Appraising Model of Mineral Resources Efficiency Based on China's Provincial Data from the Perspective of Green Growth

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Abstract: This paper integrated systematically the method of MFA, DEA, and the evaluation method of eco-efficiency, constructed an appraisement model of total factor mineral resources efficiency from the perspective of green growth. And it defined the indicator system of appraising total factor mineral resources efficiency. This paper gave an empirical research of total factor mineral resources efficiency, economic efficiency of mineral resources, environmental efficiency of mineral resources, and eco-efficiency of mineral resources, of Chinese provincial regions for the year 2012. Study results confirms: the appraisement model of total factor mineral resources efficiency of this paper, not only discussed the appraising problem of total factor mineral resources efficiency of the process of mineral resources using, but also brought economic value, environmental influence and ecological cost into appraising framework of total factor mineral resources efficiency; so it is a scientific and comprehensive method of appraising mineral resources efficiency, and is in conformity with green growth theory.
Keywords: Mineral resources, science and technology resources, material flow analysis, green growth, hidden flows

1 INTRODUCTION

Resource is the lifeblood of human society survival and development, the main resource of human society using is mineral resources, while the mineral resources are increasingly exhausted.

Green growth is the inevitable choice for the sustainable development of human society. The mineral resources, environment, ecology and economic growth exist inseparable interactions. So, it is particularly important, to explore a total factor mineral resources efficiency appraisement model, in line with green growth theory, to appraise effectively efficiency problems of the process of mineral resources extraction, processing, using and recycle-using, for a nation or region to enhance the overall utilization efficiency of mineral resources, and to develop green growth or sustainable development pattern, and to provide decision references and theory supports. This paper integrated systematically the method of MFA (Material Flow Analysis), DEA (Data Envelopment Analysis), and the appraisement model of eco-efficiency, constructed a model of appraising total factor mineral resources efficiency from the perspective of green growth, and gave an empirical research based on Chinese provincial regional data for the year 2012.

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2 THE RELATED RESEARCH REVIEW

2.1 The Literatures Review of Related Problems

Resource Efficiency and Resource Productivity is the most common and most easily confused words in the related research fields of resource efficiency. The related literatures review of Resource Efficiency and Resource Productivity are as follows.

Pearce put forward calculation method of resource productivity, that is, resource productivity is equal to the ratio of the amount of economic outputs and resource substance inputs [1]. Dahlström and Ekins studied disparities between resource efficiency and resource productivity in steel and aluminum industry in the UK [2]. Schandl and West discussed resource use and resource efficiency issues in Asia-Pacific region in the years 1970-2005 using IPAT framework[3]. Bleischwitz studied the resource productivity related issues: conjunction, measurement, empirical tendencies, innovation, and resource policies [4]. Bian and Yang discussed Chinese provincial resource and environmental efficiency based on Shannon's Entropy [5]. Strazza *et al.* explored the role of improving resource productivity for promoting cleaner production [6]. Ang *et al.* discussed sustainable development issues from the perspective of the overall resource efficiency of EU-15 countries [7]. Guo *et al.* discussed change tendencies and reasons of Metropolitan resources efficiencies in China[8]. Barrett and Scott researched the relationship between climate change alleviation and resource efficiency taking UK as an example [9]. Delmas and Pekovic studied the role of companies implement resource efficiency strategy under different market conditions [10]. Von Weizsäcker and Ayres explored the relationship between resource productivity and resource pricing [11]. Samus *et al.* explored assessment problems of natural resource forthputting and resource efficiency potential [12]. Rosen discussed the evaluation of global resource use efficiency in the industrial sector [13]. Yang *et al.* discussed the application of composite efficiency indicators in the evaluation of resource and energy [14]. Hoang analyzed resource efficiency of 116 economies with a production frontier approach [15]. Rohn *et al.* discussed the role of technology, products and strategies for mining the potential of resource efficiency [16]. Du *et al.* discussed fixed costs and resource allocation with DEA cross-efficiency [17]. Massarutto researched the role of extended producer responsibility for enhancing resource efficiency [18]. Figge *et al.* discussed the problem of rebound effect in resource efficiency [19], and other literatures, *et al.*

2.2 Limitations of Existing Research

(1) Total factor resource efficiency appraisement indicator system is imperfect. Most scholars use resource productivity instead of resource efficiency. The concept of resource productivity has a great limitations: resource productivity measure the ratio of the created value after natural resources consumption and the inputs of natural resources; neither take into account the influence of other input factors in production, nor take into account environmental pollution and ecological damage in the process of natural resource exploitation and utilization.
(2) Existing literature lacks of the appraisement model research of total factor mineral resources efficiency integrate systematically MFA, DEA and eco-efficiency evaluation method.
(3) There are close interaction relations between mineral resources, environment, ecology and economic growth, the existing literature lacks to put them into a unified analytical framework to consider.

This study made up for these shortcomings.

3 CONSTRUCTING OF APPRAISEMENT MODEL OF TOTAL FACTOR MINERAL RESOURCES EFFICIENCY FROM THE PERSPECTIVE OF GREEN GROWTH

3.1 The MFA of Mineral Resources based on the Perspective of Total Factor Productivity

Fig. 1 is a MFA framework of mineral resources based on the perspective of TFP (Total Factor Productivity).

According to the Fig. 1, we can determine the input-output indicators of the total factor mineral resources efficiency appraising; and these indicators integrated properly, it can be combined with DEA model; then introduced of DEA method, and learned from the idea of eco-efficiency evaluation method; next, conducted an appraisement model of total factor mineral resource efficiency.

Some indicators need to integrate, in the expression: **regional mineral resources substances trade balance discount = mineral resources substances which region sold − mineral resources substances which region bought**; therefore, the indicator of regional mineral resources substances trade balance discount, may replace the two indicators of mineral resources substances which region sold and mineral resources substances which region bought.

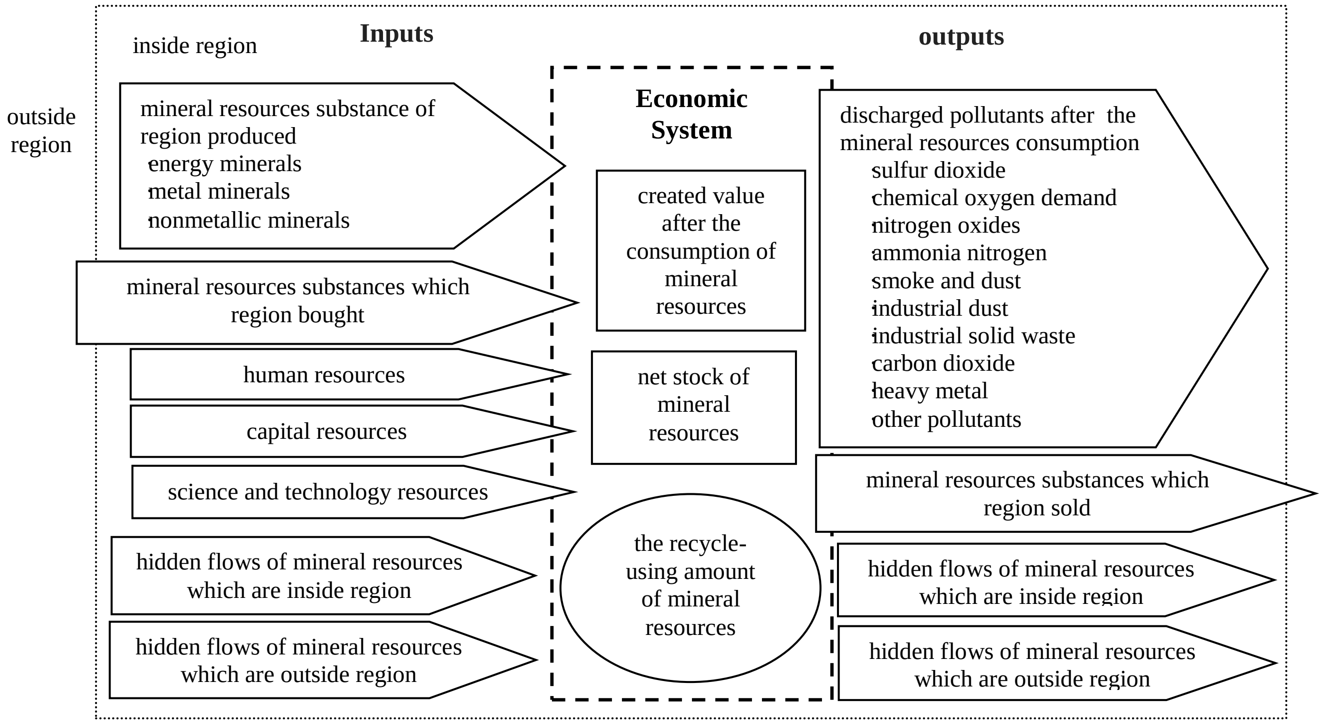

Fig. 1. MFA framework of mineral resources based on the perspective of TFP

Thus, in the MFA framework of mineral resources, the input indicators are the various elements which are inputted in production; after combined with DEA model, these elements are input indicators of DEA model. In the MFA framework, the indicators of value increased amount generated by the economic system, and the output indicators of the MFA of mineral resources, take together to correspond output indicators of DEA model.

3.2 Construction of Total Factor Mineral Resources Efficiency Appraisement Model from the Perspective of Green Growth

There is no unified and cleared definition of the concept of green growth in the world currently. The authors analyzed systematically the literature of green growth which is existing in the world, and found that the vast majority of research institutions and scholars, expresses the concept of green growth, contain basically the following idea: green growth is a nation or a region in the process of economic development, relying on scientific and technological progress, to make the consumption of non-renewable natural resources continue to decrease; and to develop vigorously renewable resources, alternative resources and new resource substance, in order to make them in the proportion of resource consumption increase gradually; to make environmental pollution and ecological destruction minimize, and to make created economic value maximize; so, it is a economic development pattern in line with the sustainable development concept. Although many research institutions and scholars defined the concept of green growth, focusing on different subject respectively, but reflected basically the concept of economic growth and resource, ecology, environment coordinate developing.

Based on the statements of green growth concept above, this paper defined some concepts, which are as follows. **Total factor mineral resources efficiency** refers to, in the process of mineral resources mining, processing, using, and recycle-using, through investments of various elements, to make environmental pollution and ecological damage minimizing as the premise, to produce the degree of economic value maximization. **Economic efficiency of mineral resources** refers to, in the process of mineral resources mining, processing, using, and recycle-using, through investments of various elements, to create the degree of value maximization. **Environmental efficiency of mineral resources** refers to, in the process of mineral resources mining, processing, using, and recycle-using, through investments of various elements, to make minimization degree of pollutant emissions. **Eco-efficiency of mineral resources** learned from the idea of eco-efficiency evaluation method, it refers to in the process of mineral resources mining, processing, using, and recycle-using, with fewer natural resources investments to create greater value as the premise, simultaneously, to produce the minimization degree of ecological damage.

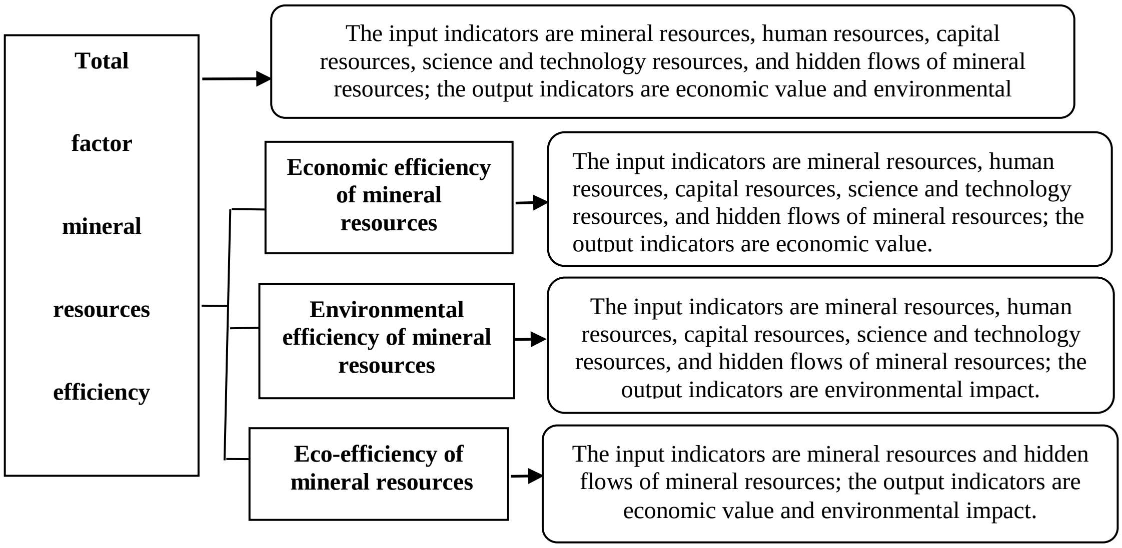

Fig. 2. Appraisement model and indicators system framework of mineral resources efficiency from the perspective of green growth

Fig. 2 is the appraisement model and indicators system framework of mineral resources efficiency from the perspective of green growth.

3.3 The DEA Model of this Paper Used

This paper used a linear data transfer function method to transfer environmental pollutants (environmental impact), which are undesirable outputs, into the desirable outputs which can be used to account by DEA model, and that are positive environmental impact.

Assume there are n Decision Making Units(DMUs) which are independent of each other, each DMU has m types of input elements x_{ij}, k types of output elements y_{ij}, emits s types of environmental pollutants b_{tj}. Using linear data conversion functions $b_{ti}' = -b_{tj} + U \geq 0$, U is a enough large vector; thus, we can transform environmental pollutants (environmental impact) b_{tj}, into positive environmental impact b_{tj}'. This paper uses BCC model, which is as follows,

$$
\begin{cases}
\min\theta_0 \\
\text{s.t.} \quad \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \min\theta_0 x_{i0}, i=1,2,\ldots,m \\
\qquad \sum_{j=1}^{n} \lambda_j y_{rj} + s_r^+ = y_{r0}, \; r=1,2,\ldots,k \\
\qquad \sum_{j=1}^{n} \lambda_j b_{tj}' + s_t^+ = b_{t0}', \; t=1,2,\ldots,s \\
\qquad \sum_{j=1}^{n} \lambda_j = 1 \\
\qquad \lambda_j, s_i^-, s_r^+, s_t^+ \geq 0
\end{cases}
$$

In this model, θ_0 represents the valid optimal solution, λ_j represents the combination coefficients, S_i^- represents inputs redundancy amount, S_r^+ and S_t^+ represents outputs insufficient amount.

4 THE EMPIRICAL TEST OF TOTAL FACTOR MINERAL RESOURCES EFFICIENCY APPRAISEMENT FROM THE PERSPECTIVE OF GREEN GROWTH

4.1 Sources and Accounting Methods of Data in this Paper

In Fig. 2, the data accounting methods of various indicators in this paper is showed in Table 1.

The data of various indicators described in Table 1, derived from ***China Statistical Yearbook (2013)***, ***China Science and Technology Statistical Yearbook(2013)***, ***China Energy Statistical Yearbook(2013), China Mining Yearbook(2013), China environment statistical Yearbook(2013), 2012 Report on the State of the Environment in China,*** Statistical Yearbook of Chinese various provincial regions in the year 2013, and other relevant statistical data.

Fixed capital stock of Chinese provincial region in the year 2012, calculated by the perpetual inventory method: that is, **fixed capital stock of each region this year = the stock of fixed capital of region the year before × (1 − the rate of depreciation of fixed assets) + fixed asset investment of region this year**. The data of fixed assets investment of Chinese each provincial region in the year 2012, can find in ***China Statistical Yearbook (2013)***, the

data of fixed capital stock and the rate of depreciation of fixed assets, reference the research method and some data of Zhang *et al.* [20], and measured the capital stock in the year 2000 as the basic data, then according to the formula calculated fixed capital stock data of Chinese provincial regions in the years 2001—2012.
The hidden flows data of unit mineral resources, referenced the research results of Li [21]**,** and converted, thus got the hidden flows data of unit standard coal, unit metal minerals and unit nonmetallic minerals.

Emissions amount data of carbon dioxide, referenced Hu *et al*. [22] had adopted method, then calculated, thus obtained it.

This paper measured heavy metal pollutant emissions of Chinese provincial regions take the following methods. According to the Chinese ***the first national census of pollution sources: produce and emission coefficient manual (2010 revision) of industrial pollution sources*** and ***the first national census of pollution sources: produce and emission coefficient manual (2010 revision) of urban domestic sources***. According to the year 2012 the metal minerals yield data of Chinese provincial regions, and industrial wastewater discharges and treatments in a variety of industries data in the year 2012 of Chinese provincial regions, and industrial waste gas discharges and treatment in a variety of industries data in the year 2012 of Chinese provincial regions,and industrial solid waste discharges and treatment in a variety of industries data in the year 2012 of Chinese provincial regions, this paper measured lead, cadmium, arsenic, mercury, hexavalent chromium, nickel, zinc, copper, the eight kinds of typical heavy metal pollutant emissions. Using factor analysis method to synthesize the eight kinds of typical heavy metal pollutant emissions to one indicator, combined with the magnitude of the eight heavy metal pollutants, obtained the composite indicator data of heavy metal pollutant emissions after the weighted in the year 2012 of Chinese provincial regions.

Table 1. The data accounting methods of various indicators in this paper

	first level indicators	**the data accounting method**	**second level indicators**	**the data accounting method**
input indicators	human resources(ten thousand people)	regional human capital stock	regional human capital stock	quantity of employment of provincial regional urban and rural
	capital resources (billion yuan)	regional fixed capital stock	regional fixed capital stock	calculated by the perpetual inventory method
	science and technology resources	Using the factor analysis method to synthesize R&D expenditure *etc.* three second level indicators to the science and technology resources composite indicator.	R&D expenditure	direct obtained in statistical data
			local financial allocation on science and technology	direct obtained in statistical data
			the number of R&D personnel of thousands of people this year	direct obtained in statistical data
	mineral resources (ten thousand tons)	the amount of mineral production in the region	the amount of mineral production in the region	the amount of energy minerals production in the region + the amount of metal minerals production in the region + the amount of nonmetallic minerals production in the region
	hidden flows of mineral resources (ten thousand tons)	the hidden flow of energy minerals+the hidden flow of metal minerals+the hidden flow of nonmetallic minerals	the hidden flow of energy minerals	the amount of energy minerals production in the region(equivalent amount of standard coal) ×the hidden flow of unit standard coal
			the hidden flow of metal minerals	the hidden flow of some kind metal minerals=the amount of metal minerals production×the hidden flow of unit metal minerals, and then summing
			the hidden flow of nonmetallic minerals	the hidden flow of some kind nonmetallic minerals=the amount of nonmetallic minerals production×the hidden flow of unit nonmetallic minerals, and then summing
	economic value(ten thousand yuan)	the total value of the region created this year	the total value of the region created this year	GDP of the region this year
	positive	Using factor analysis	emission amount of	total emission amount of sulfur dioxide

output indicators	environmental impact	method to synthesize sulfur dioxide *etc.* nine second level indicator to the environmental impact indicator b_1 ,then using linear data conversion functions, $b_1' = -b_1 + W$, to convert, thus got positive environmental impact indicator b_1' .	sulfur dioxide	of industry sources, the sources of life, and centralized pollution treatment facilities this year.
			emission amount of chemical oxygen demand	total emission amount of chemical oxygen demand of industry sources, the sources of life, agricultural sources and centralized pollution treatment facilities this year.
			emission amount of nitrogen oxides	total emission amount of nitrogen oxides of industry sources, the sources of life, motor vehicle and centralized pollution treatment facilities this year.
			emission amount of ammonia nitrogen	total emission amount of ammonia nitrogen of industry sources, the sources of life, agricultural sources and centralized pollution treatment facilities this year.
			emission amount of smoke and dust	total emission amount of smoke and dust of industry sources, the sources of life this year.
			emission amount of industrial dust	directly obtained in statistical data
			emission amount of industrial solid waste	directly obtained in statistical data
			emission amount of carbon dioxide	consumption amount of carbonaceous energy×the carbon conversion coefficient×carbon dioxide gasification coefficient
			emission amount composite indicator of heavy metal	to measure lead, cadmium, arsenic, mercury, hexavalent chromium, nickel, zinc, copper, the eight kinds of typical heavy metal pollutant emission amount, then to form emission amount composite indicator of heavy metal

4.2 Appraisement Results and Analysis of this Paper

According to Fig. 2 and Table 1, we can get the data of input and output indicators of this paper, using the common software DEAP 2.2, appraised total factor mineral resources efficiency, economic efficiency of mineral resources, environmental efficiency of mineral resources, and eco-efficiency of mineral resources, of Chinese provincial regions in the year 2012. Table 2 is the appraised results.

To analyze the various data in Table 2 below.

(1) Total factor mineral resources efficiency

Total factor mineral resources efficiency of Chinese provincial regions present basically the “under the ladder” distribution which reduces gradually from southeast to northwest. Total factor mineral resources efficiency of Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, Hainan is DEA effective, and these provincial regions form production frontier of total factor mineral resources efficiency, belong to the first echelon. The main reasons are that these province economic development level is relatively high, got substantial improvement in their level of technology and production processes, mostly carried out upgrading of industrial structure, to develop mainly low energy and resource consumption, high value-added industries, high-tech industries and the services is relatively developed; attached importance to the development of renewable resource and new energy, pay attention to the products development and application of conserving resource and protecting environment, thus, mineral resources efficiency got improved. Total factor mineral resources efficiency of Jiangxi, Anhui, Guangxi, Shandong is relatively high, belong to the second echelon. Henan, Shaanxi, Chongqing, Hunan, Hubei, basically belong to the third echelon, is the medium level. Northeast (Heilongjiang, Jilin, Liaoning) basically belong to the fourth echelon, is a lower middle level. The main reason is that the northeast is the heavy industry base of China, leading industries are more concentrated in high energy and resource consuming industries, such as, machinery manufacturing, energy and resource development, chemical, metallurgy and building materials industries, etc., therefore, lead to excessive mineral resources consumption; at the same time, saving resource mechanism is not perfect, which leads to the low mineral resources efficiency. Sichuan, Yunnan, Hebei, Gansu, Xinjiang, Inner Mongolia, Guizhou basically belong to the fifth echelon. Total factor mineral resources efficiency of Ningxia, Qinghai, Tibet, Shanxi is the lowest, belong to the sixth echelon. The main reason of Ningxia, Qinghai, Tibet, is the less developed economy, technology and equipment is relatively backward, resulting in low mineral resources output efficiency. Shanxi is a big province of coal production, consumption of coal and coke in industrial production is larger, while saving resource mechanism is not perfect, which leads to the low mineral resources efficiency.

(2) Economic efficiency of mineral resources

Economic efficiency of mineral resources and total factor mineral resources efficiency of the provincial regions showed basically a positive correlation. The regions of total factor mineral resources efficient is high, correspondingly, economic efficiency of mineral resources is relatively high. Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Guangdong, Fujian, these provincial regions, relatively lack of resources, but economic efficiency of mineral resources is the highest in China. The western region is rich in natural resources, while economic efficiency of mineral resources is far lower than the eastern region. The region with abundant natural resources need avoid a single economic structure which depend on excessively resource; to use resources to exchange necessary capital for sustained economic growth. With the capital, to continue to seek innovative development pattern, to transform to green growth pattern which is low resource consumption, low emissions, less pollution; to transform to a diversified economic structure and industrial structure. The regions should rely on scientific and technological progress, to promote resource conservation, with less resource consumption, to create greater economic development; to make resources become the necessary material condition of creating new economic growth continuously.

Table 2. Total factor mineral resources efficiency, economic efficiency, environmental efficiency and eco-efficiency of mineral resources of Chinese provincial regions in 2012

geographical district	provincial region	total factor mineral resources efficiency	economic efficiency of mineral resources	environmental efficiency of mineral resources	eco-efficiency of mineral resources
North China	Beijing	1.000	1.000	0.832	1.000
	Tianjin	1.000	1.000	0.837	1.000
	Hebei	0.749	0.746	0.625	0.674
	Shanxi	0.673	0.665	0.469	0.522
	Inner Mongolia	0.705	0.694	0.584	0.681
Northeast China	Heilongjiang	0.806	0.801	0.732	0.783
	Jilin	0.817	0.812	0.735	0.775
	Liaoning	0.802	0.793	0.738	0.754
East China	Shanghai	1.000	1.000	0.817	1.000
	Jiangsu	1.000	1.000	1.000	0.912
	Zhejiang	1.000	1.000	0.811	0.923
	Anhui	0.928	0.921	0.723	0.809
	Fujian	1.000	0.958	0.762	0.891
	Shandong	0.913	0.907	0.726	0.824
	Jiangxi	0.944	0.936	0.725	0.832
Central China	Henan	0.907	0.884	0.672	0.785
	Hubei	0.812	0.795	0.618	0.746
	Hunan	0.835	0.817	0.613	0.752
South China	Guangdong	1.000	1.000	1.000	0.924
	Guangxi	0.926	0.912	0.807	0.883
	Hainan	1.000	0.941	0.916	0.927
Southwest China	Chongqing	0.847	0.839	0.720	0.795
	Sichuan	0.791	0.773	0.645	0.758
	Guizhou	0.694	0.670	0.621	0.659
	Yunnan	0.748	0.736	0.709	0.730
	Tibet	0.623	0.618	0.604	0.612
Northwest China	Shaanxi	0.862	0.857	0.627	0.743
	Gansu	0.726	0.714	0.576	0.620
	Qinghai	0.647	0.629	0.518	0.564
	Ningxia	0.561	0.553	0.469	0.548
	Xinjiang	0.708	0.695	0.532	0.597

(3) Environmental efficiency of mineral resources

Most of the provincial regional environmental efficiency and eco-efficiency of mineral resources is lower than the economic efficiency of mineral resources. This shows that many regions of China is rapid in economic growth, at the same time, environmental pollution and ecological damage is very seriously. Rapid economic growth is at the cost of environmental pollution and ecological damage. The key problem is that local governments and enterprises have not established firmly the concept of green growth, have not established the idea of ecological civilization, pay attention to economic growth and economic output, but underrate environmental protection. Regional environmental efficiency of mineral resources closely related to total factor mineral resources efficiency. Guangdong, Jiangsu, Hainan, Tianjin, Beijing, Shanghai, Guangxi, Zhejiang, Fujian, environmental efficiency of mineral resource of these provincial regions is the highest. Mainly because economic development foundation for a long time in these regions is better, and these regions attach importance to the optimization and upgrading of industrial structure; the investment on environmental governance is comparative large, thus, protected effectively the natural environment and the living environment. Environmental efficiency of mineral resources of Shanxi, Ningxia, Qinghai, Xinjiang, Gansu is the lowest, because the level of economic development of these regions is relatively low, and economic foundation and strength is relatively weak, and technology is backward, and leading industry is high emission and large pollution; in terms of environmental inputs and environmental governance have many deficiencies. These provincial regions need to increase continuously the efforts of environmental protection, and improve continuously environmental quality.

(4) Eco-efficiency of mineral resources

Eco-efficiency of mineral resources and environmental efficiency of mineral resources is positive correlation. This shows that the ecological damage and environmental pollution often has great relevance: on the one hand, ecological damage in the process of mineral resources development and utilization often leads to environmental pollution; on the other hand, pollution of the environment, often leads to ecosystem destruction which is original good. Therefore, China must strengthen ecological protection awareness, in the process of mineral resources development and utilization, to exploit legitimately natural resources, and to avoid predatory exploitation of natural resources; for some lean ore resources which is little mining value, to implement protective measures of mine closure; and to minimize ecological damage for these mineral resources which is ready to develop; for those mineral resources which has been abandoned, need to implement the measures of recovery and reconstruction of ecosystem; to strive to reduce hidden flows(ecological rucksacks) in the process of mineral resources development and utilization.

5 CONCLUSIONS

This paper integrated systematically the method of MFA, DEA, and the evaluation method of eco-efficiency, constructed a appraisement model of total factor mineral resources efficiency from the perspective of green growth; and gave an empirical research of total factor mineral resources efficiency, economic efficiency of mineral resources, environmental efficiency of mineral resources, and eco-efficiency of mineral resources, of Chinese provincial regions for the year 2012.

The total factor mineral resources efficiency appraisement model of this paper constructed, is a more scientific and comprehensive method of appraising mineral resources efficiency which is in conformity with green growth theory. This method not only has considerable theoretical significance, but also has considerable practical significance. It can be used to appraise total factor mineral resources efficiency, for a nation or region to enhance the overall utilization efficiency of mineral resources, implement green growth pattern, provide decision references and theory supports.

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