ISSN 2616-5872 Vol.4, Issue 3: 38-44, DOI: 10.25236/AJEE.2022.040308

Analysis of the Impact of Asteroid Mining on Equality

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Abstract: *To study the impact of asteroid mining on equality, we need to measure the global equity, so we developed the NRI (National Resources Index) model, with 18 secondary indicators and 6 primary indicators to measure the NRI for 17 sample countries. We simulated the complete process of asteroid mining and combine linear programming models and Monte Carlo methods to simulate the development and profitability of each country over the next 100 years. we built the AMP (Asteroid Mining Profit) model. Then we took into account the devaluation of minerals. By using the Fisher equation to quantify the gold price changes.*

Keywords: *Asteroid Mining; Global Equity; Policy; EWM; Monte Carlo Methods*

1. Introduction

In the wave of globalization, the United Nations (UN) advocates for the promotion of global peace and the reduction of inequalities in order to promote the development of countries around the globe. However, at present, countries around the world pay more attention to equity at the domestic level and do not have a specific and complete evaluation system for global equity. Therefore, the development of an indicator evaluation model to evaluate the global equity situation is essential for equitable global development. Asteroid mining belongs to the exploitation of space resources. According to NASA and leading scientific institutions, asteroids are abundant in water resources, metal resources (e.g., iron, cobalt, nickel), carbonaceous compounds, etc. Once asteroid mining becomes practical and widespread, it will affect the resource systems of all nations. The change in resource systems will have some degree of impact on global equity.

In this paper, we used the TOPSIS method based on the AHP model to measure the natural resource index (NRI) of the selected sample countries. According to the obtained NRI, we solve for the Gini index and Thiel index. We combine the linear programming model and Monte Carlo method to fit to get the development and profit of countries in asteroid mining. We substitute the obtained profit as a new indicator into the model we developed in our 1st question, getting a table of the global Gini index changes over time.

2. Establish Global Equity Evaluation Model

We define NRI as a measure of nation resources index and develop a model to evaluate the NRI of any country which can quantify the index. With this model, we get NRI for different countries. Then we can use this data for further processing to measure global equity.

2.1. Discussion of Indicators

A country's resource system is a combination of multiple subjects. An excellent resource system means that the country has developed technology, excellent education, advanced medical care, abundant natural environmental resources, and a powerful economy. Meanwhile, the country's assistance to other countries will allow redistribution of domestic resources to other countries. To that end, we believe that NRI requires the consideration of these six indicators: technological resources, educational resources, medical resources, natural environment resources, financial resources and resources assistance to others. For a comprehensive measure of countries' NRI, six Level 1 indicators are given. A specific assemblage S is given for them:

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$$S = \{TR, ER, MR, NER, FR, RAO\} \tag{1}$$

Where TR, ER, MR, NER, FR, RAO represent Technological Resources, Educational Resources, Medical Resources, Natural Environment Resources, Financial Resources, Resources Assistance to Others.

There are several level 2 indicators under each level 1 indicator. Our NRI evaluation model considers 6 level 1 and 18 level 2 indicators, as shown in Figure 2. The determination of the weights will be discussed later. These indicators measure the NRI.

We are going to introduce the level 1 indicators and normalize all the indicators to the same pattern. After that, we will adopt a combination weighting method. to determine the weights of each indicator. The model is based on six level 1 indicators, which are determined by level 2 indicators.

2.2. Normalization of Level 2 Indicators

We normalize the level 2 indicators into the range [0,1]. Meanwhile, all of these level 2 indicators should be converted into positive indicators, which means that the larger the indicator, the greater the contribution to the level 1 indicator. Depending on the characteristics of the different indicators, we adopt the following methods in total for normalization, including the maximum normalization method, polar transformation method and minimum normalization method. We are going to show the applications of each method we use.

The specific normalization formula is as follows.

$$x' = \frac{x}{x_{max}} \tag{2}$$

Where x' is the normalized indicator; x is the original indicator; x_{max} is the maximum of the indicator.

i. For positive indicators, the specific normalization formula is as follows.

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}} \tag{3}$$

Where x_{min} is the minimum of the indicator.

The method is applied to those positive indicators, such as high-tech exports (% of manufacturing exports).

ii. For negative indicators, the specific normalization formula is as follows.

$$x' = \frac{x_{max} - x}{x_{max} - x_{min}} \tag{4}$$

The method is applied to those negative indicators, such as infant mortality rate (per 1,000 live births). The lower the indicator is, the better the situation is.

The specific normalization formula is as follows.

$$x' = \frac{|x - x_{op}|}{\max\{|x_{max} - x_{op}|, |x_{min} - x_{op}|\}} \tag{5}$$

Where x_{op} is the optimal value of the indicator.

The method is applied to those cost-type indicators, such as total unemployment. The indicator value is not larger or smaller, but an optimal value exists.

With these approaches mentioned above, we obtained all the indicators after normalization. We list the normalized data as a Y matrix.

2.3. Determination of the Weights for Indicators

To make our model more accurate, we used a combination weighting method. The combination

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weighting method we chose consists of Entropy Weight Method (EWM), Analytic Hierarchy Process (AHP), Coefficient of Variation Method (CVM). AHP is a subjective method of determining weights. EWM and CVM are two objective methods of determining weights. The combination of these three methods can effectively reduce the error of the results as well as improve the efficiency. We will discuss these three methods in detail.

The final results of the calculation are shown in Table 1.

Table 1: Wight of indicators

Objective function	Level 1	Wight of Level 1	Level 2	Wight of Level 2
NRI	TR	0.3923	T1	0.092
			T2	0.312
			T3	0.492
			T4	0.104
	ER	0.1066	E1	0.231
			E2	0.256
			E3	0.513
	MR	0.0835	M1	0.602
			M2	0.398
	NER	0.0819	N1	0.186
			N2	0.102
			N3	0.514
			N4	0.198
	FR	0.1943	F1	0.242
			F2	0.271
			F3	0.487
	REO	0.1413	R1	0.824
			R2	0.176

2.4. Calculate the NRI using TOPSIS

We selected 17 typical countries to represent the overall global condition by calculating the NRI score of these countries. Specifically, we use TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) to calculate the NRI score for these countries. The higher the score, the richer the country's resources are.

The results of NRI scores for these countries are shown in table 2.

Table 2: NRI for Countries

Country	NRI Score	Country	NRI Score	Country	NRI Score
U.S.	0.9428	Croatia	0.3449	Egypt	0.1914
Japan	0.6191	Costa Rica	0.3265	Myanmar	0.1700
U.K.	0.5459	Brazil	0.3012	Tanzania	0.1607
China	0.4879	Kazakhstan	0.2966	Gambia	0.1246
Estonia	0.4303	Turkey	0.2599	Yemen	0.0419
Russia	0.3913	Guatemala	0.2141		

3. Asteroid Mining Profit Model（AMP）

3.1. Determination of TI and AMT

In the future, asteroid mining is bound to become possible. The impact of this industry on the world will not be ignored. The development of the asteroid mining industry will be different for different countries. We will discuss this industry and its impact on global equity in more detail. And we still use the 17 countries selected above as our sample to explore.

For a country, the annual profit from asteroid mining is shown as the following formula.

$$\mathrm{AMP} = \mathrm{AMT} \times (\mathrm{SMI} - \mathrm{SMC})$$

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Where AMP is annual mining profit from asteroid mining of a country, AMT is annual mining times, SMI is single mining income of asteroid mining, SMC is single mining costs of asteroid mining. In order to get the value of AMP, we must get the values of AMT, SMI and SMC.

We introduce an important indicator, technology index (TI), which reflects the strength of a country's technology. The larger the TI, the better the country's technological development. This index is closely related to our other parameters.

As a country progresses over time, its technology index (TI) [9] will increase. We define a growth index (GI) to reflect this change. Meanwhile, we take the present time as base and then define the present TI as the base-Tech index (BTI). Moreover, since the progress of technology development will vary from country to country, we introduce a modified coefficient (MC) to modify the model. Then the TI of ith country can be shown by the following formula.

$$TI_i = BTI_i \times GI \times MC_i \tag{6}$$

Where subscript i represents the data of the ith country. We will discuss it in detail.

i. Discussion of BTI

Since we investigate asteroid mining, the BTI can be considered to be determined by space technology (ST) and technological resources (TR) as follows.

$$BTI = 0.6 \times ST + 0.4 \times TR \tag{7}$$

Where we have obtained the TR score from the NRI model. For the indicator ST, we use the data found in the literatures and websites [4] and take the TOPSIS we have used to determine. Due to space limitations, we will not show this process in detail again.

The final BTI of each country are shown in table 3.

Table 3: BTI for Countries

Country	**BTI Score**	**Country**	**BTI Score**	**Country**	**BTI Score**
U.S.	0.9428	Croatia	0.3449	Egypt	0.1914
Japan	0.8742	Costa Rica	0.3265	Myanmar	0.1500
U.K.	0.8340	Brazil	0.3012	Tanzania	0.1207
China	0.8210	Kazakhstan	0.2966	Gambia	0.1046
Estonia	0.7430	Turkey	0.2599		

3.2. Solution of the model

Monte Carlo method is a numerical calculation method guided by the statistical theory of probability.

Linear programming model is one of the most widely used methods in operations research for solving optimization problems in resource allocation.

We combine the above two methods for a combination model to solve the AMP model. The model simulates the mining activities of 17 countries for each of the next 100 years to determine the cumulative benefit for each country. Also, it is assumed that in each mining mission, each country automatically judges and travels to the mining field with the greatest benefit. The model are as follows.

$$Z = \max\left(AMP_j\right) \; j = 1,2,3 \tag{8}$$

$$S.T.\begin{cases} SMI_j - SMC_j > 0, \;\; j = 1,2,3 \\ AP_j = AMT \times \left(SMI_j - SMC_j\right), \;\; j = 1,2,3 \end{cases} \tag{9}$$

Where Z is profit, subscript j represents jth mineral field.

We used matlab to simulate asteroid mining in the selected 17 countries. The simulation results for 100 years are as follows.

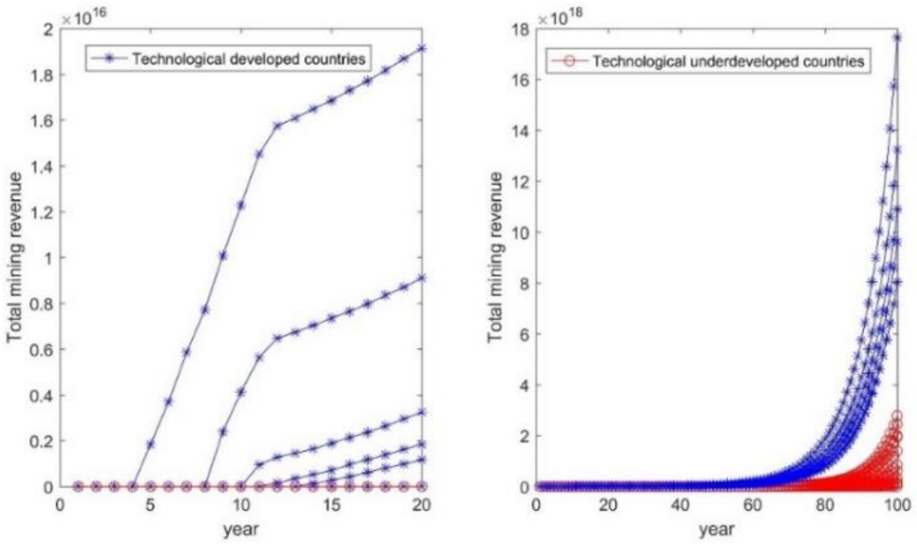

Figure 1: Total mining revenue on time

3.3. Based on AMP to Explore the Impact on NRI

Asteroid mining brings economic benefits as well as significant natural environmental resources. Therefore, we assume that asteroid mining mainly affects FR and NER in the NRI model. We add the total mining revenue index (TMRI) as level 2 indicators to the FR and NER. Meanwhile, we consider the weight of TMRI in FR to be 0.8 and the weight of the original sum of all level 2 indicators to be 0.2. Similarly, we consider the weight of TMRI in NER to be 0.5 and the weight of the original sum of all level 2 indicators to be 0.5. Based on these, we made adjustments to these two parts of the NRI model. We substitute the adjusted model into our TOPSIS to get the corresponding results. We select some NRI data listed in the following table.

Table 4: NRI for countries

County	**NRI score**					
	now	**10 years later**	**20 years later**	**30 years later**	**50 years later**	**100 years later**
U.S.	0.9428	0.8009	0.7947	0.7906	0.7798	0.7737
China	0.4879	0.4413	0.5100	0.5300	0.5614	0.5643
Estonia	0.4303	0.2435	0.2482	0.2604	0.2995	0.3387
Guatemala	0.2141	0.1289	0.1304	0.1312	0.1334	0.1411
Gambia	0.1246	0.0661	0.0668	0.0673	0.0686	0.0703
Yemen	0.0419	0.0310	0.0321	0.0327	0.0345	0.0355

3.4. Impact on Global Equity

Based on the data of 17 countries, we solve to obtain the global Gini index as shown in table 5.

Table 5: Global Gini index

Gini index					
now	10 years later	20 years later	30years later	50 years later	100 years later
0.2898	0.3806	0.3923	0.4026	0.4132	0.4072

We will come to the following conclusions.

In the future, without policy intervention, global inequities will increase for decades under the influence of the asteroid mining. And we can expect this dramatic global inequity will continue for centuries

4. Discussion on the conditions for asteroid mining

In the second model, we ignore the devaluation of metals. When there is a large quantity of mineral resources from space coming to Earth, devaluation will be inevitable. Therefore we will develop a model to consider the devaluation of metals. Based on the conclusions brought by this model, we explore the global equity implications of some changes in conditions regarding asteroid mining. We will discuss these in detail.

4.1. Principles of the model

The famous Fisher equation describes the basic principle of devaluation.

$$MV = PT \tag{10}$$

Where M is the average quantity of currency, V is the average number of turnover of currency, P is the price of the commodity, T is the number of transactions of the commodity. V and T can be considered as constants, then M and P are proportional. That is, when the quantity of currency increases, the corresponding price P also increases, thus triggering inflation. The specific rate of currency devaluation is given by the following formula.

$$Currency\ devaluation\ rate = \frac{Currency\ Issuance - Amount\ of\ currency\ needed}{Currency\ Issuance} \tag{11}$$

Based on this formula, we can obtain the formula for the metal depreciation rate as follows.

$$Metal\ devaluation\ rate = \frac{Metal\ Issuance - Amount\ of\ metal\ needed}{Metal\ Issuance} \tag{12}$$

4.2. Solution of the model

We continue to use the Monte Carlo method to calculate the relationship between the year of mining and the price of the metal. We use the demand and supply of gold for the decade 2011-2021 as our basis. The current price of gold is chosen to be the average price in February 2022. We will analyze how the price of gold and the gold devaluation rate will change over the next 100 years as asteroid mining proceeds.

We consider gold supply to be the sum of existing supply and asteroid mining. The demand for gold is the global average demand. By reviewing the literature, we obtained that the percentage of gold in asteroids is about 0.5 ppm.

The results of the simulation are shown Figure 10.

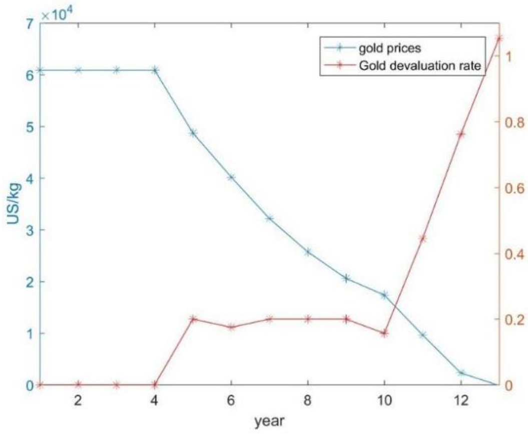

Figure 2: The trend of gold prices

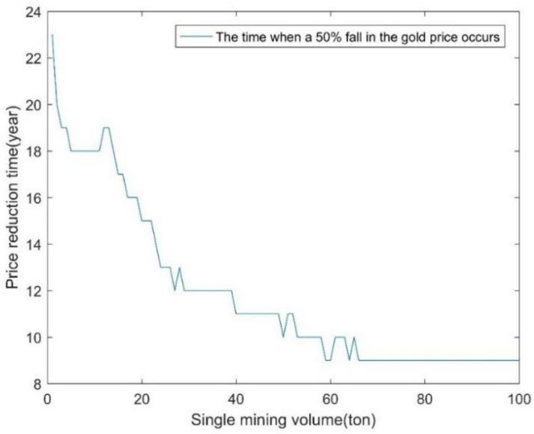

Figure 3: The relationship between the time it takes for gold to fall to the warning line and the volume of a single mine

Additionally, we simulated the production volume M from 1 ton to 100 tons per time and calculated the corresponding depreciation rate. With the gold price falling to 50% of the original price as a cautionary line, the time required for the gold price to fall to 50% of the original price was calculated for each mining volume.

ISSN 2616-5872 Vol.4, Issue 3: 38-44, DOI: 10.25236/AJEE.2022.040308

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