The Global Equity Evaluation for Asteroid Mining based on Principal Component and Hierarchical Analysis

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Abstract. As scientific and technological development progresses and asteroid mining gradually becomes a reality, the Outer Space Treaty provides the legal basis for promoting the participation of countries in this project. The fairness of this international commitment is fully guaranteed, and the international division of responsibilities among countries is reasonably quantified. Starting from global equity, a comprehensive evaluation based on principal component analysis (PCA) and hierarchical analysis is carried out to reasonably allocate resources based on population, while integrating evaluation scores. Based on K-means cluster analysis, we classify global countries in four dimensions: economic strength, scientific and technological strength, labor input, and industrial output, and based on the classification results, we delineate the international division of labor responsibilities of each country. Based on grey correlation analysis (GCA), the direct factors affecting asteroid mining are assessed as economic strength and industrial output. Based on the results of the above analysis, reasonable suggestions are made to ensure maximum global equity and promote the development of asteroid mining.

Keywords: Global equity, Asteroid mining, Principal component analysis, Hierarchical analysis, gray correlation analysis

1 Introduction

As scientific and technological development progresses and asteroid mining gradually becomes a reality, the Outer Space Treaty provides the legal basis for promoting the participation of countries in this project. The fairness of this international commitment is fully guaranteed, and the international division of responsibilities among countries is reasonably quantified.[1][2]

The essence behind the ethical issues of asteroid mining industry is the issue of resource allocation. Wang Jinqiang pointed out that the establishment of international organizations is a more effective method. In addition, the establishment and improvement of the resource allocation system is the significance of establishing international organizations.[3] The establishment of resource allocation system depends on the application of multi-index comprehensive evaluation. Principal component analysis and analytic hierarchy process are widely used in multi-index comprehensive evaluation. Wang Zichao and others have combined and improved the two methods and applied them to the multi-index integrated evaluation model. [4] In addition, it is necessary to evaluate the impact of a single index on the whole from the dimension, in which the grey correlation analysis method is more applicable. Finally, the differences between countries lead to different participation in international affairs. Each country can not be generalized. Based

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on the idea of multiple indicators classification, countries should be classified so that each country can play different roles and assume common responsibilities.

In this paper, we will first put forward the definition of global equity and take asteroid mining as the landing point. We will construct a global equity evaluation system, reasonably classify countries, use the analysis results to propose a possible future vision for the asteroid mining industry. In addition, we will also look for the main factors affecting asteroid mining, while reconstructing the global equity evaluation system to assess the impact of asteroid mining on global equity, and finally make reasonable suggestions for global equity and the future development of asteroid mining.

2 Building Models

2.1 Global Equity Evaluation System

We define global equity in the national dimension, i.e., global justice refers to a claim of distribution of globally shared resources or opportunities based on some multi-indicator construction price system. The concept of global equity we define is essentially a way of resource allocation, and the root of this allocation is the construction of a multi-indicator evaluation system. [5] The equitable distribution of resources covers many aspects and influences many factors. Here, we extract five fundamental indexes including population, area, GDP per capita, poverty rate, and resource reserves, and use these five important indexes as evaluation indicators to construct a global equity evaluation system.

The principal component analysis (PCA) method refers to the analysis of things by making the principal components of the new variable linear combinations of the original variables through appropriate mathematical transformations and selecting a few principal components that have a large proportion of the total information of the variance. A set of potentially correlated variables is transformed into a set of linearly uncorrelated variables by an orthogonal transformation, and the transformed set of variables is called a principal component. Because its idea of dimensionality reduction is very close to the requirement of sequencing multi-metric evaluation indicators, principal component analysis can be mostly used for the establishment of multi-metric evaluation models.[6]

In addition, hierarchical analysis (HA) is a combined qualitative and quantitative analysis method for evaluating decisions. The hierarchical analysis can decompose the decision problem into different hierarchical structures in the order of the general objective, sub-objectives of each level, evaluation criteria and specific alternative solutions, and then use the method of solving the eigenvectors of the judgment matrix to find the priority weight of each element of each level to a certain element of the previous level, and finally sum the final weight of each alternative solution to the general objective by the method of weighting, and the one with the largest final weight is the optimal solution.[7] In the global equity evaluation system we constructed, the population and area are generally considered to be the most important evaluation indicators that determine resource allocation, *i.e.*, global equity, with poverty rate and GDP per capital coming second and resource reserves coming second.

2.2 Global Country Classification

The *K*-means algorithm, also known as the mean algorithm, is a relatively developed method in cluster analysis, whose central idea is to divide data objects in the Euclidean space, and achieve object selection through an initial center strategy to make them the center of clusters. Then find multiple class cluster partitioning schemes such that the overall error obtained when using these class clusters to represent the corresponding classes of samples is minimized. [8]

The asteroid mining industry is based on modern industry and requires significant investment in research, capital and labor, so taking into account several important factors that have an impact on the asteroid mining industry, we have chosen four indicators to classify countries worldwide: gross national product, labor force, scientific research inputs, and gross national industrial product.

2.3 Global equity impacts of asteroid mining

To explore the impact of asteroid mining on global equity, we introduced a new indicator variable which is the contribution of asteroid mining industry in the evaluation system, reasonably quantified the indicator with reference to *K*-means clustering results, and constructed a new global equity evaluation system.

Moreover, the gray correlation (GC) is a measure of the magnitude of the correlation between two systems studying the change of factors over time or different objects; if the trend of the change of two factors is consistent, *i.e.*, the degree of simultaneous change is high, it indicates that the degree of correlation between the two is high.[9] And the number of gray correlation coefficients $\zeta_i(k)$between the reference sequence and the comparison sequence:

$$\zeta_i(k) = \frac{min_i min_k |x_0(k) - x_i(k)| + \rho \cdot max_i max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \rho \cdot max_i max_k |x_0(k) - x_i(k)|} \tag{1}$$

Finally, the correlation r_i between any two factors can be calculated as:

$$r_i = \frac{1}{N} \sum_{k=1}^{N} \zeta_i(k) \tag{2}$$

3 Results and Discussion

3.1 Model solving

Based on principal component analysis (PCA) mentioned above, we select 183 major countries in the world to be evaluated based on our constructed global justice evaluation system. The processed data are then subjected to principal component analysis (PCA) to obtain Component Matrix as shown below:

Table 1. The Component Matrix of PCA.

	Ingredients		
	1	***2***	***3***
Poverty Rate	-0.455	0.614	-0.417
Population	0.629	0.479	0.411

Area	0.795	0.332	-0.004
Petroleum	-0.484	-0.046	0.805
Total Production Value	-0.420	0.732	0.134

Let population, area, GDP per capital, poverty rate, and resource reserves, the five indicator variables are standardized as$x_1 \sim x_5$ in order to obtain the principal component expressions as following.

$$y_1 = 0.629x_1 + 0.795x_2 - 0.420x_3 - 0.455x_4 - 0.484x_5 \quad (3)$$

$$y_2 = 0.479x_1 + 0.332x_2 + 0.732x_3 + 0.614x_4 - 0.046x_5 \quad (4)$$

$$y_3 = 0.411x_1 - 0.004x_2 + 0.134x_3 - 0.417x_4 + 0.805x_5 \quad (5)$$

The eigenvector matrix can reflect the loading of each indicator on each principal component (PC)， so the first principal component we extracted mainly represents population and area, the second principal component represents poverty rate and GDP per capital, and the third principal component represents resource reserves, we use hierarchical analysis to optimize this evaluation system.[10]

We constructed the pairwise comparison matrix based on the Sandy's 1-9 scale method, normalized the matrix and calculated the weights to obtain the index weight matrix.

$$W = [0.739，0.180，0.069]^T \quad (6)$$

With the obtained index from the weight matrix, we can express the formula for the model evaluation score as:

$$Q = 0.579x_1 + 0.646x_2 - 0.169x_3 - 0.254x_4 - 0.310x_5 \quad (7)$$

The composite score for each country was calculated as shown in Figure 1.

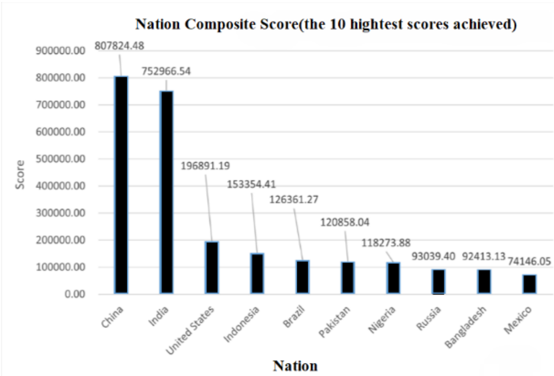

Fig. 1. National Composite Score (the 10 highest scores achieved).

Based on the evaluation system we have developed, we believe that a higher score means that the country needs to allocate more resources, and that resources can be allocated quantitatively according to the higher or lower score.

3.2 Model solving

Based on the clustering results, we can classify 183 major countries in the world as shown in Table 2.

Table 2. The results of Global Country Classification.

Country Category	Table Column Head	
	Quantity	*Typical Country*
A	12	Germany, Russia, Japan, Australia, etc.
B	1	United States
C	1	China
D	169	Nigeria, Greece, Laos, Mexico, etc.

- **Category A:** Countries with average national economic strength, a stable national labor market, a strong national scientific research strength and a high level of industry.
- **Category B:** Countries with strong national economy strength, stable national labor market, strong national scientific research strength, and high level of national industrial development.
- **Category C:** Countries with good national economic strength, strong national labor market, fair national scientific research strength, and average national industrial level.
- **Category D:** Countries with weak national economic strength, weak national labor market, lack of national scientific research strength, and low industrial level.

Based on the results of the above analysis, we propose a possible vision for the future of the asteroid mining industry in three aspects: formation of an international organization, human resource input, cost acquisition.

- Establishing the Council of the Global Alliance for Asteroid Mining, following the UN model
- By A, B, C countries to invest in research scientists and technicians, and by C, D countries to invest in applied skilled workers.
- Establishing the Asteroid Mining GAM Foundation as a cost source, which is managed directly by GAM.

3.3 Model solving

We define the composite score of each country in our newly constructed global equity system as the reference series, and the four indicators of GNP, labor force, research expenditures, and national industrial output as the comparison series, and calculate their gray correlation coefficients to obtain the following values of correlation as shown in Table 3.

Table 3. The Number of grey contacts.

Indicators	Number of grey contacts	
	Correlation	*Ranking*
Gross National Product	0.9601	1

Labor Force	0.9118	3
Scientific Research Expenses	0.9013	4
Gross National Industrial Product	0.9415	2

Based on the results in the table above, we believe that GNP and national industrial output are the direct influences of global equity.

3.4 Suggestions

Based on the model we developed and the results of the previous analysis, we propose four sound policy recommendations for updating the UN Outer Space Act so that asteroid mining can truly benefit all of humanity.

- Introduction of more reasonable evaluation indicators and continuous optimization of the global equity evaluation system
- Clarify detailed industry norms to optimize the mining resource allocation system
- Ensuring the authority of the Joint Global Organization for Asteroid Mining to lead countries in their respective roles
- Structuring a positive feedback system to achieve a win-win situation of optimizing the global equity system and enhancing national strength

4 Conclusion

In this paper, we put forward the definition of global equity and construct the global equity evaluation system with five fundamental indicators including population, area, GDP per capita, poverty rate, and resource reserve as evaluation indicators. Later, we introduce new indicator variables in order to analyze the impact of asteroid mining on global equity, we reconstruct the global equity evaluation system, and calculate the composite score of countries in the existing system. Eventually, in order to increase the global equity of asteroid mining in the future, we put forward four policy suggestions for the renewal of the United Nations outer space law.

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