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Asteroid Mining: The Future of Resource Harvesting

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ABSTRACT

Scarc resources on earth have increased the desire of human beings to upsurge. As a result of this and the rapid development in technology, exploration of outer space for potential reserves of natural resources has been accelerating. Asteroids, which are rocky objects between the planet belt of Mars and Jupiter are known to be composed of precious metals like platinum, cobalt and gold among others. Research on procuring these resources from outer space is advancing. This was mainly put forth with the idea of balancing the ever-increasing need for resources and to reduce the environmental degradation during the process of extraction of these elements on earth. However, the issues arise with respect to the cost effectiveness, financial viability, distribution of resources among countries and proprietary rights over these resources extracted from space. A major concern is the applicability of laws and legal principles that govern such activity in outer space. At present, even though the theory of common heritage of mankind over the resources is accepted, there is no prohibition or restriction on the extraction or investment by private entities in extracting it. Therefore, the liability of the entities who extract these resources and its equitable distribution thereof must be determined.

This paper sheds light on various aspects of asteroid mining and the emerging trends from the lens of legal reasoning and jurisprudence. It seeks to provide an insight into the impact and the legal liabilities owing to environment, economic and property concerns of extraterritorial mining. Further it also analyses the implication of privatization of asteroid mining and its financial viability. The article provides suggestions that can be brought through the law for optimizing the distribution of these resources in order to bridge the gap between developing and developed nations.

The research methodology adopted is doctrinal.

Keywords: *asteroids, extraterritorial mining, outer space, privatization, resources*

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I. INTRODUCTION TO ASTEROID MINING

An asteroid, as defined by NASA is “a rocky object in space that can be a few feet wide to several hundred miles wide. Most asteroids in the solar system orbit in a belt between Mars and Jupiter.”³ An asteroid is primarily made of silicon, carbon and precious metals such as gold, cobalt, platinum and others to name a few, and pose a potential threat of collision with earth. The idea of mining asteroids, was first suggested to, balance the scales of sustainable development and unstoppable development in 2016 and plans to be implemented by 2023 as the predictions go that the resources on earth will turn scare within five decades. Asteroid mining is the exploitation of raw materials from asteroids and other minor planets, including near-Earth objects⁴ which include the materials to be mined from a comet or celestial bodies.

However, the use of raw mineral so obtained from extra-terrestrial mining are restricted owing to the funding, as a supplement to the resources available on earth and research enhancing space exploration on the potential public or private use of these metals. These are speculated to act as asset to earth by engaging in renewable resource usage mechanism involving solar-power satellites and space habitats, and water processed from ice to refuel orbiting propellant depots.⁵ Currently, there is no international space law or treaty that explicitly prohibits the commercial use and extraction of space resources.⁶ So the question arises that under which statute or legislation, should the current prospects of asteroid mining be regulated. Should it be guided by domestic laws of the respective nations and if so, how will the legality under cases leading to jurisdictional conflict be resolved. Even under the current framework of the Outer Space Treaty (OST), 1967, the clause only "explicitly and implicitly prohibits only the acquisition of territorial property rights", but allows for extracting other space resources. Hence the concern to deliberate upon is to what extent can a harmonious construction be applied, in order to curb colourable use of legislations if any in place.

Therefore, the current essay seeks to provide an insight into the impact and the legal

³Brain Dunbar, National Aeronautics and Space Administration, (Oct. 25, 2020, 4:30 p.m.), <https://www.nasa.gov/audience/forstudents/k-4/dictionary/Asteroid.html>.

⁴ O'Leary, B, *Mining the Apollo and Amor Asteroids*, Science, 197 (1977-07-22).

⁵ Didier Massonnet; Benoît Meyssignac, *A captured asteroid: Our David's stone for shielding earth and providing the cheapest extra-terrestrial material*, Acta Astronautica, 59 (2006).

⁶ *Is Asteroid Mining Legal Yet?, existing treaties and laws*, The Reeves Law Group, (Oct. 25, 2020, 5:00 p.m.) <https://www.robertreeveslaw.com/blog/asteroid-mining/#:~:text=existing%20treaties%20and%20laws&text=currently%2c%20there%20is%20no%20international,and%20extraction%20of%20space%20resources.&text=under%20the%20act%2c%20u.s.%20citizens,extracted%20from%20space%2c%20including%20asteroids>.

liabilities owing to environment, economic and property concerns in furtherance of the same. This is considered through the lens of and an angle to privatization of the resources by companies and the rights involved thereof, and also to analyse the financial viability and giving inputs in form of suggestions. The concern for harvesting the resources, clusters upon the idea of exercising the rights over the resources so extracted and goes against the early followed concept of earth jurisprudence.

II. THE IMPACT OF ASTEROID MINING

The increase in the potential access to resources in outer space has economic and environmental implications among others. A significant question is whether the humans can exercise rights over the natural deposits that are not situated on earth. The belief that human beings are dominant and they have a better claim to the resources has resulted in exploitation and extinction of the planetary reserves on earth. Earth Jurisprudence is an approach contrary to this. It is defined by the Centre of Earth Jurisprudence as a philosophy and practice of law that highlights the importance of nature, its rights, interconnectedness of the natural systems and dependency of the welfare of humans on nature.⁷ This is seen as a shift from anthropocentric which is the dominance of human beings, to the eco-centric perspective which believes that the claims of human beings over the resources are no greater than other participants in nature. This casts a responsibility on the human beings to conserve resources. The enforcement of this obligation is through law and policy formulation from the lens of Earth Jurisprudence.⁸

Even though eco-centric approach refers to the resources on earth, language of the literature on this subject extends it beyond Earth to the universe as a whole. This is owing to the common origin of the solar system. An optimistic stance is the extension of earth jurisprudence to outer space. This will enable the formulation of laws with the novel idea of mutual relationship of all resources, rather than the dominance of humans which prevailed for centuries influencing the law making on Earth. However, the issue arises with respect to the execution and method of safeguarding the rights. In theory it is possible to say that all the participants of nature are mutual and equal, but translating this into reality and identifying the interests of various participants is largely unexplored.⁹ From this perspective, asteroid mining raises disputes about identifying the interest of minerals found within it, vis-à-vis the interest of human beings. The very act of mining beyond earth portrays that the needs of human

⁷ Centre for Earth Jurisprudence (Oct. 26th, 2020, 10:00 a.m.), <http://www.earthjurist.org/>.

⁸ Reed Elizabeth Loder, *Asteroid Mining: Ecological Jurisprudence beyond Earth*, 36 VA. ENVTL. L.J. 275 (2018).

⁹ Id.

beings are prioritized and due to resource deficit on earth other possibilities are explored.

On the contrary to the above approach, researchers have also argued that asteroid mining could be beneficial in conserving Earth. Mining of rare metals such as platinum, zinc, copper and phosphorus is destructive to the environment on earth and these resources are rapidly depleting. There is an upward trend in demand because newer technologies increasingly depend on such metals and there are no chemical alternatives. Due to its economic significance, the mining is widely prevalent which will exhaust these metals on earth. Hence, extracting them from asteroids which are rich in such elements can conserve the environment on earth and provide an alternative source to fulfil this economic necessity for new age technologies.¹⁰

The recent trend witnessed is the privatization of space mining. Viewing this as a commercial venture has far reaching implications on the manner in which the resources are mined and apportioned between the countries. In international law the ownership rights over an asteroid cannot be given to a particular country or corporation. However, the rights over the resources extracted from it can be exercised. This implies that the country that has the finance to invest will have a better claim. Among other countries in the world, the United States has been increasingly advocating private ventures and investment in this sphere.¹¹ This might result in monopolization of resources by the developed countries by undermining the needs of the developing countries. Therefore, a major challenge will be the manner in which the economic rights over these resources will be distributed to countries with the objective of advancing social welfare.

III. LIABILITIES UNDER ASTEROID MINING

Law is not immutable; it responds to the needs of society. The law of outer space has addressed the new political, economic, and technical needs that accompany this transit of human society into space. Space law has been expressed in broad, vague principles that have permitted the maximum flexibility necessary for exploratory space activities. But, as exploration gives way to settlement, this predominantly international law lacks the specificity and legal certainty necessary for mature commercial activity.¹²

¹⁰ Kevin MacWhorter, Sustainable Mining: Incentivizing Asteroid Mining in the Name of Environmentalism, 40 WM. & MARY ENVTL. L. & POL'Y REV. 645 (2016).

¹¹ David Sarnacki, Property Rights in Space: Asteroid Mining, 2 TEX. A&M J. PROP. L. 123 (2014).

¹² Philip R Harris, Space Law and Space Resources (Oct. 26, 2020, 3:00 p.m.), <https://space.nss.org/settlement/nasa/spaceresvol4/spacelaw.html#:~:text=Liability%20and%20Responsibility,-According%20to%20the&text=Liability%20based%20on%20fault%20is,to%20monitor%20these%20partners%20closely>.

(A) Economic perspective

Asteroid resources can be divided into three categories in terms of economics. This is determined by the value of the resources in the asteroid as well as the commercial viability of extracting and transporting it. The first category is the “resources valuable in space and on earth”. These include Platinum group metals such as gold, silver, platinum and Rare Earth Elements (REE) which are used in the manufacturing of electronic goods. The hindrance in mining them in outer space are the factors of accessibility, concentration of the element within an asteroid and determining its location. Overcoming these impediments will make this a reality and reduce the environmental costs on earth.¹³

The second category is “valuable in space and possibly valuable on earth”. Metals such as titanium fall under this category. No doubt they are valuable in space, but their viability to be transported to earth depends on the cost of extracting and refining the metals to usable forms, in comparison with the same process on earth.¹⁴ The third category is “not valuable on earth but highly valuable in space”. These are the resources such as water and oxygen, used in space as spaceship propellants. It can be utilized directly from asteroids and the moon without having to transport them from earth.¹⁵ These economic categories are significant as they help analyse the future course of investment viability and plausibility of low-cost access to space.

The United States is one country that has been constantly developing its Space law and policy. NASA had also initiated dialogues with companies such as Deep Space Industries and Planetary resources through which an asteroid redirect mission could be launched. This initiative aimed at sending the first robotic mission to collect a boulder from a near earth asteroid and place it in the orbit around moon in order to facilitate the astronauts to study this and bring samples for further research. This mission was backed by the Obama administration, but it did not materialize during the presidency of Donald Trump as per the White House Policy Directive in 2017.¹⁶

During the presidency of Barack Obama Commercial Space Launch Competitiveness Act (CSLCA) was passed. In addition to this American Space Technology for Exploring Resource Opportunities in Seep Space Act (ASTEROIDS Act) was also proposed, but it was subsumed in the CSLCA. This law protects and grants legal rights for the persons engaged in

¹³ Jeff Greason & James C Bennett, Economics of Space: An Industry Ready to Launch, RES. FOUND (2019).

¹⁴ *Id.*

¹⁵ *Id.*

¹⁶ What is NASA’s Asteroid Redirect Mission, National Aeronautics and Space Administration (Oct. 26, 2020, 3:15 p.m.), <https://www.nasa.gov/content/what-is-nasa-s-asteroid-redirect-mission>.

space mining and it allows them to sell the extracted elements from the asteroid, but not the exclusive ownership of the celestial body. This was enacted in furtherance of the obligations under the OST, 1967. This law has been criticized by Luxembourg since it applies only to the citizens of the U.S. and commercial entities in which the country has maximum investment. On the contrary, the space law enacted by Luxembourg provides for foreign investment in resource harvesting from space.¹⁷ This criticism holds merit because it would be a fallacy to include only domestic aspects when Space law is international in character and all countries must have equitable rights on outer-space reserves.

The 2010 National Space Policy of the U.S. among other aspects was also framed to develop an asteroid redirect mission and a testing platform for resource extraction. It provides for a framework of technology, industrial standards, infrastructure and competitiveness in the space sector among domestic industries through international cooperation. Through this policy the objectives of outer space resource harvesting were defined. This helped in effective resource allocation. However, the policy is broad in language creating a lacuna which can be utilized for exploiting the resources. There is also a lack of an alternative space policy in any other country that focusses on asteroid mining.¹⁸

(B) Property

Establishing ownership and property rights are for excluding others from utilizing the same resource. This factor of exclusion signifies that the property over which rights are exercised is for the exclusive use and sole benefit of the proprietor. By virtue of ownership, rights are provided to the proprietor for the exclusive use and a duty is cast on others to not interfere in the exercise of this right.

This is an uncertain area in space resources because of the common ownership of the world and few countries having more access to it than the others. The OST does not specifically state what type of an institution or person must own the resources mined from an asteroid. It provides under Article 6 and 7 that the country through which the mining is carried out is liable for the enforcement of the treaty. This means that if any corporation extracts resources from the space, the country in which it is situated would be responsible to carry out the obligations in the treaty.

Article 8 of OST states that the ownership of any object which is sent to space or any

¹⁷ Vidya Sagar Reddy, Commercial Space Mining: Economic and Legal Implications, OBS. RES. FOUND. (2017) (Oct. 26, 2020, 3:30 p.m.), <https://www.nasa.gov/content/what-is-nasa-s-asteroid-redirect-mission>.

¹⁸ A Hennig, Policy Recommendations for Economically and Socially Valuable Asteroid Mineral Resource Exploitation Activities, (2016) (Oct. 26, 2020, 5:15 p.m.), <http://scholarworks.rit.edu/theses/9147/>.

construction is made on a celestial body is not affected by its presence there or on return to earth. This means that the states retain the rights and jurisdiction over the objects that are sent to space.¹⁹ This treaty uses the term celestial body which is not defined within the instrument and it creates ambiguity about the meaning of the term. Even though the treaty states that ownership rights must not be provided on the celestial body itself, there is no specific law which regulates the title over the resources extracted from the celestial body.²⁰ In order to bring in clarity, the words utilization, consumption and appropriation must be defined from the perspective of asteroid mining. They might overlap since it is often hard to determine the change from utilization to appropriation, but there is difference in the individual meaning of each term. Therefore, it necessitates specific approach for defining these property rights to eliminate the ambiguity.²¹

A relevant concept in the ownership and property rights of space resources is the theory of The Tragedy of Common written by Professor Garrett Harding. He identifies the problem of labelling a resource as commonly owned by all. Every person who has access to the resource will maximize private gain and this will result in depletion. A similar issue arises in space resources if it is commonly owned by all the countries. Excessive accumulation by countries for private gain will result in the degradation of resources. An alternative that was proposed in his work was that the property must not be owned by anybody. It might result in underutilization of resources and disincentive in investing on it.²² This is pertinent in asteroid mining because of the huge investments that are needed to materialize the strategy. If the resources are said to be unowned, the incentive to make such investment is reduced.

1. Legal Liability:

The legal liability of a state is determined by the domestic laws of the respective country. However, they are guided and read in harmonious interpretation with the international guiding treaties especially when the concept of asteroid mining is relatively new. An example in point is The OST (1967) of the Soviet Union, also known as the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, mainly governing Moon and other celestial bodies, revolving around the earth. It is considered as the

¹⁹ Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space , Including the Moon and Other Celestial Bodies, UNOOSA, (1967) (Oct. 27, 2020, 4:00 p.m.), <https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html>.

²⁰ Frans G. Von Der Dunk, Asteroid Mining: International and National Legal Aspects, 26 MICH. St. INT'L L. REV. 83 (2017).

²¹ Annette Froehlich, Utilization - Consumption - Appropriation: Asteroid Mining Is in the Pipeline, 66 ZLW 268 (2017).

²² John Myers, Extraterrestrial Property Rights: Utilizing the Resources of the Final Frontier, 18 San DIEGO INT'L L.J. 77 (2016).

“Magna Carta” of the International Space law and was adopted by the United Nations General Assembly on December 19, 1966, and came into force on October 10, 1967.²³ The Treaty was formulated with the objective that the nations that are party to the treaty, will not be allowed to place the weapons of mass destruction in the orbit of the Earth, Moon and any celestial body. The treaty states that nations cannot subject the orbits of the earth, to fulfil any objective of weapon testing or military manoeuvring on any spatial objects and that no nation is subject to national appropriation by claim of sovereignty, by means of use or occupation or by any other means in the Outer Space including Moon and other celestial bodies.²⁴

Article VI of the aforementioned treaty, provides for direct and full state responsibility with regard to private space activities, including asteroid mining, and requires them to be subject to “authorization and continuing supervision”.²⁵ Usually, this clause is interpreted as requiring a national scheme for licensing private space operators and subjecting them to relevant obligations and procedures.²⁶ A major issue with respect to this, is interpretation of the phrase “national activities in outer space,” under Article VI which the nations embark upon.²⁷ Finally, Article IX obliges states to ensure that space activities undertaken by them or their nationals shall not cause harmful interference with other legitimate space activities unless prior consultation with possibly affected states has taken place.²⁸ This clause has gradually come to be interpreted as disallowing the causation of serious harmful interference unless overriding reasons would require that activity to go ahead any.²⁹ This implies that the clause allows for a room to interpret the legislation in a harmonious and a constructive way, not being able to demean or go against the intention behind any of the provisions. The word of the statute will be interpreted in the strict meaning and a scope for interpretation may not be given until the same is mentioned in the treaty, to the contrary.

The Moon Agreement could have provided some guidance on exploitation of space resources, as it ostensibly prohibits claiming lunar natural resources for private ownership.³⁰

²³ Vladamir Kopal, Treaty On Principles Governing The Activities Of States In The Exploration And Use Of Outer Space, Including Moon And Other Celestial Bodies, Audio Visual Library Of International Law, (Oct. 27, 2020, 6:30 p.m.), <http://Legal.Un.Org/Avl/Ha/Tos/Tos.html>.

²⁴ Article 2, The Techniques Outer Space Treaty, UNOOSA (1967).

²⁵ Frans G. Von Der Dunk, Private Enterprise And Public Interest In The European, Spacescape (1998).

²⁶ Cf. Irmgard Marboe, National Space Law (Handbook Of Space Law, 2011).

²⁷ Frans Von Der Dunk, Preface To Handbook Of Space Law XXIV (Frans Von Der Dunk & Fabio Tronchetti Eds, 2015).

²⁸ Sergio Marchisio, Article IX, (Cologne Commentary On Space Law) ; Howard A. Baker, Protection of the Outer Space Environment: History and Analysis of Article IX of the Outer Space Treaty, (12 Annals Of Air & Space L. 143., 1987).

²⁹ 1, Arnel Kerrest & Lesley Jane Smith, Cologne Commentary On Space Law, (2016).

³⁰ Robert Garcia, Regulating International Space Mining, an Enormous Industry, Pacific Council on International Policy, (Oct. 31, 2020, 3:31 p.m.) <https://www.pacificcouncil.org/newsroom/regulating-international-space-mining-enormous-industry>.

In reference to U.S. and Luxembourg spoken of earlier in the essay, it is clear prima facie that the aim hints at the commercial exploitation of space resources. The legislations in both the nations, provides for an attempt to provide a legal basis for individual citizens to encourage the practices of buying such resources, which as feared, may be characterized as prohibited "appropriation" under international law. With regard to this, the Commercial Space Launch Competitiveness Act (CSLCA) is also significant for granting legal rights and protection to US citizens engaged in space mining.³¹ It allows them to own, use, transfer and sell mined space resources without granting exclusive ownership over the celestial bodies.

2. Environmental Liability:

In the next sixty years, scientists predict that certain elements crucial to modern industry such as platinum, zinc, copper, phosphorous, lead, gold, and indium could be exhausted on Earth.³² This implies that humans must start looking for abundant resources for continued growth in form of sustainable development and come up with new strategies to implement the same. On the contrary, it is by its nature an unsustainable practice, because it involves the extraction of a finite and non-renewable resource.³³

A direct and immediate consequence of greenhouse gas emissions in the form of economic effect can be seen through nations introducing the carbon tax, to limit the amount of fuel usage and cope up to the environmental cost of environment degradation. Given the variation in CO₂ emissions on Earth and in addition, the space-based mining, only the resources deployed on earth will be penalized by imposition of tax upon them. This means that the mining on these celestial bodies, becomes out to be a more expensive affair than statistically calculated as the payment and infrastructural capacities of the developing and the developed countries are poles apart. The 10% tax could be compensated via a higher efficiency of the mining process and a potentially higher degree of renewable energy sources for electricity supply, as the majority of greenhouse gas emissions are generated by burning hard coal, at least in the case of South Africa³⁴. However, it is unclear in terms of the effect that it will have on the global economy and the willingness of the nations, seeming to be a party to the treaty, to readily pay the costs imposed upon them.

Although the OST prohibition on state sovereignty over any celestial body does not literally

³¹ Supra 15.

³² David Cohen, Earth's Natural Wealth, An Audit, New Scientist, (Oct. 31, 2020, 4:26 p.m.), <https://www.newscientist.com/article/mg19426051-200-earths-natural-wealth-an-audit/>.

³³ Bonnie J. Glaister & Gavin M. Mudd, The Environmental Cost of Platinum PGM Mining and Sustainability, (2010).

³⁴ 2, T. Bossi and J. Gediga, The Environmental Profile of Platinum Group Metals, Johnson Matthey Technol. Rev., 61 (2017).

apply to private individuals and entities, the OST makes each signatory state responsible for authorizing and supervising any launches from its territory.³⁵ The separate Liability Convention explicitly grants jurisdiction to a launching state to determine strict liability damages for injuries inflicted on Earth and negligence-based damages for off-Earth harms.³⁶ Thus, it does not appear from the terms of international laws regarding space that exercising United States jurisdiction over private activities or persons in space amounts to making a prohibited claim of state sovereignty.³⁷ It is also important to recognize that the state signatory retains complete liability for damages incurred through space activities, even by private but authorized actors.³⁸ On one hand, the Environmental Protection Agency (EPA) describes the industry as the source of more toxic and hazardous waste than any other industrial sector in the United States, costing billions of dollars to address the public health and environmental threats to communities.³⁹ Poor regulations and oxymoronic corporate definitions of sustainability, make it unclear as to just how much waste the industry actually produces.⁴⁰ However, the future financial costs and the question over the property rights of the metals so recovered will always be in limbo. The audacity of the Space Act shows how little consideration policymakers have given to their ethical obligations in space.⁴¹

IV. FINANCIAL VIABILITY OF ASTEROID MINING

Getting the hand on an asteroid and using it towards increasing the resources present on earth would definitely be a game changer for human life, as it will allow quintillions of cash towards the annual production of raw metals. However, the cost estimated in retrieving and procuring the metals and processing them to pulverised forms is quite extensive as compared to other means of procurement of these metals. Companies readily investing in the sector, such as Planetary Resources and Deep industries, are keen to invest in these prospective targets. Some of them claim to have already identified roughly 15,000 objects in close proximity near the orbit of earth which are termed as very attractive objects. The huge amount of investment stagnates the financial capability of a single entity to restore the project to its initial stage of start because of the financial support required, which is acting as a

³⁵ Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Art. IV, (1967).

³⁶ The Convention on International Liability for Damage Caused by Space Objects, Art. II, (1972).

³⁷ Reed Elizabeth Loder, Asteroid Mining: Ecological Jurisprudence beyond Earth, (Oct. 29, 2020 8:23 p.m.), (2018) http://www.velj.org/uploads/1/2/7/0/12706894/36_va_envtl_lj_275_317__2_.pdf.

³⁸ *Id.*

³⁹ National Enforcement Initiative: Reducing Pollution from Mineral Processing Operations, Env'tl. Prot. Agency, (Oct. 25, 2020, 5:17 p.m.), <https://www.epa.gov/enforcement/national-compliance-initiatives>.

⁴⁰ Glaister & Mudd, Exploring Potential Environmental Benefits of Asteroid Mining, (Oct. 25, 2020, 6:30 p.m.), (2018) <https://arxiv.org/ftp/arxiv/papers/1810/1810.04749.pdf>.

⁴¹ *Id.*

technical obstacle to overcome at this stage. The potential for extracting water from asteroids and utilizing them for space fuel has a bright side towards reducing space transportation fuel cost from earth.

Luxembourg has opened a Euro fund of 200 million in 2016 in order to attract companies interested in this venture. Similarly, NASA has also collaborated with the private sector for research and speedy implementation of resources from asteroids. Planetary Resources is one such company which has entered into partnership with both NASA and Luxembourg with the initial focus of mining water.⁴² However, the company ran into shortage of funds and it was acquired by a blockchain company called ConsenSys Inc. through asset purchase.⁴³ This shows that while there is huge potential for profits, there is also volatility and liquidity issues that the companies need to consider. The market trends forecasted is that the technological developments will reduce the cost of reaching space in the forecast period of 2020-2038. According to Space Angels, \$1.7 billion in equity capital poured into space companies in the first quarter of 2019, nearly twice as much as in the last quarter of last year. Of that, 79% went toward satellite businesses and 14% to logistical operations, like rocket launches. Hence, the project will involve cause-effect analysis technique called *Structural Equation Modelling* (SEM) using *Partial Least Squares* (PLS) to estimate the costs of an asteroid mining missions. Structural equation modeling (SEM) is a methodology for representing, estimating, and testing a network of relationships between variables (measured variables and latent constructs).⁴⁴ Using PLS in the said method will help to determine method and the description of how to evaluate analysis results while keeping into consideration the complementary analytical technique. For data ascertainment, a qualitative method called the *Delphi technique* must be used to identify the main cost drivers and quantify their influence on the overall cost model. The Delphi method was invented by Olaf Helmer and Norman Dalkey of the Rand Corporation in the 1950s for the purpose of addressing a specific military problem.⁴⁵ The aim of the Delphi method is to construct consensus forecasts from a group of experts in a structured iterative manner.⁴⁶

⁴² 6 Priyank Doshi, Regulating The Final Frontier: Asteroid Mining and The Need For A New Regulatory Regime, Notre Dame J. Int. Comp. Law (Oct. 24, 2020, 1:48 p.m.) (2016), <https://scholarship.law.nd.edu/ndjicl/vol6/iss1/15/>.

⁴³ Jeff Foust, Asteroid mining company Planetary resources acquired by blockchain firm, (Nov. 3, 2020, 5:56 p.m.) (2018) <https://spacenews.com/asteroid-mining-company-planetary-resources-acquired-by-blockchain-firm/>.

⁴⁴ Diana Suhr, The Basics of Structural Equation Modeling, (Sept. 27, 2020, 7:32 p.m.), (2006), <https://www.lexjansen.com/wuss/2006/tutorials/TUT-Suhr.pdf>.

⁴⁵ Rob J Hyndman and George Athanasopoulos, Forecasting Principles and Practice, (Oct. 20, 2020, 3:39 p.m.), (2018) <https://otexts.com/fpp2/delphimethod.html#fn6>.

⁴⁶ Supra at 38.

V. SUGGESTIONS AND CONCLUSION

From the economic perspective, the goals that a space policy must focus on with respect to the mining of resources from asteroids are the technological development to reduce the cost of searching, extracting and transporting the resources. It must also take into consideration the sustainability aspect of whether the current expenditure on infrastructure, research and technology will lead to the development of future generations. Further, it must also be international in scope apart from focusing on the domestic aspects of a country since space resources should not be monopolized by a single or handful of countries. After the preliminary economic assessment, the government's role and policy making is a succeeding step towards implementing the objectives and determining the liability of the stakeholders such as government industries and private investment.

With regard to privatization of companies, it is observed since 1998 that there is an increase of private investment when compared to government investment in asteroid mining. It is argued that private investment expands the ambition of this sector because unlike government entities their functioning does not depend on public opinion.⁴⁷ It is also seen that in the U.S., funding from the government for space projects has decreased in the federal budget, while on the other hand private entities are emerging in a rapid pace. In order to incentivize the private sector to continue with these projects, the government must formulate appropriate laws. The benefit that is obtained through the mining of these resources from space to earth exceeds the profit motive with which the private companies engage in this venture. Another issue that is seen with government entities is shortage of capital and bureaucratic intervention which will delay the project. Therefore, it is put forth that private entities are well equipped to make asteroid mining a reality and the government must frame suitable laws to foster its growth.⁴⁸ It is on these lines that the 2015 Space Act is enacted by the U.S. The basic premise of the legislation is free market and first-come, first-serve, rather than the principle of common heritage of space resources.⁴⁹

Privatization as an approach to asteroid mining is not well founded for several reasons. The goal of mining natural resources in space does not end at making it available on earth. It also extends to the manner of usage and the ultimate beneficiaries. Since it is a public resource,

⁴⁷ John Adolph, [The Recent Boom in Private Space Development and the Necessity of an International Framework Embracing Private Property Rights to Encourage Investment](https://scholar.smu.edu/cgi/viewcontent.cgi?article=1091&context=til), (Oct. 20, 2020, 2:17 p.m.), (2006) <https://scholar.smu.edu/cgi/viewcontent.cgi?article=1091&context=til>.

⁴⁸ 78 Lauren E. Shaw, [Asteroids, the New Western Frontier: Applying Principles of the General Mining Law of 1872 to Incentive Asteroid Mining](#), J. AIR L. & COM. 121 (2013).

⁴⁹ Todd Skauge, [Space Mining & Exploration: Facing a Pivotal Moment](#), 45 J. Corp. L. 815 (2020).

the countries in the world are obligated by the judicial principle of public trust doctrine to preserve it. According to this principle, the government functions as a trustee to protect and preserve the natural resources for the beneficiaries, who is the public at large.⁵⁰ In the case of *Marks v. Whitney* [6 Cal.3d 251], the Court in California stated that the doctrine can be expanded to include other areas for meeting the emerging needs of the public.⁵¹ Therefore, the areas covered under the doctrine cannot be restricted to certain natural resources and expansive interpretation of the term must be adopted.

Extending the public trust doctrine to reserves in space will ensure that it is available for the benefit of public. This will prevent alienation of resources and it restricts the power of the sovereigns to use the resource. This is in furtherance of Article 11 of the Moon Treaty which states space to be a common heritage of mankind. The benefit of the doctrine in extending it to space lies on the fact that the duty is imposed on the sovereign countries in the world infinitely and it is not bound by the government in power. It is adaptable to different situations and can be invoked by common members of the public which proves the doctrine in itself to be a substantive right. It is a cost-effective option for managing celestial bodies and outer space resources from exploitation until a clear and specific law defining the rights and duties of each country is framed.⁵²

Another question to ponder upon is the resource to be used as fuel for propulsion considering the distance to be covered back and forth, which would also involve research costs and must also keep the aspects of renewable resources, owing to sustainable development in mind. “We were all frustrated about the revenue prospects, and the business model wasn’t working out the way we’d hoped,” recalls Peter Marquez, the former director of space policy for President Obama and current vice president of Planetary Resources, who now works for a Washington, DC, advisory shop called Andart Global.⁵³ To achieve anything of this at mass scale, involving tons of money and infrastructure and technology amidst a pandemic is not possible as the economies around the world have been shaken to their core and stabilizing the finances of their country will be the priority target of any nation. Apart from this, a separate allocation of budget has to be done on research and development, on robots, building spacecrafts and other accessory technologies will increase the monetary crunch.

⁵⁰ Melissa K. Scanlan, *The Role of the Courts in Guarding against Privatization of Important Public Environmental Resources*, 7 Mich. J. Env'tl. & Admin. L. 237 (2018).

⁵¹ 20 Linda J. Bozung, Public Trust Doctrine and Transfer Development Rights, Real Prop. Prob. & TR. J. 975 (1985).

⁵² 69 Hope M. Babcock, The Public Trust Doctrine, Outer Space, and the Global Commons: Time to Call Home Economic Times, Syracuse L. Rev. 191 (2019).

⁵³ William J. Board and Kenneth Chang, Obama Reserves Bush’s Space Policy, (Oct. 15, 2020, 5:48 p.m.) (2018) <https://www.nytimes.com/2010/06/29/science/space/29orbit.html>.

The ambiguity in the OST can be clearly pointed out under Article IV and VI, where there is intent left in the interpretation of terms under the treaty such as “national activities in outer space” and “authorization and continuing supervision.” Therefore, there is a need for legislation which can be determined in strict sense by the word and liberal interpretation be only allowed, through judicial interventions for progressive development of the nations. On the other hand, environmental ethics is flouted under Commercial Space Launch Competitiveness Act (CSLCA), which allows for special legal protection towards citizens, working in furtherance of such mining activities, which may bar exclusive ownership, but allows for all other property rights to be expressed on the celestial bodies. This has the potential of leading interested and funded ventures into monopolizing the yet unexplored area, paving a smooth path for aristocratic and capitalistic business models to seep into and control the international framework. It will become as simple as the one who can pay, gets the biggest catch, which will force the third-world countries and the developing nations to be driven out, disincentivized.

The objective of asteroid mining laws must focus on achieving mutual cooperation between countries. This is possible through the creation of an alternative forum such as the United Nations Office for Outer Space Affairs (UNOOSA). Through this, the countries can facilitate technological research and development in outer space mining. As a part of this forum, a monetary fund must be created in order to enable the countries to pool its resources which can be used for investment purposes. A mechanism must be established whereby, if a country is making use of outer space resources for solely its own benefit, consensus must be taken from other countries of the forum with regards to the terms on which it can be carried out. This will help in bridging the gap between the developed and developing countries.
