A Model for Measuring the Effect of Asteroid Mining on Global Equity

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Abstract. If space exploration has been realized in the future, mankind no longer needs to worry about safety and cost. However, how to obtain resources peacefully and fairly is a problem that mankind needs to think about. To solve this problem, this paper constructs a measurement model of global equity. Then, by identifying the unknown conditions, imagine and show the possible vision of the future of asteroid mining. The impact of asteroid mining on global equity is analyzed by using the global equity model.

Keywords: Space exploration, Peacefully and fairly, Model of global equity, Asteroid mining.

1. Introduction

The Outer Space Treaty known as the 'Space Constitution', provides the legal basis for programs that facilitate multinational access to space. The United Nations established the law for the purpose of promoting global peace and reduce inequalities, but whether this commitment to global equity continues as humanity seeks access to space resources is a thought-provoking question [1,2].

Now, assuming that space exploration has been realized in the future, mankind no longer needs to worry about safety and cost. In order to explore the impact of asteroid mining on global equity and better put forward policies, this paper first constructs a model to measure global equity. Validate the model with historical and regional data. Finally, by identifying the unknown conditions, imagine and show the possible vision of the future of asteroid mining. The impact of asteroid mining on global equity is measured through the global equity model.

2. Model of global equity

2.1. Gini coefficient

Global equity means that regardless of the current level of development, every country or region has the opportunity to participate in global activities in theory and share a reasonable proportion of profits in practice. In this paper, focus on the global equity in a narrow sense. That is the equity of human activities in space.

The Gini coefficient is calculated based on the size of the area enclosed by the Lorentz curve and the absolute average (Fig.1). The formula is:

$$G = A/(A + B) \tag{1}$$

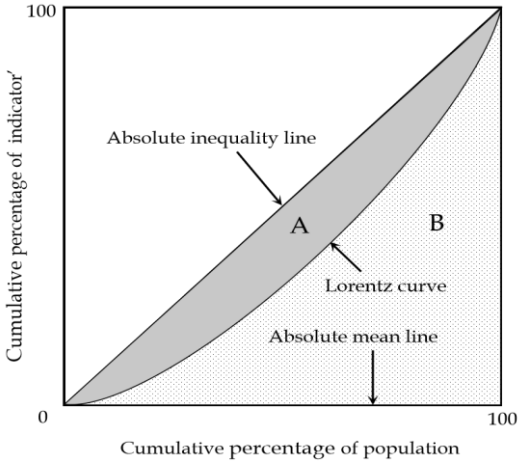

Figure. 1 Lorentz curve schematic

Gini coefficient reflects the difference of macroeconomic value distribution or the equality of a certain factor [3,4]. Its analysis is not limited by data distribution and sample size. It is useful for skew distribution data and small sample data. It can be used as an objective index to judge the fairness or consistency of resource allocation in a city and region. In recent years, Gini coefficient has been widely used in equity research in education, medical treatment, science and technology, transportation and other fields.

Therefore, the global equity of space activities is regarded as an issue of donation and resource allocation. On the one hand, how much capacity or resources does each country have to support satellite launches, moon landings, and even future mining activities. On the other hand, countries can distribute profits from space activities. Therefore, Gini coefficient is theoretically applicable to the research of this paper.

According to our definition of global equity, two dimensions of global equity are used as primary indicators, namely opportunity equity (OE) and output equity (OP).

Variable table related to Model of global equity is shown in Fig.2.

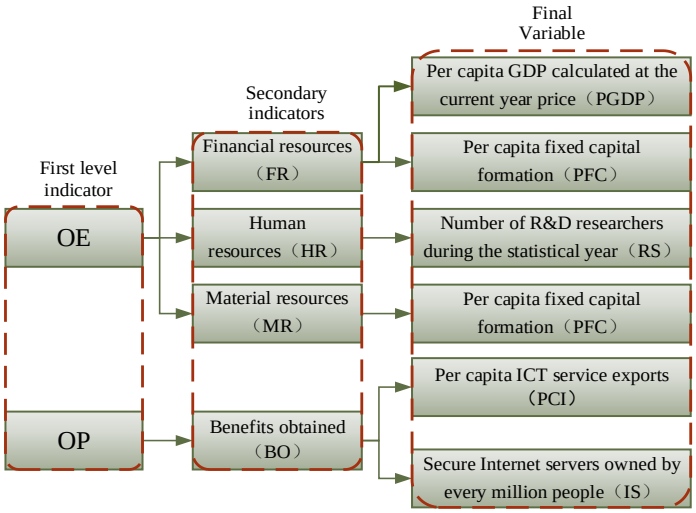

Figure. 2 Variable table related to Model of global equity

Adhering to the principle of scientific nature and rigor, we have selected the ten countries according to certain standards, including America, China, French, Canada, Germany, Britain, Serbia, South Africa, Russian, Egypt. Based on the availability of data, we set the study period to 2013-2018 [1].

Split the lorentz curve with the area enclosed by the X axis and the line X = 100% into several right-angle curved trapezoids, and then approximately calculate the area of each trapezoid to sum [5,6]:

$$S = \frac{1}{2}\sum_1^n (X_i - X_{i-1})(Y_i + Y_{i+1}) \quad (2)$$

Where *xi* is the cumulative percentage of the population sorted by per capita resource ownership, Yi is the cumulative percentage of the six indicators in Table1, that is, the coordinates of each point used to plot the Lorentz curve, so that the value of the Gini coefficient can be expressed as [3,4]:

$$G = (1 - 2S) = 1 - \sum_1^n (X_i - X_{i-1})(Y_i + Y_{i+1}) \quad (3)$$

After simplification, a more common Gini coefficient calculation formula can be obtained:

$$G = \sum_1^n (X_{i-1}Y_i - X_i Y_{i-1}) \quad (4)$$

The calculation results are shown in Table 1:

Table. 1 Gini coefficients of six indicators measuring global equity

Year	RS	PFC	FE	PGDP	PIC	IS
2013	0.31	0.468	0.275	0.395	0.507	0.593
2014	0.30	0.472	0.271	0.399	0.512	0.585
2015	0.418	0.416	0.260	0.301	0.516	0.566
2016	0.418	0.463	0.259	0.300	0.506	0.509
2017	0.418	0.462	0.264	0.308	0.498	0.469
2018	0.418	0.462	0.264	0.308	0.498	0.469

The RS curve fluctuated slightly at first and then began to rise after 14 years, and remained stable after reaching the peak. The PFC curve remained stationary as a whole and fluctuated in a small range. The FE curve stays fixed as a whole. The PGDP curve had a big decline in 2014-2015 and remained stable after reaching a low point. The PIC curve as a whole remains stable. The OVERALL IS curve shows a downward trend. Taking all the curves together, you can see that the world's equity situation is gradually improving (Fig. 3).

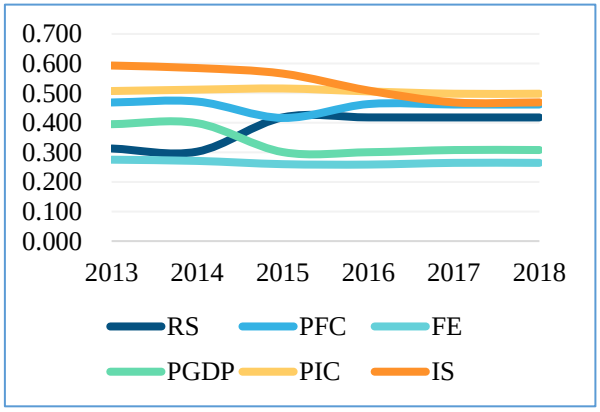

Figure. 3 Visualization of gini coefficients results

2.2. Theil index-based Measurement

According to the degree of economic development, the sample countries are divided into developed countries and developing countries. The Theil index is decomposed as follows [7].

$$T = T_W + T_B \quad (5)$$

$$T_W = \sum_{j=1}^2 \frac{X_j}{X} T_j \quad (6)$$

$$T_j = \sum_{i-1}^n \frac{X_{ji}}{X_j} \log\left(\frac{X_{ji}P_{ji}}{X_j P_j}\right) \quad (7)$$

$$T_B = \sum_{j=1}^2 \frac{X_j}{X} \log\left(\frac{X_j P}{X P_j}\right) \quad (8)$$

Table. 2 Theil index of six indicators measuring global equity

Year	RS	PFC	FE	PGDP	PIC	IS
2013	0.198	0.321	0.123	0.301	0.467	0.687
2014	0.187	0.330	0.119	0.311	0.466	0.662
2015	0.182	0.317	0.108	0.327	0.469	0.616
2016	0.179	0.324	0.107	0.331	0.453	0.529
2017	0.183	0.322	0.111	0.325	0.445	0.408
2018	0.183	0.322	0.111	0.325	0.445	0.408

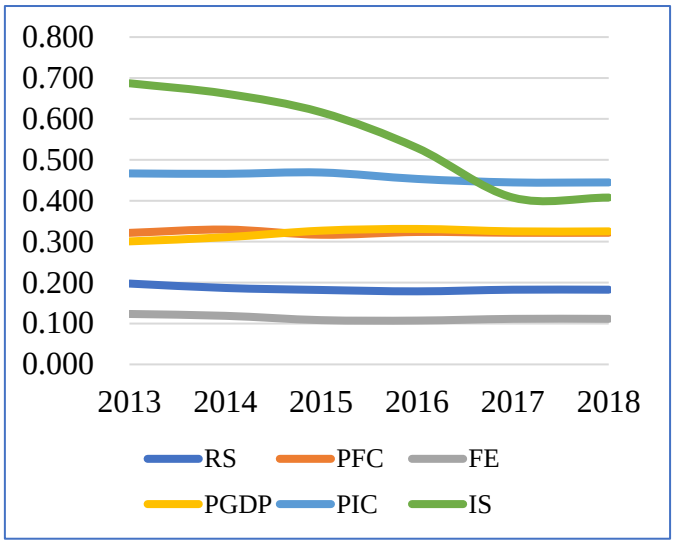

Figure. 4 Visualization of Theil index'results

RS curve remained unchanged as a whole, with slight downward fluctuation. The PFC curve remained unchanged as a whole, with slight downward fluctuation. The FE curve, the PGDP curve stays the same. The IS curve showed a downward trend as a whole, with a large decline in 13-17 years. Taking all the curves together, you can see that the world's equity situation is gradually improving (Table 2, Fig. 4).

Use TOPSIS [8] to verify the effectiveness of the conclusion. Use x_1, ..., x6 as PGDP, RS, FE, IS, PIC, PFC, the Theil index of per capita fixed capital in 2013-2018 are used as indicator variables to express evaluation. The evaluation object here is the World Equity Index from 2013 to 2018.

Through matlab modeling, the gap with the positive ideal solution is obtained (Table 3).

Table. 3 The gap with the positive ideal solution

1	2	3	4	5	6
0.8433	0.817	0.657	0.4161	0.1463	0.1463

It can be seen from the figure that since 2013, the gap between the world fairness indicator and the positive ideal solution has been shrinking, which means that the world fairness is constantly improving.

3. A vision of asteroid mining

3.1. System design

There are many similarities between the international seabed area and outer space. The international seabed area accounts for more than 65% of the marine area, contains rich mineral resources, and scientifically found that the content of manganese ore is about 2,000 billion to 3,000 billion tons, which has great development value, but the development technology is difficult.

Adopted at the final session of the Third United Nations Conference on the Law of the Sea in 1982, the United Nations Convention on the Law of the Sea (UNCLOS) has an important guiding and adjudicating role in territorial sovereignty disputes, the management of natural resources at sea, and pollution disposal throughout the world.

According to the rules of United Nations conferences and the practical experience of UNCLOS, the following three rules are established: parallel mining system, project voting system and differentiated profit distribution strategy (Fig. 5).

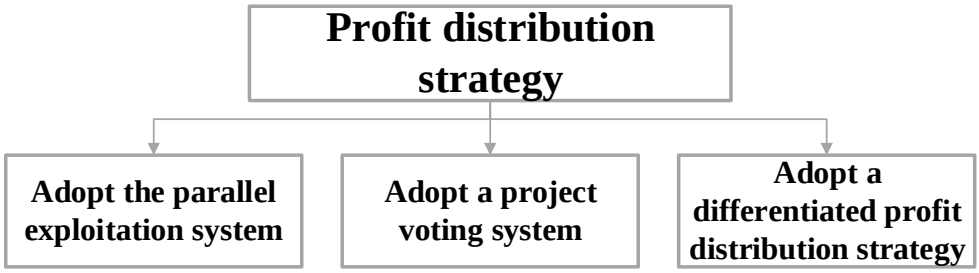

Figure. 5 Development rules[x]

3.2. Impact on global equity

3.2.1. Standards of global equity

Participating countries can invest in human, material, financial and other ways (Such as Fig. 2), but in order to better quantify, they are all expressed in monetary form (Fig. 6). The average investment of all investment projects in the country throughout the year is a reflection of a country's activity and comprehensive national strength. The average profit of all investment projects in the country for the whole year is a direct economic benefits of spcae mining.Although this value ignores the potential impact on society and the drive for other industries, it makes the calculation of the model more accurate.

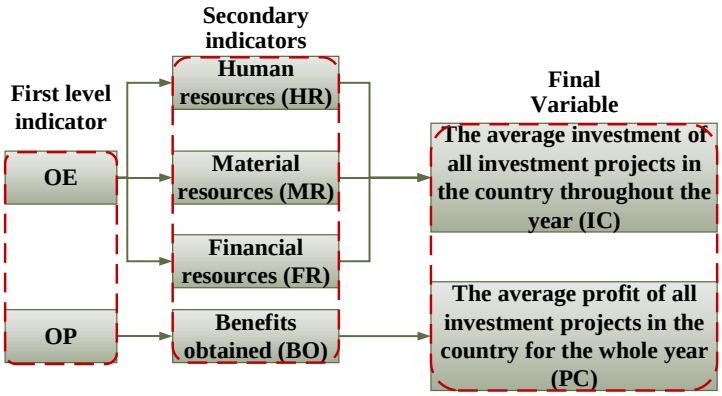

Figure. 6 Variable table related to Model of global equity

3.2.2. Scenario simulation

According to the rules and process assumptions (Fig. 5,6). There are 12 types of projects was got:

{state-sponsored, Whether exists countries in favor of the project but do not actually participate in the project (YES,NO), Result (earn, lost, breakdown)}

{ISA-sponsored, Forms of cooperation (Non-cooperative, Cooperative), Result (earn, lost, breakdown)}

A list of specific countries involved in space mining.

Assume that the ISA will pass 1200 mining projects over the next period of time. We set some values for 12 general scenarios by looking for real evidence, and then simulated each scenario 100 times through machine simulation, resulting in an average input and final return for each country and authority. The specific settings are as follows：

Assume that ten countries are the first to sign the ISA contract and will jointly conduct space prospecting for some time to come, including America, China, French, Canada, Germany, Britain, Serbia, South Africa, Russian, Egypt.

According to the classification of the degree of economic development, countries can be divided into developed countries and developing countries, respectively {America, French, Canada, Germany, Britain} and {China, Serbia, South Africa, Russian, Egypt.}

We assume that the countries that will independently conduct outer space prospecting for some time to come are the countries with lunar landing capabilities in the world today, that is America, China and Russian.

So, according to whether it has the ability to land on the moon, it can be divided into {America, China and Russian} and {French, Canada, Germany, Britain, Serbia, South Africa, Egypt.}

The amount of gained minerals, the market price of space minerals, total revenue of the project and total cost of the project.

Assume that whether a project is profitable or loss-making depends on the amount of minerals obtained from mining.

A metal-rich asteroid with a diameter of 10 meters has a net weight of about 10,000 tons, and platinum is rich in abundance of about one thousandth to one percent, and if it is one percent, it is 100 tons of platinum. Based on the current market price of about $30,000/kg, the total market value of 100 tons of platinum contained in an asteroid will exceed 20 billion yuan. In addition to platinum, the cobalt, rhodium and iridium precious metals associated with asteroids also have great commercial value.

Assume that there is only one rare metal in space. We call it "universal metal", which combines the properties of most precious metals and is priced according to the market. Then we assume that there are three cases of space ore mining: 1 ton, 10 tons, 100 tons, and the price is about three times that of the most precious metal at present, that is, $100,000 per kilogram, and the mining cost is uniformly $10 billion.

Resolution status (only for state-sponsored projects): number of votes in favour, against and abstentions, and the proportion of contributions of each subject.

For {state-sponsored, whether exists countries in favor of the project but do not actually participate in the project (NO), Result (earn, lost, breakdown)}, we assume that 5 states voted in favour, 3 against and 2 abstained. The contribution value of all countries is distributed according to the proportion of GDP of the five countries combined. Only one country with the ability to conduct space prospecting on its own is actually involved in each project, which means that only one country in the United States, China, and Russia is actually involved in one project.

For {state-sponsored, whether exists countries in favor of the project but do not actually participate in the project (YES), Result (earn, lost, breakdown)}. Assume that 7 states voted in favour, 2 against and 1 abstained. Countries that voted in favour but do not actually participate in the project are rewarded or incur losses at 1%.

For {ISA-sponsored, Forms of cooperation (Cooperative), Result (earn, lost, breakdown)}.

Assume that the ISA will choose to work with three developing countries. To control profitability and risk, the ISA contributes 80 percent, with the remaining countries allocated as a share of their GDP as a share of the GDP of the three countries combined.

The Monte Carlo method [9,10] is a stochastic simulation method based on methods of probability and statistical theory. It relates the solved problem to a certain probability model, and uses an electronic computer to achieve statistical simulation or sampling to obtain an approximate solution to the problem.

Here are two feedback tables from machine simulations (Table 4,5).

Table. 4 Simulated tables of the fifth type of projext

Project 005	Name	Result
	Taurus Plan	Earned
Proponents	Investment (%)	Profits (BOU)
America	79.60%	-7.090
Britain	11.20%	-0.998
Canada	6.65%	-0.593
Egypt	1.00%	-0.891
South Africa	1.55%	-0.138
China	0%	-0.9,00
Russian	0%	-0.9,00
Total	100%	-9.000
Amount(ton)	Price (BOU/kg)	Fees payable (BOU)
1	100,000	0

Table. 5 Simulated tables of the tenth type of projext

Project 010	Name	Result
	Capricom Plan	Earned
Proponents	Investment (%)	Profits (BOU)
ISA	80%	7.200
South Africa	3.83%	0.345
Russian	16%	1.412
Serbia	0.49%	0.044
Total	100%	9.000
Amount(ton)	Price (BOU/kg)	Value (BOU)
100	100,000	10

Through computer simulation, get the average cost and benefit of each country on all projects (Table 6,7).

Table. 6 Ten countries' average investment of all projects (million dollars)

America	China	Russian	French	Germany
15579.0	18845.6	5859.0	6593.0	8858.0
Canada	Britain	Serbia	South Africa	Egypt
4119.0	6922.0	226.4	1349.2	1392.0

Table. 7 Ten countries' average profits of all projects (million dollars)

America	China	Russian	French	Germany
40,779.00	42,792.12	14,127.66	10,806.30	21,232.80
Canada	Britain	Serbia	South Africa	Egypt
8,211.60	13,969.80	476.82	2,897.28	3,084.12

Calculate per capita project input and per capita project expenditure for each country, and calculate the Gini coefficient separately, and obtain the following results (Table 8,9).

Table. 8 Ten countries' Gini coefficient

	Per capita investment	Per capita income
America	0.210	12.477
French	0.744	3.051
Germany	0.247	9.778
Canada	0.102	16.104
Britain	0.094	25.611
China	0.090	22.154
Serbia	0.096	21.020
South Africa	0.308	6.829
Russian	0.428	5.013
Egypt	0.707	3.134
Gini Coefficient	0.413	0.357

According to the relevant provisions of the United Nations, if the Gini coefficient exceeds 0.4, it indicates that the income gap is too large. In the figure, the Gini coefficient of per capita cost is 0.413, which means that some countries may be under excessive cost pressure. The Gini coefficient of per capita income is 0.357, which is within a reasonable range, but there is still room to improve equity (Table 9).

The main variables in Table 9 are as: Breakdown of per capita input gap (BG); Contribution rate of developing countries (CC); Contribution rate between regions (CR); Breakdown of per capita input gap (BIG); Breakdown of the per capita net profit gap (BRG).

Table. 9 Ten countries' Gini coefficient

	BIG	BRG
BG	0.238	0.279
CC	0.217	0.165
CR	0.545	0.556

Theil index mainly comes from the gap between regions, and the gap within regions is small. In addition, the contribution degrees of developing countries and developed countries within the region are relatively close and small, indicating that the internal gap between developing countries and developed countries is small, and the larger gap comes from the gap between developing countries and developed countries.

3.3. Strengths and weaknesses

The application of Gini and Thiel coefficients which are commonly used to calculate income equity to global equity measurement and space resource allocation is innovative and reflects the integration of different disciplines.

Although we refer to a lot of literature for the selection of indicators, considering the availability of data and other factors, the selection of indicators is still subjective, and the indicators selected are not comprehensive enough.

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