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Research on the Evaluation of Oil Exploration Efficiency Based on Two-Phase DEA

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Abstract: Based on the previous theories for the evaluation of oil exploration efficiency, this paper analyzed the factors influencing oil exploration, and comprehensively evaluated the exploration efficiencies of four projects of SLOF from 2004 to 2009 by building a two-phase DEA model, to verify the validity of the four exploration projects under DEA.

Keywords: *Oil, Exploration efficiency, Two-phase DEA, Evaluation*

1. Introduction

As a very important mineral resource, oil is an essential part of the national economy of China. Before producing oil, we need to conduct exploration evaluation on oil and gas fields, whose results will directly influence the exploration efficiency. Therefore, oil exploration plays a very important role in the whole production process. Oil exploration is a process with multi inputs and outputs. To achieve as high efficiency as possible, the benefit of investment needs to be considered in every section of oil exploration, which is to obtain the most effective output with the least input. This requires oil enterprises to effectively reduce inefficient input, eliminate invalid input and improve the oil exploration efficiency. Considering oil exploration process is a multi inputs and outputs process and Data Envelopment Analysis (DEA) is one of the effective methods in evaluating the relative efficiency between input and output, this paper conducts evaluation and analysis on the oil exploration efficiency of four subprojects of SLOF from 2004 to 2009 adopting DEA method to provide reference information for decision makers.

Hou Fenghua and Zhang Zaixu have done considerable researches on the economic benefit of oil enterprises and exploration efficiency of oil and gas resources applying DEA method [1-4]. These researches have analyzed the process of oil and gas exploitation and the characteristics of the oil industry in detail and conduct evaluation on the efficiency applying traditional DEA model. In traditional DEA model, every decision-making unit is regarded as a "black box", which only focuses on the overall efficiency of the production system but neglects the intermediate process when the input turn into the output [5]. Färe and Grosskopf first proposed to decompose the production system into subsystems in NET-DEA model, and thus can evaluate the influence of each subsystem on the overall efficiency of the production system [6]. Two-phase DEA model is an exception in NET-DEA model, which divides the whole production system into two phases. The output in the first phase are regarded as the input in the second phase and the influence of these two phases on the whole production system is evaluated separately. Many scholars at home and abroad has done in-depth researches on the two-phase DEA model. Chen et al. studied the resource-restraint two-phase DEA model in 2006[7]. Wang el al. proposed sequence type two-phase DEA model in 1997[8]. Chen and Zhu has done further researches on this model [9]. Bi Gongbing el al. proposed a new DEA model aiming at the two-phase production system in 2007[5]. Based on this model, this paper established a new two-phase DEA model increasing external inputs in the second phase to evaluate the exploration efficiency of oil enterprises.

2. Model Establishment and Evaluation Index Selection

(1) Evaluation Model Establishment

In the production system in Figure 1, the DEA output in the first phase are also the DEA input in the second phase, which is called intermediate product. The intermediate products are consistent both in the first phase and the second phase and an external input index is considered to be added in the second phase. Assume that the intermediate product is consistent, so input-oriented DEA model can be applied to evaluate the comprehensive efficiency value of each DMU unit in the first phase. In the second phase, output-oriented DEA model is applied to evaluate the comprehensive efficiency value of each DMU unit. The returns to scale are consistent in each phase, and CCR model is adopted to evaluate the efficiency[10～13].

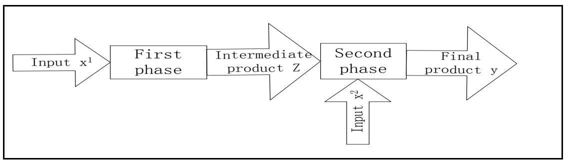

Fig. (1). *Two-phase Production System*

Set the input, intermediate product and output vector of n *MUj (1≤j≤n)* respectively as

$$x_j^1 = \left(x_{1j}^1, x_{2j}^1, \ldots, x_{mj}^1\right)^T > 0, \quad j = 1, \ldots, n$$
$$x_j^2 = \left(x_{1j}^2, x_{2j}^2, \ldots, x_{qj}^2\right)^T > 0, \quad j = 1, \ldots, n$$
$$z_j = \left(z_{1j}, z_{2j}, \ldots, z_{tj}\right)^T > 0, \quad j = 1, \ldots, n$$
$$y_j = \left(y_{1j}, y_{2j}, \ldots, y_{sj}\right)^T > 0, \quad j = 1, \ldots, n$$

Where x_j^1 represents the input index of DMU_j in the first phase and x_{dj}^1 represents the level of the dth investment consumed by DMU_j in the first phase. z_j represents the intermediate product of DMU_j and z_{dj} represents the level of the dth intermediate product of DMU_j. x_j^2 represents the extra input index of DMU_j in the second phase and x_{dj}^2 the level of the dth investment consumed by in the second phase. y_j represents the final product of DMU_j and y_{dj} represents the level of the dth final product produced by DMU_j. λ_{rj} is adopted to represent the DMU_j weight given by the subsystem r=(r=1,2) in *DMU*. θ_r represents the efficiency value of subsystem in the rth phase of *DMU* and θ represents the overall efficiency value of *DMU*.

①Establishment of Model in the First Phase

In the first phase, the intermediate product is its output, and maintaining the consistency of the intermediate product is maintaining the consistency of output in the first phase. Therefore, the input-oriented CRR model in the first phase is as follow and the equal sign of the second constraint is to maintain the consistency of the intermediate product.

$$\begin{aligned} &\min\ \theta_1 \\ &s.t. \sum_{j=1}^{n} \lambda_{1j} x_{ji}^1 + s_1^- = \theta_1 x_i^1, \quad i = 1, \ldots, m \\ &\sum_{j=1}^{n} \lambda_{1j} z_{jd} = z_d, \quad d = 1, \ldots, t \\ &\lambda_{1j} \geq 0 \\ &\theta_1 \geq 0 \end{aligned} \tag{1}$$

②Establishment of Model in the Second Phase

In the first phase, the intermediate product is a part of its input. The output-oriented CRR model in the second phase is as follow and the equal sign of the first constraint is to maintain the consistency of the intermediate product in the first and second phase.

$$\begin{aligned} &\max\ \theta_2 \\ &s.t. \sum_{j=1}^{n} \lambda_{2j} z_{ji} = z_i, \quad i = 1, \ldots, t \\ &\sum_{j=1}^{n} \lambda_{2j} x_{jk}^2 + s_2^- = x_k^2, \quad k = 1, \ldots, q \\ &\sum_{j=1}^{n} \lambda_{2j} y_{jd} - s_2^+ = \theta_2 y_d, \quad d = 1, \ldots, s \\ &\lambda_{2j} \geq 0 \\ &\theta_2 \geq 0 \end{aligned} \tag{2}$$

③Overall Efficiency Model

The model to comprehensively evaluate the overall efficiency applying output-oriented CRR model is as follow:

$$\begin{aligned} &\max\ \theta \\ &s.t. \sum_{j=1}^{n} \lambda_j x_{ji}^{1\,*} + s_3^{1-} = x_i^1, \quad i = 1, \ldots, m \\ &\sum_{j=1}^{n} \lambda_j x_{jk}^2 + s_3^{2-} = x_k^2, \quad k = 1, \ldots, q \\ &\sum_{j=1}^{n} \lambda_j y_{jd}^{\ *} - s_3^+ = \theta y_d, \quad d = 1, \ldots, s \\ &\lambda_j \geq 0 \\ &\theta \geq 0 \end{aligned} \tag{3}$$

The s_1^-, s_2^-, s_2^+, s_3^{1-}, s_3^{2-} and s_3^+ are slack variables and $x_{ji}^{1\,*} = \theta_1^* x_{ji}^1$, $y_{jd}^{\ *} = \theta_2^* y_{jd}$.

The above model is the two-phase DEA comprehensive efficiency evaluation model based on the actual situation of oil exploration. This model not only considers the intermediate product and opens the traditional "black box" of DEA, but considers the extra input in the second phase and the situation that the final product is of many dimensions. This paper evaluates the oil exploration efficiency on the basis of this model.

(2) Evaluation Index and Data

Before conducting the evaluation of oil exploration efficiency using two-phase DEA method, the input and output indexes of different phases need to be determined first. The input and output indexes selected are required to serve, submit to and comprehensively reflect the evaluation purpose.

This paper conducts evaluation and analysis on the four subprojects of SLOF between 2004 to 2009. Therefore, the indexes selected need to reflect and realize our evaluation purpose. Based on the analysis of oil exploration process, this paper divides the oil exploration into two processes. Comprehensively considering each phase of the oil exploration the input and output indexes of each phase are determined, as is shown in Table 1. The technology of three-dimension seismic exploration and measuring line in seismic exploration can greatly improve the precision of exploration compared with the technology only providing two-dimension information. Moreover, the three-dimension seismic exploration plays a dominant role in the seismic exploration, and thus only three-dimension is taken as evaluation index in the seismic exploration.

Table 1: *Evaluation Indexes*

Phase	Input index	Output index
First phase	Seism (three-dimension km2) Exploration well (number) Drill footage (104m)	New industrial oil and gas well (number) Closed loop (number)
Second phase	New industrial oil and gas well (number) Closed loop (number) Exploration well testing for oil (number) Layer of exploration well testing for oil (number)	New oil and gas reserves (104t)

The evaluation data of selected indexes are shown in Table 2. The data of new oil and gas reserves of subproject 3 a sag in 2004 are not provided and needed to be removed. Therefore, this paper does not consider the data of Subproject 3 in 2004 in the evaluation process.

Table 2: *Data*

Year	Tectonic unit	Seism	Exploratory well	Drill footage	Industrial oil and gas well	Closed loop	Well testing for oil	Layer testing for oil	New oil and gas reserves
2004	Subproject 1	125.5	8	1.9531	0	5	3	3	696.2
2005	Subproject 1	294.69	10	2.6642	1	9	1	2	1019.6
2006	Subproject 1	0	8	2.6973	5	11	7	10	328.6
2007	Subproject 1	0	10	3.3954	1	16	6	6	720.8
2008	Subproject 1	0	12	3.8079	3	23	8	8	610.7
2009	Subproject 1	0	6	1.47	2	4	3	3	83.7
2004	Subproject 2	140.32	15	5.3792	7	6	15	25	1312.45
2005	Subproject 2	128.88	17	5.1426	6	45	9	15	171.84
2006	Subproject 2	104.11	11	4.0571	6	28	12	14	644.46
2007	Subproject 2	0	9	3.2248	2	33	3	4	837.45
2008	Subproject 2	327.8	20	7.3979	3	39	5	8	0
2009	Subproject 2	0	6	1.71	1	3	4	5	2083.37
2005	Subproject 3	106.15	28	7.8769	17	44	27	41	2862.44
2006	Subproject 3	367.18	33	7.4064	10	37	20	31	36024.73
2007	Subproject 3	0	40	12.1929	20	32	29	36	1656.76
2008	Subproject 3	187.7	39	10.4853	6	35	20	30	3649.36
2009	Subproject 3	213	19	5.4	16	5	24	30	2787.86
2004	Subproject 4	559.29	53	14.3455	27	9	40	66	2198.46
2005	Subproject 4	414.3	55	15.0986	20	53	32	42	4564.62
2006	Subproject 4	332.87	44	14.0583	26	62	39	60	5109.52
2007	Subproject 4	609.54	56	23.2682	31	96	39	57	7461.57
2008	Subproject 4	124.17	56	16.4511	21	60	52	71	6375.11
2009	Subproject 4	466.76	84	20.3948	26	36	35	45	5529.22

3. Evaluation Results and Analysis

The DEA relatively effective face is the effective production frontier made of all effective decision-making units of DEA and the optimal solution of this unit is to “project” all non DEA effective decision-making units onto the effective production frontier face through decreasing input and increasing output. This paper applies MATLAB software programming to solve model (1), model (2) and model (3). Put the corresponding input and output indexes and result data respectively into model (1), model (2) and model (3) and the optimal solutions are shown in model (1), model (2) and model (3). If the optimal solution is 1, then this decision-making unit is valid. If the optimal solution is less than 1, then it is invalid.

The analysis of Table 3 proves that the Subproject 1 in 2004, Subproject 2 and Subproject 3 in 2005, Subproject 1 in 2006, Subproject 2 and Subproject 3 in 2007 and Subproject 3 in 2009 are DEA valid in the exploration in the first phase, which proves the input and output of these exploration projects reach the best condition. The rest exploration projects are not DEA valid and call for further adjustment of input and output to project them onto the effective production frontier face. The consistency of intermediate product leads to the adjustment of input and the ideal optimal adjustment is $\hat{x}^1 = \theta_1 x^1 - s_1^-$. The $\left(\hat{x}^1, z\right)$ after adjustment is the projection of corresponding decision-making units on the DEA relatively effective face. The concrete value after adjustment is not given here. Overall, the relative efficiency of Subproject 3 and Subproject 2 are relatively high in the first phase.

Table 3: *Optimal Solution of Model (1)*

Year	Sub project 1	Sub project 2	Sub project 3	Sub project 4
2004	1	0.6055	——	0.6381
2005	0.369	1	1	0.6203
2006	1	0.9445	0.7459	0.949
2007	0.4638	1	1	0.9695
2008	0.7482	0.5673	0.4153	0.6803
2009	0.7658	0.3506	1	0.5174

In the model calculating the second phase and overall efficiency, the output of Subproject 2 in 2008 is zero, so the result of the solution is insoluble. The output is zero, so this decision-making unit is DEA invalid. The insoluble result is represented by NULL and this paper treats NULL as zero. The analysis of Table 4 proves that the Subproject 1 and Subproject 4 in 2004, Subproject 1 in 2005, Subproject 2 and Subproject 4 in 2007 and four sags in 2009 are DEA valid, whose input-output ratio reaches the optimal state. The rest exploration projects are not DEA valid and call for further adjustment of input and output. The adjustment equation is $\hat{x}^2 = x^2 - s_2^-$ and $\hat{y} = y/\theta_2 + s_2^+$. The combination of input and output is the projection of corresponding decision-making units on the DEA relatively effective face. Overall, the relative efficiency of Subproject 1 and Subproject 4 are relatively high in the first phase.

Table 4: *Optimal Solution of Model (2)*

Year	Sub project 1	Sub project 2	Sub project 3	Sub project 4
2004	1	0.334128	——	1
2005	1	0.025337	0.316656	0.44023
2006	0.180914	0.159734	0.38759	0.436817
2007	0.37519	1	0.308998	1
2008	0.162076	NULL	0.338495	0.271385
2009	1	1	1	1

Model (3) is the overall optimal solution of the decision-making unit. We can see from Table (5) that only the overall efficiency of Subproject 1 in 2005 and Subproject 2 in 2009 are DEA valid and the rest exploration projects do not reach the optimal state in input-output ratio. To facilitate the analysis of the overall efficiency of each tectonic unit, this paper applies line chart to reflect the overall efficiency of these four tectonic units between 2004 to 2009, as is shown in Figure 2. We can see from Figure 2 that the overall efficiency of Subproject 3 and Subproject 4 do not experience big change during these six years and is rather stable. The efficiency of Subproject 1 and Subproject 2 fluctuate acutely in different years. The comprehensive analysis of Table 5 proves that the exploration efficiency of Subproject 2 in the first phase is relatively good and the low overall efficiency in several years is resulted from the low exploration efficiency in the second phase. Therefore, the focus of the subproject of Subproject 2 is to conduct adjustment of the exploration in the second phase.

Table 5: *Overall Optimal Solution*

Year	Tectonic unit	Model (3)	Model (2)	Model (1)	Tectonic unit	Model (3)	Model (2)	Model (1)
2004	Subproject 1	0.4752	1	1	Subproject 3	——	——	——
2005	Subproject 1	1	1	0.369	Subproject 3	0.1967	0.3167	1
2006	Subproject 1	0.0901	0.1809	1	Subproject 3	0.2995	0.3876	0.7459
2007	Subproject 1	0.2883	0.3752	0.4638	Subproject 3	0.1104	0.309	1
2008	Subproject 1	0.1832	0.1621	0.7482	Subproject 3	0.3236	0.3385	0.4153
2009	Subproject 1	0.067	1	0.7658	Subproject 3	0.2167	1	1
2004	Subproject 2	0.1552	0.3341	0.6055	Subproject 4	0.094	1	0.6381
2005	Subproject 2	0.0326	0.0253	1	Subproject 4	0.2507	0.4402	0.6203
2006	Subproject 2	0.1072	0.1597	0.9445	Subproject 4	0.234	0.4368	0.949
2007	Subproject 2	0.536	1	1	Subproject 4	0.3229	1	0.9695
2008	Subproject 2	NULL	NULL	0.5673	Subproject 4	0.2314	0.2714	0.6803
2009	Subproject 2	1	1	0.3506	Subproject 4	0.2828	1	0.5174

4. Conclusion

Oil exploration is the premise and foundation of effective utilization of oil resources by oil enterprises. The efficiency of oil exploration influences the efficiency of oil development and the economic benefit of oil enterprises as well. Therefore, it is very necessary to conduct efficiency evaluation on oil exploration by oil enterprises and then find out the project in need of improvement and the direction of improvement. The evaluation indexes established in this paper is selected on the basis of comprehensive consideration of the whole process of oil exploration. Besides, the two-phase DEA model established in this paper not only considers the intermediate product, but the extra output in the second phase. Compared with traditional models, this model can analyze the production process with intermediate product more effectively, providing a new approach for the evaluation of oil exploration efficiency.

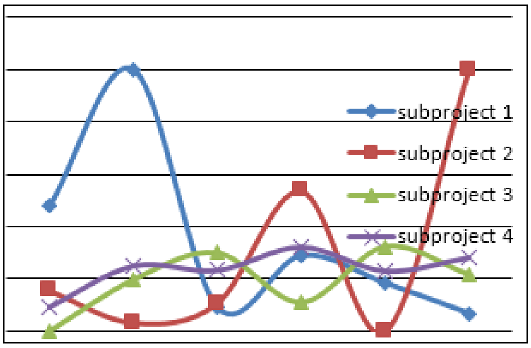

Figure 2 *： Optimal Solution of Model (5)*

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