European Journal of Operational Research 243 (2015) 964–973

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Innovative Applications of O.R.

Performance evaluation of participating nations at the 2012 London Summer Olympics by a two-stage data envelopment analysis

Yongjun Li[a], Xiyang Lei[a,*], Qianzhi Dai[a,b], Liang Liang[a]

[a] School of Business, University of Science and Technology of China, Hefei, Anhui 230026, P.R. China
[b] Institute of Policy and Management, Chinese Academy of Sciences, Beijing 100190, P.R. China

ARTICLE INFO

Article history:
Received 27 November 2013
Accepted 17 December 2014
Available online 26 December 2014

Keywords:
Data envelopment analysis
Two-stage process
Performance evaluation
Heuristic search procedure

ABSTRACT

This study measures the performance of participating nations at the Olympics, considering the quest for medals as a two-stage Olympic process. The first stage is characterized as athlete preparation (AP) and the second stage as athlete competition (AC). We extend the relational model from the *constant returns to scale* framework to the *variable returns to scale* version. The efficiency of each participating nation in the entire two-stage Olympic process is calculated as a product of the efficiencies of both stages, and a heuristic search is applied to the extended relational model. The efficiency of each stage can be obtained and directions for improving the performance of participating nations in the two-stage Olympic process can be identified. An empirical study of the 2012 London Summer Olympic Games reveals that the efficiency of the AP stage is higher than that of the AC stage for the majority of participants. In addition, a plot of the relationship between these three efficiencies shows that the efficiency of the entire two-stage Olympic process is more significantly related to that of the AC stage than that of the AP stage.

1. Introduction

The Olympic Games is one of the most popular and most important sporting and cultural events in the world. All participating nations strive to obtain many medals to enhance their international prestige and presence on the world stage. A nation's success at the Olympics can be judged by various measures including number of gold medals, total number of medals, and either of these scaled by some demographic such as population. The Olympic Committee has never published an official ranking of participating nations (Lins, Gomes, Soares de Mello, & Soares de Mello, 2003). Consequently, many researchers have analyzed the performance of participating nations in the Olympics.

Data envelopment analysis (DEA) has been widely used to evaluate the relative efficiencies of participating nations in the Olympics. DEA is a popular non-parametric technique for measuring the relative efficiencies of peer decision-making units (DMUs). This technique is popular in efficiency evaluation because it makes no assumptions on the production function and imposes no subjective weights on multiple inputs and outputs.

Prior studies on DEA-based Olympics achievements evaluation can be classified into two categories. The first category is based on a constant input model in which the input for each nation is assumed to be a constant (Hai, 2007; Soares de Mello, Gomes, Meza, & Neto, 2008, 2009). These studies have goals similar to multicriteria-based researches (Saaty, 2008; Sitarz, 2012, 2013). The second category is based on classical DEA models in which inputs vary with nations and correspond to some social economic variables. For example, Lozano, Villa, Guerrero, and Cortés (2002) considered two inputs (GNP and population) and three outputs (total numbers of gold, silver, and bronze medals) to measure the performance of participating nations in five Summer Olympic Games (1984–2000). Lins et al. (2003) considered the limited number of medals to be won and proposed a zero-sum game DEA model to analyze the performance of participating nations. Churilov and Flitman (2006) linked self-organizing maps to a DEA model to rank participating nations. To increase the validity of evaluation results, both Lozano et al. (2002) and Lins et al. (2003) applied the same set of assurance region (AR) constraints to all nations. Li, Liang, Chen, and Morita (2008) assumed that different nations impose different AR constraints and applied context-dependent AR DEA to measuring the performance of participating nations. Zhang, Li, Meng, and Liu (2009) discussed underlying preferences in DEA and proposed DEA models with lexicographic preference to measure performance. Wu, Liang, and Yang (2009b) used a cross-efficiency DEA model to effectively rank participating nations and incorporated cluster analysis to effectively set frontier targets for inefficient DMUs.

* Corresponding author. Tel.: +86 15205512589.
E-mail addresses: lionli@ustc.edu.cn (Y. Li), lxysun@mail.ustc.edu.cn (X. Lei), qianzhi@casipm.ac.cn (Q. Dai), lliang@ustc.edu.cn (L. Liang).

http://dx.doi.org/10.1016/j.ejor.2014.12.032
0377-2217/

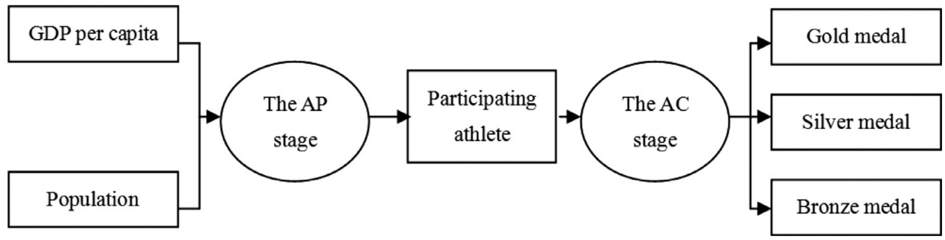

Fig. 1. Two-stage Olympic process.

Considering competition among participating nations, Wu, Liang, and Chen (2009a) modified the game cross-efficiency model of Liang, Wu, Cook, and Zhu (2008b) to assess the performance of participating nations in the Summer Olympics. Because numbers of medals are always integers, Wu, Zhou, and Liang (2010) employed an integer-valued DEA model to measure the performance of each participating nation in the 2008 Beijing Olympics. Soares de Mello, Angulo-Meza, and Lacerda (2012) proposed a non-radial DEA model to evaluate all participating nations in the 2008 Olympics, in which the input "population of each nation" is regarded as a nondiscretionary variable. Benicio, Bergiante, and Soares de Mello (2013) considered one input (the number of athletes) and three outputs (numbers of gold, silver, and bronze medals won) to measure the performance of nations in the 2010 Winter Olympics via an input-oriented, non-convex DEA model.

All of these studies treated each participating nation in the Olympics as a black box. That is, these studies ignore internal processes. When the internal processes of the DMU are considered, the efficiency score of the DMU can be assessed accurately and insights into the performance of the DMU can be obtained (Färe & Grosskopf, 2000). The two-stage DEA, which is the most common network DEA, opens the black box and has been applied to many areas, such as army recruitment (Charnes et al., 1986), education (Lovell, Walters, & Wood, 1994), banking (Seiford & Zhu, 1999), physician care (Chilingerian & Sherman, 2004), information technology (Chen & Zhu, 2004; Wang, Gopal, & Zionts, 1997), mutual funds (Premachandra, Zhu, Watson, & Galagedera, 2012), insurance companies (Chen, Cook, Li, & Zhu, 2009; Kao & Hwang, 2008), and baseball (Sexton & Lewis, 2003). However, the two-stage DEA has not been used previously in research on the Olympic Games.

In this study, we employ the two-stage DEA to measure the performance of participating nations for three reasons. First, the two-stage DEA can reveal the hidden inefficiencies of participating nations in the Olympics as compared to conventional DEA models (Moreno & Lozano, 2014). Therefore, few nations may have perfectly efficient performance in the entire two-stage Olympic process. Second, based on the two-stage DEA, we can obtain the efficiency for each stage and identify inefficient stages for each nation. Third, exploring the black box of participating nations in the Olympics can provide decision-making guidance to improve their performance.

The two-stage Olympic process considered in this study is shown in Fig. 1. The first stage is characterized as the stage of athlete preparation (AP) which includes the cultivation, training and selection of participating athletes. The second stage is described as the stage of athlete competition (AC). In the AP stage, each nation uses two inputs (population and GDP per capita) to generate the one output (the number of participating athletes). Here, participating athletes are defined as the ones selected to participate in the Olympics. Regarding the choice of inputs in the AP stage, our model assumes that the greater the population a nation has, the more participating athletes can compete in the Olympics (Lins et al., 2003). It is better, however, to also consider the conditions for athletes' training and improvement of their capacities. There is no doubt that a wealthy nation can satisfy these conditions more easily. Our model assumes GDP per capita captures the most important element of the economic power of each participating nation. Thus, GDP per capita and population are two inputs of the AP stage. The output (the number of participating athletes) of the AP stage is referred to as the intermediate measure that links both stages as shown in Fig. 1. In the AC stage, the number of participating athletes is used as the input to produce three final outputs (the numbers of gold, silver, and bronze medals). The numbers of gold, silver, and bronze medals are selected as final outputs since Olympic achievement is measured with respect to medals won. Soares de Mello et al. (2012) and Benicio et al. (2013) used inputs and outputs similar to the AC stage of this paper.

This study extends the relational model (Kao & Hwang, 2008) or the centralized model (Liang, Cook, & Zhu, 2008a[1]) to measure performance of the two-stage Olympic process and individual stages for each nation. This study assumes output orientation, because it makes no sense to cut down the population and GDP per capita for inefficient nations as would be done if we used input orientation for Olympic evaluation. Also, this study assumes variable returns to scale (VRS), because population, GDP per capita, and the number of participating athletes of all nations vary greatly. As the relational model is extended under the VRS framework, a product of free variables appears in the model. Thus, the extended relational model cannot be transformed into a linear programming problem. But we can apply a heuristic search (Li, Chen, Liang, & Xie, 2012) to calculating the global optimal solution for the extended relational model.

The rest of this study is as follows. In Section 2, several models are developed to measure the efficiencies of each nation and its two individual stages. In Section 3, the proposed models are applied to the 2012 London Summer Olympic Games and obtained results are discussed. In the last section, concluding remarks are given.

2. Two-stage methodology for analyzing the Olympics

Suppose there are n participating nations and each participating nation is denoted as a DMU. Each $\mathrm{DMU}_j (j = 1, 2, \ldots n)$ uses two inputs $X_{ij} (i = 1, 2)$ to produce the intermediate measure $Z_{dj} (d = 1)$ in the AP stage. Then, the intermediate measure is treated as an input to generate the final outputs $Y_{rj} (r = 1, 2, 3)$ in the AC stage.

When treating the DMU as a black-box, inputs of the DMU are GDP per capita and population, and outputs are the numbers of gold, silver, and bronze medals that DMU_j wins. Thus the black-box efficiency of the participating nation DMU_0 under evaluation can be obtained by applying BCC model (Banker, Charnes, & Cooper, 1984) as follows:

$$\begin{aligned}
\text{Min} \quad & \theta_0 = \frac{\sum_{i=1}^{2} v_i X_{i0} + u_0}{\sum_{r=1}^{3} u_r Y_{r0}} \\
\text{s.t.} \quad & \frac{\sum_{i=1}^{2} v_i X_{ij} + u_0}{\sum_{r=1}^{3} u_r Y_{rj}} \geq 1, \quad \forall j \\
& u_1 - u_2 \geq \xi \\
& u_2 - u_3 \geq \xi \\
& u_1 - 2u_2 + u_3 \geq \xi \\
& v_i, u_r \geq 0, \quad \forall i, r, u_0, \ \text{free.}
\end{aligned} \tag{1}$$

[1] In fact, the two models are equivalent. For details, see Cook, Liang, and Zhu (2010).