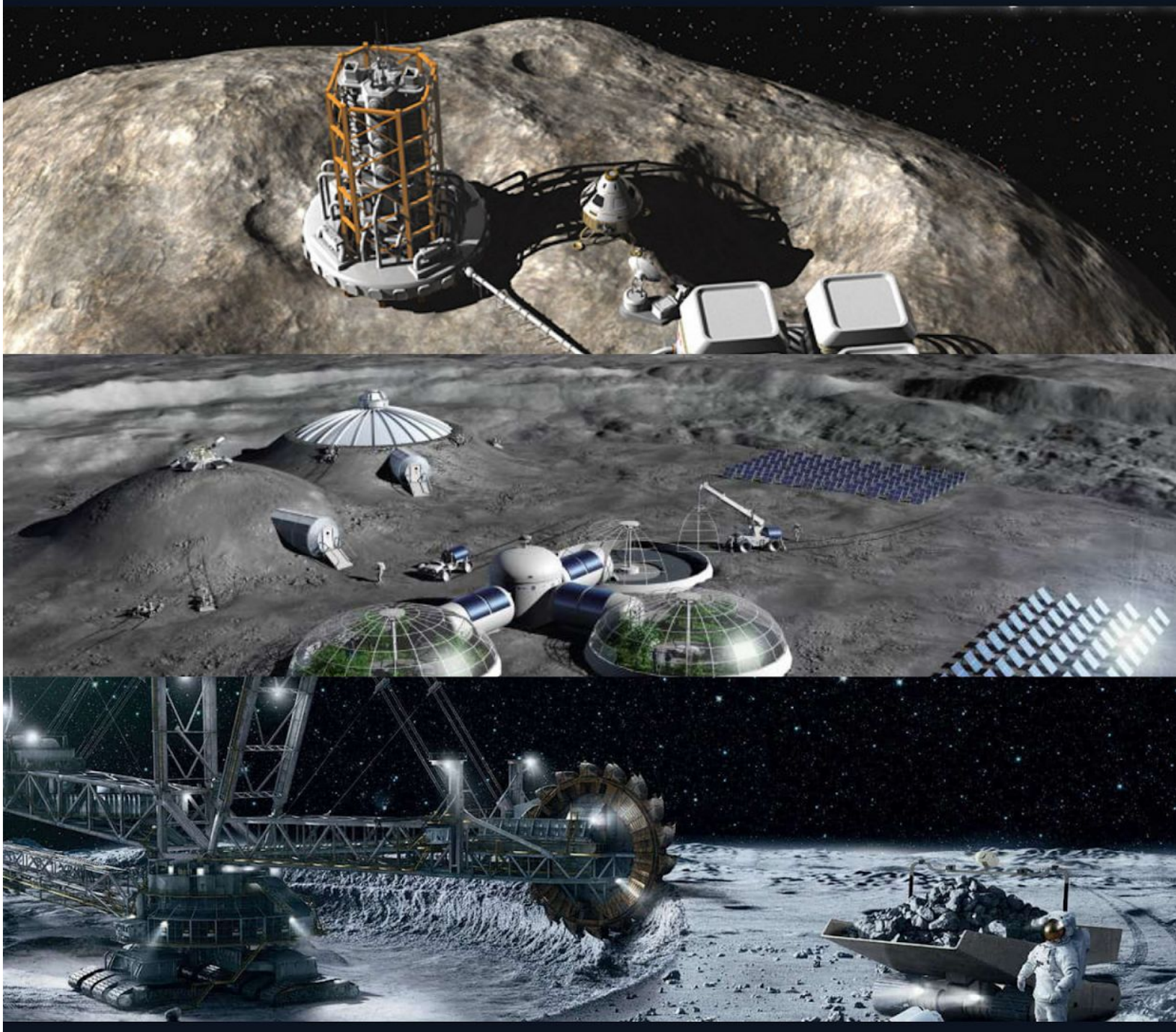
ECONOMIC EFFECTS OF REGULATING THE SPACE MINING INDUSTRY



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Economic Effects of Regulation on the Space Mining Industry

Introduction

In the words of the famed astrophysicist Neil DeGrasse Tyson, "the first trillionaire there will ever be is the person who exploits the natural resources on asteroids."[1] Space mining may appear to be a far-away fantasy, but some entrepreneurs are already looking to be among the first movers in this industry. Much like how the great industrialists of John Rockefeller and Andrew Carnegie made use of the ever-expanding American frontier to fuel their extractive industries, future business magnates will harness the power of asteroids and other celestial bodies to turn a lucrative profit. Perhaps unlike gilded-age industrialists, however, potential space entrepreneurs are being hampered by obsolete regulation. International treaties drafted to ensure the peaceful and scientific use of outer space are remnants of an era when space travel was conducted solely by government actors and are ill- equipped to handle extraterrestrial commercial interests. Indeed, it is likely that the historical framework of international extraterrestrial law has slowed the development of the extractive industry in space, resulting in recent bold regulatory changes by countries including the United States in an attempt to incentivize future development in this sector.

[1] Kramer, Katie. "Neil DeGrasse Tyson Says Space Ventures Will Spawn First Trillionaire." *NBCNews.com*, NBCUniversal News Group, 3 May 2015, www.nbcnews.com/science/space/neil-degrasse-tyson-says-space-ventures-will-spawn-first-trillionaire-n352271.

Overview of Space Mining

In order to comprehend the implications of policy on space mining, it is vital to understand the potential benefits and risks for firms looking to enter this industry. One of the major draws for space entrepreneurs is the sheer quantity of riches available in space, and both commercial and governmental actors have taken interest. The Japanese Aerospace Exploration Agency, or JAXA, has sent two *Hayabusa* probes to collect materials from asteroids and return them to Earth, and as soon as 2022 NASA plans to launch a mission to land on 16-Psyche, an M-Type, or metallic, asteroid estimated to be worth around $10,000 quadrillion (more than the global GDP).[2,3] That is not to say that humans could ever extract the full value of the asteroid, nor would the materials mined retain their full value if all placed on the market. Nonetheless, asteroids may eventually provide access to rare and unique materials with a variety of industrial purposes. M- Type asteroids such as 16-Psyche are the remains of planetary cores which have been flung into space and are filled with valuable and rare platinum group metals (PGMs).[4] The heavy weight of these PGMs means that over time they have sunk into the Earth's mantle and core, rendering them mostly inaccessible for mining operations.[5] Furthermore, the more common C- Type asteroids contain large quantities of water, which can be extracted and transformed into fuel and oxidizer in orbit for more efficient long-distance space travel or colonization.[6] In

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[2] "Asteroid Explorer 'HAYABUSA' (MUSES-C)." *JAXA*, Japanese Aerospace Exploration Agency, global.jaxa.jp/projects/sas/muses_c/.

[3] Giuliani-Hoffman, Francesca. "Psyche, an Asteroid Believed to Be Worth $10,000 Quadrillion, Is Observed through Hubble Telescope in New Study." *CNN*, Cable News Network, 1 Nov. 2020, www.cnn.com/2020/10/31/us/psyche-asteroid-ultraviolet-trnd-scn/index.html.

[4] Shevchenko, V.V. "Extraterrestrial Resources." *Oxford Research Encyclopedia of Planetary Science*, 30 Jan. 2020, oxfordre.com/planetaryscience/view/10.1093/acrefore/9780190647926.001.0001/acrefore-9780190647926-e-151.

[5] "Extraterrestrial Platinum Was 'Stirred' into the Earth." *Phys.org*, Phys.org, 30 July 2009, phys.org/news/2009-07-extraterrestrial-platinum-earth.html.

[6] National Research Council. "Chapter 4: Asteroids and Meteorites." *Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies: Framework for Decision Making*, National Academy Press, 1998, p. 44, www.nap.edu/read/6281/chapter/6.

addition to asteroids, the moon may also eventually become a mining hub as it features large quantities of helium-3, a unique isotope of helium which is almost nonexistent on Earth.[7] Helium-3 could theoretically be used to fuel fission reactors without the burden of toxic radioactive byproducts which result from Earth-based nuclear power.[8] Although constructing helium-3 reactors on the moon is currently economically unfeasible, helium-3 could eventually be the answer to achieving truly environmentally sustainable energy production.

A major limiting factor to commercial enterprises taking advantage of the wealth of rare materials in space is the upfront cost of planning and launching a space mining operation. The total cost of such an operation is estimated to be around $2.6 billion, while success is never guaranteed in extraterrestrial missions.[9] The profitability of a space mining expedition is theoretically possible, as shown by research from the Initiative for Interstellar Studies. When considering a space mining operation, a firm can predictably break even within 6 and 5.5 years for missions centered around water or platinum in a conservative scenario, respectfully. Looking at both Figure 1 and Figure 3, it is apparent that although a smaller spacecraft is beneficial for reducing initial losses; larger spacecraft and more frequent spacecraft cycles ensure for a faster return on investment and shorten the duration of time needed to become profitable.[10]

Evidently, mining on Earth is currently more profitable and less risky than doing so in space. Launch services, such as those provided by SpaceX and Arianespace, are intrinsically linked to the success or failure of any potential industry in space. This can be seen through the

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[7] "Mining Rare Mineral From The Moon." *Popular Mechanics*, 7 Dec. 2004, www.popularmechanics.com/space/moon-mars/a235/1283056/.
[8] Mining Rare Mineral From The Moon." *Popular Mechanics*, 7 Dec. 2004, www.popularmechanics.com/space/moon-mars/a235/1283056/.
[9] David, Leonard. "Is Asteroid Mining Possible? Study Says Yes, for $2.6 Billion." *Space.com*, Space.com, 24 Apr. 2012, www.space.com/15405-asteroid-mining-feasibility-study.html.
[10] Heina, Andreas M., et al. "A Techno-Economic Analysis of Asteroid Mining ." *Initiative for Interstellar Studies*, Oct. 2018, arxiv.org/ftp/arxiv/papers/1810/1810.03836.pdf.

shifting focus of Deep Space Industries from space mining to propulsion following their acquisition by the Bradford Space group.[11] DSI was founded with focus on asteroid mining and garnered considerable media attention in 2016 and 2017 for preparations and intentions to launch both Prospector X and Prospector 1. These would have allowed them to be the first interplanetary mining mission to land on an asteroid and study the potential profitability, but these projects have been completely scrapped.[12]

However, exponential growth in funding for space mining and exploration from various startups and proliferation of such firms has led to a decrease in launch prices, which is essential in ensuring the long-term financial viability of outer space industries.[13] Innovations such as SpaceX's reusable rockets and interest by national governments in funding permanent space colonies mean that the astronomical fixed costs associated with the space industry may decrease over time, but will nonetheless continue to be a significant barrier to entry for new firms. As a result, any successful commercial space regulation must focus on strong property regulations so that commercial actors can be properly incentivized to overcome large up-front costs.

Companies may consider transporting and suspending asteroids in Low-Earth Orbit If an they contain the desired resources and the expected revenue outweighs the costs of the entire process. There are several characteristics startup companies will take into account to select an asteroid to mine and whether to transport it. Suspending an asteroid in LEO is a promising

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[11] Foust, Jeff. "Deep Space Industries Acquired by Bradford Space." *SpaceNews*, 2 Jan. 2019, spacenews.com/deep-space-industries-acquired-by-bradford-space/.

[12] Dorminey, Bruce. "Deep Space Industries To Probe Near-Earth Asteroid." *Forbes*, Forbes Magazine, 18 Nov. 2016, www.forbes.com/sites/brucedorminey/2016/11/18/deep-space-industries-to-probe-near-earth-asteroid/?sh=4759bcba5e3b.

[13] Mann, Adam. "SpaceX Now Dominates Rocket Flight, Bringing Big Benefits-and Risks-to NASA." *Sciencemag.org*, Science, 20 May 2020, www.sciencemag.org/news/2020/05/spacex-now-dominates-rocket-flight-bringing-big-benefits-and-risks-nasa.

opportunity for space mining as it allows firms to maximize the frequency in which they are able to extract resources from the asteroid and, consequently, their profits.

The first of which is the proximity to a location where engineers can devise a capture strategy. The second is the mass and velocity of the asteroid, as the heavier the asteroid is and faster the asteroid is traveling, the higher the costs will be for asteroid capture. Figure 2 notes certain asteroids from the Near Earth Object Close Approach database which NASA has deemed "Ideal" for asteroid capture, but it is important to note the irregularity with the lengths of time between the approach dates. In practice there are a plethora of other unknowns which must be taken into account for these missions, including but not limited to: the surface conditions, the asteroid's spin axis, which will create complications for both the pickup strategy and location (must be at the center of mass), as well as altering the fuel consumption strategy if the asteroid has an irregular rotation. [14]

Economic Impact of International Extraterrestrial Regulations

In keeping with the nationally- funded space travel of the 20th century, international space law takes a decidedly government- oriented view of extraterrestrial affairs. That is to say, current international regulations focus more on potential territorial disputes and preventing the militarization of space rather than facilitating commerce. It is likely that this approach has hindered the progress of the space mining industry thus far. Unfriendly regulatory frameworks and poor property rights protections have brought into question the capacity for potential first movers to make a sufficient return on investment, and as such development of the space mining industry has occurred at a slow pace despite the wealth of resources in space.

[14] Covey, Stephen D. "Technologies for Asteroid Capture into Earth Orbit." *National Space Society*, May 2011, space.nss.org/technologies-for-asteroid-capture-into-earth-orbit/.

The Outer Space Treaty of 1967 may be the single most important piece of space legislation to date, and can be interpreted to take a decidedly anti- entrepreneurial approach to space. Among the most important clauses in this treaty is Article II, which states: "Outer Space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."[15] Although this clause is focused on the behavior of national actors, it may have important indirect implications on the commercialization of space. There is a question as to whether or not the outlawing of claiming territory in space applies only to national actors, or whether commercial actors are subject to this same rule. If commercial actors are deemed to be unable to claim dominion over celestial bodies or lands, this would hamper their ability to claim ownership over mines and could complicate the process for acquiring mining concessions in the first place. As permanent appropriation "by means of use or occupation" is outlawed, prospective miners would have to conduct touch-and-go missions rather than establishing permanent mines on the surface of the moon or asteroids, limiting potential return on investment.

The potential return on investment for space mining is further complicated by Article I of this treaty. One of the provisions in Article I states that "there shall be free access to all areas of celestial bodies."[16] If this non-exclusivity is to be taken literally, then investment in asteroid or moon mining may be hampered by the "free rider problem". According to economists Robert Cooter and Thomas Ulen, the free rider problem arises when one party stands to "benefit at no cost to themselves from the payment of others."[17] This is a particularly serious issue in the

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[15] Reynolds, Glenn Harlan. "Who Owns the Moon? The Case for Lunar Property Rights." *Popular Mechanics*, Popular Mechanics, 1 June 2008, www.popularmechanics.com/space/moon-mars/a3358/4264325/.

[16] *2222 (XXI). Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*. United Nations Office for Outer Space Affairs, 19 Dec. 1966, www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html.

[17] *Law and Economics*, by Robert Cooter and Thomas Ulen, Pearson, 2014, p. 41.

industry of asteroid mining. There are currently two options for mining an asteroid. Either a mining probe could intercept a suitable asteroid as it passes near Earth, or the asteroid could be placed in a stable orbit around the Earth or moon where it can be more easily and efficiently mined in the long term. The second choice allows for the asteroid to be mined continuously, rather than simply on a single occasion, and therefore will likely provide a greater long-term return on investment. However, if other actors can freely access and mine the asteroid, then there ceases to be an economic incentive to place it in stable orbit. Placing an asteroid in a chosen orbit may seem difficult, but NASA had plans to do so in 2014 before budget cuts tabled the mission.[18] Although possible, finding an adequate asteroid, placing it in a stable orbit, and mining it would be a very expensive and several years-long mission. As a result, unless capturing an asteroid renders it the exclusive property of the company who did so, it is the "free riders" who will make the greatest profit, rather than the company who made the original investment. Without exclusive rights, the free rider problem may limit asteroid miners to extracting material from asteroids passing near Earth, or miners will simply refrain from entering the industry at all if the return on investment from touch-and-go mining is not sufficient.

Protection of private property is arguably the most important commercial right for the advancement of economic progress in this industry. Without protections for private property, there is no incentive for commercial actors to improve their assets or innovate, as there is no guarantee that they will reap the rewards of their investment. Particularly in an industry with extraordinarily high fixed costs such as space mining, it is imperative that property rights ensure that early entrepreneurs can be confident enough in property protections to take the risk of investing. This has not historically been the case and is likely why interest in commercialized

[18] Wilson, Jim. "What Is NASA's Asteroid Redirect Mission?" *NASA*, NASA, 13 Apr. 2018, www.nasa.gov/content/what-is-nasa-s-asteroid-redirect-mission.

space mining did not truly appear until 2012, despite the technology for reaching other celestial bodies being available over 40 years prior.[19] Alternatively, perhaps the extraordinary fixed costs required for establishing a space mining operation are the main reason why such a project has yet to come to fruition. Nonetheless, the vague and anti- entrepreneurial regulations set in the 1967 Outer Space Treaty will certainly have done the development of the industry no favors, and if said treaty continues to be the basis for extraterrestrial commercial affairs in the future, it is difficult to imagine space mining ever becoming financially viable.

US Regulations Regarding Extraterrestrial Property Rights

Recognizing the failure of the 1967 Outer Space Treaty in fostering extraterrestrial industry, the US government and several other countries have taken a decidedly different approach, and the US in particular has been quite receptive to improving property right protections in space. US changes in regulation have come at the behest of asteroid mining startup firms. The two most prominent asteroid mining startups, Planetary Resources and Deep Space Industries, lobbied Congress in 2015 to provide favorable property rights legislation for themselves and future space mining companies.[20] The result was the US Commercial Space Launch Competitiveness Act, otherwise known as the SPACE Act. Unlike the 1967 Outer Space Treaty, the SPACE Act gives property rights to any individual who extracts material from a

[19] Abrahamian, Atossa Araxia. "How the Asteroid-Mining Bubble Burst." *MIT Technology Review*, MIT Technology Review, 26 June 2019, www.technologyreview.com/2019/06/26/134510/asteroid-mining-bubble-burst-history/.
[20] Abrahamian, Atossa Araxia. "How the Asteroid-Mining Bubble Burst." *MIT Technology Review*, MIT Technology Review, 26 June 2019, www.technologyreview.com/2019/06/26/134510/asteroid-mining-bubble-burst-history/..

celestial body, be that metals, water, or anything else.[21] Current US regulations as set by the SPACE Act essentially set a "rule of first possession" for property rights in space, as the first actor to extract a resource has the rights to said resource. This method has several advantages. Firstly, it is generally cheap and easy to prove who was the first to extract a resource. As a result, any potential disputes may be easier to adjudicate. Furthermore, this approach theoretically incentivizes rapid growth as companies vie to be the first to extract the most profitable and accessible materials, rather than risk "losing out" on these resources to competitors.

A potential drawback from the rule of first possession approach could be that companies invest and harvest too much in order to prevent rivals from acquiring resources. In economics, this phenomenon is known as "the tragedy of the commons", and according to Cooter and Ulen is defined as the "depletion of an open-access resource by overuse."[22] In theory, if there is non-exclusive access to celestial bodies, businesses will be incentivized to mine as much of the more accessible bodies as quickly as possible, so as to acquire these resources before they are inevitably mined by competitors. As a result, current legislation may incentivize rapid industrial growth at the expense of conservation and efficient use of celestial bodies.

Nonetheless, it is unlikely that such a scenario would occur in any near future. For a tragedy of the commons to occur there must be congestion and overuse of a resource. However, the cost of developing and launching a space mining operation will likely act as a sufficient barrier to prevent firms from meaningfully interfering with each other's activities and overharvesting resources. In fact, the position of space resources as uncongested common resources which require significant upfront investment uniquely suits this *open* access approach. According to Cooter and Ulen, an open access approach is when a system "allows everyone to

[21] Fecht, Sarah. "The US Senate Just Passed an Important Space Bill with Unanimous Approval." *Business Insider*, Business Insider, 12 Nov. 2015, www.businessinsider.com/senate-passes-space-act-2015-2015-11.
[22] *Law and Economics*, by Robert Cooter and Thomas Ulen, Pearson, 2014, p. 140.

use a resource, and no one can exclude anyone from using it."[23] Such a resource is accessible to the public and owned in common, which celestial bodies are, both due to this being affirmed in the 1967 Outer Space Treaty and due to the sheer difficulty of establishing boundaries in space in the first place. As boundary maintenance would be expensive (and potentially illegal) in space, and congestion to celestial bodies is currently non-existent, taking an open access approach is likely more efficient than private ownership in most cases, and does not risk a tragedy of the commons occurring in the near future.

Nonetheless, this approach still begs the question of what to do if a firm meaningfully changes the orbit of an asteroid to better extract materials from it. If the SPACE Act is interpreted so that doing so is equivalent to "extracting" a resource, then perhaps the free rider problem which stems from the establishment of *all* celestial bodies as common resources can be solved. Alternatively, if the idea of celestial bodies as open access resources is universally applied without exception, then the free rider problem remains and could hamper the most efficient use of resources. It remains to be seen how the SPACE Act will be interpreted, but it is likely that the most economically beneficial course of action is to understand space as a combination of open access resources and private ownership. Bodies which have not been significantly altered by an actor should remain common resources due to the difficulty of establishing boundaries in space, but firms which invest in significantly facilitating access to an asteroid should own the exclusive rights to said asteroid, so as to eliminate the free rider problem.

Although the SPACE Act is an important start to making space mining commercially viable, potential issues remain. One such issue is a result of the SPACE Act being a strictly US piece of legislation, rather than international law. As the SPACE Act is US legislation, there is

[23] *Law and Economics*, by Robert Cooter and Thomas Ulen, Pearson, 2014, p. 142.

no certainty that there will be any ability to claim damages caused by foreign firms, or indeed to ensure compliance in general. *The Economist* notes that "national law will only protect firms from competing claims by their compatriots," meaning that if a US firm were to have a legal dispute over property rights in space with a Chinese or Japanese firm, there is currently no clear system for international adjudication.[24] Furthermore, the guidelines for remedies as set by the SPACE Act are vague, simply stating that actors must "avoid causing harmful interference in outer space" and are allowed to sue those who do so in US court.[25] Although an important step in the right direction, the SPACE Act is clearly lacking in its establishment of suitable remedies, and it remains to be seen how any potential transnational disputes would be adjudicated. A long term solution may be the creation of an international body solely dedicated to extraterrestrial mining, similar to the International Seabed Authority which grants drilling licenses on Earth.[26] However, considering the generally business- unfriendly international space treaties of the past, including the 1967 Outer Space Treaty and the 1979 Moon Treaty (which outright bans space mining, and which no major spacefaring nation is a party to) it may be that international law would serve to increase barriers to commerce in space rather than lessen them.[27]

Another potential issue is the compatibility of the SPACE Act with the 1967 Outer Space Treaty. If the US or other spacefaring nations wished to comply with the Outer Space Treaty, it is uncertain how compatible business friendly legislation, including the SPACE Act, would be with international law. Certain aspects of the SPACE Act, including the potential for ownership and contamination of celestial bodies (depending on interpretation) may be irreconcilable with

[24] K.W. "Who Owns What in Outer Space." *The Economist*, The Economist, 12 June 2018, www.economist.com/the-economist-explains/2018/06/12/who-owns-what-in-outer-space.
[25] Palazzolo, Joe. "Did the U.S. Make Asteroid Mining Legal?" *The Wall Street Journal*, Dow Jones & Company, 1 Dec. 2015, www.wsj.com/articles/BL-LB-52649.
[26] K.W. "Who Owns What in Outer Space." *The Economist*, The Economist, 12 June 2018, www.economist.com/the-economist-explains/2018/06/12/who-owns-what-in-outer-space.
[27] Listner, Michael. "The Moon Treaty: Failed International Law or Waiting in the Shadows?" *The Space Review*, 24 Oct. 2011, www.thespacereview.com/article/1954/1.

the Outer Space Treaty. Indeed, there has already been some international outcry to the passage of the SPACE Act, with Sa'id Mosteshar, the director of the London Institute of Space Policy and Law, stating that "any U.S. entity obtaining asteroid resources would be in contravention of international law, as would the government for permitting it."[28] As a result, it remains to be seen whether domestic or international law will take precedence, and whether or not the US would be willing to flaunt international law for the sake of implementing more efficient economic policy.

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Despite the bold measures taken by the SPACE Act, there has not yet been a visible commercial boom in the space mining sector. In fact, both Planetary Resources and Deep Space Industries were eventually acquired and ceased to exist as space mining-oriented entities, regardless of the potential fortunes to be made in the sector. Simply put, these companies could not be profitable on timescales that would be palatable to investors, with timescales of 15 or

[28] Palazzolo, Joe. "Did the U.S. Make Asteroid Mining Legal?" *The Wall Street Journal*, Dow Jones & Company, 1 Dec. 2015, www.wsj.com/articles/BL-LB-52649.

more years touted to be necessary to turn a profit.[29] As a result, once the early excitement surrounding these companies wore off, pragmatic investors slowly turned their backs.[30]

Indeed, it appears that telecommunications, launch, and data industries are currently the vanguard of space commerce, with 79% of investor capital in Q1 2019 going to satellite-related companies.[31] Nonetheless, this does not mean that space mining will forever be relegated to science fiction fantasy. Even in the aftermath of the collapse of Planetary Resources and Deep Space Industries, there are smaller and potentially more versatile startups looking to push the sector forward. Among these are Asteroid Mining Corporation, which has a prospecting mission planned for 2023, and Trans Astronautica Corporation, which will use optical mining to extract water from asteroids to be used in long-term space travel.[32, 33] Additionally, larger firms such as Jeff Bezos's Blue Origin have taken interest as well, with Blue Origin having begun preliminary research into establishing mining colonies on the moon.[34] Private enterprises combined with governments' investments in establishing a moon base could eventually be vital both to lowering costs of mining on the moon and of capturing asteroids in a stable orbit to be mined. As a result, there is certainly reason to be bullish about the space mining industry's future despite past failures. Furthermore, perhaps past ventures have been too focused on the extraction of space resources to return to Earth. Such an operation would be ludicrously expensive any time in the near future, and as a result there is not enough of a financial incentive for space mining to replace terrestrial mining. However, if SpaceX and others' vision of putting humans on other

[29] Abrahamian, Atossa Araxia. "How the Asteroid-Mining Bubble Burst." MIT Technology Review, MIT Technology Review, 26 June 2019, www.technologyreview.com/2019/06/26/134510/asteroid-mining-bubble-burst-history/.
[30] Ibid.
[31] Ibid.
[32] "Our Missions." Asteroid Mining Corporation, asteroidminingcorporation.co.uk/our-missions.
[33] "Optical Mining." Trans Astronautica Corporation, https://www.transastracorp.com/optical-mining.html/
[34] Boyle, Alan. "One Year after Planetary Resources Faded into History, Space Mining Retains Its Appeal." GeekWire, 4 Nov. 2019, www.geekwire.com/2019/one-year-planetary-resources-faded-history-space-mining-retains-appeal/.

planetary bodies is to be successful, we may necessarily need in-space mining to make such expeditions feasible. Water and fuel are both remarkably heavy, and their transportation represents a significant limiting factor to long-distance space travel. Therefore, the first successful space mining ventures may not tap into the endless sources of rare Earth materials at all, but rather function as a means to facilitate the continued human colonization of the cosmos.

International Policy Surrounding Space Mining

At the forefront of commercial space mining sits Luxembourg, a small western European nation known for its extensive wealth. Given that there were and are little to no competitors in the field, Luxembourg's quick expansion into the industry is a signal to the possibly lucrative future of asteroid mining. Luxembourg has already labeled itself as the "Silicon Valley of Space", speaking to the future-focused technology sector, and by doing so has also guided focus away from investment into American companies and towards intra-European investment. By diversifying their economy and expanding into space, Luxembourg is solidifying their pledge to private space mining and exploration.

Their commitment to space mining began in a 2016 investment into American company Planetary Resources, a firm designed to explore future possibilities of using asteroids for their resources. Luxembourg also invested a substantial amount in Deep Space Industries to explore the possibilities of water/minerals being found in space, alluding to a greater interest in the space industry as a whole. As there is a strong lack of governance surrounding space mining, Luxembourg passed their own piece of legislation detailing their framework for intergalactic

mining. Essentially, they voted that any private company is allowed to mine/use the asteroids for their resources, though no one group can ever privately own the entity.

In order for private firms to begin crafting long-term plans regarding space mining, they require transparency from governments regarding the institution of property rights. Although nations must first define their own individual legislation, it is also crucial that there be international cooperation and universal code regarding space mining, just as there is in any economic system that involves earthly resources. As established, the United States is one of many countries that has created such legislation; in 2017 Luxembourg became the first European country to design space property rights, and according to the Harvard Business Review, Japan and the United Arab Emirates have also recently established extraterrestrial property rights laws.[35] However, in order for firms to plan for the future, there must be a more comprehensive international agreement so that companies can be certain that their private property will be recognized across borders, especially as space becomes increasingly populated with actors from different countries.

Conclusion

The space mining industry is still very much in its infancy. As such, regulations and protections for potential commercial actors remain weak, and there is significant international disagreement over whether or not space should eventually become a business hub. Outdated legislation such as the 1967 Outer Space Act has acted as a barrier to any potential entrepreneurs and has called into question whether or not space mining would ever be profitable. Nonetheless, the potential benefits of space mining are so significant that startups such as Planetary Resources

[35] Weinzierl, Matt. "The Commercial Space Age is Here" *The Harvard Business Review*, 12 Feb. 2021, https://hbr.org/2021/02/the-commercial-space-age-is-here.

and Deep Space Industries came into existence despite uncertainty over the legality of the industry at the time. Although these enterprises eventually failed, the legacy they left behind may transform the economic viability of the industry. Their role in lobbying for the 2015 SPACE Act set an important precedent in the battle for property rights in space and opened the door for future brave entrepreneurs to take their place. Without sufficient property protections and business- friendly regulations, it is unlikely that the space mining industry will ever reach its full potential. Nevertheless, if the cost of space travel continues to decrease, the precedents set in the 2015 SPACE Act may fuel the expansion of a space mining industry which could provide unprecedented access to rare materials and transform humanity's role in space forever.

Figures

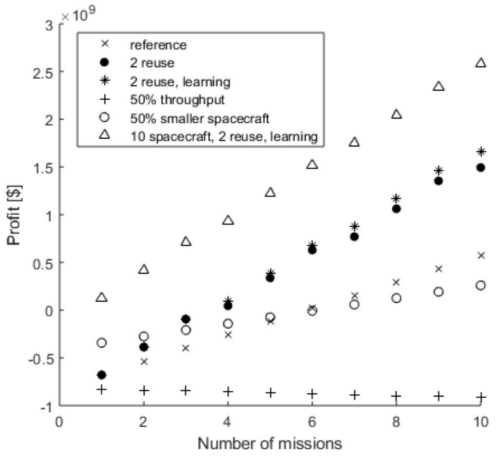
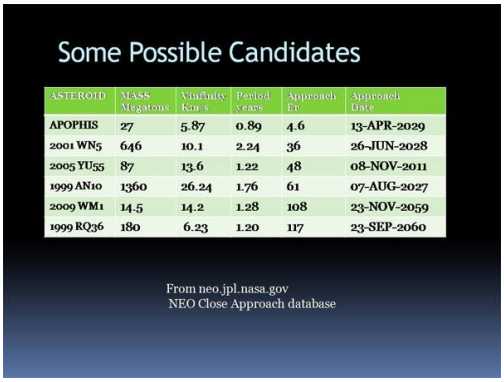


Figure 1: Water asteroid mining conservative scenario



ASTEROID	MASS Megatons	Vinfinity Km/s	Period years	Approach Er	Approach Date
APOPHIS	27	5.87	0.89	4.6	13-APR-2029
2001 WN5	646	10.1	2.24	36	26-JUN-2028
2005 YU55	87	13.6	1.22	48	08-NOV-2011
1999 AN10	1360	26.24	1.76	61	07-AUG-2027
2009 WM1	14.5	14.2	1.28	108	23-NOV-2059
1999 RQ36	180	6.23	1.20	117	23-SEP-2060

Figure 2

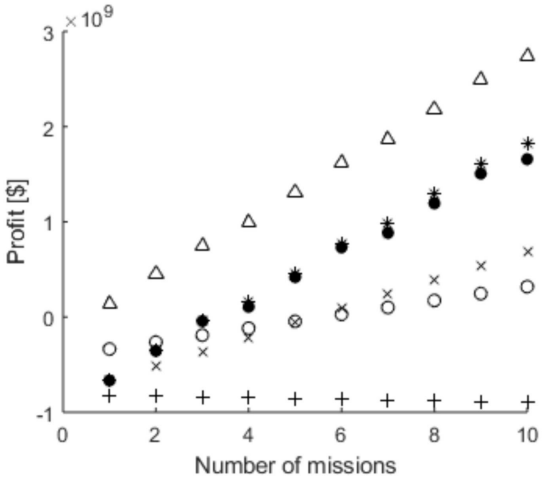


Figure 3: Platinum mining conservative case

Works Cited

2222 (XXI). Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies. United Nations Office for Outer Space Affairs, 19 Dec. 1966, www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html.

Abrahamian, Atossa Araxia. "How the Asteroid-Mining Bubble Burst." *MIT Technology Review*, MIT Technology Review, 26 June 2019, www.technologyreview.com/2019/06/26/134510/asteroid-mining-bubble-burst-history/.

"Asteroid Explorer 'HAYABUSA' (MUSES-C)." *JAXA*, Japanese Aerospace Exploration Agency, global.jaxa.jp/projects/sas/muses_c/.

Boyle, Alan. "One Year after Planetary Resources Faded into History, Space Mining Retains Its Appeal." GeekWire, 4 Nov. 2019, www.geekwire.com/2019/one-year-planetary-resources-faded-history-space-mining-retains-appeal/.

David, Leonard. "Is Asteroid Mining Possible? Study Says Yes, for $2.6 Billion." *Space.com*, Space.com, 24 Apr. 2012, www.space.com/15405-asteroid-mining-feasibility-study.html.

"Extraterrestrial Platinum Was 'Stirred' into the Earth." *Phys.org*, Phys.org, 30 July 2009, phys.org/news/2009-07-extraterrestrial-platinum-earth.html.

Fecht, Sarah. "The US Senate Just Passed an Important Space Bill with Unanimous Approval." *Business Insider*, Business Insider, 12 Nov. 2015, www.businessinsider.com/senate-passes-space-act-2015-2015-11.

Giuliani-Hoffman, Francesca. "Psyche, an Asteroid Believed to Be Worth $10,000 Quadrillion, Is Observed through Hubble Telescope in New Study." *CNN*, Cable News Network, 1 Nov. 2020, www.cnn.com/2020/10/31/us/psyche-asteroid-ultraviolet-trnd-scn/index.html.

K.W. "Who Owns What in Outer Space." *The Economist*, The Economist, 12 June 2018, www.economist.com/the-economist-explains/2018/06/12/who-owns-what-in-outer-space.

Kramer, Katie. "Neil DeGrasse Tyson Says Space Ventures Will Spawn First Trillionaire." *NBCNews.com*, NBCUniversal News Group, 3 May 2015, www.nbcnews.com/science/space/neil-degrasse-tyson-says-space-ventures-will-spawn-first-trillionaire-n352271.

Law and Economics, by Robert Cooter and Thomas Ulen, Pearson, 2014

Listner, Michael. "The Moon Treaty: Failed International Law or Waiting in the Shadows?" *The Space Review*, 24 Oct. 2011, www.thespacereview.com/article/1954/1.

Mann, Adam. “SpaceX Now Dominates Rocket Flight, Bringing Big Benefits-and Risks-to NASA.” *Sciencemag.org*, Science, 20 May 2020, www.sciencemag.org/news/2020/05/spacex-now-dominates-rocket-flight-bringing-big-benefits-and-risks-nasa.

“Mining Rare Mineral From The Moon.” *Popular Mechanics*, 7 Dec. 2004, www.popularmechanics.com/space/moon-mars/a235/1283056/.

National Research Council. “Chapter 4: Asteroids and Meteorites.” *Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies: Framework for Decision Making*, National Academy Press, 1998, p. 44, www.nap.edu/read/6281/chapter/6.

“Optical Mining.” Trans Astronautica Corporation, https://www.transastracorp.com/optical-mining.html/

“Our Missions.” Asteroid Mining Corporation, asteroidminingcorporation.co.uk/our-missions.

Palazzolo, Joe. “Did the U.S. Make Asteroid Mining Legal?” *The Wall Street Journal*, Dow Jones & Company, 1 Dec. 2015, www.wsj.com/articles/BL-LB-52649.

Reynolds, Glenn Harlan. “Who Owns the Moon? The Case for Lunar Property Rights.” *Popular Mechanics*, Popular Mechanics, 1 June 2008, www.popularmechanics.com/space/moon-mars/a3358/4264325/.

Shevchenko, V.V. “Extraterrestrial Resources.” *Oxford Research Encyclopedia of Planetary Science*, 30 Jan. 2020, oxfordre.com/planetaryscience/view/10.1093/acrefore/9780190647926.001.0001/acrefore-9780190647926-e-151.

Wilson, Jim. “What Is NASA's Asteroid Redirect Mission?” *NASA*, NASA, 13 Apr. 2018, www.nasa.gov/content/what-is-nasa-s-asteroid-redirect-mission.