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The Efficiency Change and the Relationship with Reform Using DEA Model and Malmquist Index

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Original Article

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Abstract

The study uses the technical efficiency and the mathematical model data envelopment analysis (DEA) in an attempt to analyze the performance the Iranian thermal power plant. The DEA is a nonlinear programming technique designed to calculate technical efficiency achieved by decision-making units. Total factor productivity (TFP) change for common set of thermal power plants operating from 2002 to 2008 was examined using a Malmquist productivity index using prowess database. The TFP was divided into efficiency change (caching up phenomena) and technical change (innovations). Improvement in productivity, efficiency change, and technical change was confirmed in Iranian power plants between 2002 and 2008; therefore, the results enable TAVANIR Co. to monitor and spot changes in productivity of its thermal units. In addition, the agents can utilize the result to build their efficiency profile as a function of their competitors. They also can find recommendations for improvement of inefficiency. Given the trend of privatization in Iran's power generation market, the results confirmed improvement in efficiency and productivity of thermal power plants in the country. Furthermore, a relationship was found between the restructuring and enhancing productivity.

Keywords:
Data envelopment analysis (DEA),
Malmquist productivity index,
Efficiency changes,
reform,
Thermal Power Plants

INTRODUCTION

This paper presents a case study in which we applied data envelopment analysis (DEA) models to measure the relative efficiencies and employed Malmquist productivity index to measure productivity changes for thermal power plants operated by the Iranian production management companies.

This study was motivated by a real problem, and thus, aimed to fill the gap for evaluating the performance of the thermal power plants. In particular, this study employs nonparametric Malmquist productivity index to study the productivity changes, which can be classified into efficiency and technology aspects, of the plants from 2002 to 2008.

DEA models offer a practicable approach for evaluating the relative efficiency of decision making units (DMUs) in various contexts. However, the relative efficiency and the productivity changes of Iranian thermal power plants have seldom been addressed in existing studies.

The rest of this paper is organized as follows. Section II describes the fundamentals of this study including DEA models and Malmquist productivity index and also reviews the related literature. Section III describes an empirical study on the productivity changes of thermal

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power plants in Iran. in Section IV We have concluded that the reform process, through the privatization, has brought about an improvement in the allocation of resources; i.e. the reformed firms attain greater efficiency. finally Section V concludes with discussions and results.

Literature Review

The efficiency is measured using the ratio of the aggregated output to the aggregated input. Following Charnes *et al* [1], an evaluated entity is said to be efficient if it is not possible to increase (decrease) the level of an output (input) without increasing the use of at least one other input or decreasing the generation of at least one other output. DEA measures the efficiency or inefficiency of each Decision Making Unit (DMU) by mathematical programs that enable one to measure the distance of each DMU from the efficiency frontier. It is a tool for nonparametric evaluation, which differs from parametric techniques, such as stochastic frontier analysis. The great advantage of DEA is that there is no need to assume specific functional forms and it is possible to deal with many products.

DEA models have been effectively applied for measuring the relative efficiency of the DMUs in many fields, including schools and universities, hospitals, banks and court systems [2].

DEA is a linear programming method that can deal with multiple inputs and multiple outputs simultaneously, yet DEA does not require the assignment of predetermined weights to the input and output factors.

In this work, DEA was applied to measure technical efficiency, using both classic models CRS (constant returns to scale) and VRS (variable returns to scale) with output orientation, in which one seeks output maximization with use a particular input level. The CCR model produces a constant returns to scale (CRS) efficiency frontier. The evaluated relative efficiency of the CCR model is an overall (or aggregated) efficiency score. The BCC model produces variable returns to scale (VRS) efficiency frontier and evaluates both the pure technical efficiency and the scale efficiency. Thus, the overall efficiency can be decomposed into the pure technical efficiency and the scale efficiency. Indeed, the value of pure technical efficiency times the value of scale efficiency is equal to the value of overall efficiency.

Also we calculate the productivity change of Iranian thermal power plant by applying the nonparametric Malmquist index approach. The Malmquist productivity index was introduced by Caves et al. (1982). The empirical potential of the approach was shown by Fare et al. (1994) who demonstrated how the values of distance functions needed in the approach could be computed by applying linear programming techniques used in data envelopment analysis. The basic idea of the Malmquist productivity index is to measure total factor productivity change (TFP).

As generally in productivity measurement, an index of output is divided by an index of inputs. The key question for productivity indices is the determination of weights. The advantage of Malmquist index is that price information or cost share information is not needed for weighting in this approach. This is an invaluable property for public sector applications since for public services reliable price information is often missing. An important advantage of applying Malmquist index to panel data is that one can decompose productivity change into two components: efficiency change (catching-up effect) and technological change (shift of the efficiency frontier).

This kind of information is useful since productivity improving policy measures depend on the pattern of productivity change. The appropriate policy responses will be different for productivity slowdown due to the catching-up being modest, and when the slowdown is due to the lack of change of the frontier technology.
Malmquist index is constructed from distance functions, allowing explicit calculation and isolation of changes in inefficiency.

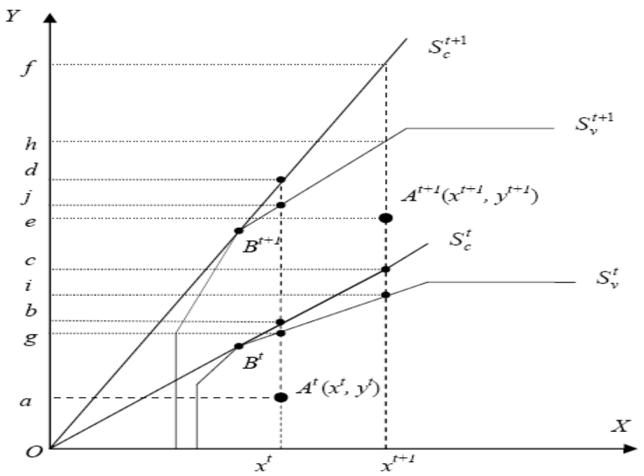

Fig 1. Output Distance Function and the Malmquist TFP Change Index.

Figure 1 shows the calculation of output distance functions. In Figure 1 S_c^{t+1} and S_c^t represent CRS production frontiers, while S_v^{t+1} and S_v^t represent VRS production frontiers, at times t+1 and t respectively. Under CRS, the measures of various output distance functions are:

$$D_c^t\ (x^{t+1}, y^{t+1}) = \frac{oe}{oc} \qquad D_c^{t+1}\ (x^t, y^t) = \frac{oa}{od}$$

$$D_c^t(x^t, y^t) = \frac{oa}{ob} \qquad D_c^{t+1}(x^{t+1}, y^{t+1}) = \frac{oe}{of}$$

Fare et al.'s Malmquist TFP change index can $M^{fare}(x^{t+1}, y^{t+1}, x^t, y^t)$ then be defined as

$$M^{fare}(x^{t+1}, y^{t+1}, x^t, y^t) = \left[M^t M^{t+1}\right]^{1/2} = \left[\frac{D_c^t(X^{t+1}, Y^{t+1}) D_c^{t+1}(X^{t+1}, Y^{t+1})}{D_c^t(X^t, Y^t) D_c^{t+1}(X^t, Y^t)}\right]^{1/2} = \frac{D_c^{t+1}(x^{t+1}, y^{t+1})}{D_c^t(x^t, y^t)} \times \left[\frac{D_c^t(x^{t+1}, y^{t+1}) D_c^t(x^t, y^t)}{D_c^{t+1}(x^{t+1}, y^{t+1}) D_c^{t+1}(x^t, y^t)}\right]^{1/2}$$

The ratio outside the brackets is defined as technical efficiency change (TEC) and the ratio inside the brackets as Technological Change (TECHCH) or Frontier Technology Shift (FS)

Normally, if VRS is assumed then there is $D_c(x, y) = D_v(x, y) \times SE(x, y)$

where SE represents the scale efficiency. Based on this Equation, Fare et al. further decomposed the TEC term into two more components under the VRS frontier: Pure Technical (Managerial) Efficiency Change (PECH) and scale efficiency change (SECH).

$$\frac{D_c^{t+1}(x^{t+1}, y^{t+1})}{D_c^t(x^t, y^t)} = \frac{D_v^{t+1}(x^{t+1}, y^{t+1})}{D_v^t(x^t, y^t)} \times \frac{SE^{t+1}(x^{t+1}, y^{t+1})}{SE^t(x^t, y^t)}$$

In terms of Figure 1 the ratio forms of $PECH$ and $SECH$ can be written in the following ratio forms:

$$PECH = \frac{D_v^{t+1}(x^{t+1}, y^{t+1})}{D_v^t(x^t, y^t)} = \frac{oe}{oh} \times \frac{og}{oa}$$

&

$$SECH = \frac{SE^{t+1}(x^{t+1}, y^{t+1})}{SE^t(x^t, y^t)} = \frac{oh}{of} \times \frac{ob}{og}$$

Finally then, Fare et al.'s Malmquist $M^{fare}(x^{t+1}, y^{t+1}, x^t, y^t)$ TFP change index is decomposed as:

$$M^{Fare}(x^{t+1}, y^{t+1}, x^t, y^t) = PECH_v \times SECH \times FS_C$$

Computation of Malmquist indices can be carried out by applying linear programming techniques for determining the type of efficiency measures introduced by Farrell [3].

We compute Malmquist indices for years 2002-2008. Malmquist indices applying a fixed base year. We carry out the calculations with the constant returns to scale assumption and in the output orientation.

There are a number of DEA studies on power systems and power industry, while DEA has been successfully applied in different domains. For example Ali Emami Meibodi [4] measured the efficiency of 30 Thermal power plants in Iran. His findings indicate that a more effective check on the efficiency of individual electricity industries, power plants and distribution organizations is required to avoid the unnecessary use of resources. Fare et al.[5] applied DEA to evaluate the relative efficiency of electric utilities regulated by Illinois Commerce Commission, in which an output (net generation) and three inputs (fuel, labor, and capital) were considered.

Athanassopoulos et al. [6] developed the data envelopment scenario analysis for setting targets to electricity generating plants in the United Kingdom, in which four outputs (electricity produced, plant availability, accidents incurred, and pollution generated) and three inputs (fuel, controllable costs, and capital expenditure) were considered in the DEA models. Park and Lesourd [7] evaluated the operating efficiency of 64 conventional fuel power plants in South Korea and considered an output (net electrical energy) and three inputs (fuel consumption, installed power, and labor).

Sueyoshi and Goto [8] proposed a slack-adjusted DEA model to examine the performance of Japanese electric power generation companies from 1984 to 1993 and considered total generation as the output and used three inputs (capacity, total fuel consumption, and total employees). Raczka [9] evaluated the performance of 41 thermo-electric power plants in Poland, in which a single output (heat production) and three inputs (labor, fuel, and air pollution penalty) were considered.

Cook and Green [10] developed a two-stage hierarchical model to evaluate a set of power plants and the individual power generating units, in which three inputs (forced derating, maintenance expenditure, and occupied hours) and two outputs (full capacity operating hours and number of outages) were considered for the analysis.

Golany et al. [11] evaluated the operating efficiency of power plants in the Israel Electric Corporation, in which four outputs (generated power, operational availability, deviation from operational parameters, and SO2 emissions) and three inputs (installed capacity, fuel consumption, and manpower) were considered. Lee et al. [12] studied the Korean electric power industry using data from 1990 to 1995, in which three inputs (labor, capacity,

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and fuel) and one positive output (annual power generation) and three undesired outputs (emissions of SOx, NOx, and total suspended particulates) were studied. Fare et al. [13] compared the TE of 209 electric utilities before (in 1993) and after (in 1997) the implementation of the legislation to control acid rain. They considered three inputs (labor, capacity, and fuel) and one positive output of annual power generation, and one undesired output of SO2 emissions. Kumar jha et al [14] evaluated performance of the hydropower plants owned by Nepal Electricity Authority (NEA).

They considered four output (Annual energy generation , Energy generated in the driest month ,Summer season peaking capacity ,Winter season peaking capacity) and inputs (Installed capacity of the plant , Annual O&M cost ,Number of staff (Permanent) , Plant tripping , Unit tripping).

Empirical study

This empirical study involves three major tasks including problem structuring, determination of input and output factors for measuring the relative efficiency of the selected DMUs, and discussion of the DEA results.

Problem structuring

This section deals with an investigation into technical efficiency of the Iranian thermal power plants. Consistent data was collected for 48 power plants. our analysis uses this data collected on thermal power plants. This selection ensures that plants in the sample constitute a homogenous technology.

There are four categories of thermal power plants; steam turbine, gas turbine, combined cycle and diesel generator. During the period 2002-2008 the share of gas turbines in the country's electricity production was risen while the share of diesel generators has remained at a low level. In 2008, around 19.5% of the electricity produced by the Ministry of Energy came from gas turbines, about 3.1% came from hydro, 48.2% was from steam power plants, 29.1% came from combined cycle and the remaining 1% was produced by diesel generators. Then the electricity supply industry has been based mostly upon thermal power plants.

In iran, some existing open cycle gas turbine are being converted to combined cycle operation through adjusting the steam cycle equipment. As can be seen later on, the use of gas turbines in combination with steam turbines in combined cycle plants is advisable.

The application of the Malmquist DEA methods to panel data provides an appropriate tool to calculate indices of total factor productivity, technological, technical and scale efficiency changes in power plants of Iran.

Determination of input and output factors

The choice of variables is based on the availability of data, and on our previous discussion of the current literature. A reliable efficiency analysis depends clearly on the quality of the data. To understand the results and policy implications, it is important to get a real feel for the data. The data necessary was extracted from seven series of annual statistical reports. The major source of Iranian data is the statistics of the Ministry of Energy. The selection of factors to enter the efficiency analysis was carried out in two stages.

Stage 1

First a long list of candidate factors (output and input) was compiled. in this step we choose from them the ones it's frequency of usage in articles was bigger because this factors was carried out by experts. you can see usage frequency of factors in figure2 and figure3.

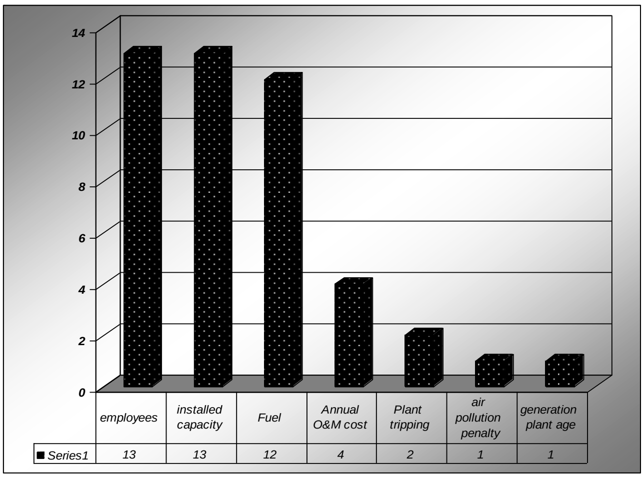

Fig 2. Input Factors**.**

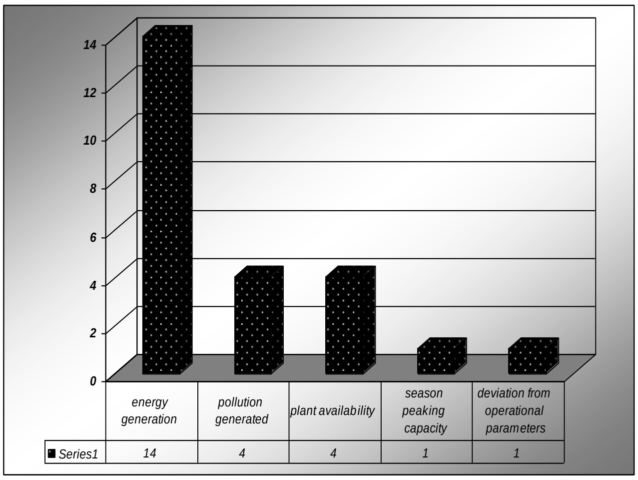

Fig 3. Output Factors.

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The energy generation is the major output since the function of the plants is to supply electricity to meet demand. The installed capacity is a fundamental input factor that differentiates plant productivity. Meanwhile, the total number of employees is an important input, and in fact, personnel cost is also a critical input factor in state-owned enterprises. Fuel consumption also is the input factor that covers the cost of supporting plant operations.

Three inputs (employees, installed capacity and fuel) and one output (energy generation) passed the first stage.

Stage 2 regression analyses

The factors remaining after the first screening process were analyzed for correlation between pairs. The resulting is given in table2. This analysis identified potentially redundant factor, where a low correlation was found between inputs with output.

Table 2. Correlation among factors.

Factors	Installed Capacity	Fuel	Employees	Energy Generation
installed capacity		0.899	0.523	0.896
fuel			0.614	0.975
employees				0.609
energy generation				

Observing again table2 we see that the factors above are associated with various levels of correlation coefficients. Installed capacity and fuel consumption are highly correlated (0.896 and 0.975) to the energy generation. But Employees is weakly correlated (0.609) to the energy generated.

the results of fitting a multiple linear regression model to describe the relationship between Energy Generation and 3 independent variables show that :

Energy Generation = -422616.0 + 388.132*Employees + 0.000395062*Fuel + 601.712*Installed Capacity

Notice that the highest P-value on the independent variables is 0.2360, belonging to employees. Since the P-value is greater or equal to 0.10, that term is not statistically significant at the 90% or higher confidence level. Consequently, we should consider removing employees from the model.

At the end of screening procedure the following 3 factors; installed capacity& fuel as input , energy generation as output were finally chosen.

The measurement of outputs and inputs followed standard practice found in the literature. The fuel input includes natural gas, gas oil and fuel oil. These fuels are used in the generation stage and are aggregated into a single input by summing over their Btu (or terajoules) equivalents. Installed capacity, measured in MW.

Table 3 lists the sample of annual data of 48 power plants used in this study from 2002 to 2008. Using the annual data can reduce the influence of seasonal effects. Moreover, considering seven time periods can effectively evaluate the productivity change of the plants along the time.

Table 3. Sample of Input and Output Data of Thermal Power Plants In 2002.

Type	Total DMU	DMU	Installed Capacity{I}	Fuel{I}	Energy Generation {O}
steam	19	Firozi	50	771,770	226,743
gas	17	Mashad_g	196	2,617,008	774,034
cycle	12	Montazer gha_c	998	7,484,873	3,998,330

Discussion of the DEA results

DEA Results for thermal Power Plants

After having organized the matrices, the models were solved using the EMS - Efficiency Measurement System software, taking an output orientation to obtain the efficiency levels. The efficiency measures with constant and variable returns made it possible to obtain the scale efficiency for each plant, given by the ratio between the measures of overall technical efficiency with constant returns and pure technical efficiency with variable returns.

Tables 4, 5, 6 summaries the DEA results in which the 48 plants in the same peer group are compared over a seven-year period. The average pure technical efficiency is 80.9%, indicating that the Iranian power plants were 19.1% pure technical inefficient over the period 2002 to 2008. Steam power plants sector achieved the highest scores (0.917) and form the reference frontier or reference technology, indicating that it has good operational management. At the second level was cycle power plants with the score (0.827). Gas power plants sector achieved the lowest scores (0.688) and therefore model indicates that the increasing share of steam power plant in power stations has a significant effect on efficiency improvement. The finding implies that there is immediate benefit from a combined cycle pattern, so that the gas power stations should be converted into combined cycle plants. Also we can see the average of pure technical efficiency in steam and gas is improved after reform.

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Table 4. Pure Technical Efficiency in Thermal Power Plants (2002-2008).

Type	2002	2003	2004	2005	2006	2007	2008
All	0.808	0.798	0.807	0.816	0.818	0.792	0.824
Average	0.804			0.812			
2002-2008	0.809						
Ave steam	0.904	0.903	0.911	0.928	0.918	0.937	0.919
Average	0.906			0.926			
2002-2008	0.917						
Ave gas	0.694	0.664	0.681	0.704	0.723	0.649	0.699
Average	0.679			0.694			
2002-2008	0.688						
Ave cycle	0.841	0.849	0.832	0.815	0.810	0.791	0.851
Average	0.841			0.817			
2002-2008	0.827						

Table 5. Overall Technical Efficiency in Thermal Power Plants (2002-2008).

Type	2002	2003	2004	2005	2006	2007	2008
All	0.700	0.708	0.710	0.709	0.73	0.677	0.732
Average	0.706			0.712			
2002-2008	0.709						
Ave steam	0.845	0.850	0.857	0.873	0.863	0.886	0.854
Average	0.851			0.869			
2002-2008	0.861						
Ave gas	0.505	0.508	0.501	0.502	0.545	0.447	0.527
Average	0.505			0.505			
2002-2008	0.505						
Ave cycle	0.829	0.836	0.822	0.790	0.798	0.741	0.836
Average	0.829			0.791			
2002-2008	0.808						

Table 6. Scale Efficiency in Thermal Power Plants (2002-2008).

Type	2002	2003	2004	2005	2006	2007	2008
All	0.867	0.887	0.881	0.869	0.892	0.855	0.889
Average	0.878			0.876			
2002-2008	0.877						
Ave steam	0.935	0.942	0.941	0.941	0.940	0.945	0.929
Average	0.939			0.939			
2002-2008	0.939						
Ave gas	0.728	0.765	0.736	0.713	0.755	0.688	0.753
Average	0.743			0.727			
2002-2008	0.734						
Ave cycle	0.985	0.985	0.988	0.970	0.985	0.936	0.983
Average	0.986			0.969			
2002-2008	0.976						

The average overall technical efficiency is 70.9%, indicating that the Iranian power plants were 29.9% technically inefficient over the period 2002 to 2008. Steam power plants sector achieved the highest scores (0.861). At the second level was cycle power plants with the score (0.808).Gas power plants sector achieved the lowest scores (0.505). The average scale efficiency is 87.7%, indicating that the Iranian power plants were 12.3% scale inefficient over the period 2002 to 2008. For entire organizations, the average pure technical efficiency and scale efficiency are 80.9% and 88.7% respectively. The average overall technical efficiency in thermal power plants was found to be relatively low at 71%. This finding is in agreement with the argument that efficiency in power sectors has been a neglected goal for public policy in many power plants. The relatively high average scale efficiency score (0.877) suggests that scale inefficiency (12.3%) is a less serious problem than managerial (pure) inefficiency (19.1%) in the power plants of Iran under investigation. Managerial inefficiency is a very serious problem for some plants, namely for gas turbines.

Power plants, in general, are operating at a scale less than the long-run optimum (constant returns to scale). Most of these power plants exhibit increasing returns to scale. This suggests that if they were not efficient, scale expansion should improve performance. The managerial (pure) technical efficiency of the electricity sector in different type of plants varies widely from 68.8 percent to 91.7 percent. The overall technical efficiency of Iran is 0.709. Therefore, Iran could be able to reduce the consumption of capital and energy inputs by 29.1% without reducing electricity output.

Notably, production technology might have changed during the seven-year time frame. Therefore, this study also applies the Malmquist output-based productivity index to investigate the productivity changes of the 48 plants from 2002 to 2008 using the panel data as sample data listed in Table 3.

Productivity Changes of the Power Plants

Tables 7, 8 show the total factor productivity changes by company and by year, respectively. Table 7 summarizes the results of the overall productivity changes via Malmquist index, which can be further decomposed into technical efficiency changes and Technological Changes as addressed earlier. Panel data was available for 48 power plants from 2002 to 2008, and a Malmquist index was constructed to identify the differences in the total factor productivity of power plants.

2002 is set as the base period to be the reference point for observing the annual changes. Table 7 presents the average Malmquist productivity index and its decomposition; technological change, pure technical and scale efficiency changes. Recall that the distinction between efficiency growth and technological change is important because they are essentially different phenomena, and so different policies may be required to handle them. The improvements in the technological change component are evidence of innovation while improvements in the efficiency-change component are evidence of catching-up with the frontier. This decomposition provides an attractive way of examining convergence of productivity growth, as well as allowing identification of inefficiencies. These calculations indicate that power plants experienced productivity growth between 2002-2008. The results suggest that there was technological progress in most (40) power plants. However, eight power plants (Firozi, zarand, mashad_b, tous, Montazeri, konarak, kangan and Shiraz) displayed technological regress in this period.

The Malmquist index varies widely across power plants in the period 2002-2008. The highest total productivity progress (1.297) occurs at the shariati_cycle power plant. However, on the other hand, the mashad_b power plant registered highest technological regress (0.983) during this period; so much its total productivity progress originates from scale efficiency. The greatest productivity slowdown is found at the zahdan power plant due mainly to technical inefficiency (0.877). The principal finding is that low pure technical (managerial) efficiency change (1.006) decrease Technical efficiency Change (TEC).

So technological progress(1.023) dominated at TEC in power plants in the period 2002-2008. The moderate total productivity progress over the period is due mainly to technological progress and scale efficiency.

Fig. 4. Malmquist index and it's decomposed of power plant (2002-2008).

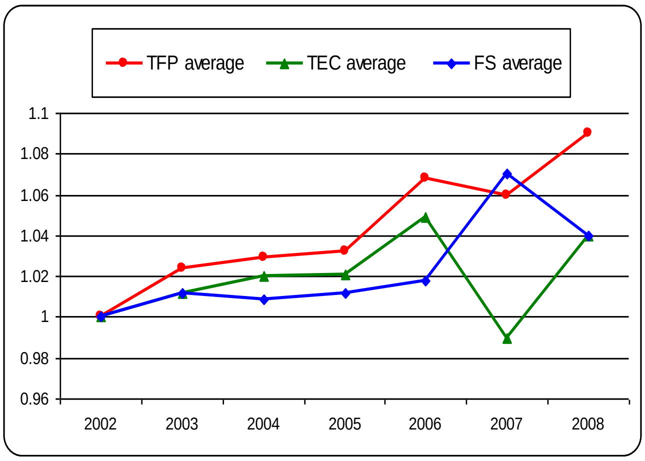

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Table 7. Malmquist Index Summary of Power Plant Means (2002-2008)

DMU	(TEC)	(FS)	(PECH)	(SECH)	TFP	DMU	(TEC)	(FS)	(PECH)	(SECH)	TFP
Firozi	0.954	0.988	1.000	0.954	0.942	Sufian	1.019	1.028	1.014	1.004	1.048
Zarand	1.038	0.991	1.009	1.028	1.028	Tabriz_g	0.907	1.021	1.029	0.881	0.926
Mashad_b	1.007	0.983	1.001	1.006	0.990	Orumieh	1.007	1.028	1.003	1.004	1.036
Loshan_b	0.925	1.005	1.000	0.925	0.929	Rey	0.972	1.044	1.009	0.963	1.015
Besat	1.082	1.005	0.988	1.095	1.088	Shariati	0.917	1.036	0.984	0.932	0.950
Iranshahr	1.267	1.023	1.022	1.239	1.296	Ghaen	0.949	1.073	1.000	0.949	1.018
Tous	0.995	0.995	0.994	1.001	0.990	Bushehr	1.016	1.057	1.000	1.015	1.074
Montazer ghaem_b	1.027	1.021	1.013	1.013	1.048	Kangan	1.211	0.987	1.022	1.184	1.196
Bistun	1.043	1.027	1.007	1.035	1.071	Shiraz	0.959	0.997	0.996	0.962	0.955
Isfahan	1.007	0.994	0.996	1.011	1.001	Yazd_g	1.137	1.050	0.996	1.141	1.194
Rajaee_b	1.015	1.020	0.999	1.016	1.035	Zanbagh	1.092	1.065	0.974	1.122	1.163
Mofateh	0.907	1.038	0.979	0.926	0.941	Modhej_g	1.030	1.042	0.998	1.033	1.074
Bandarabbas	1.101	1.021	1.016	1.084	1.125	Montazer	0.968	1.027	0.984	0.983	0.993
Shazand	1.027	1.032	0.998	1.029	1.060	Rajaee_cycle	1.011	1.028	1.009	1.002	1.039
Montazeri	1.030	0.987	1.000	1.030	1.017	Salimi_cycle	0.962	1.021	1.035	0.930	0.982
Salimi_b	1.021	1.012	1.007	1.014	1.033	Khoy_cycle	1.054	1.023	1.016	1.038	1.078
Ramin	0.933	1.033	0.994	0.938	0.964	Qum_cycle	1.067	1.019	1.004	1.063	1.087
Tabriz_b	1.059	1.033	1.023	1.035	1.095	Nishabur_cycle	1.240	1.035	1.033	1.200	1.283
Modhej_b	0.993	1.025	0.991	1.002	1.018	Shariati_cycle	1.261	1.029	1.034	1.220	1.297
Mashad_g	0.929	1.014	0.966	0.962	0.942	Kazerun_cycle	1.066	1.037	1.044	1.021	1.106
Loshan_g	1.054	1.044	1.037	1.016	1.101	Fars_cycle	1.112	1.023	1.017	1.094	1.137
Zahdan	0.873	1.004	0.973	0.897	0.877	Kerman_cycle	0.970	1.040	1.030	0.942	1.009
Konarak	1.057	0.993	1.020	1.036	1.049	Gilan_cycle	0.969	1.019	0.995	0.974	0.988
Hesa	0.910	1.075	1.000	0.910	0.978	Yazd_cycle	0.982	1.021	1.018	0.965	1.002
Average	1.020	1.023	1.006	1.014	1.043						

Table 8. Total Factor Productivity Change (TFP) (2002-2008)

DMU	2002	2003	2004	2005	2006	2007	2008	ave	DMU	2002	2003	2004	2005	2006	2007	2008	ave
1	1	0.99	0.913	0.942	1.005	0.813	0.940	0.933	25	1	0.97	0.973	0.966	1.274	1.067	1.112	1.056
2	1	0.99	1.116	0.937	1.037	1.031	1.086	1.033	26	1	0.97	0.871	0.926	0.979	0.717	1.063	0.914
3	1	0.94	0.853	1.050	0.984	0.984	1.138	0.989	27	1	1.01	0.996	1.007	1.235	0.922	1.103	1.042
4	1	0.99	0.874	0.952	0.783	0.911	1.011	0.918	28	1	1.01	1.022	1.045	1.090	0.850	1.108	1.018
5	1	1.03	1.166	1.156	1.195	1.115	0.970	1.103	29	1	0.95	0.928	0.908	1.085	0.846	0.945	0.942
6	1	1.01	1.260	1.370	1.608	1.588	1.372	1.353	30	1	0.98	1.044	1.029	1.020	1.032	1.015	1.021
7	1	0.98	0.986	1.000	1.002	0.954	1.006	0.988	31	1	1.05	1.099	1.002	1.091	1.222	1.067	1.087
8	1	0.98	1.012	1.104	1.036	1.070	1.139	1.056	32	1	1.23	1.259	1.097	1.225	1.305	1.288	1.232
9	1	1.10	1.109	1.111	1.034	1.039	1.104	1.083	33	1	1.15	0.972	0.765	0.926	0.880	1.039	0.948
10	1	0.97	1.008	0.981	1.016	1.005	1.028	1.001	34	1	1.02	1.172	1.457	1.207	1.290	1.263	1.230
11	1	0.99	1.055	1.054	1.060	1.039	1.039	1.041	35	1	1.00	0.991	1.149	1.300	1.357	1.422	1.192
12	1	0.98	0.937	0.906	0.876	0.968	0.923	0.932	36	1	0.98	1.014	1.010	1.067	1.329	1.155	1.087
13	1	1.17	1.125	1.115	1.134	1.199	1.133	1.147	37	1	1.00	0.992	1.002	0.985	1.062	0.912	0.992
14	1	1.07	1.056	1.134	1.059	1.086	1.020	1.071	38	1	1.01	1.018	1.007	1.000	1.154	1.087	1.045
15	1	1.03	1.001	1.003	1.013	1.011	1.058	1.020	39	1	0.83	0.887	0.799	0.988	1.146	1.321	0.979
16	1	1.01	1.071	1.032	1.028	1.057	1.035	1.039	40	1	0.99	1.110	1.067	1.094	1.110	1.185	1.092
17	1	0.92	1.032	0.944	0.946	1.009	0.894	0.958	41	1	1.08	1.111	1.116	1.093	1.133	1.077	1.102
18	1	1.13	1.141	1.119	1.108	0.969	1.210	1.111	42	1	1.35	1.367	1.286	1.311	1.376	1.335	1.337
19	1	0.98	0.973	1.047	0.981	1.181	0.978	1.021	43	1	1.36	1.403	1.378	1.386	1.261	1.337	1.355
20	1	0.94	0.877	0.937	1.115	0.965	0.789	0.933	44	1	0.93	1.083	1.109	1.092	1.168	1.404	1.124
21	1	1.03	1.081	1.211	1.080	1.044	1.287	1.118	45	1	1.15	1.158	1.159	1.176	1.159	1.164	1.162
22	1	0.94	0.798	0.800	0.915	0.805	0.892	0.858	46	1	1.02	0.934	0.934	0.921	1.113	1.160	1.011
23	1	1.03	0.978	1.013	1.089	1.094	1.148	1.058	47	1	0.99	1.002	0.993	0.994	0.948	0.991	0.986
24	1	0.99	0.987	0.990	0.973	0.947	0.956	0.974	48	1	0.92	0.906	0.861	1.055	1.142	1.174	1.003

Table 9. Total Factor Productivity Change (TPF) In Defferent Sectors (2002-2008)

Factor / Year	2002	2003	2004	2005	2006	2007	2008	Geomean
(TEC)	1.	1.012	1.020	1.021	1.049	0.99	1.04	1.020
Tech (FS)	1.	1.012	1.009	1.012	1.018	1.07	1.04	1.023
Total (TFP)	1.	1.024	1.029	1.032	1.068	1.06	1.09	1.043
STEAM (TFP)	1.	1.017	1.031	1.045	1.038	1.04	1.05	1.032
GAS (TFP)	1.	1.016	0.998	1.008	1.092	1.02	1.08	1.031
CYCLE (TFP)	1.	1.045	1.067	1.047	1.083	1.13	1.16	1.076

Reform process

Our results suggest certain differences in the TFP between before and after reform. In order to test the hypothesis we use, a parametric test, (Paired Samples T Test) between geomean of TFP of power plants before (2002-2004) and after (2005-2008) reform.

First:

Results of distribution fitting

Data variable: TFP_geomean_ before, 48 values ranging from 0.904 to 1.243

Fitted normal distribution: mean = 1.01971 and standard deviation = 0.0681616

Data variable: TFP_ geomean_ after, 48 values ranging from 0.851 to 1.48

Fitted normal distribution :mean = 1.06994 and standard deviation = 0.126912

then two variables TFP_ geomean_ before and TFP_ geomean_ after fitted normal distribution

second:

results of **Paired Samples T Test** in $\alpha = \%5$

$$H_0 : \mu_1 = \mu_2$$

$$H_1 : \mu_1 \neq \mu_2$$

Using the .05 level of significance, the two dependent means are significantly different.

DISCUSSION

In studying the productivity performance of power plants in iran, the distinction between technological progress (innovation), changes in managerial efficiency and scale efficiency is extremely useful. In this regard, the Malmquist index is a unique tool. An attractive feature of Malmquist productivity index is that it can be decomposed into economically relevant sources of productivity changes- technological change, managerial and scale efficiency changes.

In the output-based Malmquist index calculation, a value greater than one means productivity growth occurred from period t to t +1. If there is productivity retardation, then the Malmquist index lowers than one. The unity value of the Malmquist index indicates there is no change in productivity.

The Malmquist productivity index and its decomposition for 48 power plants of Iran for 2002 to 2008 relative to 2002 is presented in Table 7. By decomposing the Malmquist index, the sources of productivity growth/retardation were identified. The remedy for a productivity slowdown caused by a decline in efficiency could be the elimination of waste and increasing efficiency. If the problem were an adverse shift in the best-practice frontier, the relevant plant goals might be re-evaluated in light of the technological temptation, or more funding for research and development (R&D). The improvements in the technical-change component are considered to be evidence of innovation. Knowledge of scale economies, and changes in scale are relevant for choosing the optimal size of plants, and ultimately the structure of the industry.

As can be seen in table 7, the results suggest that there were total productivity gains in 33 plant and total productivity losses in 15 plants. The Malmquist index varies widely across the power plants of Iran. The greatest productivity progress (1.297) occurs in the shariati_cycle plant. The greatest productivity slowdown (0.877) is found in zahdan's power plants.

As shown in figure 4, the overall productivity indices increase from 2002 to 2008. The average improvement of overall productivity index (TFP) was 1.043. The purpose of this research paper was to estimate efficiency and productivity changes in the 48 thermal power plants in Iran during the period 2002 -2008.

Efficiency estimates, obtained with DEA, as well as the total factor productivity change obtained using the Malmquist index, show that improvements in efficiency and productivity were lower in the first years following the implementations of the reforms within the sector. With regard to the total factor productivity that the Malmquist index reports for the 2002–2008 period, the annual average is 4.3%, the vast majority, 2.3%, is explained by technological changes. The results show that Pure technical Efficiency change (0.6%) were minimal or irrelevant during the period analyzed.

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