wu, Zhou & Liang, 2010; Chiang, Hwang & Liu, 2011; Mello, Angulo-Meza & Lacerda, 2012), London 2012 (Bi et al., 2014; Li et al., 2015; Yang, Li & Liang, 2015) and Rio 2016 (Del Corral, Gonzalez & Santos, 2017; Jablonsky, 2018) Olympic Games. Nevertheless, the two-stage contextual DEA model has not been used previously in research on the Olympic Games.

In this study, we employ the two-stage DEA model to evaluate the efficiency of the countries that participated in the Rio 2016 Olympic Games. In the first stage, we use a DEA model to calculate the efficiency scores of participating countries. We considered one input (number of participating athletes) and three outputs (total number of gold, silver, and bronze medals). In the second stage, we utilized a regression model to examine the effect of economic, demographic and political factors on the efficiency levels.

2. Methods

A typical two-stage contextual study first obtains efficiency scores through DEA and then correlates these scores with various contextual factors through regression analysis (Silva et al., 2019; Liu, Lu & Lu, 2016; Liu et al., 2013). In this paper, in the first stage, we denote each participating country as a DMU. Each DMU_j (j = 1, 2,…, n) uses one input X_{1j} to generate the three outputs Y_{rj} (r = 1, 2, 3). Based in Li et al. (2015), Benicio, Bergiante & Soares (2013) and Mello, Angulo-Meza & Lacerda (2012), the input is the number of participating athletes by each country. Likewise, the majority of models concerning Olympic evaluation, the outputs are the numbers of gold, silver, and bronze medals won. Thus the efficiency of the participating country, DMU_0, under evaluation, can be obtained by applying the output-oriented BCC model (Banker, Charnes & Cooper, 1984) as follows:

$$\begin{aligned} \max\ & \theta_O = \frac{\sum_{r=1}^{3} u_r Y_{rO}}{v_1 X_{1O} + u_O} \\ s.t.\ & \frac{\sum_{r=1}^{3} u_r Y_{rj}}{v_1 X_{1j} + u_j} \le 1 \\ & u_1 - u_2 \ge \xi \\ & u_2 - u_3 \ge \xi \\ & u_1 - 2u_2 + u_3 \ge \xi \\ & v_1, u_r \ge 0, \forall r, u_O, free. \end{aligned} \tag{1}$$

where θ denote the optimal objective function value, which is the efficiency for DMU_0, and v_1 and u_r are unknown non-negative weights attached to the input and outputs, respectively. The three assurance regions $u_1 - u_2 \geq \xi$, $u_2 - u_3 \geq \xi$ and $u_1 - 2u_2 + u_3 \geq \xi$ indicate the relative importance among gold, silver, and bronze medals. For example, $u_1 - u_2 \geq \xi$ means that a gold medal is more important than a silver one; $u_2 - u_3 \geq \xi$ expresses the idea that a silver medal is more important than a bronze, and $u_1 - 2u_2 + u_3 \geq \xi$ indicates that the difference in importance between a gold medal and a silver medal should be higher than the difference between a silver medal and a bronze medal (Li et al., 2015). The non-Archimedean infinitesimal ξ is imposed to avoid the particular condition that the three medals are equally valued. Of the 206 countries participating at the Rio 2016, the DMUs set consists of 87 countries who won at least one medal. The input and outputs data derives from the official website of the Olympics. The EMS software was used to calculate the efficiency scores.

In the second stage, we adjusted regressions in which the dependent variable was the efficiency calculated in the first stage. Define which regression model is the most proper is a subject of intense debates (Liu, Lu & Lu (2016)), we used the Tobit regression model indicated by Banker (2008) and truncated regression model (quantile) recommended by Simar & Wilson (2007). In line with previous studies about the determinants factors success at the Olympic Games (Noland & Stahler, 2017; Calzada-Infante & Lozano, 2016; Franchini & Takito, 2016; Lowen, Deaner & Schmitt, 2016; Oliveira Neto & Bertussi, 2015; Sun, Wang & Zhan, 2015; Emrich et al., 2012; Vagenas & Vlachokyriakou, 2012; Szymanski, 2011), we used three explanatory variables: Gross Domestic Product (GDP), population and political regimes. These exogenous variables include factors that cannot be treated as traditional inputs because the countries, in the short term, do not control them directly. We utilize the data of GDP (2015, in trillions US$) and population (2015, in billions) coming from the World Bank database. As a proxy of the political regime, we used the Democracy Index (2016), available in the Economist Intelligence Unit website. This variable bases on electoral process and pluralism, civil liberties, the functioning of government, political participation, and political culture. The Gretl software was used to estimate the regressions.

3. Results and discussion

Table 1 presents efficiency scores based on DEA model. Although there are only six countries with a score equal to 1. Comparing our results with similar ones published by other authors, it is verified that only the United States was also efficient at the London 2012 (Li et al., 2015) and Beijing 2008 (Mello, Angulo-Meza & Lacerda, 2012). Given the number of participating athletes, Azerbaijan, Independent Olympic Athletes[1], Tajikistan, Grenada, and Niger have to be efficient. However, these countries did not stand out in the medals ranking of the Rio 2016, which uses lexographic preferences to rank the countries that won medals, ratifying the idea that the absolute result in terms of medals does not necessarily reflect the efficiency of a country due to its Olympic Games performance.

In Table 2, we show that countries with higher GDP per capita (columns 1-5) and lower democracy index (column 5) tend to be more efficient. However, the impacts of these variables are significant only in the less efficient countries (Table 3, columns 7-8). Richer countries have more resources to invest in sports programs and thus, would be more likely to win medals at the Olympics (Del Corral, Gomez-Gonzalez & Sánchez-Santos 2017). Also, authoritarians countries tend to have greater Olympic success because politicians view these major sporting events as a way of securing an endorsement for their non-democratic regimes

[1] Independent Olympic Athletes was composed of Kuwaiti athletes, as the Kuwait Olympic Committee had been suspended by the International Olympic Committee.

(Oliveira Neto & Bertussi, 2015). However, the population and GDP per capita did not affect the efficiency scores. While most populous countries may have various talented athletes, are often resource constrained and unable to reallocate resources towards sports (Rathke & Ulrich, 2008). For example, Grenada, the least populous country, was classified as an efficient country. Nevertheless, Switzerland, the country with the highest GDP per capita, held the middle position in the efficiency ranking.

Table 1: Efficiency scores based on DEA model

N	Country	Efficiency	Ranking Rio 2016	N	Country	Efficiency	Ranking Rio 2016	N	Country	Efficiency	Ranking Rio 2016
1	United States	1.000	1	30	Slovakia	0.498	37	59	Puerto Rico	0.219	54
2	Azerbaijan	1.000	39	31	France	0.489	7	60	Taipei	0.214	50
3	Independent Olympic Athletes	1.000	51	32	Germany	0.483	5	61	Ukraine	0.211	31
4	Tajikistan	1.000	54	33	Thailand	0.478	35	62	Poland	0.211	33
5	Grenada	1.000	69	34	Cuba	0.475	18	63	Lithuania	0.197	64
6	Niger	1.000	69	35	Denmark	0.463	28	64	Norway	0.197	74
7	Jamaica	0.977	16	36	Netherlands	0.411	11	65	Bulgaria	0.188	65
8	Jordan	0.923	54	37	Singapore	0.401	54	66	Romania	0.187	47
9	Kosovo	0.923	54	38	Italy	0.394	9	67	Brazil	0.180	13
10	Great Britain	0.881	2	39	New Zealand	0.381	19	68	Argentina	0.177	27
11	DPR Korea	0.877	34	40	Bahrain	0.371	48	69	Tunisia	0.159	75
12	Russian Federation	0.876	4	41	Czech Republic	0.368	43	70	Mongolia	0.159	67
13	Kenya	0.869	15	42	Bahamas	0.354	51	71	Mexico	0.154	61
14	Ethiopia	0.813	44	43	Serbia	0.350	32	72	Republic of Moldova	0.134	78
15	Uzbekistan	0.799	21	44	Switzerland	0.345	24	73	Qatar	0.133	69
16	Côte d'Ivoire	0.782	51	45	Greece	0.345	26	74	Algeria	0.131	62
17	China	0.765	3	46	Philippines	0.339	69	75	Ireland	0.131	62
18	Georgia	0.724	38	47	Australia	0.313	10	76	Israel	0.125	77
19	Croatia	0.628	17	48	Slovenia	0.308	45	77	Venezuela	0.110	65
20	Malaysia	0.626	60	49	Canada	0.306	20	78	Egypt	0.110	75
21	Armenia	0.619	42	50	South Africa	0.306	30	79	Dominican Republic	0.098	78
22	Indonesia	0.599	46	51	United Arab Emirates	0.296	78	80	Trinidad and Tobago	0.098	78
23	Kazakhstan	0.598	22	52	Turkey	0.294	41	81	India	0.074	67
24	Iran	0.574	25	53	Spain	0.293	14	82	Estonia	0.063	78
25	Hungary	0.561	12	54	Sweden	0.291	29	83	Finland	0.063	78
26	Vietnam	0.545	48	55	Belarus	0.271	40	84	Morocco	0.063	78
27	Japan	0.528	6	56	Belgium	0.263	35	85	Austria	0.037	78
28	Republic of Korea	0.505	8	57	Colombia	0.225	23	86	Nigeria	0.037	78
29	Burundi	0.500	69	58	Fiji	0.219	54	87	Portugal	0.037	78

Source: calculations made by the authors

Table 2: Determinants of efficiency scores – Tobit regression model

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
GDP	**0.0422*** **	**0.0410*** **	**0.0424*** **	**0.0250***	**0.0498*** **	-0.0318
	(0.0103)	(0.0118)	(0.0121)	(0.0131)	(0.0177)	(0.0246)
Population		0.0001	0.0000	-0.0004	-0.0018	-0.0008
		(0.0009)	(0.0009)	(0.0009)	(0.0008)	(0.0008)
GDP per capita			-0.006			
			(0.0021)			
GDP x Population				0.0002		
				(0.0001)		
Democracy					**-0.0548*** **	**-0.0696*** **
					(0.0134)	(0.0158)
GDP x Democracy						**0.0154** **
						(0.0062)
Intercept	0.3888**	0.3870***	0.392***	0.4023***	0.7110***	0.8012***
	(0.0345)	(0.0365)	(0.044)	(0.041)	(0.1001)	0.1153
Log-likelihood	-20.8106	-20.7986	-20.7588	-20.1740	-7.1442	-5.0197
Observations	86	86	86	86	82	82

Source: calculations made by the authors.
Note: * p < 0.10, ** p < 0.05, *** p < 0.001. In parenthesis standard errors.

Table 3: Determinants of efficiency scores – Quantile regression model

	(7)	**(8)**	**(9)**
GDP	**0.0349***	0.0038	-0.0384
	(0.1402)	(0.0332)	(1.7885)
Population	-0.0006	-0.0003	-0.0005
	(0.0006)	(0.0010)	(0.0029)
Democracy	**-0.032***	**-0.0534** **	-0.0887
	(0.018)	(0.0273)	(0.0615)
GDP x Democracy	0.0031	0.0053	0.0101
	(0.0034)	(0.0193)	(0.2120)
Intercept	0.3748***	0.7078***	1.1195**
	(0.1403)	(0.1774)	(0.4457)
Quantile (tau)	0.25	0.50	0.75
Observations	82	82	82

Source: calculations made by the authors.
Note: * p < 0.10, ** p < 0.05, *** p < 0.001. In parenthesis standard errors.

4. Conclusion

In this study, we adopted two-stage DEA approaches to evaluate the efficiency of the countries that participated in the Rio 2016 Olympic Games. Empirical evidence shows that GDP and low levels of democracy are positively associated with efficiency scores, especially in less efficient countries. These findings may contribute to broadening the debate on the performance of countries in the Olympic Games.

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