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The politics of space mining – An account of a simulation game

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A R T I C L E I N F O

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A B S T R A C T

Celestial bodies like the Moon and asteroids contain materials and precious metals, which are valuable for human activity on Earth and beyond. Space mining has been mainly relegated to the realm of science fiction, and was not treated seriously by the international community. The private industry is starting to assemble towards space mining, and success on this front would have major impact on all nations. We present in this paper a review of current space mining ventures, and the international legislation, which could stand in their way - or aid them in their mission. Following that, we present the results of a role-playing simulation in which the role of several important nations was played by students of international relations. The results of the simulation are used as a basis for forecasting the potential initial responses of the nations of the world to a successful space mining operation in the future.

1. Introduction

Celestial bodies like the Moon and asteroids contain materials and precious metals such as platinum, gold, iron, and helium-3, which are valuable for human activity on Earth and beyond. According to various estimates, an asteroid may contain more platinum than the amount that was produced to date on the Earth. Space mining has so far been mainly relegated to the realm of science fiction, and was not treated seriously by the international community. Although this dream has not yet been realized, many involved in space exploration assume that it is only a matter of time until a breakthrough is achieved. In the past several years, a few companies were created in order to pursue this goal, and were able to raise significant funds to realize their ambitions, thus leading to a new race between governments, international bodies and the industry, to set the terms by which private companies will perform mining operations in space.

2. Current state of affairs

In April 2012, a press release was published by the newly established company Planetary Resources [1]. The company, founded in 2009, has finally announced its plan to mine near-earth asteroids. The materials that Planetary Resources is searching for range from water to precious metals, with platinum cited as an example. Mining operations are supposed to be executed by robots and extremely low-cost yet highly sophisticated space vehicles. Planetary Resources is not quite ready yet to mine asteroids. Regardless, investments in the company have come from impressive sources, which demonstrates the faith investors place in asteroid mining. Investors include the multi-billionaires Larry Page, Google's CEO and co-founder; Eric Schmidt, Google's ex-CEO; extremely successful venture capitalist Ram Shriram; Warren Buffett and others. In 2013, the company received a vote of confidence in the form of a large investment by the Bechtel Corporation [2] – the largest construction and engineering company in the U.S.

Planetary Resources is not alone in the race to space. Deep Space Industries (DSI), another American private company, was founded recently. DSI's purpose is similar to that of Planetary Resources: to mine asteroids for precious metals and water. DSI is currently in the process of developing a number of spacecrafts, which include [3].

- Fireflies – small robotic vehicles that will be dispatched to intersect with near-Earth asteroids and assess their physical properties (size, spin rate, structure, etc.). The time for the one-way trips to the asteroids is estimated to be six to 24 months.
- Dragonflies – larger, more complex robotic vehicles that will carry samples from the asteroid back to Earth, and conduct several tests in space. The round trip mission of these vehicles is estimated to take two to three years.

Finding details about the last stage of the mission, i.e. the mining

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operation itself, is difficult. We assume that this is quite simply because autonomous mining technologies in space are yet to be developed and tested. At the moment they are largely nonexistent. In 2013, despite the glaring lack of autonomous robotic mining tools, DSI declared its plans to launch a fleet of Fireflies by 2015, and actually begin mining asteroids by 2023, merely eight years in the future [4].

Another company to join the private asteroid mining race is Kepler Energy and Space Engineering (KESE, LLC). KESE is distinguished from the other two companies by its insistence to make use of existing and proven space technologies from past missions, and adapt them to asteroid mining. KESE's robotic asteroid mining system is named Cornucopia, a not-so-subtle reference to the mythological Horn of Plenty. According to KESE, Cornucopia should be fully functional by the end of the decade, and will bring approximately 40 metric tons of asteroid material to low-Earth orbit. Indeed, one of the company's declared goals is " … to extract valuable minerals like rare earths, gold, and platinum group metals for Earth consumption." [5].

Finally, Asteroid Mining Corporation is a new British firm established in 2016, with intentions to launch a prospecting sample return mission to a near earth asteroid in the next decade [6]. The firm is currently lobbying the British government to create and shape a legislative framework for space mining.

Realistically, none of the four companies described rely solely on asteroid mining for consumption on Earth as their sole economic model. Instead, all four are just as interested in providing materials, water, hydrogen and oxygen (chemicals used for fuel generation) for satellites and space settlements in Earth or lunar orbits. Many consider this proposition a more feasible economic model. However, one cannot ignore the fact that all four companies are also committed to bringing resources from space to Earth.

Disruptive technologies often raise social, political and economic issues and dilemmas which need to be addressed by institutions that are not suited for the task and so require adaptation to fit the new reality. In addition, such institutions are usually slow to acknowledge the changes and thus tardy in addressing the underlying issues at stake. The gap between technological implementation in society and the necessary adjustments by the political and economic institutions breeds instability, and often results in economic and political crisis. Once space mining, and especially the ability to transport mined materials to Earth, becomes technologically and economically feasible, it will have a dramatic and disruptive effect on the global economy and on world politics. Furthermore, these imports would have dramatic impact on individual state economies and global supply chain economies, and will affect a large number of countries regardless of their space capabilities, bearing significant consequences for security and global stability. Nonetheless, the social and political aspects of space mining have not been fully addressed by scholars of international relations and political economics.

Current literature on space mining is divided into four main categories. First is literature which focuses on the technological feasibility and engineering challenges of launching platforms to celestial bodies, possible methods or techniques of mining and returning the products to Earth [7]. In the second group are works which concentrate on the economic potential and commercial aspects of space mining [8]. In the third category are works that explore regulatory and legal questions of future space mining. These works mainly scrutinize existing space treaties, and mainly address ownership issues. They point to the fact that the international community needs to reach an understanding regarding the "Moon Agreement", especially with regards to the controversial definition of the "Common Heritage of Mankind". Furthermore, there is a need to better define "activity for the benefit of all mankind". In this respect, and in order to conform to the requirements of international space law, a clear definition of mining activities must also be drawn up and agreed upon [9]. Some scholars point out that several gaps exist, and regulations are unclear about issues of liabilities and responsibilities in case of damage or contamination caused by and during space mining activities [10]. For example Tronchetti argues that a debris problem may develop due to space mining operations and may lead to an environmental pollution. This futuristic scenario requires a better framework for responsibility and legal mechanisms for liability issues [11]. Others try to envisage the sociological and economic implications of human exploration beyond Earth and efforts to colonize space and mine other celestial bodies [12]. Finally, literature in the fourth category, which would deal with the political aspects and consequences of space mining on world politics, is scarce. Such works would highlight the challenges and difficulties in achieving international cooperation due to conflicting interests, different political concepts as well as lack of trust between states [13]. We believe that it is vital to minimize the aforementioned gap by developing novel political, economic and legal frameworks on such issues in advance. Early thinking is usually better in providing long-term sustainable mechanisms, because it has the capacity and time to address a large range of ideas and considerations.

To that purpose, and as a preliminary exercise, we have conducted a simulation concerning the possibility of space mining and its political and economic consequences for world politics. By describing this futuristic simulation we aim to underline the complexity of this subject in order to promote advanced thinking processes. We do not intend to cover the full spectrum of the complexity of this issue, but to raise some of the central dilemmas facing world politics vis-à-vis space activity in the future, and offer potential directions for solutions. For this reason, we focused the simulation on a scenario in which materials mined in space are brought back to Earth. Participants in the simulation were not asked to address a scenario in which materials mined in space are used in space and are not returned to Earth. The main insights arising from the simulation involve the primary actors and their national interests, major international controversies, and potential directions for solution. Among the identified issues is the importance of an inclusive international process followed by the development of creative mechanisms, which will allow for international involvement and sharing of space mining products.

The article is composed of three parts. The first section depicts the rationale for space mining and describes the current and future technological state of this field. In the second part, we portray the simulation. We analyze the political outcomes which should be addressed by the international community in the third part. We then conclude with some lessons for further discussion of potential mechanisms to mitigate the primary dilemmas and concerns which would be raised once the technology becomes a reality.

2.1. *Feasibility and potential timeline for asteroid mining*

In futuristic and complicated fields such as space mining, we have no way of forming an opinion other than relying on the views of experts. A report released in 2012 by the Keck Institute for Space Studies of Caltech concludes that by the year 2025, dragging a near-earth asteroid of a weight up to 500,000 kg Into a lunar orbit would be a feasible venture [14]. Building on many variables involved, Kurt Callaway constructed a scenario for asteroid mining which was presented at the World Futures Society Conference 2014. According to the scenario, asteroid water mining for Earth consumption will be achieved by 2027, whereas the products of asteroid metal mining will arrive in 2033 or later [15].

While it is clear that asteroid mining as a whole is not about to be accomplished in the immediate future, many of the technologies required for the task have already been successfully demonstrated and are currently in the stages of refinement. Forecasts for asteroid mining range from 2020 (KESE) and 2023 (DSI) to 2033 (Callaway) and even 2055 (FutureTimeline [16]). Regardless of the exact date, the concept of asteroid mining merits lively debate as its consequences are likely to be far-reaching and impact nations and individuals.

2.2. *Governmental activity and current projects*

While asteroid mining is promoted by the private sector, several government agencies are advancing related projects. These projects are oftentimes not directly connected to asteroid mining per se, but the technologies developed under their auspices could easily be used for asteroid mining. This state of affairs assures that private companies who wish to commercialize space can rely on a subtle, indirect subsidy in research and development stemming from these government agencies. A limited list of governmental projects related to asteroid mining includes [17].

- Japan's Hayabusa, a sophisticated spacecraft, which landed on an asteroid in 2005, collected samples of asteroid material and returned them to earth in 2010.
- Japan's Hayabusa-2, which was launched in December 2014, in order to make contact with a target asteroid in 2018 and return to Earth in 2020.
- NASA's OSIRIS-Rex mission, which was launched in September 2016.
- NASA's Asteroid Redirect Mission.
- China's Department of Lunar and Deep Space Exploration promulgated a vision to mine the riches of the Moon, and wants to build a mining base on the Moon by 2023.
- The European Space Agency's Asteroid Impact Mission (AIM), which is currently in the preliminary design stage. Should the mission be confirmed, the AIM will be launched in 2020 to survey a binary asteroid system.

The above evidence shows that governments are paying heed to the beginnings of the race to mine outer space, and are supporting it with government-funded projects.

2.3. Economics of asteroid mining

Current economics on Earth are based on a model of scarcity – i.e. having limited resources, and being forced to compete for them. Both nations and commercial companies find it necessary to secure geographical territory for current and future exploitation of natural resources located therein. However, humanity is rapidly burning through its natural resources, leading to the assessment that between 1980 and 2008, available natural resources per capita declined by 20% in the United States and 17% in China [18].

While there are clear and massive uses for asteroid mining to provide water, air and fuel to space stations located in space, on the Moon or on other space objects, our focus in this paper is on resources that can be transported to Earth. Of those, most analysts specify heavy metals in particular, such as Platinum Group Metals (PGM). Platinum is used as a catalyst worldwide, particularly in the automotive industry [19], and is a necessary ingredient for making the switch into the vaunted hydrogen economy. However, should all 500 million vehicles on Earth be converted to a hydrogen basis, the known platinum quantities on Earth would be depleted within 15 years [20]. It comes as no surprise that the U.S. National Research Council's recently assessed that PGMs are highly critical for continued industrial development [21].

Near-Earth asteroids are expected to contain vast deposits of PGMs, at concentrations comparable to those of the most profitable mines on Earth [22]. A single tiny asteroid, 30 m long, can hold an amount of platinum worth up to 50 billion USD, according to Planetary Resources' CEO [23]. The resources potentially minable from asteroids are not limited to PGMs, but may also include more base metals, such as iron and nickel.

Clearly, asteroid mining is a "disruptive" technology, which will have profound and deep impact on many different industries, and on the economy as a whole. Should asteroid mining be used to its maximum potential, it will change the economic models currently in practice regarding scarcity of natural resources. Similar changes have occurred in the past, always driven forward by technological developments. Aluminum, for example, was a highly priced metal in the 19th century – so much so that Napoleon III served food to his prominent guests on aluminum plates. In 1896, however, a novel method was developed to cheaply extract aluminum from bauxite, and within a few decades the metal became common, and is now in use in countless household appliances. This example from the past could be repeated in the future for many other metals, by virtue of asteroid mining. The economic potential carries significant strategic and political consequences.

2.4. Legal state of affairs

The normative and legal framework of space activity is rooted in the days of the Cold War. The space race, especially the race to the Moon, increased the need for regulation and rule-setting. In an attempt to regulate human activity, the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies", known as the International Outer Space Treaty, was drawn up. It was officially signed and ratified in 1967 by UN-Committee On the Peaceful Uses of Outer Space (COPUOS) [24]. The treaty was meant to set out and solve some divisive problems, such as appropriation and claims of sovereignty, liability, control and follow-ups of space launches, etc. Two main principles, which are relevant to this paper, emerge as central to the treaty: (a) the ban of any annexation of space or planetary bodies to any state on Earth, either by use, by appropriation, by conquering some areas (including the Moon) or in any other way. (b) Outer space shall be free for exploration and use by all States [25]. The Outer Space Treaty has been ratified by most states, including the main space-faring nations, and up until today, is treated as the basis for all space regulation [26].

In the succeeding years, three more international treaties were signed by many space faring nations. Their purpose was to enlarge or accentuate some principles that appeared in the original treaty: the "Rescue Agreement", the "Liability Convention", and the "Registration Convention" [27]. The fourth agreement, which raised the greatest debate, is the 1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, also known as the "Moon Agreement". These space treaties are based upon the fundamental principles found in Article II of the Outer Space Treaty which conclude that space and its planetary bodies are not subject to national sovereignty and thus should not be the property of a single country [28]. The Moon Agreement was not ratified by most states, including the main space faring nations [29]. The reasons for this were some provocative sections regarding the use of natural resources. Specifically, the Agreement stated that the Moon and its natural resources are the common heritage of all humankind. Moreover, it states that an international regime should be established to govern the exploitation of such resources, when such exploitation is about to become feasible.

Those suggestions and stipulations are what most states, including the leading space faring nations, object to, and so they have refrained from endorsing and signing the treaty. They expressed fear that their activities in space will be hampered by international control bodies. Moreover, of importance is the doubt it casts over private initiatives; no investor would be willing to invest a fortune when profits are not assured because of the demand for equality [30]. Treaties and agreements only bind states parties to them. Therefore, the Moon Agreement is not relevant to most states that have not ratified or acceded the agreement and are not bind by it.

While the Moon Agreement offered a model of ownership of all resources by all of humankind, the "Outer Space Treaty" established the rule of no ownership in space and free access to all states [31]. In this, the Outer Space Treaty was similar to the 1982 UN Convention on the Law of the Seas, which defines the rights and responsibilities of nations with respect to their use of the world's oceans [32]. Another weak point of the Moon Agreement and other treaties is that its main items are broadly sketched and do not provide answers to complicated questions.

Scientific activity on celestial bodies is for the most part, covered, arranged and ratified by existing treaties. However, when commercial and ownership problems appear, legal entanglements will appear too [33]. As mentioned above, there is a need for better regulations regarding issues of liabilities and responsibilities in case of damage or environmental contamination caused by and during space exploitation operations, such as damage caused from debris, exacerbation of debris problem into an environmental pollution and so forth [34].

In addition to international legal framework, there is also a need for national legislation. 2015 will be remembered as the year in which the first national legislation to address space mining was adopted. In the US, the Commercial Space Launch Competitiveness Act was signed into law by US President Barack Obama in November 2015. This Act stipulates that the United States does not assert sovereignty or exclusive rights or jurisdiction over, or the ownership of, any celestial bodies. Nevertheless, it includes provisions to protect the property rights of private companies that will mine asteroids for minerals [35].

In 2016, the government of Luxembourg announced it would seek to develop an industrial sector to mine asteroid resources in space, by creating regulatory and financial incentives [36]. Under this initiative, the government would invest more than $200 million in research, technology and the direct purchase of equity in companies relocating to Luxembourg [37]. In November 2016, it has adopted a draft law to create the legal framework for such companies to operate in Luxembourg [38]. In July 2017 Luxembourg was the first to first European nation to offer a legal framework for utilization of space resources [39]. Other governments are following suit by developing legislation and other mechanisms to support such initiatives.

3. Simulations and roleplaying games as a forecasting method

Roleplaying and war-games are a widely used method for forecasting decisions by two or more parties in a conflict. The origin for these methods stems from the 18th century, when officers and generals in the Prussian army utilized *Kriegsspiel* ["wargame" to practice strategy and tactics. The Prussian victory in the Franco-Prussian war in 1871 was partly attributed to their use of wargames to provide superior training of their officers [40]. Since then, roleplaying games have become an accepted method for forecasting the way in which conflicts are resolved in business, law and politics. Roleplaying is also used to train professionals for future events and cases; this practice is particularly relevant in the legal field [41].

Roleplaying games have shown their merit, particularly in cases in which groups have conflicting and complicated wants and needs. Often in such cases, it has been discovered that even though negotiators can find a zone of agreement, they still fail to reach decisions that are accepted by all. It turns out that expert negotiators often do not realize the emotional and personal needs, desires and difficulties that shape the decision making process. Roleplaying games do not suffer from this oversight, since the players are asked to fully emulate a certain character or side, and the needs and desires of the characters are automatically absorbed into the game's decision making process [42].

Roleplaying games are also of particular use when trying to forecast the impact and consequences of large changes. Experts have an advantage in understanding the results of small changes in their field of expertise, but they lose this benefit when confronted with major and disruptive changes that span many fields. Roleplaying games can provide a different venue for forecasting the results of such cases: the actors react to the changes by consulting with each other in real time, and providing solutions that rise from the group as a whole [43].

4. The scenario and process of the space mining simulation

The scenario was designed with the help of space professionals with backgrounds in space engineering and technology, space politics and international law. The primary purpose was to produce a general, workable scenario that would serve as a starting point to trigger processes and trends in the international system. The simulation was conducted as part of a graduate class in Space Politics at Tel Aviv University, during the spring 2014 semester. The simulation game was presented to the students at the beginning of the semester. About 20 graduate students from the graduate program for security studies and the graduate program for diplomacy participated in the simulation. It should be noted that as often happens with graduate students in Israel, some of them had professional backgrounds in military service, the diplomatic corps, etc.

The initial goal of the simulation was for the students to get a sense of the variety of issues related to the politics of space: political economy, environmental issues, power and security of states, cooperation, diplomacy and international relations, technology, international law, etc.; raise their awareness of actual political dilemmas; and enable them to have at least some first-hand experience in the related process. In conducting the simulation, we made no pretense that we were going to encompass all the issues related to space mining. Rather, the objective was to raise awareness of some of the major issues involved and encourage creativity in searching for potential solutions.

The scenario began in the year 2035, in which Earth's population has grown dramatically, and alternatives must be found to the dwindling natural resources that are essential for the continued growth of the global economy. In an attempt to deal with this challenge, a number of private companies and national space agencies from the U.S. Russia, China, India, and Japan, have been working for several years on developing technologies to extract minerals from space and ship them back to Earth. In January 2035, "Human Welfare", an American based company, is the first to successfully mine minerals in space and transport the cargo back to Earth. The shipment contains large amounts of gold and platinum, which are only a small part of the riches that the mined asteroid contains. Processing enterprises need to be established to transform the raw minerals brought to Earth into usable material for global industries. The technological demonstration, together with an optimistic business plan showing economic viability, produces a new economic and technological reality that has great political and economic implications. The immediate consequence on the global market is a dramatic decrease in the value of gold, the price of which fell by 50% on the World Mercantile Exchange Market. In light of these dramatic developments, the UN Office for Outer Space Affairs (UNOOSA) announces that the annual meeting of COPUOS, held every year in June, will be devoted to the issue of space mining. The meeting will take place in the form of open-ended consultations at UN installation in Vienna. Member states and observer states are invited to express their opinions and discuss the matter.

Several factors contribute to the reliability of the forecasts produced by simulations and roleplaying games. In the experiment described herein, we made use of each factor, as follows:

4.1. Actors must take their role seriously

It is believed that actors can largely be ignorant regarding the dispute in question, as long as they receive the relevant reading material on the subject, and take their role seriously [44]. For that purpose, we asked graduate students to take part in the roleplaying game at the beginning of the semester, while the actual game was played at the end of the semester. First, each student was assigned to a country that he or she was to represent in the simulation [45]. The first task, which lasted for two weeks, was that each student had to get acquainted with the overall characteristics of the country he/she represented: its economy, geo-strategic environment, political issues and so forth. Students were also asked to learn about the country's space policy and activities. Based on this information, in the second task, the students had to define and analyze their country's primary interests and considerations, and evaluate and asses the approach it would take regarding the new technological reality presented in the scenario. For this task students had four weeks to prepare. The final assignment was to prepare the actual simulation game, which was played at the end of the semester. It should be noted that from the beginning, students were aware of the fact that their final grades depended on their performance in all stages of the simulation game, including preparation for it. Thus, most of the students seemed to take their tasks seriously.

To help students prepare for the simulation and specifically for their role in it, they were provided with a list of issues and questions to guide them in thinking about the various aspects of space mining and its potential consequences for world politics. For example, students were encouraged to think about the potential impact of space mining on the international balance of power, and whether they expected the present balance of power to change? Will the status of some nations change? Which countries would be interested in creating their own mining capabilities and companies, or at least directly benefit from the new developments? Which governments would object to space mining and act to stop or disrupt it? What can nations do to avoid or minimize potential damage to their economies?

4.2. Realistic environment

The players need to feel as if they really were the characters they were supposed to be [46]. We simulated the 78th meeting of UN-COPUOS. We provided each player with a flag of the nation they represented; as moderators of the event we conducted the game as though it was an actual meeting of the committee in question. The simulated discussion was divided into three parts. The first part began with a statement by the chairs of the session (played by the authors of this article), who called on the representatives of the different countries present to take responsibility and act together for stability and peace on Earth for future generations. The chairs then invited all the representatives to participate in the discussion. Students then delivered short national statements prepared in advance on behalf of their countries, in which they explained the country's approach and perspective towards the new reality. Among the issues raised in these statements were global challenges, global opportunities, national concerns and national objectives.

The second part simulated a recess in the formal meeting. During this recess, the representatives had the option of approaching and interacting with other representatives, in order to discuss various ways of addressing the issues raised in the statements. The third part of the simulation was another formal session conducted as an open discussion in which the representatives commented on each other's statements. They raised potential mechanisms to mitigate challenges and ways to reach international collaboration. After a total of 3 h, the chairs closed the discussion, thanking all of the participants for their constructive participation. As the final semester assignment, the students were required to compose a position-paper advising the government of the country they represented about the expected new reality.

4.3. Allowing time for collaboration

It is generally recommended to allow time for the parties involved to collaborate with each other, particularly if they're supposed to present a united front in the game [47]. To that purpose, as noted, we allowed the players time before the game to think about their strategies and arguments, and also provided a recess period during which the players talked with each other informally and agreed on strategies and alliances for the rest of the game.

Naturally, a simulation game, such as the one presented here, has limitations. In this case, limitations are primarily outcomes of the characteristics and requirements of the program under which this class took place. First, since this was a graduate class, it had fewer than 20 students. Thus, a large number of countries could not be included. For this reason, we decided not to include non-state organizations, which in real life may affect the future of space-mining. Second, it was not possible to conduct a long simulation. Third, the students were not space professionals, and therefore lacked technical and other relevant knowledge. Nevertheless, it turned out that this limitation was potentially an advantage, because students were very open-minded about the issues.

Fourth, it must be noted that students from one country and culture are limited by necessity in their ability to emulate the mindset of people from other nations and cultures. While this limitation is difficult to mitigate completely, the students were asked to prepare for the simulation by reading about the nations they were representing, including details about their populations, cultures, and religious beliefs.

5. Simulation outcomes

The discussion that ensued during the simulation can be divided into three main sections. First, the discussion concentrated on the possible consequences of the ability to transport materials mined from space to Earth on the stability of the international system and the world order. In this context, the right to exploit commonly held resources, ownership issues, share of profits and knowledge, were discussed. Second was a discussion of the potential opportunities for economic growth, development, and prosperity. In this context, ideas were also raised regarding the potential solutions for the distribution of technological development and the actual distribution of goods. A way was sought to enable a wide range of countries to benefit from the new reality, even if they do not directly engage in space mining, for example, by processing the imported space minerals on Earth.

Third, a brainstorming session was held regarding the various mechanisms which could and should be developed at the global level. Such mechanisms will be necessary to mitigate the challenges, maximize the opportunities, and reach a broad international consensus among participant states regarding the conduct of world politics in the new international reality.

The resulting discussion highlighted the tensions between powerful countries and less powerful or weaker countries in the context of the global struggle for resources and power. In general, the participants divided into three main groups of countries. The first group contained spacefaring countries, which have substantial space capabilities and are therefore capable of actively participating in mining minerals in space and transporting them to Earth. For the most part, this group contains the leading world powers. In the simulation, it became clear that the countries in this group compete with each other for leadership of the process of space mining, and the tangible goods and intangible benefits involved, such as the considerable political power accrued. Countries such as the US advocated for an approach that would not restrict development, and instead would encourage innovation and entrepreneurship, while searching for ways to facilitate proper solutions to reach international cooperation. For this reason, during the debate and in response to objections and criticism by other less developed countries, representatives of the leading spacefaring countries highlighted the fact that the new technological breakthroughs would be enjoyed by everyone. They would provide opportunities for all nations to improve their economies, and increase the well-being of their citizens. These statements were aimed at easing the antagonism of the less developed countries, and raising their solidarity and support, in order to achieve a most favorable world-wide political and psychological impact.

Emerging spacefaring countries composed the second group. Under the leadership of the leading spacefaring nations, these countries were looking for ways to maximize their gains from the new reality. Representatives of these countries focused their efforts on maximizing their chances of taking an active part in the overall process, and upgrading their position in the evolving economy of space mining. The strategic approach they adopted was to find ways to integrate their country into the value chain of space mining, whether in outer space or on Earth as soon as possible and to the maximum extent, in a way that would assure long-term commitment of the leading countries. For example, they bargained with the leading spacefaring nations concerning the establishment of some of the infrastructure on their territories, and negotiated to be part of the future technological development through international collaborations.

The third group consists of countries with no meaningful space capabilities. Many of the representatives of these countries argued against space mining and the transport of materials to Earth. For them, the new technological and economic reality is a distant and unreachable dream, which imposes serious threats for their economies and stability. In general, their approach represents a historic colonial tension. Their approach can be defined as a serious lack of confidence in the global diffusion of wealth. Many of them argued that the technological and economic development at stake widens the existing gap between them and the developed and advanced countries. They expressed deep concerns that the new reality would work against them, because it would perpetuate current economic and political gaps. Moreover, it would deprive them of their fair and proper participation in the global share of resources, and thus seriously damage their future chances of development. Some of them even demanded that space mining be banned. On a more practical level, they called for a much more inclusive process regarding space mining. In addition, the representatives of these countries called on the international community to develop mechanisms for compensation, which would be provided to them by the countries directly benefiting from space mining. This way, it was argued, they too would be able to enjoy and benefit from the new economic order, and the concept of the "benefit to all mankind" would have practical fulfillment.

In addition, tensions were also reflected within each of the aforementioned groups. These tensions originated from differing national interests, various approaches to the management of innovation and the aspirations of individual countries in the international system. For example, in the group of spacefaring countries, there was disagreement between the U.S. and other countries, including some of its allies, which often took different positions regarding this issue. Russia and China expressed a more favorable approach to the developing countries, by calling for the development of global mechanisms of compensation.

In the open discussion conducted in the third part of the simulation, a number of ideas about the proper ways to manage the new situation internationally were raised. Among them was the development of international mechanisms for regulation, licensing, and taxation of space mining, similar to other such international mechanisms, which were adopted in order to organize, regulate and control activities by nations in the global commons, such as the International Seabed Authority. In this capacity, the students suggested the establishment of a "world space bank", which would be entrusted with the financial management of the revenues from the licensing and taxation. The money thus collected would be used to achieve the following global objectives:

(a) Financial compensation for the countries whose economies would be directly and significantly affected by the new economic order. These countries are generally the ones wherein the economies are based on minerals and natural resources, the value of which would significantly drop.
(b) Develop technological knowhow and expertise, as well as build up infrastructures, in countries lacking the national capacity to develop indigenous space expertise with their own resources. For example, the Space Bank would conduct training for students and professionals from developing countries, in order to enable these countries to develop initial national capacity in space technology. Another possible direction would be for the Bank to sponsor the establishment of space centers in these countries.
(c) Support the establishment of needed infrastructure in developing countries, so as to take part in the value-chain of space mining, especially on Earth.

Provide funding for global activities to assure safe and sustainable use of space by all countries. For example, funding would be provided to a designated UN agency which would be responsible for monitoring and regulating space traffic, tracking space debris, and conducting active removal of such objects. This innovative idea of establishing a "world space bank" testifies to the creativity which is needed by all players in this "global game" i.e. spacefaring nations, emerging spacefaring nations and players with no significant capabilities. In order to avoid potential conflicts over this expected disruptive capability the challenge leading and emerging spacefaring nations are facing is to find ways to make as many nations as possible parties to the value chain of space mining. The challenge of weaker states is to persuade spacefaring nations to incorporate them into this chain. In addition, the adoption of such mechanisms would demands adaptation by the international legal framework.

5.1. Lessons about space mining

The lessons of this simulation indicate several issues. First, the game highlighted different group behavior in world politics concerning the new reality, with a sharp distinction between the haves and have-nots. Second, it provides insight regarding different approaches to innovation on the national level and international level. Unsurprisingly, in general, the stronger countries operated according to the principles of "first come, first served", while others held to the approach of "space for humanity". Nevertheless, the strong players expressed a pragmatic approach, in which they expressed an understanding of the overall concerns and needs of the international community. They suggested ways to utilize the new reality for the development of mechanisms which would provide service to the overall space environment.

The concerns raised by the representatives from the developing countries which lack minimal space expertise, regarding the expanded gaps between them and the leading spacefaring nations, are perfectly understandable. Nevertheless, is the strong opposition they expressed to the overall new reality indeed the strategy they should adopt? Would a compensation mechanism work in their favor and serve their long-term goals optimally? What does that tell us about international approaches to innovation and entrepreneurialism? We conclude that under the guise of a demand for a fair distribution of goods, the approach reflected by these countries in the simulation focuses on imposing restrictions on countries rather than on actually developing opportunities to get involved in the process. The focus on mechanisms of compensations rather than on mechanisms to develop capabilities may evolve to be a "self-fulfilling prophecy", which will preserve and expand existing gaps. Further research is needed to examine the potential effect of compensation methods on the economy and innovation systems in these countries. In the long-run it may turn out that such methods do not optimally serve these countries, rather they will perpetuate their lack of development and lower status.

An important concern raised by the US representatives was that restrictions on technological development could lead to stagnation and damage the spirit of innovation that pushes the market in general. Indeed, compensation mechanisms by themselves do not produce incentives and opportunities for development. In the long term, compensation mechanisms which are not followed by mechanisms for actual development of skills and knowledge perpetuate and exacerbate the gaps. Instead of resisting development and demanding compensation, these countries should act to achieve full partnership in space mining ventures, which would also contribute to their development.

On the legal issue, motivation to further develop mechanisms and regulations for this new reality stems from the fact that most items included in the existing space treaties were established when human activity in space was dominated by governmental activity. Therefore, these treaties reflect the perspectives and needs of states. Nowadays, the development of private and commercial enterprises in space requires new perspectives and thinking regarding regulation [48].

Finally, looking ahead to the time when space mining will become a reality, and given its positive potential and negative challenges, we advise that this issue be discussed in international forums sooner than later. Scholars and professionals should put their minds to the variety of technological, scientific, legal, political and economic issues that are expected to arise. By doing so ahead of time, they will be able to develop principles and frameworks that can maximize the benefits of the new reality while minimizing the risks to global stability.

5.2. Lessons for future simulations

Overall, the simulation proved to be a success – both in pedagogically and in the way it encouraged thinking about a disruptive technological subject, identifying some of its complex consequences on the world, and devising ways to deal with them.

When asked for insights about the simulation, the students' responses were overwhelmingly positive. Indeed, several students requested that such simulations be held throughout the semester, starting with an introductory session in which the students introduce their nations to each other.

One of the students expressed his opinion in the following manner, which highlights the usefulness of the simulation as a way to analyze issues international relations:

> “I actually understood how international relations are really made, who 'my friends' are, who's against me and who stands with me …. ”

One of the main lessons derived from the simulation concerned the necessity of having breaks between the three discussion sessions. Breaks, even short ones of only a few minutes, enabled the participants to talk with each other privately, frequently reaching understandings and agreements ‘behind the scenes’. Coalitions and collaborations arose mainly as a result of such breaks in the discussions.

We strongly believe that simulations and role playing games could be used to analyze and better understand other international situations as well, and look forward to conducting similar simulations in the future.

6. Conclusions

In this study, we examined the potential impact that could result from a successful space mining venture, and the initial responses by nations around the world. We found that while spacefaring nations were largely eager to exploit resources from space, most developing nations in the simulation were far less excited about the possibility, and understandably feared that this technological breakthrough would disrupt their own growth and development by making their natural resources virtually worthless overnight.

We believe that successful ventures in the field of space mining would have to address these international issues and tensions sooner or later. One potential solution that arose from the simulation was creating a mechanism of a Space Bank that would tax successful space mining ventures, and use the money to help promote space-related science and technology in developing nations. This Space Bank would thus serve as a ‘ladder to space’ that would support the advancement of all nations in their outreach towards outer space.

The methodology underlying the simulation has proven to be particularly useful, both for teaching about this complex topic, and for promoting brainstorming and out-of-the-box thinking. We believe that similar simulations could be used to analyze the consequences of many other disruptive developments. Other simulations could be used, for example, to analyze the possibility of using the mined resources to sustain a “deep space economy”, or to examine the security risks posed by asteroids dragged into orbits around Earth. Finally, larger simulations in the future should include non-state actors, such as commercial firms, terrorist groups and representatives of the scientific community.

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