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Using Data Envelopment Analysis and Stochastic Frontier Analysis Methods to Evaluate Efficiency of Hydroelectricity Centers

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ABSTRACT

This study clarifies efficiency scores and also ranks of hydroelectricity centers by using data envelopment analysis and stochastic frontier analysis methods. Applying copula technique in the stochastic frontier analysis is an advantage to our study between similar activities.

Keywords:*Data Envelopment Analysis, Stochastic Frontier Analysis, Copulas, Efficiency.*

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1. INTRODUCTION

Undoubtedly nowadays industrial, economical growth and also life quality in any country is based on electricity industry. This is an evidence that why many researchers study for new methods on electricity production. In the most countries of the world, one of the best and safe methods forelectricity production is based on dams and Iran also benefits from this technology.

According to studies and statistics from office of the vice president of strategic planning in Iran[1]in 21.03.2014 to 21.03.2015[2], gas power plants by 14 thousand and 300 MW[3] productions are in the first place in the country's electricity production. There are 8 thousand and 900 MW electricity productionsby combined cycle power plants, 7 thousand and 100 MW productions by hydroelectricity, and finally diesel turbines, have 380 MW electricity productions. It is notable that there are approximately potential of 26 thousand MW productionsby hydroelectric in Iran which the most part of it, is funded by Karun, Karkheh and Dez rivers. However, at this moment there are 7 thousand MW productions by hydroelectricity. A lot of discussionsare about construction of hydroelectric plants that on top of them is dehydration in the recent years. Researchers are trying to find the best solution for renewable electricity productions.

The main aim of this study is to investigate efficiency of 32 hydroelectricity centers which have placed on Iranian dams by using Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) methods. These models apply on the mentioned hydroelectricity centers by using data of applications in 21.03.2014 to 21.03.2015 (1393 Iranian Year). In DEA, we concentrate on input-oriented CCR and BCC models. Beside standard SFA model, copula technique is used for modeling dependence structure of composed error terms. Using copula in SFA models, is an advantage to this study between similar papers. After calculating efficiency scores of the mentioned 32 hydroelectricity centers, correlation matrix is prepared for ranks of resulted efficiency scores by the mentioned models. This correlation matrix is used to show the compatibility of results in the models. Finally, by using mean of the resulted efficiency scores of any model, a single score is calculated for any hydroelectricity center and this new efficiency score is used for final decision on efficiency and rank of each hydroelectricity center.

The rest of the paper is organized as follows. Section 2 reviews methods of measuring efficiency scores. Applications of the discussed models are in Section 3. Finally, conclusions are given in Section 4.

2. METHODS OF MEASURING EFFICIENCY

Measuring efficiency of firms (DMUs) has an important role in economy and managements. Farrel for the first time proposed methods in measuring efficiency of firms, and in 1970 the mentioned models were applicable by parametric and nonparametric methods. Let's just recall that nonparametric methods require minimal assumptions respect to structure of production and also they do not impose restrictions on the functional forms relating inputs and outputs. From parametric methods, SFA, Thick Frontier Analysis (TFA) and Distribution Free Analysis (DFA) can be mentioned. DEA and Free Distribution Hull (FDH) are nonparametric models and so require minimal assumptions respect to structure of production and also they do not impose restrictions on the functional forms relating inputs and outputs.

This study uses DEA and SFA methods in measuring efficiency of 32 hydroelectricity placed on Iranian dams. So these methods are described in the following subsections.

2.1. Data Envelopment Analysis

Data envelopment analysis is a nonparametric method for evaluating the relative efficiency of firms on the basis of multiple inputs and outputs. In recent years DEA has had important role in application of many fields such as energy (Sözen et al., 2009;Dedoussiset al. 2010; Alp and Sözen, 2011; Vaz et al. 2012; Najjari and Mirzapour, in press), banking (Mercan et al., 2003), sport (Anderson and Sharp, 1997; Alp, 2006; Najjari et al. in press) etc.

The first introduction on DEA was practiced by Charnes et al. (1978). They proposed CCR model which is also called as Constant Return to Scale (CRS). The CCR model evaluates both technical and scale efficiencies via optimal value of the ratio form. The modified version of CCR model is BCC model, which is also called variable returns to scale, was proposed by Banker et al. (1984). The BCC model is used to estimate the pure technical efficiency of DMUs by reference to the efficiency frontier. Primal form of input-oriented CCR (CRS) model for the efficiency score of DMU_k is as follows:

[1]http://files.spac.ir/هفته%20نامه%20برنامه/Barnameh%20gozashteh/240/p9.htm

[2] This duration is year of 1393 by Iranian calendar

[3] Megawatt

$$
\begin{aligned}
&\text{Max } \textstyle\sum_{r=1}^{s} u_r y_{rk} \\
&\text{Subject to} \\
&\sum_{i=1}^{k} v_i x_{ik} = 1 \\
&\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} \geq 0; \quad j = 1,2,\dots,n \\
&v_i, u_r \geq 0, \quad i = 1,2,\dots,m, \quad r = 1,2,\dots,s
\end{aligned} \tag{1}
$$

Where n is number of firms with s outputs denoted by y_{rk} , $r = 1,2,\dots,s$ and m inputs denoted by x_{ik} , $i = 1,2,\dots,m$. And u_r, v_i are the weights on output r and input i, respectively.

Primal form of input-oriented BCC (VRS) model is considered in this paper and it is given as follows:

$$
\begin{aligned}
&\text{Min } \theta_k \\
&\text{Subject to} \\
&\theta_k x_{ik} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \\
&\sum_{j=1}^{n} \lambda_j y_{rj} - y_{rk} \geq 0 \quad j = 1,2,\dots,n \\
&\sum_{j=1}^{n} \lambda_j = 1 \\
&\lambda_j \geq 0, \quad i = 1,2,\dots,m, \quad j = 1,2,\dots,n, \quad r = 1,2,\dots,s
\end{aligned} \tag{2}
$$

where θ_k is efficiency score of DMU_k and x_{ik}, y_{rk} (all nonnegative) are i^{th} input and r^{th} output of the DMU_k respectively, and λ_k is intensity of DMU_k. If the θ_k is equal to one, then DMU_k is called an efficient DMU. For more details see Ramanathan (2003). Some extensions of the above models are given by Bal and Örkçü 2007;2008;2010; Örkçü and Bal 2011;2012.

2.2. Stochastic Frontier Analysis and Copulas

SFA is a method of economic modeling and for the first time introduced by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). The production frontier model without random component can be written as:

$$y_i = f(x_i;\beta).TE_i, \quad i = 1,2,\dots,I, \tag{3}$$

where y_i is the observed scalar output of the producer $i, i = 1,..I$, x_i is a vector of N inputs used by the producer i, $f(x_i;\beta)$ is the production frontier and β is a vector of technology parameters to be estimated. TE_i denotes the technical efficiency defined by the ratio of observed output to maximum feasible output. $TE_i = 1$ shows that the i^{th} firm obtains the maximum feasible output, while $TE_i < 1$ provides a measure of the shortfall of the observed output from maximum feasible output.

To describe random shocks affecting the production processa stochastic component is added to (3). These shocks may come from weather changes, economic adversities or plain luck, on the other hand, theyare not directly attributable to the producer. These effects are denoted with $exp(v_i)$. It is assumed that the shocks are random and they are described by a common distribution. So, the stochastic production frontier will become:

$$y_i = f(x_i;\beta).TE_i.\exp(v_i), \ i = 1,2,\dots,I. \tag{4}$$

It is assumed that TE_i is also a stochastic variable, with a specific distribution function, common to all producers. It iswritten as an exponential $TE_i = \exp(u_i)$, where $u_i \geq 0$, since we required $TE_i \leq 1$. Thus, we obtain the following equation:

$$y_i = f(x_i;\beta).\exp(u_i).\exp(v_i), \quad i = 1,2,\dots,I. \tag{5}$$

Let consider the traditional stochastic frontier model proposed by Aigner et al. (1977) and Meeusen and Van Den Broeck (1977),

$$lny_i = \beta_0 + \sum_n \beta_n lnx_{ni} + v_i - u_i, \quad i = 1,2,\ldots,I$$

where $\varepsilon_i = v_i - u_i$ and $i = 1,2,\ldots,I$ denotes firms. v_i is the noise component, which almost always it is considered as a two-sided normally distributed variable, and u_i is the non-negative technical inefficiency component. Together they constitute a compound error term, with a specific distribution to be determined, hence the name of *composed error models* is often referred. Common choices for u include the Exponential, the Half-Normal, the Truncated Normal and the Gamma distributions, and for v it is typically the Normal distribution. Readers for more details are referred to see Kumbhakar (2000).

2.2.1. Copulas Functions

We begin with the definition of bivariate copula. A copula is a function C: $[0,1]^2 \to [0,1]$ which satisfies:

(a) for every u, v in $[0,1]$, $C(u,0) = 0 = C(0,v)$ and $C(u,1) = u and C(1,v) = v$.

(b) for every u_1, u_2, v_1, v_2 in $[0,1]$ such that $u_1 \le u_2$ and $v_1 \le v_2$,

$$C(u_2, v_2) - C(u_2, v_1) - C(u_1, v_2) + C(u_1, v_1) \ge 0.$$

The importance of copulas in statistics is described in Sklar's theorem: Let X and Y be random variables with joint distribution function H and marginal distribution functions F and G, respectively. Then there exists a copula C such that $H(x,y) = C(F(x), G(y))$ for all x, y in $\mathbb{R}$. Conversely if C is a copula and F and G are distribution functions, then the function H is a joint distribution function with margins F and G. If F and G are continuous then C is unique. Otherwise, the copula C is uniquely determined on $Ran(F) \times Ran(G)$. Conversely if C is a copula and F, G are distribution functions then the function H is a joint distribution function with margins F and G. As a result of the Sklar's theorem, copulas link joint distribution functions to their one-dimensional margins.

Archimedean Copulas (AC) are one of important classes of copulas. These copulas are very easy to construct, many parametric families belong to this class and have great variety of different dependence structures. Basic properties of AC are presented below, more information could be found in Nelsen (2006). Let φ be a continuous, strictly decreasing function from [0,1] to $[0,\infty]$ such that $\varphi(1) = 0$. The pseudo-inverse of φ is given by

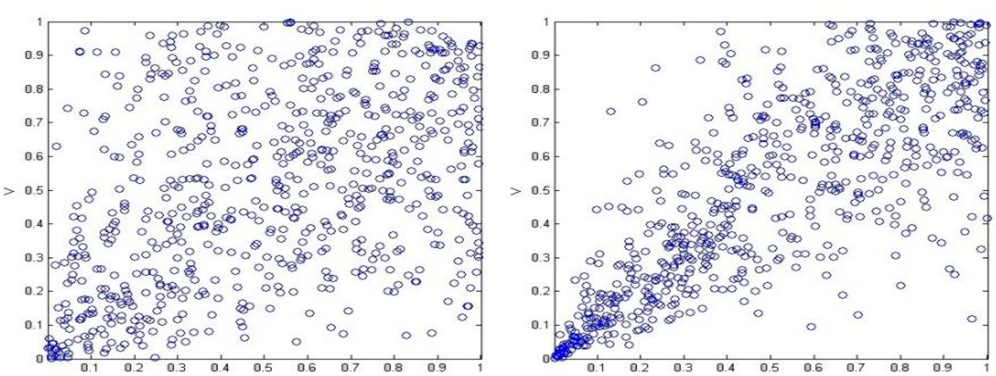
$$\varphi^{[-1]}(t) = \begin{cases} \varphi^{(-1)}(t), & 0 \le t \le \varphi(0) \\ 0, & \varphi(0) < t \le \infty. \end{cases}$$

Copulas of the form $C(u,v) = \varphi^{[-1]}(\varphi(u) + \varphi(v))$ for every u, v in [0,1], are called AC and the function φ is called a generator of this copulas. If $\varphi[0] = \infty$ we say that φ is a strict generator. In this case, $\varphi^{[-1]} = \varphi^{-1}$ and $C(u,v) = \varphi^{-1}(\varphi(u) + \varphi(v))$ is said a strict Archimedean copula. In the application section of this study Clayton family is used which is one of the most used and well-knownArchimedeanfamilies. Details of this family are as follows:

$$C(u,v) = \max\left(\left[u^{-\theta} + v^{-\theta} - 1\right]^{-\frac{1}{\theta}}, 0\right), \quad \varphi(\theta) = \frac{1}{\theta}\left(t^{-\theta} - 1\right), \quad \theta \in [-1,\infty) - \{0\}$$

Kendall's coefficient for this family is $= \frac{\theta}{\theta+2}$, where $\tau \in (0,1]$. Scatterplots of Clayton family for $\theta = 1$ and $\theta = 3$ are shown by Figure 1. In the Clayton family there is no dependence in upper tail, while lower tail has $2^{\frac{-1}{\theta}}$ dependency.

Figure 1. Scatterplots of Clayton family for $\theta = 1$ (left) and $\theta = 3$ (right)



2.2.2. Stochastic Frontier Analysis by Copulas

There are seldom efforts that are related with stochastic frontier by copulas in the literature. Smith (2008) was one of the first peoples which proposed copula technique in SFA. Then Carta and Steel (2012) used copulas to introduce a new methodology for multi-output production frontiers. El Mehdi and Hafner (2014) and Amsler et al. (2014) are between researchers whose were used copulas in SFA. As it is discussed in the Section 2.2, $\varepsilon = v - u$ and usually researchers assume that error terms u and v are independent. Smith (2008) was one of the first peoples which proposed a potential dependence between u and v and he used copulas on modeling this dependence and then estimating parameters in the SFA models. There is an overview on modeling this dependence by copulas as follows:

Let to consider Aigner et al. (1977) and Meeusen and Van den Broeck (1977) classic model,

$$lny_i = \beta_0 + \sum_n \beta_n lnx_{ni} + v_i - u_i, \quad i = 1,2,\dots,I. \quad (6)$$

Assume that there is potential dependence between u and v, also v_i (and u_i) are independent over i (where $i = 1,\dots,I$).Let G_1 and G_2 denote the distribution functions of u and v respectively and H be joint distribution function of $u$and v. Then by the Sklar Theorem there is copula C_θ which satisfies in relation,

$$H(u,v) = C_\theta\big(G_1(u), G_2(v)\big),$$

and so its joint density function is as follows,

$$h(u,v) = g_1(u)g_2(v)C_\theta\big(G_1(u), G_2(v)\big). \quad (7)$$

By using$\varepsilon = u - v$, and marginal distribution of $h(u,v)$ we get

$$h(\varepsilon) = \int_0^{+\infty} g_1(u)g_2(u+\varepsilon)C_\theta(G_1(u), G_2(u+\varepsilon))\,du. \quad (8)$$

Replacing $\varepsilon = lny - f(x;\beta)$ in the (8) gives density of y. Using the maximum likelihood estimator (MLE) is a way to obtain more efficient estimator of stochastic frontier models. Clearly, copulas allow to model marginal distributions separately from their dependence structure, so we have a flexible joint distribution function, whose marginals are specified by the researcher. After estimating stochastic frontier models we desire to calculate technical efficiency of DMUs. This technical efficiency is conditional expected value as follows,

$$TE = E(\exp\{-u\}\,|\varepsilon),$$

by using (7) and (8) we get

$$TE = \frac{1}{h(\varepsilon)} \int_{\mathbb{R}^+} \exp\{-u\}\, h(u,\varepsilon)du. \quad (9)$$

Details could be found in Smith (2008), El Mehdi and Hafner (2014). In this study we use log-linear Cobb-Douglas form and also we assume that $u \sim N^+(0,\sigma_u^2)$, $u \geq 0$ and $v \sim N(0,\sigma_v^2)$. It is not difficult to show$E(u) = \sigma_u\sqrt{2/\pi}$and $Var(u) = (\pi - 2/\pi)\sigma_u^2$. If we assume that MLE of

Table 1. Details 32 hydroelectricity centers of Iranian

	Hydroelectricity Centers	Domestic Consumption (MW)	Average Annual Operating (hours)	Gross Production (MW)
1	Araz	2335	4728	49958
2	Mahabad	32	2340	5865
3	ZaiandehRoud	672	3612	126323
4	Kalan	599	2736	87233
5	Amir Kabir	1494	1464	82599
6	Letian	229	1044	30602
7	Taleghan	182	1992	8230
8	Luark	1	2508	64488
9	Karun 4	5896	2016	1471422
10	Kouhrang	422	3060	55331
11	Dez	10649	7968	1998493

12	ShahidAbbaspour	9807	3708	2209666
13	MasjedSoleiman	3652	2280	2543206
14	Karkheh	829	504	108978
15	Karun 3	27104	1656	1844931
16	Marun	881	5460	242091
17	Getond	8598	3384	2155926
18	Molasadra	613	1764	94002
19	Drudzan	22	1320	10594
20	ShahidTalebi	1	4500	3622
21	Jiroft	58	2376	42241
22	Piran	45	1152	6417
23	Pole Klo	31	2664	4464
24	Krik2	9	2376	3657
25	Krik3	28	2784	4041
26	Pole Klo2	31	2796	4462
27	Pole Klo 1	23	2556	3334
28	Sefidroud	395	1932	131854
29	Takam	129	3060	24040
30	SiyahPisheh	4573	1068	514665
31	Gamasiyab	39	3912	3823
32	DarehTajht 2	5	4998	1624

Parameters $\vartheta = (\sigma_u,\ \sigma_v,\ \theta,\ \beta)$ are $\hat{\vartheta} = (\hat{\sigma}_u,\ \hat{\sigma}_v,\ \hat{\theta},\ \hat{\beta})$ then by replacing these estimators in (9) we get to TE_{ML} which is the MLE of TE. As $\varepsilon = v - u$ then by

$$Var(\varepsilon) = Var(u) + Var(v) - 2Cov(u, v) \quad (10)$$

it is seen that positive dependence between u and v reduces variance of $Var(\varepsilon)$ and so model (6) has better results, and negative dependence between u and v increases variance of $Var(\varepsilon)$ and so model (6) tends to worse results. Let's recall that in this study by using Half-Normal, Normal distributions respectively for u and v, SFA model and also SFA with Clayton family will be used in application section.

3. INVESTIGATING EFFICIENCY OF 32 HYDROELECTRICITY CENTERS

In this section, the mentioned models in the Section 2, are used to clarify efficiency of 32 hydroelectricity centers placed on Iranian dams. Details of the hydroelectricity centers summarized at Table 1, and they come from Iranian Ministry of Energy, Energy balance sheet in 21.03.2014 to 21.03.2015 (1393 Iranian Year), to know more about these data we recommend seeing [1]. As it is seen by Table 1, the amount of Domestic Consumption (in Megawatt), Average Annual Operating (in hours), and finally Gross Production (in Megawatt), are available for the main hydroelectricity centers of Iran. For investigating efficiency of the hydroelectricity centers by mentioned DEA and SFA models, from these data, two parameters, are selected as inputs and one parameter is selected for outputs as follows,

Input 1: Domestic Consumption (MW). Input 2: Average Annual Operating (hours)and Output is Gross Production (MW).

In calculations, estimating technical efficiency of SFA models and also SFA models with copulas, Matlab software had been used. "fminsearchbnd" command in Matlab had an important role in the calculating. We recall that Half-Normal and Normal distributions respectively selected for u and v, in the SFA model and also SFA with Clayton family. In the rest of paper, standard SFA model is called as "SFA" and SFA model with Clayton family is shown by "SFA-Clayton". In evaluation efficiency scores by CCR and BCC models, EMS program had been used.

Table 2. Estimation of the parameters in SFA and SFA-Clayton models

	$\hat{\sigma}_u$	$\hat{\sigma}_v$	$\hat{\theta}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	τ
SFA	0.5850	0.5850	-	11.2563	0.7390	0.2093	-
SFA-Clayton	0.6281	0.6005	1.3292	9.6751	0.7676	0.2232	0.3993

Table 3. Efficiency scores and also ranks of the hydroelectricity centers

	Hydroelectricity Centers	CCR		BCC		SFA-Clayton		SFA	
		T.E	Rank	T.E	Rank	T.E	Rank	T.E	Rank
1	Araz	59.83%	24	73.98%	22	35.24%	32	87.78%	32
2	Mahabad	54.98%	26	61.79%	26	41.29%	22	88.07%	22
3	ZaiandehRoud	78.89%	13	97.34%	17	48.66%	15	88.25%	15
4	Kalan	34.93%	31	40.92%	32	45.57%	18	88.19%	17
5	Amir Kabir	78.87%	14	80.92%	18	39.78%	25	88.05%	25
6	Letian	81.79%	11	98.09%	16	44.44%	19	88.16%	19
7	Taleghan	28.50%	32	55.51%	29	36.18%	31	87.84%	31
8	***Luark****	***100.00%***	***1***	***100.00%***	***3***	***100.00%***	***1***	***99.79%***	***1***
9	***Karun *4***	***100.00%***	***4***	***100.00%***	***11***	72.23%	4	88.49%	4
10	Kouhrang	57.57%	25	59.99%	27	43.17%	21	88.14%	21
11	***Dez****	64.04%	21	***100.00%***	***2***	57.90%	9	88.39%	9
12	ShahidAbbaspour	53.43%	27	54.66%	30	67.79%	7	88.47%	6
13	***MasjedSoleiman****	***100.00%***	***2***	***100.00%***	***1***	***100.00%***	***2***	***99.25%***	***2***
14	***Karkheh****	69.75%	17	***100.00%***	***7***	50.85%	13	88.28%	14
15	***Karun 3****	99.88%	6	***100.00%***	***14***	48.94%	14	88.28%	13
16	***Marun****	74.28%	16	***100.00%***	***5***	55.23%	11	88.34%	10
17	***Getond****	88.94%	10	***100.00%***	***10***	71.33%	5	88.49%	5
18	Molasadra	66.78%	19	68.35%	24	47.67%	16	88.23%	16
19	***Drudzan****	***100.00%***	***3***	***100.00%***	***9***	55.69%	10	88.31%	11
20	***ShahidTalebi****	***100.00%***	***5***	***100.00%***	***6***	96.29%	3	98.55%	3
21	Jiroft	75.76%	15	79.51%	19	70.70%	6	88.45%	7
22	***Piran****	81.44%	12	***100.00%***	***12***	41.18%	23	88.07%	23
23	***Pole Klo****	91.26%	9	***100.00%***	***8***	39.28%	26	88.00%	26
24	Krik2	97.88%	8	99.83%	15	46.64%	17	88.18%	18
25	Krik3	67.89%	18	70.23%	23	39.09%	28	87.99%	28
26	Pole Klo2	45.21%	30	56.37%	28	39.21%	27	88.00%	27
27	Pole Klo 1	46.55%	29	66.49%	25	38.95%	29	87.99%	29

28	***Sefidroud****	98.22%	7	***100.00%***	***13***	61.26%	8	88.39%	8
29	Takam	65.27%	20	74.66%	21	43.98%	20	88.15%	20
30	SiyahPisheh	63.88%	23	78.40%	20	52.22%	12	88.31%	12
31	Gamasiyab	49.02%	28	50.83%	31	37.14%	30	87.90%	30
32	***DarehTajht 2****	64.01%	22	***100.00%***	***4***	41.06%	24	88.05%	24

Result of calculations for estimation of the parameters in SFA and SFA-Clayton models are summarized in Table 2. It is seen that, dependence parameter θ estimation is 1.3292. This value is evidence on the dependence between u and v. So $\tau = \frac{\theta}{\theta+2} = 0.3993$, namely there is 39.93% dependence between u and v. As discussed in the relation (10), a positive correlation between u and v reduces the variance of $Var(\varepsilon)$ and a negative correlation between u and v increase the variance of $Var(\varepsilon)$. It means that in the mentioned model by (6), the minimum variance tends the model to the closest estimation.

Table 3. demonstrates efficiency scores and also ranks of the mentioned hydroelectricity centers by the models which their estimated parameters are given in the Table 2. Also technical efficiency (T.E.) of the input-oriented CCR and BCC models are provided for the mentioned data to compare their results by the mentioned SFA models.It is seen that by the CCR model, 5 hydroelectricity centers are selected as efficient centers, which Lurak has the first rank, while by the BCC model, there are 15 efficient centers and first rank belongs to MasjedSoleiman center. Lurak and MasjedSoleiman have been selected as efficient centers with SFA and SFA-Clayton models, also they are respectively in the first and second ranks by both of these models.

Table 4. Correlations between ranks of the hydroelectricity centers by the mentioned models

	CCR	BCC	SFA-Clayton	SFA
CCR		0.7551	0.6331	0.6195
Sig. (2-tailed)		0.000	0.000	0.000
BCC	0.7551		0.5660	0.5546
Sig. (2-tailed)	0.000		0.001	0.001
SFA-Clayton	0.6331	0.5660		0.9985
Sig. (2-tailed)	0.000	0.001		0.000
SFA	0.6195	0.5546	0.9985	
Sig. (2-tailed)	0.000	0.001	0.000	

Table 4. consists of (Pearson) correlations efficiency of the hydroelectricity centers by the mentioned models in Table 3. These correlations are based on ranks of the hydroelectricity centers in every model. SFA and SFA-Clayton models approximately have resulted same ranks for the hydroelectricity centers as correlation between them is 99.85%, and the minimum compatibility is between results of BCC and SFA models which is 55.46%. Compatibility between results of CCR and BCC models is 75.51%, and between results of CCR and SFA-Clayton models is 63.31% and also between results of CCR and SFA models is 61.95%. This fact between results of BCC and SFA-Clayton models is 65.60%.

It is seen that any model has a different values on ranks of the hydroelectricity centers. There for making a decision to select the best hydroelectricity center really is difficult. To have a solution, for any center, we define a new efficiency score which is mean of the efficiency scores of that center, by the mentioned models. Results are summarized at Table 5. By this new ranks for any center, it is seen that, Lurak and MasjedSoleiman have been selected as efficient centers also they respectively are in the first and second ranks by these models. Efficiency of the center Marun is the last one.

Table 5. Mean of efficiency scores of the centers, by the mentioned models

	Hydroelectricity Centers	T.E.	Rank		Hydroelectricity Centers	T.E.	Rank
1	Araz	64.21%	25	17	Getond	87.19%	5
2	Mahabad	61.53%	27	18	Molasadra	67.76%	22
3	ZaiandehRoud	78.29%	13	19	Drudzan	86.00%	7
4	Kalan	52.40%	31	20	ShahidTalebi	98.71%	3
5	Amir Kabir	71.90%	19	21	Jiroft	78.60%	12
6	Letian	78.12%	14	22	Piran	77.67%	15
7	Taleghan	52.01%	32	23	Pole Klo	79.64%	10
8	***Luark****	***100.00%***	***1***	24	Krik2	83.13%	9
9	Karun 4	90.18%	4	25	Krik3	66.30%	23
10	Kouhrang	62.22%	26	26	Pole Klo2	57.20%	29
11	Dez	77.58%	16	27	Pole Klo 1	60.00%	28
12	ShahidAbbaspour	66.09%	24	28	Sefidroud	86.97%	6
13	***MasjedSoleiman****	***100.00%***	***2***	29	Takam	68.01%	21
14	Karkheh	77.22%	17	30	SiyahPisheh	70.70%	20
15	Karun 3	84.27%	8	31	Gamasiyab	56.22%	30
16	Marun	79.46%	11	32	DarehTajht 2	73.28%	18

Correlations (Pearson) between ranks of the hydroelectricity centers by the new efficiency scores in the Table 5 and the mentioned models in Table 3 are summarized in Table 6.

Table 6. Correlations between ranks of the hydroelectricity centers by the new efficiency scores and the mentioned models

	CCR	BCC	SFA-Clayton	SFA
Mean of the efficiency scores	0.957	0.836	0.757	0.747
Sig. (2-tailed)	0.000	0.000	0.000	0.000

It is seen that the new efficiency scores, has maximum compatibility with results of the CCR method which is 95.76% and it has minimum compatibility with results of the SFAmethod which is 74.7%.

4. CONCLUSION

In the aim of satisfying efficiency scores and ranks of 32 Iranian hydroelectricity centers, we have relied on input-oriented CCR and BCC, also SFA and SFA with using Clayton copula models. For any center, we defined a new efficiency score by mean of the efficiency scores of the mentioned models, as the mentioned any model had different values on ranks of the hydroelectricity centers. By this method, Lurak and MasjedSoleiman selected as efficient centers also they respectively were in the first and second ranks by these models. Efficiency of the center Matun, was the last one.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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