2022
Problem Chosen | MCM/ICM | Team Control No.
F | Summary Sheet | 2221793

Summary

Global equity is a concept that has been discussed for years and is part of the discussion when talking about introducing asteroid mining. Global equity is defined to be equal access and opportunity to the global market place for all countries. The way we measure global equity is through multiple indicators from 4 main factors: Political, Economic, Social, and Technological. We selected raw data for these factors from twenty indicators of forty countries from 2019. Then we inspect each variable in order to create a framework of evaluating global equal through a designed response variable. As a result of making a model with these factors, we concluded that there were 5 most important indicators that could measure global equity: **Gross Domestic Product (GDP), Stock Market Capitalization, Research Development (R&D) expenditure, Population size, and Economic Globalization Index.**

But when we introduce **asteroid mining** into the future, we have to think about how it affects global equity and in what ways can we implement policies to promote more global equity. Though we may not be able to control asteroid mining without policies put in place, we concluded that adding in an indicator that represents asteroid mining would affect the global equity indicator as it affects the 5 indicators that represented global equity.

The most significant aspect of the asteroid mining sector and space missions is the impact that they will have on Earth's environment. And the best way to approach the eminent threat of Global Warming is to propose a **Cap-and-Trade System** on a global scale. The goal of this policy is to steadily reduce carbon dioxide and other greenhouse gas emissions by allowing the market to determine a price on carbon, and that price drives investment decision and eventually spurs market innovation enhancing global equity.

Finally, we discussed the strengths and weaknesses of our model, allowing for ideas of further studies.

Keywords: GDP, Structural Equation Model, Linear Regression Model, International Bureau of Space Overwatch, Cap-and-Trade System

Table of Contents

1 Introduction

1.1 Background

The United Nations' Outer Space Treaty of 1967[1] was signed by most of the world in efforts that space exploration would be "carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind".[1] The treaty was created to allow for projects that needed access to space at an international approach such as the International Space Station. The United Nations (UN) is an international organization that aims to increase economic and political cooperation between its countries and to minimize global inequities. But if space exploration turns into an economic opportunity, would the world lose the purpose of the treaty?

The idea of extracting valuable minerals and materials from asteroids can be an economic opportunity that might impact global equity. Asteroid mining is a topic that has been questioned with conversations about space exploration. Is it possible? Would the benefits outweigh the costs? Should this be controlled by private companies, governments, or international organizations? How would the world fund this venture? The questions have not been answered but will be explored throughout our analysis.

1.2 Restatement of problem

Our team will be addressing the following questions:

1. What is global equity, and how might we measure it?
2. What might asteroid mining look like in the future, and how might asteroid mining impact global equity?
3. How do changes in the conditions that we've selected in defining a vision for the future of asteroid mining impact global equity?
4. What policies could be implemented to encourage the asteroid mining sector to advance in a way that promotes more global equity?

In order to address these questions, we will create a model encompassing global equity, analyze if and how factors of space exploration could affect our model, and then explain what ways we could affect our model to promote more global equity. We

[1]The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies, of 27 January 1967, United Nations RES 2222 (XXI).

will also talk about policies that can be put into place to allow for global equity to thrive in a future with asteroid mining.

2 Assumptions

2.1 General Assumptions

1. Assume that all data collected is reliable and accurate. The data that we collected was from statistic websites such as the Global Economy[2] and Our World in Data[3].
2. Assume that asteroid mining is feasible at some point in the future and could allow humans to bring valuable minerals back to Earth relatively safely and at a cost that is financially worth the investment.
3. Assume that the indicators we chose for our main factors are a great representation of the main factors.
4. Assume the global equity can be measured by our main factors.
5. Assume that all parameters outside of our indicators remain constant.

2.2 Symbol explanation

Symbol	Meaning
GDP	Gross Domestic Product
UMR	Unemployment rate
ROL	Rule of Law index
VAI	Voice and Accountability index
PSI	Political Stability index
PRI	Political Rights index
CLI	Civil Rights index
OP	Oil Production
SMC	Stock Market Capitalization
II	Innovations index
RDE	Research and Development Expenditure
HTE	High Technology exports
PA	Patent applicants
PS	Population size
HSPC	Health spending per capita
GI	Gini income
PSOE	Public spending on education
EGI	Economic Globalization Index
PGI	Political Globalization Index
SGI	Social Globalization Index
Level	Global Equity

3 Main factors and Data Selection

3.1 Main Factors

In order to measure global equity, we need to define what global equity is. Global equity can be defined as equal opportunity and equal access to the global market place. The way we thought about measuring global equity is taking into account 4 main factors: Political, Economic, Social, and Technological measures. We wanted to have a great representation of each main factor, so each main factor consists of 5 metrics that relates to its categorization.

3.1.1 Political

The political factor takes political indicators to represent the political structure and environment of a country. The political indicators consist of political stability index, political rights index, voice and accountability index, rule of law index, and political globalization.

Political stability index - likelihood that government will be overthrown by violent means, including politically-motivated violence and terrorism.
Political rights index - evaluates electoral process, electoral voting system and participation, and the functioning of government.
Voice and accountability index - the extent at which citizens are able to participate in selecting their government, freedom of expression, and free media.
Rule of law index - the extent at which citizens have confidence in and abide by the rules of society, and the quality of enforcement, property rights, the police, and the courts.
Political globalization - the number of embassies in a country, the number of international organizations, the number of UN peace missions a country participated in, and the number of treaties signed between two or more states.

3.1.2 Economic

The economic factor takes economic indicators to represent how good a country is doing economically and if their economy is thriving. The economic indicators consist of GDP, unemployment rate, stock market capitalization, gini income inequality index, and economic globalization index.

Gross Domestic Product (GDP) - the sum of gross value added by all producers in the economy plus any product taxes and minus any subsidies not included in the value of the products.

Unemployment rate - the portion of labor force that is without work but available for and seeking employment.
Stock Market Capitalization - the share price times the number of shares outstanding for listed domestic countries.
Gini income inequality index - the extent to which the distribution of income among individuals or households within an economy deviates from a perfectly equal distribution.
Economic globalization index - includes actual economic flows and restrictions to trade and capital. Actual economic flows explains the data on trade, FDI, and portfolio investment. Restrictions to trade ans capital explains hidden import barriers, mean tariff rates, taxes on international trade, and an index of capital controls.

3.1.3 Social

The social factor takes the social indicators to represent the social environment and interests of a country to expand their knowledge of cultures. The social indicators consist of population size, health spending, education spending, civil liberties index, and social globalization.

Population size - Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship.
Civil Liberties Index - freedom of expression and belief, associational and organizational rights, rule of law, and personal autonomy and individual rights.
Social Globalization index - A three dimensional metric determined by: personal contacts, information flows, and cultural proximity. Personal contacts includes international telecom traffic, foreign population, etc.Information flows includes number of internet users, share of households with a television set, etc. Cultural proximity includes trade in books and number of McDonald's restaurants.
Health Spending per capita - Estimates of current health expenditures include healthcare goods and services consumed during each year.
Education spending - government expenditure on education (current, capital, and transfers).

3.1.4 Technological

The technological factor takes technological indicators to represent how advanced or developed a country is with their innovations and technology. The technological indicators consist of innovations index, research and development spending, high technology exports, patent applications, and oil production.

Innovations index - based on seven pillars (Institutions, Human Capital and Re-

search, Infrastructure, Market sophistication, Business sophistication, Knowledge, and Technology outputs and creative outputs), these pillars are divided into sub-pillars which consist of individual indicators

Research and development spending - includes both capital and current expenditures in the four main sectors: Business enterprise, Government, Higher Education, and Private non-profit, this also covers basic research, applied research, and experimental development.

High Technology exports - products that need research and development, such as aerospace, computers, scientific instrument, and electrical machinery.

Patent applications - filed through the Patent Cooperation Treaty procedure, for a product that provides a new way of doing something or offers a new technical solution to a problem.

Oil production - oil produced by a country

3.2 Data Selection

When looking at the indicators to use for the factors, we also wanted to distinguish what countries we were going use and what year of data that is sufficient and relevant. We decided to include the countries that had a statistic for every indicator between the years 2010-2019 and took their most recent statistic. This resulted in our sample size of countries to finalize at 40 countries. This allowed our data to be complete without missing values and thus we could use our model on our data.[2]

Table 2. 40 Countries Selected (in alphabetical order)

Country	Abb.	Country	Abb.	Country	Abb.	Country	Abb.
Algeria	ALGR	Mexico	MEX	Poland	POL	Sri Lanka	LKA
Australia	AUS	Morocco	MAR	Portugal	PRT	Switzerland	CHE
Austria	AUT	Namibia	NAM	Romania	ROU	Thailand	THA
Belarus	BLR	Nepal	NPL	Russia	RUS	Tunisia	TUN
Belgium	BEL	Netherlands	NLD	Rwanda	RWA	Turkey	TUR
Brazil	BRA	Norway	NOR	Serbia	SRB	Ukraine	UKR
Luxembourg	LUX	Pakistan	PAK	Slovakia	SVK	United Arab Emirates	ARE
Malaysia	MYS	Panama	PAN	Slovenia	SVN	United Kingdom	GBR
Malta	MLT	Peru	PER	South Korea	KOR	United States	USA
Mauritius	MUS	Philippines	PHL	Spain	ESP	Vietnam	VNM

[2] "Download Data: GDP Growth, Inflation, and Other Indicators." TheGlobalEconomy.com, https://www.theglobaleconomy.com/download-data.php.

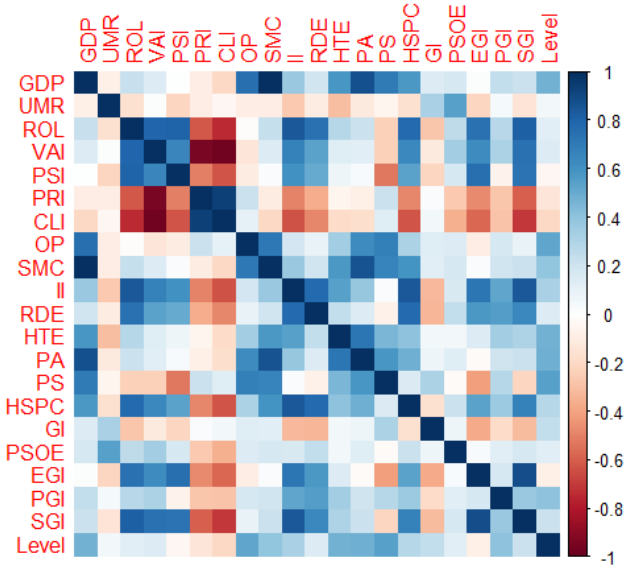
Table 3. Indicators for Main Factors

Factor	Indicator	Symbol	Unit
Political	Political stability index	F_{P1}	(-2.5 weak, 2.5 strong)
	Political rights index	F_{P2}	(7 weak, 1 strong)
	Voice and accountability index	F_{P3}	(-2.5 weak, 2.5 strong)
	Rule of law index	F_{P4}	(-2.5 weak, 2.5 strong)
	Political globalization	F_{P5}	(0-100)
Economic	Gross Domestic Product (GDP)	F_{E1}	billion USD
	Unemployment rate	F_{E2}	% of Population
	Stock Market Capitalization	F_{E3}	billion USD
	Gini income inequality index	F_{E4}	(0 equality, 100 inequality)
	Economic globalization	F_{E5}	(0-100)
Social	Population size	F_{S1}	in millions
	Social globalization	F_{S2}	(0-100)
	Civil liberties index	F_{S3}	(7 weak, 1 strong)
	Health spending per capita	F_{S4}	USD
	Education spending	F_{S5}	% of GDP
Technological	Innovations index	F_{T1}	(0-100)
	Research and Development spending (R&D)	F_{T2}	% of GDP
	High Technology exports	F_{T3}	USD
	Patent applications	F_{T4}	# of Population
	Oil production	F_{T5}	thousand barrels per day
Global Equity	Level (created indicator)	GE	(0 low, 1 high)

4 Model Construction

In this section, we entered in initial data processing and visualizing stage where we looked at all the variables collected by examining the correlations of one another. From there, we built up the global equity model by interpreting the relationship between some of the independent variables and the response variable (Level). We were able to run factor analysis and make a diagnosis of the structural equation model of each country. The initial process can be described with the following graph.

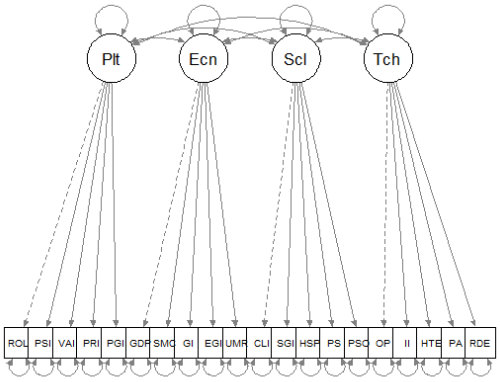
Figure 1. Corrplot of all indicators



4.1 Determine the adequacy of indicators

The main method we used to determine the weight was the Kaiser–Meyer–Olkin test. We analyzed the independent variables and discovered that three variables needed to be reduced based on the threshold value of 0.5 for the Measure of Sampling Adequacy (MSA). With those three variables deduced from our dataset, two multivariate normality tests were performed to check if there was any outstanding skewness or kurtosis.

Figure 2. Model 1 (Original Model)



4.2 Formation of Structural Equation Model

After our data set has been modified, we proceeded to structural Equation Modeling (SEM) method to construct inner-workings of maintained predicting variables, as shown in Figure 2. However, According to the output gathered from the model, we found that a response variable is desired to hypothesize how global equity is defined and what matrix it is measured in.

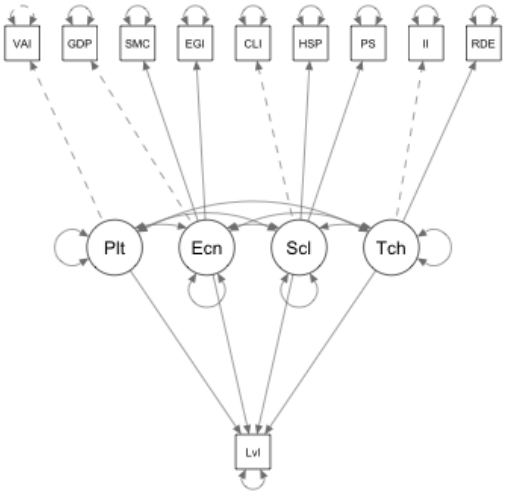
4.3 Application of Step-wise Linear Regression Model

Due to the absence of response variable, we introduced "Level" as a substitution to uncover how global equity can be evaluated where "1" represents the country whose **Gross Domestic Production (GDP)** value is above the average **GDP** of all countries' **GDP** combined and "0" represents the country whose **GDP** is below the average. Step-wise Linear Regression Modeling (LRM) method was used when establishing the most preferred function of Level. A total of nine predicting variables were selected to form our function in which five of them have significant P-values that are considered to be the most influential indicators to measure global equity.

4.4 Modification of Structural Equation Model

After finalizing the LRM function, we renovated the SEM model with nine suggested predicting variables that gives a better representation of what framework we recommend to use for global equity in Figure 3.

Figure 3. Model 2 (Finalized Model)



5 Asteroid Mining and Equity Initiatives

With Earth's population growing at a rapid pace, the strain on our planet's resources continues to grow. And although ecologists project that we have not reached the tipping point, the Earth has a finite amount of resources. So without a doubt there will need to be a plan developed in order to sustain humanity for hundreds of years to come. And asteroid mining might be the most lucrative and environmentally-friendly solution.

Asteroid mining is an endeavor that aims to acquire natural resources from comets, asteroids, and other minor planetary bodies in our solar system. Space mining and the exploration of natural resources present at least two value propositions. First, the availability of resources will be critical to supporting the continued exploration of outer space and potential colonization of other planets. Natural resources (including water) will be valuable, if not essential, to these long-term and sustainable efforts. Second, there are significant resources that can be mined for use and commercial ventures back on Earth. As additional innovative technologies are developed, the feasibility of space mining becomes increasingly possible to achieve both of these value propositions. But in the arena of space mining, developments are bringing many legal, regulatory, and contractual challenges and considerations that need to be kept in mind to support the successful launch of a new industry.

The only questions that remain: who are the ones mining, how will this venture be funded? And who would receive the resulting benefits of said minerals or the profits from the sales of those minerals?

5.1 Funding

The financial support for the research and application of related technology is essential. In particular, commercial incentives could promote investment in the exploration of space resources and enable the development of the most efficient use of resources. With the prospect of property rights, private sectors would make every effort to invest and develop technology for profits. For instance, Deep Space Industries (DSI) is pioneering a new capability for space exploration with low cost and great performance. However, without government interference, the commercial approach generates extreme distributions of wealth. And unfortunately, abundance does not always bring about sustained environments of economic growth and development. It can actually have an adverse effect. And due to the huge economic and technological disadvantages, developing countries may be left far behind by space-faring countries. As a result, the international community must carefully balance the interests of developed/developing countries which are reconcilable and not mutually exclusive.[5]

5.2 International Bureau of Space Overwatch

In light of recent technological advancements in the launch industry and the accelerating development of the private space economy, the regulation of space mining is becoming an increasingly pressing matter. The **International Bureau of Space Overwatch** (IBSO) is a regulatory regime for space mining that does not only provide legal clarity on how to acquire mining rights for certain celestial bodies but must also do this in a way that does not hinder investment in companies in this sector. Additionally, to encourage a progressive development and prevent the formation of market monopolies, the regime's mechanism for acquiring mining rights must be designed to promote the continued investment in new space mining companies, once the first movers have proven the concept. Under the oversight of the Bureau, involved parties (Space-faring nations) must fulfill the requirements of each of the factors of the aforementioned model (Political, Economical, Social, and Technological). They must also agree that all that space resources can be extracted and used consistent with the provisions of the Outer Space Treaty.[6]

5.3 Policy

Probably the most significant aspect of the asteroid mining sector and space missions is the impact that they will have on Earth's environment. Aircraft Rocket launches release significant amounts of greenhouse gases into the atmosphere. The fuel on board the first stage of a rocket burns in Earth's atmosphere to form carbon dioxide. For kerosene-burning rockets, one kilogram of fuel creates three kilograms of carbon dioxide (CO2). And reentries are just as damaging, producing Nitrous oxide (N2O) which is 300 times more potent than CO2. In addition, the mining industry on earth speaks for itself, being one of the leading causes of climate change itself. The mining industry estimates that producing one kilogram of platinum alone on Earth releases around 40,000 kilograms of carbon dioxide.
After mentioning the following, the best way to approach the eminent threat is to propose a **Cap-and-Trade System** on a global scale. The goal of the program is to steadily reduce carbon dioxide and other greenhouse gas emissions by allowing the market to determine a price on carbon, and that price drives investment decision and eventually spurs market innovation. Any country that decides to go over the emissions target will pay a significant fee. And the revenue generated from these fees will help support and fund other space mining programs around the world (developing or not).[7]

6 Strengths and Weaknesses

6.1 Strengths

- **We have established clear criteria for global equity.**
  Global equity is defined based on our main factors and indicators. Our method clearly states what indicators are significant and represents how global equity can be defined as.

- **We have calculated our model based on the data collected.**
  Our model was calculated from the step-wise function that filtered out the indicators that were redundant. The result of the step-wise presented us with our finalized model that was based on the data collected from our indicators.

- **We can take any additional indicator, apply it to the model, and see if it affects global equity.**
  In order to see if asteroid mining could affect global equity, we can apply an indicator that measures asteroid mining in our model, and then see if the new indicator changes the result of global equity. We can then do this same process for other indicators that reflect a certain topic and see the resulted global equity indicator change.

- **Our model can easily be replicated by following our process.**
  Throughout the process of creating models from our indicators, we used a step-by-step process through R programming[8]. We also used this to create our figures that represent our models that were chosen.

6.2 Weaknesses

- **Our sample size of countries is relatively small.**
  When determining our sample size, we took data from 40 countries that allowed for us to have complete data for all indicators. However, if we included more countries like 200 or more, then we could have had a better representation of global equity based on more countries' data collected.

- **Our data only takes in account data from 2010-1019.**
  When selecting the data that we used from the Global Economy website, we took the data from the years 2010-2019. However, what happens to a country that just develops in 2010? We don't have the data from before they were developed, so this data heavily influences the model through the most recent data.

- **The five indicators we chose to represent each factor are subjective.**
  The indicator we chose for our model were taken from a data set that col-

lected from government reports but ultimately was chosen to best represent the following factors: Political, Economic, Social, and Technological.

References

[1] The Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies, of 27 January 1967, United Nations RES 2222 (XXI).

[2] "Download Data: GDP Growth, Inflation, and Other Indicators." TheGlobalEconomy.com, https://www.theglobaleconomy.com/download-data.php.

[3] "Cumulative Number of Objects Launched into Outer Space." Our World in Data, https://ourworldindata.org/grapher/cumulative-number-of-objects-launched-into-outer-space?tab=map&country=OWID_WRL-USA-RUS-CHN-GBR-JPN-FRA-IND-DEU-European%2BSpace%2BAgency.

[4] "Innovations in Space: Space Mining." JD Supra, https://www.jdsupra.com/legalnews/innovations-in-space-space-mining-9603506/.

[5] Xu1, Fengna. "IOPscience." IOP Conference Series: Materials Science and Engineering, IOP Publishing, 1 Jan. 2020, https://iopscience.iop.org/article/10.1088/1757-899X/738/1/012014.

[6] Steffen, Olaf. "Explore to Exploit: A Data-Centred Approach to Space Mining Regulation." Space Policy, Elsevier, 2 Dec. 2021, https://www.sciencedirect.com/science/article/pii/S0265964621000515.

[7] "Trade in Raw Materials." OECD, https://www.oecd.org/trade/topics/trade-in-raw-materials/.

[8] R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.