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Development of the Group Malmquist Productivity Index on non-discretionary Factors

Abbaspour, M.[1], Hosseinzadeh Lotfi, F.[2], Karbassi, A.R.[3*], Roayaei, E.[4] and Nikoomaram, H.[5]

[1]Graduate Faculty of Environment and Energy, Science and Research Campus of IAU, P .O. Box 14515-775, Tehran, Iran and School of Mechanical Engineering, Sharif University of Technology, P. O. Box 11155-8639, Tehran, Iran
[2]Department of Mathematics, Science and Research Campus of IAU, P .O. Box 14515-775, Tehran, Iran
[3]Graduate Faculty of Environment, University of Tehran, P. O. Box 14155-6135, Tehran, Iran
[4]EOR Research Institute, National Iranian Oil Company (NIOC) - Research & Technology Directorate, ZIP Code 1969813771, Tehran, Iran
[5]Department of Environmental Management, Science and Research Campus of IAU, P. O. Box 14515-775, Tehran, Iran

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ABSTRACT: Data envelopment analysis (DEA) measures the relative efficiency of a homogenous set of decision-making units (DMUs) when multiple inputs and outputs are present. The DEA-based Malmquist productivity index measuring the productivity change of DMUs over time has proven itself to be a valid tool to compare group performance. However, in the previous models developed for this purpose, it was supposed that all factors were controllable or discretionary. It is noteworthy that in most real cases, there are some inputs and outputs that are non-discretionary or semi-discretionary. Therefore, the main objective of the present study was to develop the DEA-based Malmquist productivity index on such factors to compare group performance at the same period of time. The applicability of the proposed model has been illustrated by the comparison of environmental performance – concerning HSE-MS principles – between the two groups of Iranian and International oil and gas general contractors. Involving the controllability level of factors in comparing group performance, the model offers an scalar that can easily be interpreted to compare the performance of the two groups and to determine the superior performance.

Key words: Environment, Performance, Health, Safety, Management, Non-discretionary

INTRODUCTION

Using linear programming techniques, data envelopment analysis (DEA) (Charnes *et al.,* 1978) provides an appropriate way to measure the relative efficiency of peer decision-making units (DMUs) when multiple inputs and outputs are present. It also generates an efficiency score for each unit, relative to a reference technology based on the sample of efficient units. In other words, the DEA approach defines a non-parametric best practice frontier and then measures the efficiency relative to that frontier. The DEA frontier DMUs are those with maximum output levels given input levels or with minimum input levels given output levels (Odeck, 2000; Chen and Iqbal Ali, 2004). For more thorough introduction and discussions on various DEA models and software, see Zhu (2002).Färe et al. (1992) developed a DEA-based Malmquist productivity index (MPI) which measures the productivity change of DMUs over time. The MPI was first introduced by Malmquist (1953) as a quantity index for use in the analysis of consumption of inputs. Färe *et al.,* (1992)

*Corresponding author E-mail:arkarbaasi7389@yahoo.com

combined ideas on the measurement of efficiency from Farrell (1957) and the measurement of productivity from Caves *et al.,* (1982) to construct the Mamlmquist productivity index directly from input and output data using DEA (Chen and Iqbal Ali, 2004).

This DEA-based Malmquist productivity index has proven itself to be a useful tool to measure the productivity change of DMUs. There is a substantial body of applications that use the DEA-based Malmquist productivity index. For example, productivity developments in Swedish hospitals (Färe *et al.,* 1994), changes in agricultural productivity in 18 developing countries (Fulginiti and Perrin, 1997), telecommunications productivity, technology catch-up and innovation in 74 countries (Madden and Savage, 1999), total factor productivity evolution in Organization for Economic Cooperation and Development (OECD) countries (Maudos *et al.,*1999) and a non-radial Malmquist environmental performance index for modeling the change of environmental performance of OECD countries (Zhou *et al.,* 2007).The MPI is multiplicatively decomposed into two components: one measures the technical efficiency change which is defined as the ratio of a DMU's present efficiency to the same DMU's past efficiency, and the other measures the technological change or frontier shift which determines the efficiency change of a DMU relative to the change in the efficiency frontier.

The main advantages of the DEA Malmquist productivity index that make it suitable for measuring the productivity change over time are: (I) it allows the simultaneous analysis of multiple inputs and multiple outputs, (II) it does not require priori information on tradeoffs among inputs and outputs, (III) it measures the productivity change of DMUs between two different periods of time and (IV) it determines the superior performance between two groups of DMUs at the same period of time (Asmild *et al.,* 2004).As mentioned above, one of the applications of the DEA Malmquist productivity index is measuring group performance for which related models have been developed (Camanho and Dyson, 2006). The point is that, in the previous models, it was supposed that all inputs and outputs were discretionary or controllable. However, in most real cases, there are some inputs and outputs that cannot be changed or controlled by managerial efforts. Such factors are called non-discretionary or uncontrollable factors (Banker and Morey, 1986).

Therefore, the main objective of the present study is to develop the DEA-based Malmquist productivity index on non-discretionary factors to compare group performance at the same period of time. The proposed model has been applied to compare the environmental performance – based on HSE-MS principles – between the two groups of Iranian and International oil and gas general contractors.Exploration, exploitation and production of oil and gas are governed by a wide range of laws and regulations related to health, safety and environmental issues and all companies involved in this field should implement and maintain a sound HSE-MS to meet legal and operational requirements. Health, safety and environmental management system (HSE-MS) is a process that applies a quality systems approach to managing HSE activities. This approach uses a cyclical process (i.e. plan, implement, assess and adjust) that takes experience and learning from one cycle and uses them to improve and adjust expectations during the next cycle. The system focuses on protecting people health, facility safety and surrounding environment by pulling together company HSE policies, legal requirements and business strategies into a set of company expectations or requirements to achieve continual improvement in overall HSE performance (API, 1998).

From among the three dimensions of HSE-MS, this paper focuses on the environment section and aims at developing a valid and appropriate model possessing strong mathematical concepts to compare the environmental performance of two different groups and to find the superior performance. Since some of the environmental performance indicators are non-discretionary or semi-discretionary, it is necessary to develop the DEA-based Malmquist productivity index on such indicators to compare group performance.The paper proceeds as follows: in the next part, technical backgrounds of data envelopment analysis as well as Malmquist productivity index are described. The development of the DEA-based Malmquist productivity index on non-discretionary factors to compare group performance is discussed in part 3. The case study, related data and application of the proposed model to compare the environmental performance of Iranian and International oil and gas contractors are presented in part 4. Part 5 interprets the model results, and the last part concludes.

MATERIALS & METHODS

This section consists of two sub-sections. The first briefly defines data envelopment analysis and presents its primary models. The second part introduces Malmquist productivity index and concludes with the model developed to measure the productivity change over time.The proposed model of the present study has been designed on the basis of a mathematical method known as "data envelopment analysis". DEA has been recognized as an excellent method for analyzing performance and modeling organizations. It measures the relative efficiency of peer units when multiple inputs and outputs are present and generates an efficiency score for each unit, relative to a reference technology based on the sample of efficient units (Charnes *et al.,* 1978).

Consider a set of homogeneous decision-making units (DMUs) as DMU_j, $j = 1, 2, \dots, n$. Each DMU consumes m inputs to produce s outputs. Suppose that $X_j = (x_{1j}, x_{2j}, \dots, x_{mj})$ and $Y_j = (y_{1j}, y_{2j}, \dots, y_{sj})$ are the vectors of inputs' and outputs' value of DMU_j respectively and X_j e" 0 , X_j '" 0 and Y_j e" 0 , Y_j '" 0.The CCR (Charnes, Cooper and Rhodes) model for assessing the performance of DMU_p is as follows (model 1):

$$
\begin{aligned}
&Min \quad \theta \\
&s.t. \quad \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta x_{ip} \qquad , \quad i = 1,\dots,m \\
&\qquad\ \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{rp} \qquad , \quad r = 1,\dots,s \qquad (1) \\
&\qquad\ \lambda_j \ge 0 \qquad\qquad\qquad , \quad j = 1,\dots,n
\end{aligned}
$$

The value of λ and θ will be calculated by solving model (1). The value of θ^*, the optimal solution of model (1), is called the relative efficiency of DMU_p.In order to differentiate high-efficiency DMUs from weak ones, Pastor *et al.,* (1999) developed the Enhanced Russell Graph Efficiency Measure in which all inputs and outputs are supposed to be strictly positive. Model (2) shows the Enhanced Russell Graph Efficiency Measure:

$$
\begin{aligned}
&Min \quad \mathrm{Re}_p = \frac{\frac{1}{m}\sum_{i=1}^{m}\theta_i}{\frac{1}{s}\sum_{r=1}^{s}\varphi_r} \\
&s.t. \quad \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta_i x_{ip} \qquad , \quad i = 1,\dots,m \\
&\qquad\ \sum_{j=1}^{n} \lambda_j y_{rj} \ge \varphi_r y_{rp} \qquad , \quad r = 1,\dots,s \qquad (2) \\
&\qquad\ \theta_i \le 1 \qquad\qquad , \quad i = 1,\dots,m \\
&\qquad\ \varphi_r \ge 1 \qquad\qquad , \quad r = 1,\dots,s \\
&\qquad\ \lambda_j \ge 0 \qquad\qquad , \quad j = 1,\dots,n
\end{aligned}
$$

Practically in model (2), each x_i reduces to $\theta_i x_i$ and each y_r increases to $\varphi_r y_r$. Therefore, proportional expansion of inputs and proportional reduction of outputs are the only inefficiency sources (Cooper *et al.,* 2000). It is apparent that DMU_p in model (2) is the Pareto efficient unit if and only if $\mathrm{Re}_p^* = 1$ and this only happens when:

$$
\begin{aligned}
&\forall i, \theta_i^* = 1 \\
&\forall r, \varphi_r^* = 1
\end{aligned} \qquad (3)
$$

If DMU_p in model (2) is not efficient, then it will be efficient under the following project:

$$(x_{1p},\dots,x_{mp},y_{1p},\dots,y_{sp}) \rightarrow (\theta_1^* x_{1p},\dots,\theta_m^* x_{mp},\varphi_1^* y_{1p},\dots,\varphi_s^* y_{sp}) \qquad (4)$$

Recently, the MPI has become the standard approach to productivity measurement over time within the non-parametric literature. Malmquist (1953) first proposed constructing input quantity indices as ratios of distance functions. To introduce the concept of a distance function, consider that in time period t, DMUs are using X^t inputs to produce Y^t outputs. The input distance function $\theta(X^t, Y^t)$ is defined as the maximal feasible reduction of X^t that still enables the production of Y^t (Camanho and Dyson, 2006).The MPI was only treated theoretically until its enhancement by Färe et al. (1992). They achieved to measure the productivity change of DMU_p in time periods $t+1$ and t by defining the following index (index 5):

$$MPI_p = \left[\frac{\theta_p^{t+1}(X_p^{t+1},Y_p^{t+1})}{\theta_p^{t+1}(X_p^{t},Y_p^{t})} \cdot \frac{\theta_p^{t}(X_p^{t+1},Y_p^{t+1})}{\theta_p^{t}(X_p^{t},Y_p^{t})}\right]^{1/2} \qquad (5)$$

Färe *et al.,* also defined that $MPI_p > 1$ indicates productivity gain, $MPI_p < 1$ indicates productivity loss, and $MPI_p = 1$ means no change in productivity from time t to $t+1$ (Chen and Iqbal Ali, 2004).Another achievement of Färe *et al.,* was to show how to decompose index (5) into two components: one measures the technical efficiency change and the other measures the technological change. These components are obtained by rewriting index (5) as follows (index 6):

$$MPI_p = \frac{\theta_p^{t+1}(X_p^{t+1},Y_p^{t+1})}{\theta_p^{t}(X_p^{t},Y_p^{t})}\left[\frac{\theta_p(X_p^{t+1},Y_p^{t+1})}{\theta_p^{t+1}(X_p^{t+1},Y_p^{t+1})}.\frac{\theta_p(X_p^{t},Y_p^{t})}{\theta_p^{t+1}(X_p^{t},Y_p^{t})}\right]^{1/2} \quad (6)$$

The ratio outside the bracket measures the input technical efficiency change between time periods t and $t+1$. The geometric mean of the two ratios inside the bracket captures the technological change (or shift in technology) between the two periods, evaluated at the input-output levels (X^t, Y^t) at time period t and at the levels (X^{t+1}, Y^{t+1}) at time period $t+1$(Camanho and Dyson, 2006).

RESULTS & DISCUSSION

Assume that in evaluating and measuring Malmquist productivity index, there are some inputs and outputs that either cannot be controlled or can be controlled to some extent. For example, the number of years that a company has been working in special fields cannot be changed or controlled by managerial efforts and such an indicator should be considered non-discretionary. So, to measure MPI when non-discretionary or semi-discretionary factors are involved, model (2) should be modified as model (7).It is noteworthy that in order to differentiate high-performing companies from weak ones and to determine the inefficiency sources (both combined and technical inefficiencies) of inefficient companies, one of DEA non-radial models (Enhanced Russell Graph Efficiency Measure) has been applied and developed on non-discretionary factors.where $\theta_p^L(X_p^K,Y_p^K)$ shows the efficiency value of DMU_p at time period K relative to the efficiency frontier at time period L. $\acute{a}_i$ and $\hat{a}_r$ represent the controllability level of x_i and y_r respectively. If $\acute{a}_i = 0$, then the correspondent x_i is completely uncontrollable and if $\acute{a}_i = 1$, then the correspondent x_i is completely controllable. If $\hat{a}_r = 0$, then the correspondent y_r is completely uncontrollable and if $\hat{a}_r$ '! +", then the correspondent y_r is completely controllable. It has to be mentioned that the values of $\acute{a}_i$ and $\hat{a}_r$ are determined by decision-makers. Since model (7) is a Linear Fractional Programming, it needs to be linearized by the following transformation:

$$\begin{aligned}
\theta_p^L(X_p^K,Y_p^K) &= Min \quad \frac{\frac{1}{m}\sum_{i=1}^{m}\theta_i}{\frac{1}{s}\sum_{r=1}^{s}\varphi_r} \\
s.t. \quad & \sum_{j\in L}\lambda_j x_{ij}^L \le \theta_i x_{ip}^K \quad , \quad i=1,..,m \\
& \sum_{j\in L}\lambda_j y_{rj}^L \ge \varphi_r y_{rp}^K \quad , \quad r=1,..,s \\
& (1-\alpha_i) \le \theta_i \le 1 \quad , \quad i=1,..,m \\
& 1 \le \varphi_r \le (1+\beta_r) \quad , \quad r=1,..,s \\
& \lambda_j \ge 0 \quad , \quad j \in L
\end{aligned} \quad (7)$$

$$\frac{1}{\frac{1}{s}\sum_{r=1}^{s}\varphi_r} = t \quad (8)$$

In this way, model (7) is changed to model (9):

$$\begin{aligned}
\theta_p^L(X_p^K,Y_p^K) &= Min \quad \frac{1}{m}\sum_{i=1}^{m}\theta_i \\
s.t. \quad & \sum_{r=1}^{s}\varphi_r = s \\
& \sum_{j\in L}\lambda_j x_{ij}^L \le \theta_i x_{ip}^K \quad , \quad i=1,..,m \\
& \sum_{j\in L}\lambda_j y_{rj}^L \ge \varphi_r y_{rp}^K \quad , \quad r=1,..,s \\
& t(1-\alpha_i) \le \theta_i \le t \quad , \quad i=1,..,m \\
& t \le \varphi_r \le t(1+\beta_r) \quad , \quad r=1,..,s \\
& \lambda_j \ge 0 \quad , \quad j \in L \\
& t \ge 0
\end{aligned} \quad (9)$$

In order to calculate MPI to compare group performance (i.e. to compare the performance of group A with that of group B), the following four versions of model (9) should be solved:

- Consider $L = K = A$, if model (9) is solved for each DMU of group A, then $\theta_p^A(X_p^A,Y_p^A)$ will be calculated.

- Consider $L = B$ and $K = A$, if model (9) is solved for each DMU of group A, then $\theta_p^B(X_p^A, Y_p^A)$ will be calculated.
- Consider $L = A$ *and* $K = B$, if model (9) is solved for each DMU of group B, then $\theta_p^A(X_p^B, Y_p^B)$ will be calculated.
- Consider $L = K = B$, if model (9) is solved for each DMU of group B, then $\theta_p^B(X_p^B, Y_p^B)$ will be calculated.

After solving the above models for all correspondent DMUs, the performance of group A would easily be compared with that of group B through the following Comparing Index (index 10):

$$CI^{AB} = \left[\frac{\left(\prod_{j\in A} \theta_j^A(X_j^A, Y_j^A)\right)^{1/\delta A}}{\left(\prod_{j\in B} \theta_j^A(X_j^B, Y_j^B)\right)^{1/\delta B}} \cdot \frac{\left(\prod_{j\in A} \theta_j^B(X_j^A, Y_j^A)\right)^{1/\delta A}}{\left(\prod_{j\in B} \theta_j^B(X_j^B, Y_j^B)\right)^{1/\delta B}} \right]^{1/2} \quad (10)$$

If $CI^{AB} > 1$, then the performance of group A is superior to that of group B.
If CI^{AB} Â 1, then the performance of group B is superior to that of group A.
If $CI^{AB} = 1$, then the performances of the two groups are the same.

The case study of this research comprised the two groups of Iranian and International oil and gas upstream general contractors (GCs), which provide the Iranian oil and gas industries with special technical and engineering services ranging from seismic and geological survey, drilling and exploration to oil and gas production. The group of Iranian contractors consisted of six GCs which were the total number of contractors working as upstream GCs at the time of data gathering (2005). Similarly, the group of International contractors consisted of six international GCs' representatives which were the total number of international upstream GCs working in Iran at the time of data gathering (2005).

Since the aim of the present study was to compare the environmental performance based on the HSE management system, it was required to incorporate managerial indicators. To do this, the contractors were asked to submit such indicators which then, were thoroughly investigated and finalized by HSE professionals. In order to separate indicators into inputs and outputs, the views of contractors' top managers were taken into account. Finally, 8 indicators (2 inputs and 6 outputs) were considered as the environmental performance indicators.Each indicator comprised a number of components helping the accurate measurement and auditing of the indicator. Inputs and outputs and their relevant components are expatiated in the following part:

Input #1 (I_1): This indicator shows the number of years that the contractor has been working in the field of oil and gas. It is self-evident that the contractor background affects its performance in all aspects. (i.e. the more the company background is, the more each output's level and consequently the more the efficiency value are expected to be). So this indicator is considered as a factor entering the system. Moreover, since this input cannot be changed by the administrative part of the company, it is considered as an uncontrollable (non- discretionary) factor.

Input #2 (I_2): This indicator expresses the contractor's training programs. Top-down commitments to environmental protection principles are not met unless appropriate training courses help employees better perceive the significance of environmental issues. Holding periodical workshops, preparing books and pamphlets and presenting educational films are the components of training programs respected as one of the most important sub-elements of HSE-MS. Similar to the first input, it is expected that an increase in the quality and quantity of training programs raises each output's level and consequently the efficiency value. So this indicator is considered as a factor entering the system. Although training programs are related to the contractor's previous activities, they can still be improved by managerial efforts to some extent. Therefore, this input is considered as a semi-discretionary factor:

Output #1 (O_1): This indicator presents the contractor's awareness of environmental laws, regulations and standards in the field of oil and gas. A company expecting a high environmental performance should thoroughly be aware of and comply with the relevant laws and standards. This output consists of such components as awareness of international and regional environmental conventions and agreements, awareness of national and local environmental laws and regulations and awareness of current national and local environmental standards in the field of oil and gas.

Output #2 (O_2): This indicator shows the contractor's achievements of indentifying adverse environmental impacts arising from its activities. Detecting all sources of environmental pollutants including atmospheric emissions, aqueous waste streams, solid wastes, noise pollution, etc. is one of the preliminary stages for developing any preventive measures and mitigation methods. This may help the contractor identify major and persistent environmental impacts and allow it to timely and financially allocate its resources to reduce, control and eliminate those impacts. The contractor's attention towards performing "environmental impact assessment" (EIA) and preparing "environmental impact statement" (EIS) before starting any project are also considered in this output.

Output #3 (O_3): This indicator aims at environmental risks reduction measures considered as a part of risk assessment, which is one of the most important elements of HSE-MS. Having reports on the past environmental incidents, studying and analyzing the factors involved in environmental incidents, developing "emergency response plan" (ERP) and required actions in case of environmental incidents, the level of success in preventing environmental incidents and in reducing pollutants in the environment are considered as the components of this output.

Output #4 (O_4): This indicator points out the contractor's success in reduction of projects' costs and expenses. Cost reduction has been the subject of interest for companies seeking a high performance. Some components such as the contractor's success in employing "pollution prevention" (P2) techniques (i.e. preventing pollution at the source), recycling and reusing wastes and applying "clean energy" technologies to reduce the need for fossil fuels and to decrease environmental pollution may result in the reduction of projects' costs and expenses usually within a long time.

Output #5 (O_5): This indicator presents the level of success in the environmental management process concerning HSE disciplines. Protection of the environment in all aspects is not met unless the company becomes successful in implementing a systematic environmental management process. This output consists of seven components as follows: assigning a codified environmental policy, the level of advancement in particular operational objectives developed to achieve high standards of environmental compliance, the staffing and organizing adequacy of the contractor's environmental department, monitoring and auditing the performing environmental activities, recognizing the contractor's weaknesses and strengths in the performing environmental activities, detecting reasons for not achieving the desired standards, providing necessary plans for mitigation methods or improving the situation of the environment.

Output #6 (O_6): This indicator shows the number of valid certificates (i.e. ISO 14001 and OHSAS 18001) the contractor has received. These certificates represent that the contractor was able to meet the requirements of "environmental management system" (EMS) and "occupational health and safety assessment series" (OHSAS). Moreover, they may provide appropriate grounds for implementation of HSE-MS.(Table 1) represents the study inputs and outputs.

Table 1. Indicators required for comparing the environmental performance

Inputs	I_1. Number of years that the contractor has been working in the field of oil and gas
	I_2. Company's training programs
Outputs	O_1. Awareness of environmental laws, regulations and standards in the field of oil and gas
	O_2. Identification of adverse environmental impacts arising from the contractor's activities
	O_3. Environmental risks reduction measures
	O_4. Reduction of projects' costs and expenses
	O_5. Environmental management process concerning HSE disciplines
	O_6. Number of international certificates received in the scope of HSE-MS

To gather data, a checklist including inputs and outputs and their relevant components was designed. Then, a professional audit group including environmental, HSE and management experts teamed up to audit the environmental performance in each company and finally to measure and determine the score of each indicator through the checklist. Tables (2) and (3) show inputs' and outputs' scores of Iranian and International contractors respectively.

Table 2. Indicators' scores of Iranian contractors

Indicators \ DMUs	7	8	9	10	11	12
I_1	5	≥ 5	≥ 5	2.5	≥ 5	≥ 5
I_2	10	8	10	7.6	5	8.6
O_1	9.3	9.6	9	10	7	9.3
O_2	9.4	9.8	9.2	10	7.4	9.4
O_3	9.8	9.8	9.2	10	9	9.8
O_4	9.6	8.3	9	6.6	7	8.3
O_5	10	9.5	9	9.2	7.7	9.8
O_6	0	0	1	0	1	1

Table 3. Indicators' scores of International contractors

Indicators \ DMUs	7	8	9	10	11	12
I_1	≥ 5	≥ 5	≥ 5	2.5	≥ 5	≥ 5
I_2	10	8	10	7.6	5	8.6
O_1	9.3	9.6	9	10	7	9.3
O_2	9.4	9.8	9.2	10	7.4	9.4
O_3	9.8	9.8	9.2	10	9	9.8
O_4	9.6	8.3	9	6.6	7	8.3
O_5	10	9.5	9	9.2	7.7	9.8
O_6	0	0	1	0	1	1

In the present case, the group of Iranian contractors is considered as group A and the group of International contractors is considered as group B. It is also assumed that $\alpha_1 = 0$, which means that the first input is completely uncontrollable and $\alpha_2 = 0.7$, which means that the second input is %70 controllable. All outputs are supposed to be completely controllable. It is also noteworthy that the importance of all indicators from the decision-makers' point of view is considered the same (i.e. all indicators have the same weight).The results of solving the four versions of model (9) for the correspondent DMUs are shown in tables (4) and (5):

Table 4. Relative efficiency and technological change of group A

		Technological change $\theta_p^B(X_p^A, Y_p^A)$	Relative efficiency $\theta_p^A(X_p^A, Y_p^A)$
DMUs of group A	1	1	1.33333
	2	1	4.3
	3	0.65	1.04348
	4	0.69444	1.88889
	5	1	1.83333
	6	0.79905	1.01355

Table 5. Relative efficiency and technological change of group B

		Technological change $\theta_p^B(X_p^B, Y_p^B)$	Relative efficiency $\theta_p^A(X_p^B, Y_p^B)$
DMUs of group B	7	0.96387	0.65
	8	0.94617	0.65
	9	1	0.725
	10	1	0.85826
	11	1	0.88516
	12	1	0.78793

By putting the above values into index (10), the comparing index is easily calculated ($CI^{AB} = 1.374$). Since $CI^{AB} > 1$, the performance of Iranian contractors (group A) is superior to that of International contractors (group B) at the same time period (2005).In the previous models designed to compare group performance based on the DEA Malmquist productivity index, it was supposed that all factors were controllable or discretionary. However, in most real cases, there are some inputs and outputs that are non-discretionary or semi-discretionary. Therefore, the main objective of the present study was to develop the DEA-based Malmquist productivity index on such factors to compare group performance at the same period of time. The proposed model was applied to compare the environmental performance – concerning HSE-MS principles – between the two groups of Iranian and International oil and gas general contractors.

CONCLUSION

To sum up, the proposed model is well defined since (1) it offers an scalar that can easily be interpreted to compare the performances of two groups and to distinguish the superior performance, (2) it determines both combined and technical inefficiencies of inefficient DMUs, due to employing one of DEA non-radial models (Enhanced Russell Graph Efficiency Measure), (3) it calculates an overall performance measure through decomposing it into a part comparing the efficiency spread among DMUs in each group (referred to as within-group efficiency spreads) and a part capturing the difference in the efficiency frontiers of two groups (referred to as the productivity gap between the frontiers), and (4) it involves the controllability level of factors in comparing group performance as well as in interpreting the results. Despite the above advantages and capabilities, the proposed model may become infeasible when special data are involved. In addition, the model is only capable of comparing group performance at the same time period (not at different time periods). However, it would be possible to apply the DEA-MPI technique for developing appropriate models capable of comparing group performance at different time periods.Finally, it is worth mentioning that, in the future, it could be interesting to study the behavior of the proposed model when other kinds of inputs/ outputs such as undesirable ones are involved. It would also be possible to weigh indicators based on their relative importance from the decision-makers' point of view. In this way, weight constraints would be incorporated to the model and the results would accordingly be interpreted.

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