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Formulation of Asteroid Mineral Resources Allocation Scheme Based on an Ideal Equity Allocation Model and Real Economic Allocation Model

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Abstract: *At present, the huge prospect of asteroid mining makes the investment and benefit allocation of asteroid mining become a hot issue. The research explored how to allocate the mineral resources of asteroids fairly. Firstly, the factors influencing the ideal equity allocation were determined by putting forward a method to measure global equity. After the determined factors were given appropriate weights by entropy weight method, the grey prediction model was used to establish an ideal equity allocation model. Secondly, after analyzing the indexes that affect the fair allocation of real economy, the weights of these indexes were determined by using the fuzzy comprehensive evaluation method combined with the analytic hierarchy process. Then, the equity allocation shares of various national groups were calculated based on the established equity allocation model of real economy. The results show that the established equity allocation model is accurate and reasonable within a certain period of time. The research provides ideas for the equity allocation of asteroid mineral resources exploitation in the future.*

Keywords: *Asteroid Mining; Global Equity; Fuzzy Integrated Evaluation Method; Equity Allocation Model; Gray Prediction Model*

1. Introduction

Mineral resources on asteroids in space are good and abundant human resources that can be exploited and utilized. How to develop and distribute the mineral resources of asteroids has become an urgent problem of human development. At present, some countries are trying to mine asteroids, and it is foreseeable that the precious mineral resources of asteroids will be brought back to Earth in the near future. At that time, how to allocate the resources of asteroids can meet the global equity, so that all countries in the world have the opportunity to benefit from the asteroid mining industry, which is an important issue that needs to be considered at present.

The goal of the research is to propose a way to measure global equity and to develop an equity allocation model that is as equity as possible to rationally distribute asteroid mineral resources to countries around the world, in order to promote equity and benign asteroid mining and allocation development globally.

2. An ideal equity allocation model

2.1. Definition of the ideal global equity

Today, with the deepening and closeness of globalization, countries are getting closer to a community with a shared future for mankind, and global equity has become a common need of all countries in the world [1]. We believe that from a limited perspective of the future, achievable global equity should be reflected in these aspects: people in all countries enjoy equal status and rights, and people in all countries have balanced conditions for survival, health, production, and education. The following factors that determine the ideal equity allocation are based on these aspects.

2.2. Identification of factors that determine the ideal equity allocation

We think that in the ideal equity allocation model, the total population of a country is a very important factor in the allocation of public resources. Per capita GDP is used as an index to measure the poverty level of a country. The lower the per capita GDP, the lower the people's economic level, the more they need to be subsidized. In an ideal world of global equality, giving poverty reduction assistance a greater weight than the actual situation should be seriously considered. In addition, Countries with a high level of allocation equity should be given certain rewards to encourage them to actively improve equity. This study selected two indicators, the proportion of educational expenditure to GDP and the average number of years of education, to measure the degree of educational equity in a country.

2.3. Development of an ideal equity allocation model

2.3.1. Data preprocessing

It is limited to classify countries simply according to their geographical location. We can consider the population, economy and education level to evaluate a country's comprehensive strength more authoritatively. Therefore, this study collected the data of the total population, per capita GDP, the proportion of education expenditure to GDP and the average number of years of education.

The K-means clustering method was adopted to divide all countries in the world into 15 clusters. Through combined clusters containing similar elements, and the original 15 clusters were compressed into 8 clusters. In other words, countries in the world were divided into eight categories according to GDP, population and education level: India, small backward countries, small developed countries, the United States, China, Russia and its surrounding areas, Australia and its surrounding areas, Britain and Japan.

2.3.2. Determination of factor weights

It is very important to determine the weight of each factor in equity allocation. In this study, the method was used to determine the weight of each influencing factor: entropy weight method (EWM). The method determines the weight of data by analyzing the differences of data in different countries or regions.

Entropy method determines the weight according to the idea of information theory, and uses formula (1) to calculate the weight.

$$E_j = -\ln(n)^{-1}\sum_{i=1}^{n} p_{ij}\ln(p_{ij}) \tag{1}$$

Where E_j represents the information entropy of the *j* factor, p_{ij} represents the proportion of the *j* factor of the *i*th country or region.

2.3.3. Introduction of a grey prediction model

Grey prediction model was introduced to evaluate the global equity allocation from 2016 to 2020. Considering that the equity allocation system itself can't be fully understood, we think the grey prediction is reasonable. The principle of grey prediction model is as follows.

The original sequence $x(1),\ x(2),\cdots,x(n)$ needs to be subjected to rank ratio detection, that is:

$$\lambda(k) = \frac{x^0\left(k-1\right)}{x^0\left(k\right)},\ k=1,\ 2,\ \cdots,\ n \tag{2}$$

It always need to be satisfied in between $\left(e^{-\frac{2}{n+1}},\ e^{\frac{2}{n+1}}\right)$.And then it was established as follows:

$$x^0(k) + a_Z^1\left(k\right) = b \tag{3}$$

The corresponding bleaching model which named GM(1,1) was obtained, and the final predicted value was calculated by solving the bleaching model. Finally, the residual test was carried out to determine the rationality of the scheme.

The corresponding residuals were calculated:

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$$\varepsilon(k)=\frac{x^0(k)-\hat{x}^0(k)}{x^0(k)},\ k=1,\ 2,\ \cdots,\ n \tag{4}$$

If all of the $|\varepsilon(k)|$ are less than 0.1, they are considered to meet higher requirements. if all of the $|\varepsilon(k)|$ are less than 0.2, they are considered to meet the general requirements.

2.4. Solution of an ideal equity allocation model

After considering the total population, per capita GDP, the proportion of education investment in GDP and the average years of education, the global equity allocation was obtained. It was used to represent the equity share of eight countries under the ideal global equity allocation model. In addition, after the feasibility of the prediction scheme was confirmed by the rank ratio test, the equity ratio of each country from 2021 to 2023 was predicted by using the grey prediction model. The prediction result is shown in Figure 1.

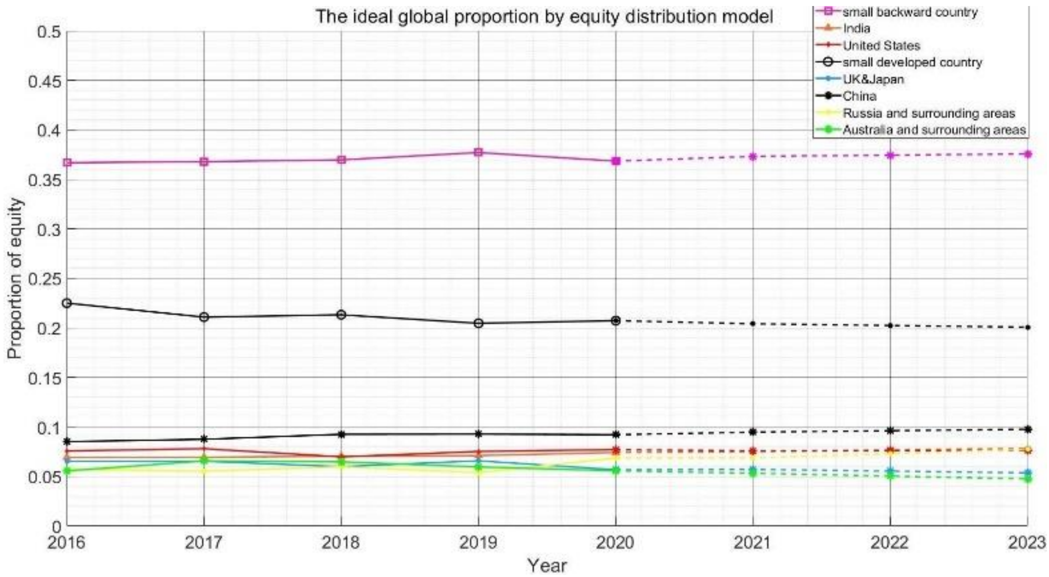

Figure 1: Equity proportion of countries predicted by EWM-based the grey prediction model

The prediction results of the equity proportion of countries show that the allocation of global equity among countries was quite stable within a certain period of time. A few relatively powerful countries had gained the largest share of global equity, while most of the remaining countries could only compete for less than half of the share.

3. A real economic equity allocation model

3.1. Identification of indexes that affect the real economic equity allocation

By referring to and analyzing other cases and existing solutions of similar problems around the world, such as the development of marine environment [3], population management [4], joint space exploration and global carbon emission reduction [5], etc. It is considered that the exploitation scheme and allocation scheme of asteroids will be an economic benefit-oriented scheme after comprehensive consideration of various factors. The program aims to meet the needs and expectations of as many countries and regions as possible, while taking into account equity as much as possible.

There are many indexes affecting the allocation of asteroid mineral resources. After comprehensive measurement, industry participation and poverty relief are mainly considered. Industry participation includes technical participation, labor participation and capital participation. Poverty relief is an aspect that has little influence but can't be ignored, and its regulation is subsidy relief for relatively backward countries. In the study, 1-2 relatively representative evaluation indexes were selected from each evaluation aspect as the factors influencing the true and equity allocation.

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(1) Industry participation

The more countries participate in industries, the greater their responsibilities and costs in asteroid mining, the greater their contribution and the greater their equity share. As the main influencing factor, its score is much higher than other factors. In this respect, it mainly analyzes the cost sharing, investment participation and other labor participation. For cost sharing, the total number of full-time R&D personnel (FTE) and the ratio of R&D expenditure to GDP of each country were selected as the evaluation indexes of science and technology participation [2]. For participating in investment, the total GDP was regarded as the potential of participating in investment. Finally, the total population was selected as the index to measure the input of other labor resources.

(2) Poverty relief

In order to ensure that countries with low technology development level and low investment cost can also benefit from asteroid mining, some opportunities for labor participation and investment should be provided. However, due to technical and financial constraints, the influence of its participation is still low. Limited subsidies need to be provided to the underdeveloped countries in order to achieve a equity global allocation. The PPP coefficient and GDP per capita were used to measure the strength of poverty assistance.

3.2. Establishment of a real economic allocation model

3.2.1. Application of the fuzzy comprehensive evaluation method

Different categories of evaluation objects have different importance. According to other similar cases and related expert scores in the world, fuzzy comprehensive evaluation method is used to evaluate the importance of selected indicators that affect the equity allocation of real economy. Table 1 below shows the scoring results of these indicators.

Table 1: Results of the importance scores of the indexes

Part	Symbol	Level	Symbol	Index	Symbol	Score
Industry participation	B_1	Cost sharing	C_1	FTE	D_1	5
				ratio of R&D expenditure to GDP	D_2	6
		Participate in investment	C_2	total GDP	D_3	8
		Other labor participation	C_3	total population	D_4	2
Poverty assistance	B_2	Degree of assistance	C_4	PPP coefficient	D_5	2
				GDP per capita	D_6	2

3.2.2. Application of the analytic hierarchy process method

After the above index data are normalized and standardized, AHP was applied to determine their weights. A comparison matrix was constructed to determine the weight coefficients, and the consistency was tested with the consistency index (CI) and the consistency ratio (CR) calculated according to Eqs. (5)-(6) respectively, as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{5}$$

$$CR = \frac{CI}{RI} \tag{6}$$

Where λ_{max} and n represent the maximum eigenvalue and order of the comparison matrix, respectively, and RI represents the average random consistency index corresponding to n. When CR<0.10, the comparison matrix can be considered acceptable; otherwise, the comparison matrix needs to be adjusted and modified.

In the study, the comparison matrix and weight calculation results from AHP are described in Table 2. The CR value (0) was less than 0.1, that is, the comparison matrix passed the consistency test and was thought to have good consistency, so the weight coefficients calculated by the constructed comparison matrix is reliable.

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Table 2: Comparison matrix and weights from AHP for the evaluation hierarchy

	Comparison matrix						Weight
	D_1	D_2	D_3	D_4	D_5	D_6	
D_1	1	5/6	5/2	5/8	5/2	5/2	0.200
D_2	6/5	1	3	3/4	3	3	0.240
D_3	2/5	1/3	1	1/4	1	1	0.080
D_4	8/5	4/3	4	1	4	4	0.320
D_5	2/5	1/3	1	1/4	1	1	0.080
D_6	2/5	1/3	1	1/4	1	1	0.080
			$\lambda_{\max}=6,\ CI=0,\ RI=1.59,\ CR=0$				

3.3. Determination of equity share

Using formula (7), the scores of six dimensionless matrices of 8 national groups were calculated. The score is the equity share of each country and region.

$$s_i=\sum_{i=1}^{6}\omega_i D_i \tag{7}$$

Where ω_i is the weight of the ith evaluation index, and D_i is the standardized data of 6 evaluation indexes in 8 countries and regions.

The final equity share of each country group is shown in Figure 2 below.

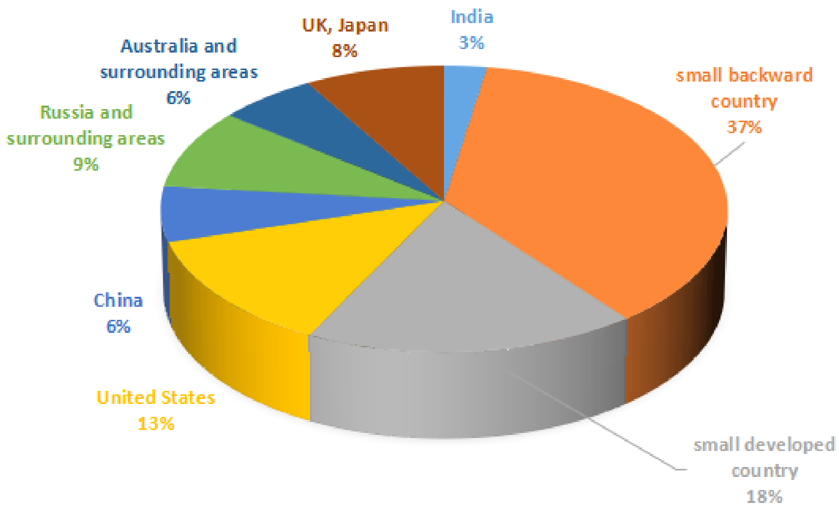

Figure 2: Final equity share of each country group

Figure 2 shows that the small backward countries do not share much in each country. The per capita equity share of small developed countries was much higher than that of backward small countries; The per capita equity share of the United States was higher than that of small developed countries; China's per capita equity share was lower than that of small backward countries; The per capita equity share of Britain and Japan was slightly lower than that of small developed countries; The situation in India was similar to that in China. The results show that, on the whole, the per capita share ratio of highly developed countries is much higher than that of backward countries and developing countries in the real economic equity allocation scheme oriented by economic interests.

4. Model evaluation

This study discusses the rational allocation of asteroid mineral resources. The characteristics of the study are as follows. The first is accuracy. All the data we used are from authoritative official websites, and we have made standard calculations. The second is comprehensiveness. We have comprehensively considered all aspects of the evaluation of the equity allocation scheme, including population, development, economy, science and technology, education and resources, etc., and scored reasonably according to the actual importance of different indicators in all aspects. The last is applicability. We use

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the latest data to build a model, and we can provide a reasonable and feasible allocation scheme by using our model to predict the future equity allocation.

However, research also has such limitations. No matter in the process of establishing the ideal equity allocation model or the real equity allocation model, it is full of subjectivity, which is mainly reflected in two aspects: determining the weight of factors and scoring the importance of indicators. The existence of subjectivity makes the model not objective enough, and different applications get different results. Therefore, the model can be optimized from these two aspects in the future, so as to provide a more reasonable and equity allocation scheme.

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