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Policy Recommendations for Economically and Socially Valuable Asteroid Mineral Resource Exploitation Activities

By Anthony Hennig

*Masters of Science
Science, Technology and Public Policy
Thesis Submitted in Partial Fulfillment of the
Graduation Requirements for the*

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ABSTRACT

Asteroids are quickly moving from a speculative resource to potentially economically valuable deposits of a variety of mineral resources. There is a potential for a large scale disruptive innovation within the fundamental resource base, and at the same time policy does little to ensure that asteroid resource exploitation is socially and economically valuable. Existing international policies were put into place to prevent militarization of space and related basic risks, and the first national policies focusing on basic ownership rights are only now being put into place.

We identify five major technology, policy, and social issues that must be addressed: surveying duties, technology development, mining and ownership right, and profitability or market demand. We use analysis of existing proposals and relevant historical cases from other resource rushes to evaluate regulatory concepts and determine who (international, national, or private agents) should exercise these policies. The goal is to use history and anticipatory governance to ensure the social and economic value of space resource extraction activities.

Developing technologies to support the exploitation of space mineral resources would be best supported through intellectual property right support as well as public/private contests in light of the overlap of interests between public and private space systems developers. Surveying programs should share location data as a public service, but be allowed to maintain the characterization data as intellectual property to help substantiate a licensed claim or to be bought and sold. Ownership policies should mimic the actual licensing mechanisms seen with orbital allocation to mineral resources, and a claim system should encourage further risk mitigation, exploitation, and surveying done by private agents to strengthen and sustain a claim. Finally, infrastructure development for market creation and transportation of mineral resources from space to surface is fundamentally an applied research issue, and should be handled by private agents because the public and private benefits of these projects has yet to be determined.

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1 INTRODUCTION

The field of space policy is a relatively new field, and in November 2015, it fundamentally changed with the passing of the SPACE Act. The SPACE (Spurring Private Aerospace Competitiveness and Entrepreneurship) Act was the first major space policy passed that allowed United States of America citizens as private asteroid miners to actually possess and own space resources, a sudden reversal from the previous fifty years of the *Common Heritage of Mankind* precedent. The current state of knowledge, technology development, and economic pressures indicate that space mineral resource mining might be a possibility in the near future, and consequently, policy needs to be written such that the future development of this industry maximizes its social and economic benefit.

The policies on mining and resource exploitation have been developed over thousands of years, with many of the policies being traced back to early Roman laws. However, space policy is only fifty years old, and there has been very little policy written on the explicit ownership of space resources, and very few parallels that could be drawn until now. To support the development of space mineral mining programs, there are a few fundamental policy questions that should be asked and answered to ensure the economically and socially valuable development of this brand new industry and the industrial and technological developments associated with it:

- What are policies that could be implemented to allow and support the exploration and potential development of these new industries if they do prove to have some value?
- What elements of proposed policies or those in place could be used to support future goals?
- What can be learned from previous resource management policies that could support future asteroid resource exploitation?

There are interested politicians, a populace interested in space, and several agenda makers and policy proposals that are filling the policy gap; now is the time to develop new policies. There are no entrenched interests yet and few incumbent powers save for national governments who have had a fifty year history of public basic research programs, but not much applied work on asteroid mining and international treaties that limit their participation in space mineral resource programs. Policy written now, before serious investments are made in the engineering and technology, will have a substantial effect of the future development of the systems and business plans.

In light of a lack of direct space policy heritage, parallels can be made throughout history to better understand the development of this field and how policy might play a role. For any major economic mining activity or resource exploitation policy and strategy, policies have been put into place to help support the surveying of the resources, the technology development to exploit those resources, the infrastructure to further develop and decrease the costs, and most importantly the ownership policies to ensure that miners can spend money on investing into the land and recovering those resources. Because space mineral resource mining is on the technological horizon and there is a great deal of industrial, economic, public, and political interest, policy written now can address these needs. By looking at the utilization of minerals in case studies such as gold rushes or deep seabed minerals, biologically reproducing or *fructus* stocks, and telecommunications resources including geostationary orbit or radio spectrum allocation, analogies can be drawn about the development of these resources that ensures equitable use, an impetus to exploit, and appropriate policies to reduce the risk of development.

From reviewing this history, four major policy recommendations can be made to support the development of an economically and socially valuable space mineral mining policy regime and the reasoning behind these will be expanded in the following chapters.

- Technology policy should be written to support the use-specific research relevant for taking the basic research already done by national space programs and focusing it on resource exploitation business plans (rather than the applied research necessary for space mineral resource mining), and focus on prizes and contests and intellectual property protections to reflect the current state of technology
- Surveying should be mandatory, with the option of the identification of asteroids being a shared responsibility between public sky-watch and private mining agents. These private agents can participate in publically subsidized sky watch programs, while private agents can keep the intellectual property of characterization for themselves
- Ownership policy should reflect a traditional heritage of licensing structures here on Earth and even in space to some extent with geostationary orbit allocation, rather than the *res communis* (first actor appropriation) or complete ownership policies promoted by asteroid miners and the SPACE Act as licensing prevents exclusivity while still maintaining basic protections. Additionally, the *Common Heritage of Mankind* principle previously used has failed when economic and social pressures have been applied in Antarctica and the Deep Seabed, and it could be expected the same will happen now that similar pressures are being applied to space.
- Infrastructure development for transportation and market creation is more of an applied research need, and consequently in light of the unknown public and private benefits of this field, should be put off into the future until these benefits are identified. The subsidies and tax incentives recommended by many space mining advocates are more appropriate for later technology development stages and more developed industries.

The analysis is structured starting with the background in chapter two, which reviews the changing status quo that has created this field with advances in the changing resource knowledge,

decreasing technology stocks, and a steady increase of the knowledge of mineral wealth of these bodies. Over time, the policies in place have allowed space mineral resource mining to come into being but in the process has left substantial policy gaps that have yet to be addressed in a few major fields.

Chapter three reviews relevant historical analogs, focusing primarily on resource rush scenarios, a parallel that is often drawn to asteroid mineral resource mining right now, and identifies salient characteristics, context, and history throughout that example. Each example is drawn to provide some evidence on the potential implications of various policy regimes and provided to give some context when the historical analog is used again in the following chapters.

Chapters four, five, six, and seven analyze four major issues found through the policy gaps as well as policy proposals, technology development, surveying responsibilities, ownership policies, and infrastructure development policy. Each one of them uses a base of historical examples to analyze previous policies driving resource rushes and compare them as well as identify the context that made that policy succeed or fail in its intent. Historical outcomes, their context, and their initial intent are compared to determine the best potential policy mechanisms based on criteria for that specific issue developed from academia and relevant historical criteria.

Chapter eight is an overview of the previous findings and the presentation of the policy as a single regime. Ultimately, this analysis only provides a recommendation for future pathways based on previous historical examples, but the general regime described could be sufficient to develop the field more in the near future and provide base protections for a variety of issues.

2 SPACE RESOURCE EXPLOITATION BASICS AND RISKS

The space mineral resource mining industry is beginning to form after a decade of work by a few private mining firms developing the first technologies, performing the initial assays, and even helping make the basic policies necessary for a successful mining architecture.¹ The asteroid miner's appearance was not accidental; it was the product of increasing scarcity of mineral resource deposits on Earth with associated price volatility, and an increasing knowledge of the resource deposits within asteroids identified by sky watch programs. At the same time, the costs to operate in space have been steadily decreasing, as a byproduct of basic research programs and relaxed policy gaps on the private use of space resources. These policies have also allowed private space mineral resource mining programs to come into being, but in the process leave several policy gaps open in the regimes of responsible technology development, surveying for the public and private good of potential ore bodies, ownership of privately gathered space mineral resources, and the responsibility for transportation and market infrastructure. Policies have been proposed and some issues have been addressed, but there are many disagreements. Some have made it into law, such as the SPACE Act which conferred an ownership right of space minerals to United States of America citizens, but there are still more policy issues to address.

2.1 THE CHANGING STATUS QUO OF SPACE MINERAL RESOURCES

Today, the mines of Earth operate on economic resource deposits, where a profit will be gained from the exploitation of a chosen resource deposit.² These profitable mining locations are defined by:³

¹ Architecture being defined as the system of components, vehicles, processes, and business applications to complete a given task (Werz, Everett, & Puschell, 2011)

² (Martin L., 2004)

1. Technology capability
2. Future demand of resource
3. Current price of resource
4. Cost for the exploitation of the resource
5. Availability of substitute and recycled materials

Space mineral mining programs are benefiting from several factors changing the economic, business, and technological landscape.⁴ The availability of these space-based resources are becoming more well-known through a variety of sky watch programs that have identified that asteroids contain Platinum Group Metals (PGM's) and Rare-Earth Metals (REM's) in often higher abundance than the economic resource deposits on Earth. Exacerbating this economic resource base shift to asteroid mining is a reducing number of usable resource deposits on Earth which is also increasing the economic and environmental costs of mining traditional resource deposits.⁵ In contrast to increasing terrestrial prices, reducing technology costs for spaceflight coupled with the growing prices and growing demand is making space mineral exploitation more and more realistic and profitable. Ultimately, all of these factors are creating an environment conducive to further development of a space mineral resource mining program.

2.1.1 Growing Body of Knowledge on Asteroid Composition and Location

Four and a half billion years ago, when our solar system was beginning to form, everything that would eventually become the planets, asteroids, and sun started out as a homogeneous nebula of simple molecules, gas, and dust.⁶ As the constituent components collapsed into an accretion disk through gravity and the conservation of the original nebula's angular momentum, the individual

³ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 27-29

⁴ (Soucek & Brunner, Outer Space in Society, Politics, and Law, 2011) p14-15

⁵ (Glaister & Mudd, 2010)

⁶ (Montmerle, Augerau, Chaussidon, Gounelle, Marty, & Morbidelli, 2006) p 66-69

particles were attracted to each other and eventually grew into planetismials.⁷ Several of these planetismials continued to grow through accretion, eventually getting to a critical mass that maintained molten cores which started tectonic movement of the minerals and molecules that made up the planet.⁸ Differentiation began to occur, with heavier minerals and elements settling near the core, and lighter elements resting on top of this molten surface, forming the crust.⁹ Many of these protoplanets would be destroyed through impacts, creating more asteroids of varying composition, but four of them would become the terrestrial planets of the inner solar system (disregarding 1 Ceres, a dwarf planet just outside of Mars with a diameter of nearly 1,000 kilometers).¹⁰ These terrestrial planets are similar in geological composition.¹¹ They have light, non-metallic crusts of silicon, carbon, and gases, and heavy and dense cores of platinum group metals (PGM's), rare-earth metals (REM's), radioactive minerals, nickel, and iron.¹² Some planetismials never grew large enough to collide and reform, establishing the population of asteroids seen, observed, studied, and target for exploitation today.¹³

In the early 1980's, there were only a few hundred discovered asteroids and little data on their composition.¹⁴ Thanks to two decades of sky-watch programs to identify potential NEA threats, much has been learned about asteroid location, composition, geology, and potential value. HR4489, as part of the 103rd United States of America Congress in 1994, was the first major policy among industrialized nations that created a public service, Spaceguard, to identify 90% of all Near Earth Asteroid (NEA) impactor threats, within a decade's time.¹⁵ In 1998 these policies were

⁷ (Meyer, Hillenbrand, Backman, & Beckwith, 2006) p 118

⁸ (Rubie, Nimmo, & Melosh, 2007) p 54-60

⁹ (Park, Hu, Gao, Campbell, & Gong, 2012) p 63-64

¹⁰ (Reimold, Koeberf, Gibson, & Dressler, 2004)

¹¹ (Pop, Appropriation in outer space: the relationship between land ownership and sovereignty on the celestial bodies, 2000)

¹² (Blair & Gertsch, Asteroid Mining Methods, 2010)

¹³ (NASA Goddard Spaceflight Center, 2016)

¹⁴ (PAN STARRS Science Consortium)

¹⁵ (Martin P. , NASA's Efforts to Identify Near-Earth Objects and Mitigate Hazards, 2014) p 2

enhanced with more funding to find more asteroids as public interest in the field grew and it was soon discovered that there were no estimates for the upper limit of the number of asteroids.¹⁶ These sky-watch programs have continued to develop detector technology in terms of imaging sensors, spectrometers which generate information about composition from light, and automation to search parts of the sky without direct human control.¹⁷ For the public scientific benefit, spectroscopy data collected provided insight into the differentiated and non-differentiated composition of asteroids to aid planetary geology and geochemistry.¹⁸ Over the past two decades of detector and automation improvement, the detection rate is still increasing, and the number of economically valuable NEA asteroids continues to grow, surpassing 16,000 out of the total discovered population of 750,000 asteroids in our solar system (Figure 1).¹⁹ From this surveying data, publically released under Articles X and XI of the Outer Space Treaty,²⁰ it was found that asteroids only experienced light differentiation into various types, and some had higher valuable mineral concentrations than economic mines on Earth.²¹

¹⁶ (Evans, Shell, & Stokes, 2003)p 199-202

¹⁷ (NASA Near Earth Object Program, 2013)

¹⁸ (Safi, 2014)

¹⁹ (Bidstrup, Michelsen, Anersen, & Haack, 2004)

²⁰ (United Nations Office of Outer Space Affairs, 2016)

²¹ (Gupta & Dasgupta, 2009) p 2-5

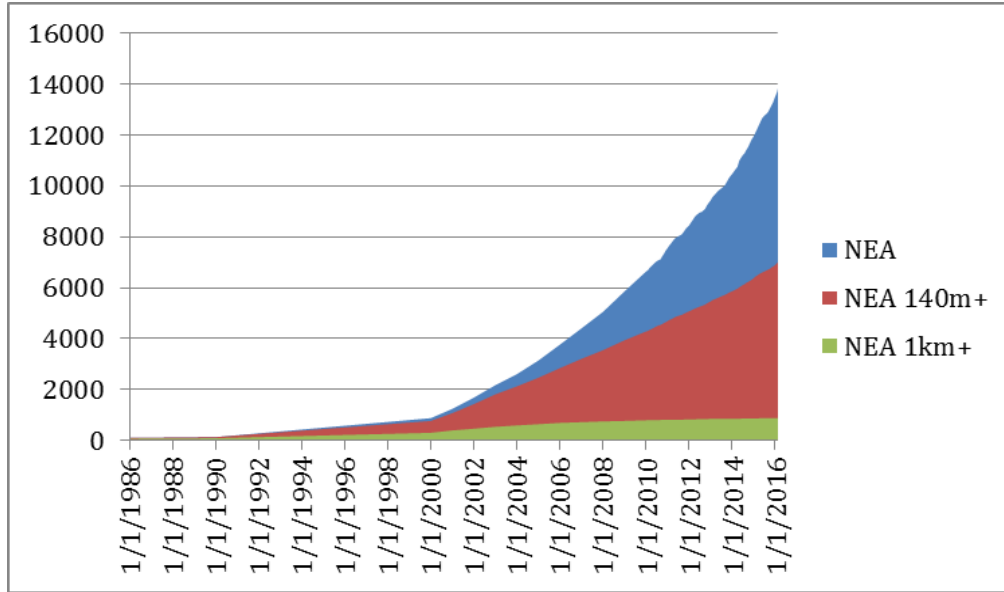


Figure 1: NEO Program Discovery Rates²²

M-type asteroids (metallic) are often the target of space mineral resource miners and exploiters, as they have some of the most valuable mineral compositions.²³ These asteroids comprise approximately 5% of the asteroid population and often contain 80% or more of nickel-iron mixture,²⁴ where the remainder is comprised of REMs like gallium (11 to 55 ppm), germanium (25-190 ppm), and iridium (0.3 to 2ppm).²⁵ Platinum concentration might be upwards of 50 ppm in M-type asteroids (at least 10% of the M-type composition), in comparison to densities of 20 to 30 ppm found in the economic mines for platinum on Earth.²⁶ These valuable metallic elements could be used for in space manufacture and assembly or even for their high mineral value here on Earth.²⁷

The other major types of asteroids, C-type (carbonaceous)²⁸ and S-type (stony),²⁹ which constitutes 80% and 10% of the number of asteroids respectively, have large amounts of water

²² (JPL Near Earth Object Program, 2016)

²³ (Lewis, *Mining the Sky*, 1997) P172-174

²⁴ (Gerlach, 2005)

²⁵ (Lewis, *Asteroid Mining 101*, 2014) p 180

²⁶ (Yarnoz, Sanchez, & McInnes, 2013)

²⁷ (Farrell, 2013)

²⁸ (Lewis, *Asteroid Mining 101*, 2014) p 140-142

²⁹ (Mazanek, Merrill, Brophy, & Mueller, 2014)

locked within the carbon-based compounds and hydrolyzed stony minerals in their surfaces as identified by the few sample return missions done to these asteroids.³⁰ They tend to have high mineral and volatile compositions, but low metallic composition from 1% to 20% by weight.³¹ They might not be very profitable now, but are thought to be necessary for further infrastructure development and the potential settlement of space.³² The volatile and organic compounds could be used for plastics or manufacturing needs and the stony minerals could be used for fabrication (along with the metals found in M-types) or for the water locked up in their minerals.³³ Water by itself could be used for a variety of purposes, from fuel cells to generate electricity, to propulsion by recombining the hydrogen and oxygen.³⁴ Even without sophisticated chemical reactions, pure water could be used as a propellant for thermal or steam rocketry, or to support crewed exploration as drinking water, atmosphere, or radiation protection.³⁵

2.1.2 Mineral Resource Scarcity and Demand is Increasing Economic Pressure

The differentiation process of the large terrestrial planets fundamentally altered the structure of the planet, taking the original homogeneous mass and spreading the mineral resources throughout the crust and core, making the crust lighter, and the core heavier.³⁶ The crust is primarily composed of lighter elements and gases, with iron and nickel forming the primary components of the Earth's core along with PGM's, REM's and radioactive minerals.³⁷ In order to economically mine PGM's and REM's on Earth, there are very few sites where these materials exist in high enough densities on the crust to make mining profitable, such as in the Sudbury Basin in

³⁰ (NASA Goddard Spaceflight Center, 2016)

³¹ (Crawford, Gump, Lewicki, & Seager, 2013)

³² (Sonter M., 2006)

³³ (Lewis, Asteroid Mining 101, 2014) p 165

³⁴ (Werz, Everett, & Puschell, 2011)

³⁵ (Adams, 2012)

³⁶ (Blair & Gertsch, Asteroid Mining Methods, 2010)

³⁷ (Campbell, Handley, Wise, & King, 2009)

Canada (PGM and REM),³⁸ Gobi Desert in China (PGM and REM),³⁹ and highest in the Merensky Reef and Bushveld Mining Complex (20-30 ppm PGM concentration) in South Africa.⁴⁰ When looking at terrestrial PGM and REM resource stocks, there is a technology capability to mine these resources, a future demand for the resource, and a capability to use recycled materials to some extent,⁴¹ but all of them have upper limits to their efficacy and capacity.⁴²

PGM's are very difficult to mine, requiring high temperatures and toxic reagents like mercury to remove them from ore.⁴³ Because of this, PGM mining costs are very high, typically above \$20,000 to \$30,000 USD/kilogram, which is only exacerbated with how few sites are actually economically exploitable.⁴⁴ Other factors, such as environmental regulations, labor shortages, and national conflicts continue to increase these prices and increase their volatility.⁴⁵ Prices have ranged from \$15,000 USD per kilogram in the early 2000's to over \$70,000 per kilogram in 2008 (Figure 2).⁴⁶ This has made these mineral deposits highly conditional in nature, with mines turning on and off as the costs to exploit that alternate between making a profit or not based on demand and the stockpiled supply.⁴⁷ The low prices since 2010 can be mostly attributed to large stockpiling of PGM's from the last major resource boom in 2008.⁴⁸

³⁸ (Reimold, Koeberf, Gibson, & Dressler, 2004)

³⁹ (United States Geological Service, 2014)

⁴⁰ (Johnson Matthey Precious Metals Management)

⁴¹ (Msimang & Makhuvela, 2014)

⁴² (Campbell, Handley, Wise, & King, 2009)

⁴³ (Gertsch & Gertsch, 2005)

⁴⁴ (Martin L., 2004)

⁴⁵ (United States Geological Service, 2014)

⁴⁶ (United States Geological Service, 2014)

⁴⁷ (Walker, Breaking the Rare-Earth Monopoly, 2010) p 47-49

⁴⁸ (Massari & Ruberti, 2013)

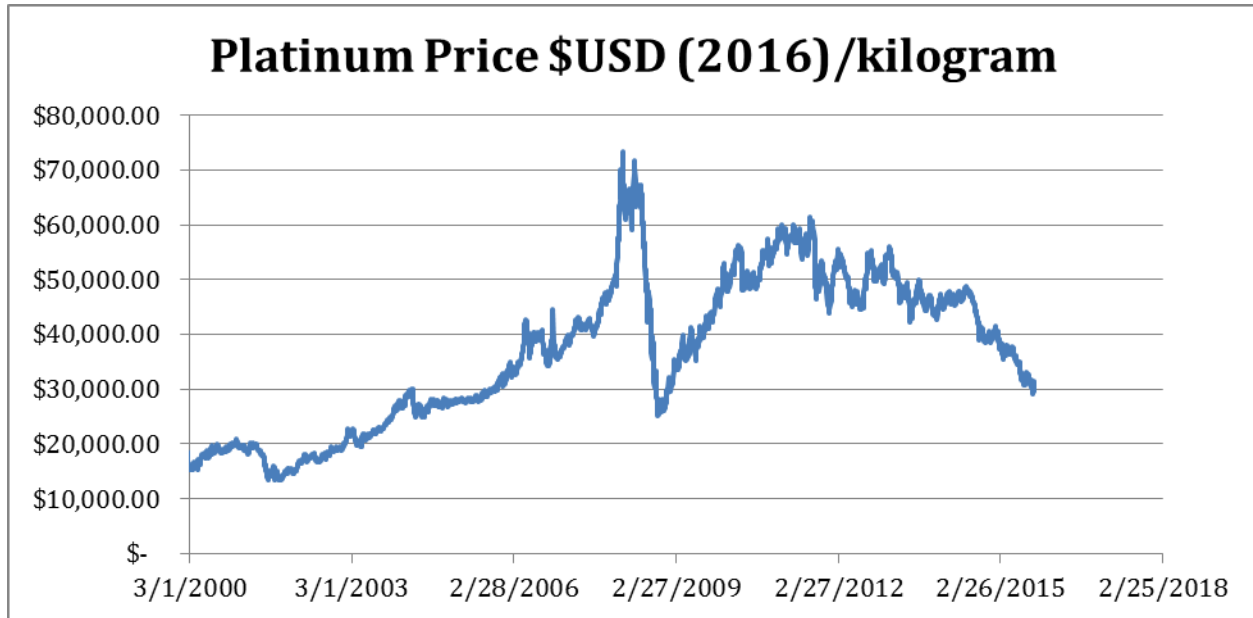


Figure 2: Global Platinum Prices⁴⁹

With REM and radioactive mineral resources, there are growing environmental costs associated with the economic mining of these resources.⁵⁰ Originally, REM were refined from economic concentrates in the sands of South Africa, but due to the exhaustion of these resources, production shifted heavily to ore deposits in North America and China in the 1950's.⁵¹ In these ore deposits, rare-earth metals are collocated with radioactive and heavy metal resources, which have severe environmental and health consequences when exploited, which increases costs and has caused some nations to reduce mining capacity.⁵² Early compositional data via spectrometry indicates that REM's are found in similar or higher densities than Earth's economic sites and would have negligible impact on the space environment if they were refined in situ.⁵³

The same is also true with PGM metal mining. Throughout the early 21st Century, South Africa was the key producer of PGM's in the world, at nearly 80% of world production. Mining

⁴⁹ (United States Geological Service, 2014)

⁵⁰ (Campbell, Handley, Wise, & King, 2009)

⁵¹ (Walker, Breaking the Rare-Earth Monopoly, 2010) p 47-49

⁵² (Walker, Breaking the Rare-Earth Monopoly, 2010) p 46

⁵³ (Lewis, Asteroid Mining 101, 2014)

platinum is very difficult, as concentration within rock is usually only at a few grams per metric ton mining (with PGM mining now operating at 99.99% waste due to its low concentration),⁵⁴ and to mine these resources, a great deal of energy is used to mine and refine (Table 1), some water is used, and in the process, and large amounts of CO₂ are produced⁵⁵ (a 21 mpg or 8.92 kilometer per liter car driving 1,000 miles/1609 kilometers a month will generate approximately 6 metric tons of CO₂ a year).⁵⁶ Combined with this is that many mining agencies in the western world also have to dedicate a great deal of time and energy in ensuring that the mining of mineral resources is environmentally safe, with those inspections and controls being put in place increasing the cost even more, sometimes upwards of 10-20% as part of contingency costs, but can increase substantially in reaction to cleanups for acid leaching.⁵⁷ Mining in space removes the energy production issues by working with material in dust form rather than ore form and removes the potential for contamination in the sterile space environment.⁵⁸

	Mining	Milling	Energy	Energy	Water	Water	CO2
	MJ/t rock	MJ/t ore	GJ/kg PGM	MJ/t Ore	m3/kg PGM	m3/t ore	Emissions t CO2/kg PGM
Minimum	21	130	28.5	107	192	0.509	2.3
Average	365	204	141	519	511	2	33
Maximum	1268	487	241	1755	1612	12.6	78.3
Standard Deviation	361	110	59	389	399	3	18
Number of Surveyed Sites	8	8	13	13	13	13	10

Table 1: Energy Requirements of Platinum Mining⁵⁹

⁵⁴ (Glaister & Mudd, 2010)p 448

⁵⁵ (Chen, Lundqvist, & Platell, 2005)

⁵⁶ (Glaister & Mudd, 2010) p 444

⁵⁷ (Rudenno, 2012) p 26-27

⁵⁸ (Endsor, 2014)

⁵⁹ (Glaister & Mudd, 2010)p 448

For PGM, REM, and many other valuable mineral resource stocks, there is also a growing potential for exhaustion of these resources.⁶⁰ In some cases, expecting extreme resource growth at 10% per year, a variety of PGM and REM resources could be completely economically depleted by 2175.⁶¹ Recycling of PGM's is getting better, as evidenced by the recycling of 155 tons of a globally used 200 tons in 2014, but these processes is unable to keep up with growing demand (Table 2).⁶²

	Platinum Production (kilograms)			Palladium Production (kilograms)			PGM Reserves
	2013	2014	2015	2013	2014	2015	Current
United States	3,720	3,660	3,700	12,600	12,400	12,500	900,000
Canada	7,000	8,500	9,000	16,500	20,000	24,000	310,000
Russia	25,500	23,000	230,000	80,000	83,000	80,000	1,100,000
South Africa	131,000	94,000	125,000	75,000	58,400	73,000	6,300,000
Zimbabwe	12,400	12,500	12,500	96,000	10,100	1,000	⁶³
Other Countries	3,870	4,800	4,800	8,900	9,000	8,000	800,000
Total	183,000	147,000	178,000	20,3000	193,000	208,000	800,000

Table 2: Platinum Production, Supply 2013-2015⁶⁴

A 10 meter asteroid, smaller than any other visited already, could contain 625 metric tons of nickel iron and 50 kilograms of platinum.⁶⁵ 21 Letutia, an M-type visited by Rosetta on the way to a comet, has a mass of 1.7×10^{15} metric tons, with a high density indicating 40% or more of metal. If one were to assume that this asteroid had a nickel-iron weight density of 40%, 21 Letutia would contain more than 420,000 times the world use of nickel-iron steel in 2013.⁶⁶ 16 Psyche, which is over ten times the mass of 21 Letutia, is thought to be the failed core of another protoplanet and comprised of nearly pure nickel-iron.⁶⁷ Using stochastic methods, it is currently assumed that there

⁶⁰ (Cohen, 2007)

⁶¹ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 28

⁶² (United States Geological Service, 2014)

⁶³ Included in Other Countries

⁶⁴ (United States Geological Service, 2014)

⁶⁵ (Endsor, 2014)

⁶⁶ (World Steel Association, 2014)

⁶⁷ (Davis, Farinella, & Mazari, 1999)

are at least ten (with three or more being discovered every year) potential ore bodies greater than one kilometer in diameter that would require less energy to reach than the moon with at least \$1 billion USD in PGM's alone (disregarding the other metals, water, and volatiles).⁶⁸

Besides the highly valuable metal supplies, water, one of the most common resources available, could potentially be valuable in space if delivered from a space-based source to the people who need it. Normally, to operate the International Space Station and keep its crew of six alive, 300 kilograms of water are sent every few months to the orbiting outpost for food and drink and other architecture needs.⁶⁹ Every kilogram costs \$10,000 to get into space, based on mass and energy costs alone.⁷⁰ This comes out to \$3 million USD in water alone, nearly \$30 million every year (ten flights per year) which is just used for drinking. Water could be used for more things, such as radiation shielding, operating fuel cells to generate electricity (as seen on the Space Shuttle, Apollo and Gemini flights),⁷¹ or even as propulsion as the use of space increases.⁷² Volatiles or carbon-rich compounds could also be extracted from C-type asteroids, and used in plastics, medicine, fertilizer, and more for early space settlers.⁷³ By procuring resources in space rather than bringing them up from the surface, there could be a potential cost savings and public good enabling greater future use of space.

Ultimately, the resources found in asteroids are highly desirable on Earth, might be more economical to mine in space, and are found in greater concentrations in asteroids than in the crust of Earth. This potential has gotten many excited about the potential colonization and exploitation of resources, and addresses many of the necessary economical resource deposit characteristics. If the

⁶⁸ (Elvis, 2014)

⁶⁹ (National Space Society)

⁷⁰ (Werz, Everett, & Puschell, 2011)

⁷¹ (Adams, 2012)

⁷² (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 162-163

⁷³ (Lewis, Mining the Sky, 1997) p 108-110

material is there, and there is a demand for it, technologies and techniques to mine them are the last major requirement that must be met.

2.1.3 Decreasing Technology Costs for Spaceflight

The past century of spaceflight has helped lay a foundation that made asteroid mining possible today. The early basic research done by national space agencies, as well as the rudimentary infrastructure construction (ranging from launch pads to tracking and data relays), have made space more open to numerous private agents who didn't have to take on the risks of figuring out how to work in space at the very beginning.⁷⁴ Over fifty years, private agents have helped reduce cost, increased performance, added new opportunities for access and use, and allowed space systems to be made inexpensively, including systems for space mineral resource mining.⁷⁵

Early aerospace system development was driven by nations, mostly between the United States of America and now defunct Soviet Union locked in a Cold War, aiming to gain a technological advantage in warfare by dominating the high ground of space.⁷⁶ In the process, they developed the first rockets, satellites, crewed capsules, and robotic systems, while building launch pads and ground stations to run the missions.⁷⁷ Some initial scientific programs and missions experimented at the basic research level on the potential uses of space for industry, military, defense, and science.⁷⁸

The basic research done by nations out of scientific curiosity and national interest for defense allowed private industry to recognize the potential value for operating in space for research, defense, telecommunications, and remote sensing. The applied research and private

⁷⁴ (Angelo, 2007) p 19-20

⁷⁵ (Werz, Everett, & Puschell, 2011) p 308

⁷⁶ (Werz, Everett, & Puschell, 2011) p 5-7

⁷⁷ (Neal & Smith, 2008) p138

⁷⁸ (Angelo, 2007) p 306

interest provided enough economic and technological pressure to lower costs, open the field up to more competitors and better process improvement, further reducing costs, and increasing participation. Policies such as the Outer Space Treaty⁷⁹ heavily limited national operations in space and it has terms approved by nearly all nations (Figure 3), such as prohibiting military operations in space,⁸⁰ but the private industry grew as quickly as they could while still being supported by national space programs looking to invest and growing national economic strength.⁸¹ These national space policies would continue to promote an environment of technology development that would continue to support the development of novel private industries that use space as a resource today (the most recent US Space Policy being published in 2010).⁸²

This basic research has not solely focused on the development of basic rocketry and infrastructure, but also has helped the development of In Situ Resource Utilization (ISRU) systems. The development of these systems is intended to provide mass savings for exploration based flights, where fuel, life support, and other resources could be refined or produced from materials found in space.⁸³ Through the 1990's, ISRU has been developed for crewed Mars exploration to reduce the total amount of mass needed to launch from Earth.⁸⁴ This research is done through procurement services and even public competitions to extract water and oxygen from lunar regolith. For asteroid miners, these same systems could be used as the basis for further research into developing refinery and mining systems to extract PGM's, REM's, and water.

As a product of all of this basic research, there has been a direct reduction in costs for launch services and for space systems, which is driving further privatization of who is accessing and

⁷⁹ (United Nations Office of Outer Space Affairs, 2016)

⁸⁰ Article I of the Outer Space Treaty "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"

⁸¹ (Hogan, 2007) p 65

⁸² (National Space Policy of the United States of America, 2010)

⁸³ (Hogan, 2007) p 26

⁸⁴ (Neal & Smith, 2008) p 7

using space.⁸⁵ Most visible is the growth of launch service providers and new rocketry companies such as SpaceX, Blue Origin, and OrbitalATK now competing against the incumbent United Launch Alliance in the United States of America, providing cheaper launches.⁸⁶ Services for telecommunications have also steadily been growing, such as the satellite phone network, Iridium, which uses a constellation of over 80 satellites, DirecTV which streams television from geostationary orbit, or providing internet broadband with a constellation of 900 satellites in Low Earth Orbit (LEO).⁸⁷

The costs for spaceflight are decreasing and the number of suppliers and operators of spaceflight hardware is increasing.⁸⁸ The basic research for ISRU has already been done, and the applied developments of the past century potentially can make the application and implementation of a space mineral exploitation regime even more possible at a lower cost⁸⁹ (the full flight and operation of an asteroid redirect mission to be undertaken by NASA to bring back 70 metric tons of mass is estimated at \$2 billion USD).⁹⁰ Ultimately, the exploitation of space mineral resources and asteroid resources is on the technological horizon, requiring a few more developments in the business aspect to be achieved.

2.1.4 The Potential for a Space Resource Industry

In light of the growing body of knowledge, the increasing value of mineral resources, and the reduction of cost for spaceflight implementation, space mineral resource exploitation plans were experimented with throughout the 1990's as an academic exercise, demonstrating that it might be very profitable.⁹¹ The first major contribution to the literature on asteroid mineral

⁸⁵ (Werz, Everett, & Puschell, 2011) p 308

⁸⁶ (Werz, Everett, & Puschell, 2011) p 859

⁸⁷ (Clark, 2015)

⁸⁸ (Werz, Everett, & Puschell, 2011) p 356

⁸⁹ (Keck Institute for Space Studies, 2012)

⁹⁰ (Mazanek, Merrill, Brophy, & Mueller, 2014)

⁹¹ (Lewis & Lewis, Space Resources: Breaking the Bonds of Earth, 1987)

resource exploitation appeared in 1997, with the publication of *Mining the Sky* by Dr. John Lewis.⁹² Earlier than most, Lewis saw that there was an opportunity to reduce mineral scarcity, promote space flight, and bring new opportunities for technology development through the use of space-derived mineral resources.

Others added to Lewis' original analysis, one of the most notable being Mark Sonter, who now works with Lewis at Deep Space Industries, designing business plans and advocating for policy such as the SPACE Act.⁹³ His analysis, from an economic standpoint, set the precedent seen today in evaluating that asteroid resource mining is highly profitable. This early work in 2000 determined that an M-type asteroid (roughly 10% of the NEA population) could yield \$500,000 in nickel-iron, PGM, and REM based on prices at the time (less than \$30,000/kilogram of platinum seen today).⁹⁴ If launch costs decreased (one of the largest drivers he recognized) to approximately \$10,000 USD/kilogram, the exploitation of space mineral resources could be profitable.⁹⁵ Through the work of basic technology development done by national space programs, this has been achieved, with launch prices potentially going as low as \$2,200/kilogram.⁹⁶ Ultimately, Mark Sonter also laid out a set of salient characteristics necessary for an environment to support space mineral resource mining, based on a variety of historical examples and academic research on the topic:⁹⁷

- I. There needs to be a market for the products
- II. There needs to be adequate spectral data indicating presence of the desired materials
- III. The location of the ore bodies and their orbits need to be well known
- IV. There needs to be feasible engineering systems behind a mining architecture
- V. There needs to be feasible mineral return architectures

⁹² (Lewis, *Mining the Sky*, 1997)

⁹³ (Sonter M., 2006)

⁹⁴ (Sonter M. J., 1997)

⁹⁵ (Simberg, 2012)

⁹⁶ (Soucek & Brunner, *Outer Space in Society, Politics, and Law*, 2011) p 61

⁹⁷ (Sonter M. J., 1997) p 638

- VI. With the architectures, they need to generate a profit from the mineral resources returned

To achieve Characteristic I and Characteristic VI, M-type asteroids might be very economically advantageous due to their high metal, PGM, and REM composition. Platinum is one of the most expensive elements on Earth,⁹⁸ currently evaluated at \$30,000 USD per kilogram (the highest value being nearly \$70,000 USD per kilogram in 2008), much more than at the time of Sonter's original analysis.⁹⁹

In 2008, there was a massive boom in the PGM commodity markets which triggered the founding of two asteroid mining companies, Deep Space Industries and Planetary Resources Incorporated.¹⁰⁰ These two companies believed that the PGM demand could be met with space-derived mineral resources, not realizing that the conditional deposits on Earth increasing their production in response would quickly lower the price again and that the severity was not as extreme as thought. The massive price drop in the following years for PGM's did weaken some business prospects, even though Planetary Resources was able to successfully collect over \$40 million USD in venture capital over those first few years from a crowdsourced funds and investors such as James Cameron and Sergei Brin of Google.¹⁰¹

The PGM price instability in 2008-2010 demonstrated that PGM focused mining programs were not going to be very successful. Early after Sonter, Shane Ross, another early economic analyst, had been arguing that the focus should be on water. Where platinum proved to be unstable in its prices,¹⁰² Thomas Coffee argued to focus on water and volatile resources to decrease the cost

⁹⁸ (Crawford, Gump, Lewicki, & Seager, 2013)

⁹⁹ (United States Geological Service, 2014)

¹⁰⁰ (United States Geological Service, 2014)

¹⁰¹ (Octa Finance, 2015)

¹⁰² (Ross, 2001)p 14-18

of in-space operations,¹⁰³ and in 2014, Lewis reevaluated the possibility of PGM's paving the way for space mineral resource activities and argued for a focus more on rare-Earth metals, water, and other resource developments that would enable more infrastructure growth in orbit and consequently more demand in orbit and on the surface.¹⁰⁴ Despite the economic problems they faced with unstable PGM prices, these companies managed to adapt and have continued to develop their space resource exploitation plans.

Ultimately, with regards to Sonter's original analysis of the six salient characteristics of a successful asteroid mining community, many of them have been met over the past two decades of space mineral resource exploitation business development. Characteristic III, location of economic resources, has been underway through a variety of sky-watch programs identifying NEA's that could be economical to mine and Characteristic II, the basic characterization has partially been done. Characteristic I, a known market for the products, and Characteristic VI, the potential for profit generation, are possible through the demand for a variety of minerals in space and on Earth, and there are decreasing costs to potentially mine these ore bodies. These two companies, Deep Space Industries and Planetary Resources, who function more like a Silicon Valley startup than a traditional mining company, both generally agree on the space mission architecture to do this; surveying by telescope, deploying a refinery, deploying a tug to gather the material, and return it to some depot and then returning that tug back to the refinery to continue to mine and exploit.¹⁰⁵ Deep Space Industries is primarily focused on a societal constructivism approach, arguing and supporting policy developments before they start their mining process.¹⁰⁶ They have been heavily involved with the proposal of the ASTEROIDS Act (American Space Technology for Exploring

¹⁰³ (Coffee, 2002)

¹⁰⁴ (Lewis, Asteroid Mining 101, 2014)

¹⁰⁵ (Andrews, et al., 2015)

¹⁰⁶ (Deep Space Industries, 2016)

Resource Opportunities in Deep Space)¹⁰⁷ in 2014 and the passing of the SPACE Act in fall 2015 that provided US citizens with an ownership right for space-derived mineral resources.¹⁰⁸ The other, Planetary Resources, has already started flying craft, arguing that the policy will come later.¹⁰⁹ They launched a testbed prospector telescope probe in the summer of 2015, and are planning to launch more every summer until they deploy a full orbital telescope system to track, identify, and analyze asteroids to further guide exploitation.¹¹⁰

2.2 POLICIES IN PLACE FOR SPACE UTILIZATION

Space mineral resource companies have developed, thanks to previous policies steadily changing the nature of the utilization of space. Original national policies favored technology development for military and scientific purposes, but the military aspects were quickly limited by the international community. In November 2015, the first official space policy supporting space mineral resource engineering came out, fundamentally changing the way that these private miners interact with the national and international community. This policy development has only been in place for fifty years, but its impact on the highly risky spaceflight industry is important to understand when discussing new policy issues and potential policy mechanisms to fix those gaps.

2.2.1 The Outer Space Treaty

In the middle of the 20th Century, the United Nations developed a variety of treaties and conventions on regions considered to be previously unclaimed by no individual or country; the Antarctic, the deep seabed, and outer space.¹¹¹ All were written with the same intent: protecting the global commons and environment, ensuring that there is free use and access, and holding the

¹⁰⁷ (Stotler, 2014)

¹⁰⁸ (GovTrack, 2015)

¹⁰⁹ (Planetary Resources, 2016)

¹¹⁰ (Planetary Resources, July)

¹¹¹ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 99

international community accountable to the successful future use of these unclaimed lands for economic, scientific, and industrial benefit, under a legal concept called the *Common Heritage of Mankind*.¹¹² Unlike the other two policy regimes regarding these territories, the Outer Space Treaty was a direct product of the Cold War between the United States of America and now defunct Soviet Union, and specifically designed to inhibit militarization while also preventing nations from claiming the resources of space and promoting free access to space.¹¹³

This 1967 treaty, written right before the first Moon landing in 1969, contains several articles which have fundamentally altered the way that nations pursue spaceflight. The underlying intent of this document was to prevent a steady militarization that potentially would limit the access others could have to space, which many saw similar to the seas, as well as promote the scientific use and sharing of that knowledge among nations in light of the great disparity between the few spacefaring nations¹¹⁴ and all of the others at the time:¹¹⁵

- Outer space shall be free for the use and exploitation of all states, and there shall be freedom of exploration and cooperation (Article I)
- Outer space is not subject to national appropriation through sovereignty, use, occupation, or any other means (Article II)
- States of the treaty shall carry out exploration and use of outer space in accordance to international law and the charter of the United Nations (Article III)
- Nuclear weapons and other devices of mass destruction are prohibited from being placed in space (Article IV)

¹¹² (Mann, 2012)

¹¹³ (Shackelford, 2009) p 122

¹¹⁴ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 17-18

¹¹⁵ (United Nations Office of Outer Space Affairs, 2016)

- Astronauts under distress shall be allowed emergency landing and docking and returned to their respective nations (Article V)
- States bear the responsibility of all activities in space for nations flying the flag of their nation (Article VI)
- National liability is placed on the nation who launched or procured a system that damages another nation's vehicle (Article VII)
- If a vehicle flying the flag of one nation lands in the territory of another state, the vehicle shall be returned to the original state (Article VIII)
- States shall provide assistance and cooperation opportunities for any activities in space (Article IX)
- States have full rights to observe the flights of other nations launched under national control for scientific purposes (Article X)
- All data collected by nations doing exploration must be freely shared to all nations as soon as possible and practically (Article XI)
- Stations, bases, and outposts shall be free for access on a basis of reciprocity (Article XII)

Under the *Common Heritage of Mankind* as outlined in Articles I through III, the Outer Space Treaty (OST) protected space resources from national appropriation under the premise that they had existed without ownership for the entirety of humanity's history and that all of mankind had a shared interest in these resources.¹¹⁶ The remainder of the document continued to reduce the rights of national programs and their direct, named agents such as Articles X and XI that mandated that all data collected by national programs must be shared, effectively preventing any data collected by nations from being held privately.¹¹⁷ At the time, spaceflight was primarily handled by public agents, often working through public research groups or procuring technology

¹¹⁶ (Abundant Planet, 2009)

¹¹⁷ (United Nations Office of Outer Space Affairs, 2016)

developments through private industry. The OST was able to recognize the potential implications of this trend, and established that private agents are governed by the laws of their origin location (Article IX) and that these policies could supersede elements of the OST (Articles XIII) as long as it was for the scientific or industrial use of space resources.¹¹⁸

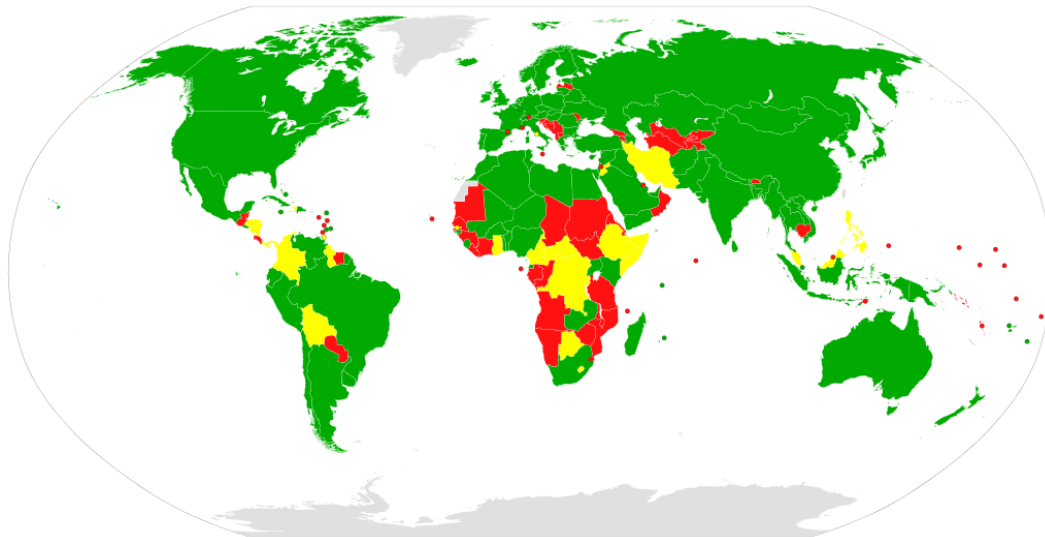


Figure 3: Signatories of the Outer Space Treaty (Green-Party to, Yellow-Signatory of, Red-No Party)¹¹⁹

The OST fundamentally altered the national exploration of space.¹²⁰ Before, space developments were driven by both military and scientific interests and Articles I, II, and III prohibited exploitation, land claims, and militarization in favor of scientific exploration done cooperatively by nations, under the *Common Heritage of Mankind*.¹²¹ It succeeded in just about every way, with the military programs moving from offensive weapons to passive detectors and intelligence services. The threat of a “red moon” was never fully actualized as well,¹²² and the potential of having military outposts shoot down other satellites was nullified.¹²³ It was an

¹¹⁸ (Lee, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, 2012) p 98-100

¹¹⁹ (Wikimedia Foundation; Happenstance, 2015)

¹²⁰ (Pop, *Who Owns the Moon*, 2009) p 26

¹²¹ (Lee, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, 2012) p 203-205

¹²² (Laver, 1986)

¹²³ (Coffee, 2002)

outstanding example of how law and political arrangements could keep pace with science and technology. The OST, through the use of the *Common Heritage of Mankind* prevented the militarized use of space resources and it was widely accepted with little conflict (Figure 3) and created the international space community seen today.¹²⁴

With the language used, the OST did succeed in preventing limitations on the free use of space being put in place by nations through military or other means, but it did create several serious policy questions that have plagued the industrial development of space mineral resource mining as a business. First and foremost, Articles X and XI require that data collected throughout the exploration of space must be disseminated if the data is collected as part of a national interest. In the process, the characterization data that determined the mass, composition and potentially the wealth of an asteroid ore body had to be shared. Previously, individual knowledge of an economic resource site was a substantial enough grounds for a mining claim, but now, much of the basic geology data is freely shared and there are unclear implications about the private use of space generating information about space resources for private benefit when public benefit could be had at the same time.

Secondly, the language of the OST identifies that national operation and procurement of space missions (Article VI and VII) would have the same preventions on ownership and possession of space resources (Article I). However, public agents are no longer the only agents operating in space, and technology development is becoming steadily hybridized (encompassing public and private interests and risk sharing). Applying *Common Heritage of Mankind* to private agents now would fundamentally change whether or not miners could own the resources they mine and then

¹²⁴ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 101-102

sell them. The national appropriation of space resource is expressly forbidden in Article I, and even the United States of America's lunar rocks collected through the Apollo missions are not owned.¹²⁵

This policy gap has been well discussed over the past fifty years. In the late 1970's, a group of nations drafted the Moon Treaty, which would extend the *Common Heritage of Mankind* to all human agents, including private actors.¹²⁶ However, industrialized nations rejected the plan (Figure 4),¹²⁷ as this policy regime provided no economic advantage to the use of these space resources and would interfere with the industrial development of remote sensing and telecommunications by private industry.¹²⁸ Without any policy regime in place, the use of space remained *res communis* and was to be freely accessed and used by private agencies on a first come first serve basis or as dictated by coordination policies at that time.¹²⁹

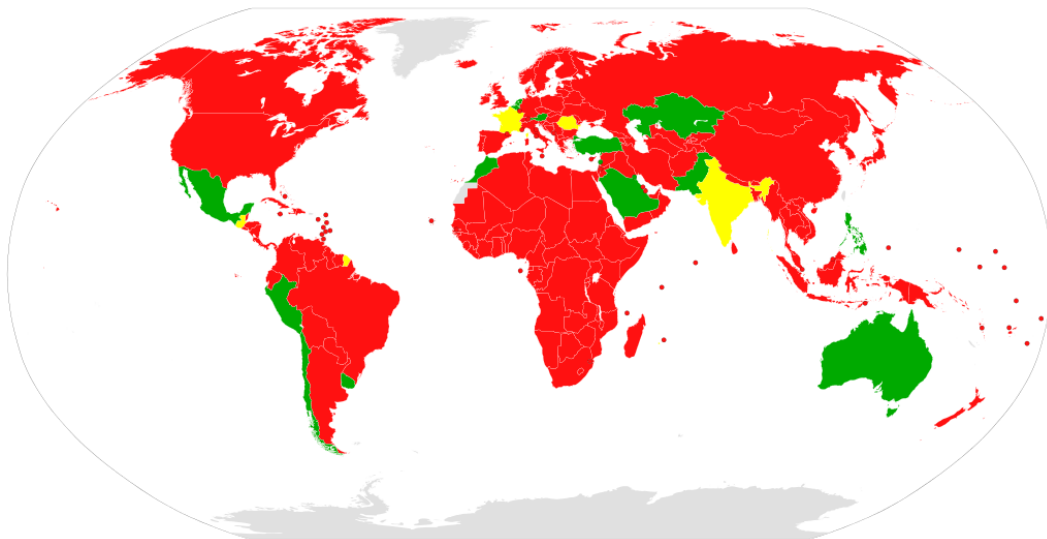


Figure 4: Signatories of the Moon Treaty (Green-Party to, Yellow-Signatory of, Red-No Party)¹³⁰

¹²⁵ (NASA Lyndon B Johnson Space Center, 2007)

¹²⁶ (Smith D., 1983) p217

¹²⁷ Countries that accepted the terms of the Moon Treaty included Australia, Austria, Belgium, Chile, Kazakhstan, Kuwait, Lebanon, Mexico, Morocco, Netherlands, Pakistan, Peru, Philippines, Saudi Arabia, Turkey, Uruguay

¹²⁸ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 258-262

¹²⁹ (Pop, Who Owns the Moon, 2009) p25-27

¹³⁰ (Wikimedia, 2013)

In 2000, before asteroid mining was seriously considered, it was argued that “a minority of authors consider that the Outer Space Treaty prohibits only the national appropriation of outer space and celestial bodies,”¹³¹ and in 2010, the International Institute of Space Law argued that private activities are permitted according to Articles II and IV, but legally claiming space mineral resources through private activities were still very dubious, creating a major policy gap dealing with the ownership of asteroids and working with space mineral resources.¹³² To a private agent, space mineral resources were completely unowned with no ownership policy regime placed on them and there was no clear indication of ownership. It wasn’t until 2014 when the private ownership policy issue would begin to be addressed, leading to the ASTEROIDS Act and eventually SPACE Act, discussed later.

2.2.2 National Space Policy of the United States of America

Evolving and being rewritten by every President and their respective cabinets, advocacy groups, industry, research groups and many more, the National Space Policy of the United States of America sets the goals of the public civilian space program and any other public organizations involved or interested in operating in space.¹³³ Among western states, the policies bear strong resemblances, with differing focuses on specific technologies or destinations for missions. These National Space Policies are then used to design Authorization Acts which allocate funds directly to specific research projects and programs and to local research groups based on feedback gathered and evaluation of national programs.¹³⁴

The 2010 United States of America National Space Policy, which is still in effect through at least 2016, was partially written to support the development of an asteroid redirect mission to

¹³¹ (Pop, Appropriation in outer space: the relationship between land ownership and sovereignty on the celestial bodies, 2000)

¹³² (International Institute of Space Law)

¹³³ (Handberg, 2014) p33-34

¹³⁴ (Neal & Smith, 2008) p

demonstrate the technology of asteroid dock and capture, to test planetary defense through a gravity tractor program to divert asteroids away from Earth, to perform planetary science, and to potentially serve as an In Situ Resource Utilization (ISRU) test platform for resource and mineral exploitation.¹³⁵ ISRU is of great interest to basic researchers, as the technology would potentially allow crewed Mars mission design architectures to be possible by producing propellant in deep space, so an opportunity to actually perform it with actual space mineral resources would be perfect.

Along with the push for an asteroid program, the National Space Policy also sets the standards for what is deemed valuable to develop in terms of technology or infrastructure, or what to explore scientifically or industrially.¹³⁶ The intent of the policy is to share responsibility for the use of space resources, develop a competitive commercial space sector, follow the intent of the Outer Space Treaty, develop and protect infrastructure for using space or deploying operations in space, and look at using space to aid in defensive programs.¹³⁷ The goals for the national space policy are to develop competitive domestic industries,¹³⁸ expand international cooperation, strengthen stability in space,¹³⁹ increase the assurance of mission-essential functions,¹⁴⁰ pursue human and robotic initiatives,¹⁴¹ and to improve space-based observation capabilities. Specific guidelines include:

- Strengthen United States' leadership in space-related science, technology, and industrial bases

¹³⁵ (National Space Policy of the United States of America, 2010)

¹³⁶ (Mari, 2011) p151-164

¹³⁷ (National Space Policy of the United States of America, 2010)

¹³⁸ Satellite manufacturing, satellite-based service, space launch, terrestrial applications, and increasing entrepreneurship

¹³⁹ Improved information collection and sharing for collision avoidance, protection of supporting infrastructures, and mitigating orbital debris

¹⁴⁰ Developing infrastructure to support launch for civil, scientific, and industrial craft

¹⁴¹ To develop innovative technologies, increase humanity's understanding of the Earth and space

- Enhance capabilities for assured access of space
- Maintain and enhance space-based position, navigation, and timing systems
- Develop and retain space professionals
- Improve development and procurement of space-related technology
- Strengthen interagency partnerships and develop transparency measurements
- Preserve the space environment (namely with regards to debris in the low earth orbit)
- Foster the development of space collision warning measures

These policy goals have been developed to prevent the pursuit of expensive space systems technology to falling into the trap of unfettered research and focus the entirety of the nation on a few, broad goals.¹⁴² There is also a section focused primarily on the commercial space sector that argues for more infrastructure development and infrastructure building, as well as a specific claim under the civil space guidelines to “pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize near-Earth objects to reduce the risk of harm to humans from an unexpected impact on our planet and to identify potentially resource-rich planetary objects.”¹⁴³

The language of this constantly changing policy raises a few interesting questions that asteroid miners want to answer through policies and proposals of their own. The language of the technology development section casts light about national support for systems development and who should perform development. Some sections are strongly in support of the development of space systems to potentially exploit mineral resources.¹⁴⁴ Some sections might actually inhibit this

¹⁴² (Sarewitz, 1996)

¹⁴³ (National Space Policy of the United States of America, 2010)

¹⁴⁴ For technology development

- “Pursue potential opportunities for transferring routine, operational space functions to the commercial space sector where beneficial and cost-effective, except where the government has legal, security, or safety needs that would preclude commercialization; “

development,¹⁴⁵ but usually only if the final technology tool is being actively used by national government, and in violation of the Outer Space Treaty.

Additionally, another major concern of proponents for space mineral resource exploitation is that infrastructure is greatly needed in the transport of resources as well as the launch of refinery and mining equipment to space. National Space Policy charges government to develop general infrastructure to support space access,¹⁴⁶ but only if there is some benefit to be gained, which has not yet been demonstrated with the one technology demonstration mission flown. In line with this, there is also the specific language in the National Space Policy about finding asteroids of high mineral resource with no indication how that would fit into pre-existing policies to find asteroids and how that could potentially interact with the act of asteroid discovery for private agents.

The National Space Policy is broadly written, designed to empower a nation and help ensure basic policy and political protection for the development of technology, to grow the knowledge about space, and to expand infrastructure and support. However, its broad language has left many potential policy gaps open, increasing the risk of space mineral resource exploiters who are unsure

-
- “Departments and agencies shall: conduct basic and applied research that increases capabilities and decreases costs, where this research is best supported by the government; encourage an innovative and entrepreneurial commercial space sector; and help ensure the availability of space-related industrial capabilities in support of critical government functions. “
 - ““Implement a new space technology development and test program, working with industry, academia, and international partners to build, fly, and test several key technologies that can increase the capabilities, decrease the costs, and expand the opportunities for future space activities;”

¹⁴⁵ Against

- “Purchase and use commercial space capabilities and services to the maximum practical extent when such capabilities and services are available in the marketplace and meet United States Government requirements;” Which could prevent violation by government of the OST through the operation of space mining hardware

¹⁴⁶ Infrastructure Arguments

- “Enhance operational efficiency, increase capacity, and reduce launch costs by investing in the modernization of space launch infrastructure;”
- “Assure space-enabled mission-essential functions by developing the techniques, measures, relationships, and capabilities necessary to maintain continuity of services;”
- “Ensure that United States Government space technology and infrastructure are made available for commercial use on a reimbursable, noninterference, and equitable basis to the maximum practical extent; “

about the support that they can gain for their activities at the national level. No other nation's space policy, publically available, discusses the operations in space to harvest mineral resources from asteroids.

2.2.3 The SPACE Act

The SPACE (Spurring Private Aerospace Competitiveness and Entrepreneurship) Act fundamentally changed the policy regime of space resource ownership harvested by private mineral resource agents, placing it in a *res communis*, (first come, first serve) ownership policy regime when passed in November 2015. Partially written by space mineral resource agents working with legislators, the SPACE Act fundamentally reduced the risk of private ownership by ensuring that once possessed, citizens own the space resources they've claimed. However, the passing of this bill into law has increased other risks of potential dangerous policy regimes moving ahead of over exploitation and a lack of protections from interference.¹⁴⁷ The SPACE Act is the first bill ever passed directly supporting the act of space mineral resource exploitation, and a good first step in starting the policy discussion. The act only focuses on the ownership risk with its current policy state, and disregards any other potential risks or technological, infrastructure, and surveying needs for space mineral resource mining.

The first revision of the SPACE Act focused on reducing all of the risks discussed previously of the space mineral mining act. Representatives Posey and Kilmer first proposed the ASTEROIDS (American Space Technology for Exploring Resource Opportunities in Deep Space) Act in September 2014 in front of the House Committee on Space, Science and Technology as HR 5063.¹⁴⁸ The Act was designed to support the growth of the space mineral resource industry by removing governmental barriers and charging the president to design a regime of ownership, infrastructure,

¹⁴⁷ (Tronchetti, The Space Resource Exploration and Utilization Act: A move forward or a step back?, 2015)

¹⁴⁸ (Tronchetti, Private property rights on asteroid resources: Assessing the legality of the ASTEROIDS Act, 2014) p 193-194

market creation, technology development, surveying, and conflict mediation between ownership claims.¹⁴⁹ Most importantly, the bill created a *res communis* policy domain for the acquisition of asteroids and then the ability to completely control the asteroid and protect it from any harmful interference through litigation in the courts of the United States of America.¹⁵⁰ This bill was heavily sponsored by Deep Space Industries and Planetary Resources, who argued that it was necessary for their development of a private industry.¹⁵¹

In response, the International Institute of Space Law's Joanne Gabrynowicz, along with others in the space law field such as Fabio Tronchetti, argued that there were major legal issues with the ASTEROIDS Act as proposed.¹⁵² The bill was lacking in a variety of ways, such as with the misuse of the court systems and legal terms within the document about "harmful interference" and "first in time" concepts, or the general disregard to resource extraction being a "volatile and contentious issue at the international level," and even a lack of discussion about the cross cutting infrastructure and technology development issues not yet addressed with mining and policy mechanisms.¹⁵³ Additionally, the bill was primarily designed to help promote the interests of particular companies, and not the industry as a whole, leading to an undesirable and potentially exclusive state.¹⁵⁴ The ASTEROIDS Act was never passed due to other issues superseding it in Committee,¹⁵⁵ but the core element of the text regarding the ownership of space resources was brought up in the next Congress as part of the SPACE Act.

¹⁴⁹ (Tronchetti, Private property rights on asteroid resources: Assessing the legality of the ASTEROIDS Act, 2014) p 193-195

¹⁵⁰ (Tronchetti, Private property rights on asteroid resources: Assessing the legality of the ASTEROIDS Act, 2014) p 194

¹⁵¹ (Stotler, 2014)

¹⁵² (Smith M., 2014)

¹⁵³ (International Institute of Space Law)

¹⁵⁴ (Smith M., 2014)

¹⁵⁵ (House Committee on Science, 2014)

The *res communis* policy regime proposed by the ASTEROIDS Act was the only major element that survived its transition to the SPACE Act, where it was added without review March 15th, 2015 to the larger Space Resource Exploration and Utilization Act in the House of Representatives, a bill intended to promote the development of space industry, infrastructure, and private support services.¹⁵⁶ This new revision was heavily supported by Deep Space Industries¹⁵⁷ and Planetary Resources,¹⁵⁸ and was put into place without much discussion or review.

Contained within the last few sections of this bill originally designed to “...facilitate a pro-growth environment for the developing commercial space industry by encouraging private sector investment and creating more stable and predictable regulatory conditions, and for other purposes,”¹⁵⁹ is Title IV, the Space Resource Utilization Act. The language of this law is clear, as any United States Citizens “...engaged in commercial recovery of an asteroid resource or a space resource under this chapter shall be entitled to any asteroid resource or space resource obtained, including to possess, own, transport, use, and sell the asteroid resource or space resource obtained in accordance with applicable law, including the international obligations of the United States.”¹⁶⁰ Also contained within Title IV, section 51302 charges the President of the United States of America through the appropriate Federal Agencies to:

- Facilitate commercial exploration of space resources
- Discourage government barriers for viable, safe and stable industries, and

¹⁵⁶ (GovTrack, 2015)

¹⁵⁷ (Deep Space Industries, 2015)

¹⁵⁸ (Planetary Resources, 2015)

¹⁵⁹ (GovTrack, 2015)

¹⁶⁰ (GovTrack, 2015)

- Promote the right of the United States citizens to engage in commercial exploration subject to the authorization and continuing supervision by the Federal Government, just as it was seen in the ASTEROIDS Act¹⁶¹

Fabio Tronchetti, in his analysis, determined that the SPACE Act only provides a provisional ownership right until a later report is submitted, and it only vaguely recommends that citizens are consistent with international obligations.¹⁶² Arguably, the policy allows the United States of America to confer an ownership right without any regulations on location (the use of "in situ" indicates in place, but the other language contradicts this such as "in possession of"), duration, intent, or international implementation of the Act. Tronchetti argues that the SPACE Act "is instrumental towards achieving such a goal [exploitation of asteroidal resources]," but functionally, it can be opposed by other states, potentially allow for competing interests and policies to take root in the international community, cause instability in current space policy, seen as a violation of space treaties so far, and ultimately be ineffective in both promoting the industry and technology development and do more harm than good.¹⁶³

2.3 THE EXPOSED POLICY GAPS

Space policy is a new field and has succeeded in developing basic technologies, but has very little history to draw from and has an even smaller number of stakeholders. The number of analysts in the field is very low, and the current state of space policy is severely lacking in historical scope, leaving the community vulnerable to a wide variety of suggestions about how to progress.

¹⁶¹ (GovTrack, 2015)

¹⁶² (Tronchetti, The Space Resource Exploration and Utilization Act: A move forward or a step back?, 2015)p 7

¹⁶³ (Tronchetti, The Space Resource Exploration and Utilization Act: A move forward or a step back?, 2015)p 8-9

During the hearing on the ASTEROIDS Act, Joanne Gabrynowicz, the Director of the International Institute of Space Law, recognized that the policy itself seems to be potentially written for the benefit of Planetary Resources and Deep Space Industries rather than the field as a whole and that there are some serious concerns that should be met to make asteroid mineral resource programs more accessible for all.¹⁶⁴ Because there are no direct historical precedents of when space mineral resources were mined before for private benefit, and there was a high cost to entry which prevent nearly everyone besides large national space programs from operating in space, these policies were not needed before. Referring back to those salient characteristics that Sonter first proposed back in the 2000's,¹⁶⁵ there are policy needs to develop markets and infrastructure, technology and ultimately what is necessary to protect the ownership right of asteroid miners as well.¹⁶⁶

Vidvuds Beldavs, a banker in Latvia, proposes that asteroid mining be handled through a central bank established in his home country.¹⁶⁷ This bank, similar to the function of the World Bank's development funds for mines, would require space miners to return a sample of asteroid material for assay, which would then award the company a loan appropriate to that amount of material as well as a temporary licensing claim for that asteroid.

The Space Settlement Prize Act, proposed by Rand Simberg of the Competitive Enterprise Institute, pulls heavily from the Homestead Act, establishing a licensing ownership regime based on private development of infrastructure and technology.¹⁶⁸ There is a role of government in the process to prevent land fraud by being an impartial surveyor, but otherwise the policy argues that

¹⁶⁴ (Smith M., 2014)

¹⁶⁵ (Sonter M. J., 1997) p 638

¹⁶⁶ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012)

¹⁶⁷ (Beldavs, 2013)

¹⁶⁸ This includes 600,000 square miles or 4% of lunar surface or 1/6th of the area of the United States of America or 3,600,000 square miles of Mars being awarded to those agents who can develop infrastructure for the safe and reliable transport of human crews

there is little role for federal government, just like the Competitive Enterprise Institute's motto (Simberg's employer) of "Free Markets and Limited Government."¹⁶⁹

The Abundant Planet think-tank argued that NASA should be redeveloped into a Space Resource Development Agency, to promote the exploration of NEA to determine their mineral composition and economic value.¹⁷⁰ This policy would argue that surveying, infrastructure, and technology development be primarily handled by this agency, while the actual business operations and applied research be handled by private agents, and that in the process, the two develop an advanced licensing system for ownership as an interpretation of the original 1958 charter of NASA.¹⁷¹

One of the most well reviewed policies comes from Dr. Ricky J. Lee, a preeminent scholar of space law and policy and Principal Administrator of the International Air and Space Law Academy, to develop an International Space Resource Development Authority. This organization would borrow heavily from the design of the International Seabed Authority and develop an impartial international government with a Registry that would coordinate a license and claim system, a General Assembly to deal with litigation, and a Secretariat to promote technology development, prevent environmental damage, and perform surveying duties.¹⁷²

Ultimately, in light of this new policy window opening on a previously unregulated policy space, now is the time to develop and implement policy. There are increasing public and political

¹⁶⁹ (Simberg, 2012)

¹⁷⁰ The functions of the Space Resource Development Agency would be:

1. Fund the development of sky survey telescopes and observation programs
2. Deploy 100 spacecraft to 200-300 NEA's to discover, tag, and track mineral content of asteroids
3. Run competitions to develop asteroid mineral extraction and processing technologies
4. Deploy robotic miners to the most attractive asteroids
5. Purchase transportation from commercial suppliers to and from the Near Earth Objects
6. Develop an international asteroid property right

¹⁷¹ (Abundant Planet, 2009)

¹⁷² (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 297

interests and there are actual realistic and feasible engineering proposals to mine these asteroids. At this early stage of development, technologically and business-wise, policy will have long standing effects, and as it will be evidenced later, a radically changing policy scheme is disruptive and dangerous. There is an opening and there are questions to answer:

- What are policies that could be implemented to allow and support the exploration and potential development of these new industries if they do prove to have some value?
- What elements of proposed policies or those in place could be used to support future goals?
- What can be learned from previous resource management policies that support future asteroid resource exploitation?

2.3.1 Technology Development

A long history of public science and basic research policies have developed the field of space systems and have made them increasingly cheaper and more available to a larger number of people. In light of the current high prices to develop the technology for a single asteroid redirect mission, there are concerns about how to develop new basic and applied technologies necessary for these expeditions. Sonter discussed the development of low cost space mineral mining technologies and transportation systems as two major salient characteristics for a successful space mining environment.¹⁷³ Technology development has been mentioned in numerous policy proposals on the subject, such as the funding for private technology development being supported by an assay mission,¹⁷⁴ or being the only focus of a redirected NASA designed to exploit the resources of space.¹⁷⁵

¹⁷³ (Sonter M. J., 1997) p 638

¹⁷⁴ (Beldavs, 2013)

¹⁷⁵ (Abundant Planet, 2009)

At this point, questions need to be asked about who is responsible for technology development, as well as what policy mechanisms should be applied if it is deemed appropriate that policy get involved in the process. Participation of various public and private agents would be determined on the potential value for these activities and the development of associated technologies. Ultimately, the goal is to produce the most public good for applied research programs and only assist in the development of applied research if there is a public benefit to do so at the current time.

2.3.2 Surveying Duties

The surveying claim was a fundamental element of the early mining process, and also critical to the development of a successful mining community (Sonter's Characteristics for adequate characterization data and location data).¹⁷⁶ Previously, it acted as a single action that demonstrated the knowledge of a resource, access to the region, and access to the resource. However, the modern sky-watch programs have separated knowledge of a resource from access by finding potential orebodies as a way to protect Earth. The use of remote sensing and its low fidelity characterization data has separated the knowledge of the resource from the access demonstrations. The free sharing mandated by the Outer Space Treaty of location and composition data further has reduced the strength of private mining claims, reducing the economic advantage for private agents to participate in remote sensing and physical assay of asteroids, despite the potential public and private benefits that could be derived.

Right now, the data collected through sky watch programs to protect the Earth from impactors (or just recognize that they might be there) does not include thorough enough data to substantiate mining claims. Policy proposals within the space mineral mining field propose that

¹⁷⁶ (Sonter M. J., 1997) p 638

government undertake this activity and release that data only to national programs,¹⁷⁷ mandate the assay process to receiving funding and a license,¹⁷⁸ or that these processes are organized by international bodies¹⁷⁹ or left to be completely private mining activities.¹⁸⁰ There are many disagreements about the importance of these activities and the responsible parties.

In light of the public good in identifying potential Near Earth Asteroids, should those programs be continued, or shut down, or supported by the activities and applied research of private miners? At same time, in light of the changing nature of the survey process, should remote surveys be sufficient, or is more necessary, especially in light of the difficulty of space mineral resource mining?

2.3.3 Ownership

The ownership regime currently in place is one of the most fiercely debated issues related to space mineral resource activities. The recent passing of the SPACE Act represents a tremendous change in the legal paradigm of space material ownership, and many argue that the current state is insufficient in its protections against interference and complications with international law at the same time.¹⁸¹ There is an agreed upper bound preventing national procurement of space systems technology under the *Common Heritage of Mankind* and a lower *res communis* bound put in place, with great disagreement, by the SPACE Act, but as demonstrated throughout history, *res communis* policies among private agents leads to over utilization or a potential for a totally exclusive space environment.¹⁸² Ownership regimes have been proposed to be a total ownership regime,¹⁸³ to a

¹⁷⁷ (Abundant Planet, 2009)

¹⁷⁸ (Beldavs, 2013)

¹⁷⁹ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012)

¹⁸⁰ (Simberg, 2012)

¹⁸¹ (Smith M., 2014)

¹⁸² (International Institute of Space Law)

¹⁸³ (Simberg, 2012)

heavily licensed one based on demonstrated assay,¹⁸⁴ to simply keeping the systems *res communis* and first come, first use in nature.¹⁸⁵ Ultimately, is there a policy regime that prevents exclusivity as well as preventing interference between agents at a level that reduces the risk of asteroid mining operations at the decadal timeframe?

2.3.4 Infrastructure Development

Finally, transportation infrastructure (salient Characteristic V) and market creation (to support I and VI of Sonter's Characteristics) is a large risk for space mineral resource developers. They wish to develop these systems at a low cost by having government involvement based on the promise of potential future public and private benefit through the reduction of system costs. The concept appears in a variety of texts, sometimes being the critical representation of an ownership claim,¹⁸⁶ or simply something handled by the infrastructure-building public policy system.¹⁸⁷ Are these claims substantiated, and if so, under what premises and assumptions of future benefit?

¹⁸⁴ (Beldavs, 2013)

¹⁸⁵ (Lee, Creating a Practical Legal Framework for the Commercial Exploitation of Mineral Resources in Outer Space, 2009)

¹⁸⁶ (Simberg, 2012)

¹⁸⁷ (Abundant Planet, 2009)

3 METHODOLOGY OF THIS ANALYSIS

There are few precedents that can be drawn on to develop policies to support the further development of space mineral resource activities. The closest analogies for space mineral resource mining on Earth are resource rushes, where suddenly a new resource opens up for utilization, often without any policy precedent. To best understand the effect of policy in the context of asteroid mineral resource exploitation, historical policies were analyzed and compared to the current state of asteroid mineral exploitation against the desired end states.

3.1 HISTORICAL ANALOGS

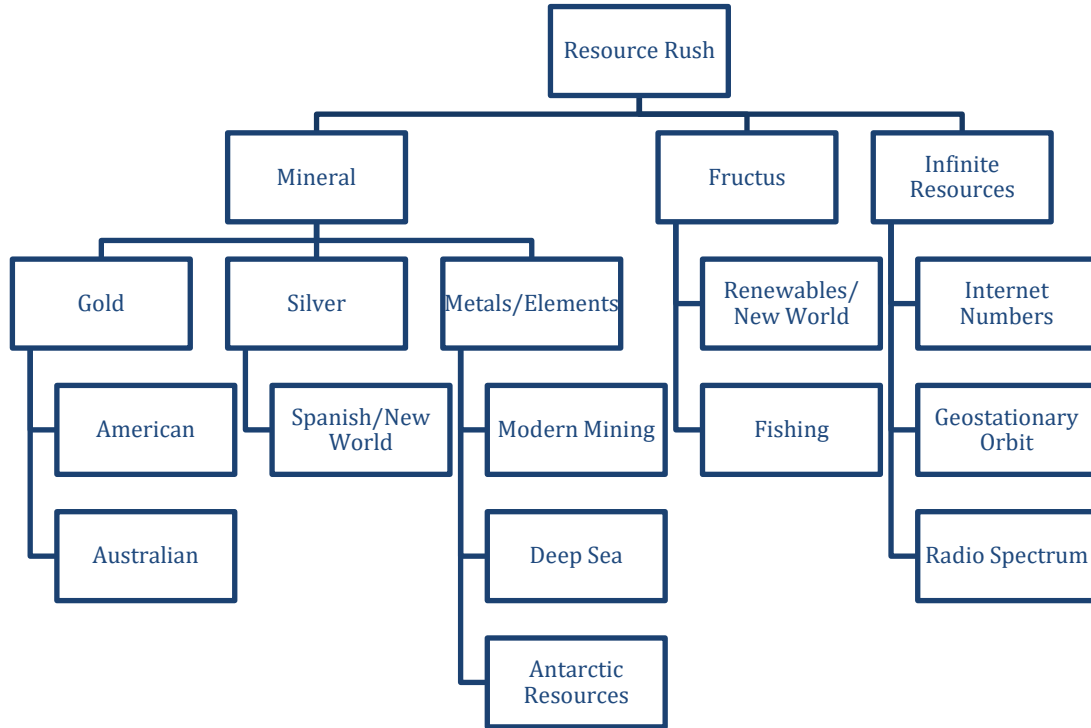
There are a variety of historical analogs to be drawn on for this analysis. Typically when discussing asteroid mining, advocates focus on the American Gold Rush, Antarctic Treaty System, and the Convention on the Law of the Sea without reviewing other resource rushes and the policies that came with them. For this analysis, a resource rush is defined as a situation where:

- There is an undetermined policy state or sudden change that opens up a resource stock for exploitation
- New resources are found through surveying or exploration
- New technologies make resource stocks available for exploitation
- The cost for access decreases through the development of new infrastructure

Resource rushes have happened for a variety of resource types with varying context and timeframes that policy lessons could be learned from. Stemming from the classic example of a mineral rush,¹⁸⁸ the American Gold Rush, the body of related resource management policies can be expanded to the Australian Gold Rush and diamond mining. Expanding the scope to include *fructus*,

¹⁸⁸ (Adams, 2012)

or reproducing stocks, as well as telecommunications technologies and digital resources can provide increasing insight into the developments of resource regulation policy in a variety of regimes.



Resource rushes have been an element of the terrestrial mining process for hundreds of years, and now there is the opportunity for the same to happen in space and with the riches of celestial bodies. By looking at the previous history of resource rushes, many things can be learned about how to regulate the exploitation of these new resources. This is especially important with space mineral resource mining as there are no previous precedents, and previous discussions have been based on superficial reviews of the gold rush in America and the use of *Common Heritage of Mankind* in the Antarctic and deep seabed. By expanding the definition of a resource rush and analyzing more resource management policy regimes, the effects of various policy treatments can be seen. Ultimately, this facilitates a better understanding of how to manage the potential resource rush of space mineral resources. There are no direct precedents to space mineral resource mining in terms of the actual mechanics, technologies, and scope, but by using a large body of previous

resource management experiences, each situation can contribute to a set of general policy recommendations for the future of space mineral resource exploitation.

3.2 MINERAL MINING

Mineral mining are the most common resource rushes of the past millennia, as the resources in question are particularly high value or there is a sudden change in some way that allows competitive industry to take root and develop. These are the easiest minerals to mine and industry has been centered on the exploitation of these materials for thousands of years. In the process, mining and the technological developments associated with it has been fundamental in shaping policy and the role of government.¹⁸⁹ For asteroid miners, many believe that mineral mining on Earth is the most direct analog to mineral mining in space. This thesis argues that besides the typically referenced American Gold Rush, the Australian Gold Rush, silver exploitation in the New World by the Spanish, diamond mining in South Africa, and the attempted resource exploitations eventually blocked by the *Common Heritage of Mankind* are some of the most direct analogs to space mineral resource exploitation, and much can be learned from the policy attempts to control ownership, develop technology and infrastructure, and perform surveys.

3.2.1 Spanish Silver Exploitation

The exploitation of silver by the Spanish in the 1500's through the 1700's laid a fundamental framework that would drive economic mineral mining today. The Crown of Spain did manage to help promote surveying, spur technological development,¹⁹⁰ help support an economic mining of minerals through infrastructure development, and create rudimentary ownership policy on licensing, leading to a successful exploitation of the continent's resources for a short period of time. However, a narrow focus, and too tight of a coupling between the federal infrastructure and

¹⁸⁹ (Sonter M. J., 1997) p 163

¹⁹⁰ (Hamilton, 1929)

private miners caused long-term instabilities that eventually led to the collapse of the Spanish mining empire.

In the late 1400's, there was a massive European mining technology boom, and throughout the remainder of that century into the next, Europeans were looking for new sources of mineral resources, particularly precious metals outside their own continent, which was limited in size with strong borders preventing movement and the free exploitation of mineral resources.¹⁹¹ Expeditions were launched across the Atlantic Ocean for a variety of reasons, but one explorer found North America and indigenous peoples who seemed to have access to various valuable mineral resources.¹⁹² Further surveying discovered more deposits of silver that could be easily exploited with European technology, and Spain, under the Crown of Castile Ferdinand II of Aragon, directed merchants to exploit these resources and colonize the New World.¹⁹³

The surveying undertaken by Spanish explorers and the investment by the Crown into these expeditions formed the fundamental basis of their claim to the continent, as it demonstrated that they could access the resources and it was a way for them to protect their investment into exploration and discovery of resource goods.¹⁹⁴ The Crown claimed the land as their own, and then began licensing specific regions for use and mining. Private mining operators were the ones who operated the mine sites, and their license was sustained by a steady and constant use of the land and their ability to generate revenue for the Crown and themselves. The foundations laid by the Spanish, which required constant use and exploitation to sustain a license to operate on a given patch of land, would eventually form the basis of the American mining codes.¹⁹⁵ These policies were

¹⁹¹ (Martin L. , 2004) p 21-22

¹⁹² (Martin L. , 2004)

¹⁹³ (Lueck, 1995)

¹⁹⁴ (Brading & Cross, 1972) p 560-561

¹⁹⁵ (Shanks)

intended to promote the use of the land, prevent interference, and protect initial investments into mining and long-term investments in infrastructure development.¹⁹⁶

Spanish government also recognized the importance of the technology development of the mining process. The basic technologies of extracting valuable minerals from ore had been developed centuries before, and Spanish miners supported the writing of *De re metallica* by Georgius Agricola in 1556 which brought new mercury amalgamation techniques from Europe to the Spanish silver mines, increasing their process efficiency.¹⁹⁷ Merchants and miners brought new technologies and capabilities from their travels, such as Pachuca Bartolome de Medina, who discovered lead smelting processes and brought them to industrial mines.¹⁹⁸ In the lands of the New World, Spanish miners had to develop new techniques for going deeper into the Earth.¹⁹⁹ To promote increasing efficiency, and to some extent increasing tax revenues for the Crown, taxes were reduced when mines were to perform upgrades.²⁰⁰ This reduced the risk for technology improvement, while ultimately better serving the public and private good over time.²⁰¹

In order to further maximize the efficiency and profit for the Crown of the operation of New World silver mining, Spain created a monopoly on the mercury required for the amalgamation process and controlled the mint and dissemination of silver through a mercantilist approach.²⁰² By controlling a necessary resource that allowed technology to be used, the Spanish Crown could make profit off of the otherwise private industries. Standard rates were set on mercury, which was necessary for the infrastructure of silver mining.²⁰³ Additionally, once the silver arrived on Spanish

¹⁹⁶ (Hamilton, 1929)

¹⁹⁷ (Brading & Cross, 1972) p 545-546

¹⁹⁸ (Brading & Cross, 1972) p 551-553

¹⁹⁹ (Brading & Cross, 1972) p 549

²⁰⁰ (Hamilton, 1929)

²⁰¹ (Martin L., 2004)

²⁰² (Brading & Cross, 1972) p 560-561

²⁰³ (Brading & Cross, 1972) p 564

shores, the tax levied on the mines was equal to 20% of total production (decreased to 10% by 1736), and 0.5% was deducted for assay and surveying costs for originally finding the continent.²⁰⁴

Silver went through its first economic boom during the 1530's because of new mines opening and new logistics structures to pass silver through the Spanish mints.²⁰⁵ The purchasing power of the Spanish empire fluctuated due to inflation and recession, dropping precipitously in the 1536-1540, 1556-1560, and 1600's due to over inflation and over exploitation.²⁰⁶ With all of the success of the mining industry, profit was high at the beginning and steadily was reduced over time as over production reduced the value of the previously rare silver stock.²⁰⁷ Eventually, technical difficulties reduced some elements of that mercury supply that Spain controlled and several mines suddenly were exhausted, leading to greater instability in the mining market, heralding the collapse of the Spanish silver mining empire.²⁰⁸ Reactionary, large-scale taxing regime changes continued to decrease profitability more than investments could make them back.²⁰⁹ The tight coupling and price fluctuations of the mercury and silver market led to the eventual downfall of the large empire in the 1650's.²¹⁰ The government simply took on too much risk by controlling the crucial supplies to enable silver amalgamation, maintaining a mint, enforcing a high tax, and managing the use of land resources. In a modern mineral mining program, no one entity, especially a government, would take on all of this risk regardless of the amount of potential riches and economic prosperity that might exist.

From the profit and pitfalls of the Spanish, it is evident that there are some positive ways to encourage technology development, and ensure that ownership allows for protection, while

²⁰⁴ (Brading & Cross, 1972) p 561

²⁰⁵ (Brading & Cross, 1972) p 568-571

²⁰⁶ (Flynn, Fiscal Crisis and the Decline of Spain (Castile), 1982) p 142

²⁰⁷ (Flynn & Giraldez, Born with a Silver Spoon: The Origin of World Trade of 1571)

²⁰⁸ (Brading & Cross, 1972) p 572

²⁰⁹ (Flynn, Fiscal Crisis and the Decline of Spain (Castile), 1982) p 146-147

²¹⁰ (Hamilton, 1929)

encouraging use for public and private benefit. However, overexploitation and instabilities from a lack of infrastructure as well as tight coupling between the governmental supply chains eventually led to a downfall of the program, the mining network, and even to some extent the Spanish empire in its entirety.

The exploitation of space mineral resources could potentially bear a great similarity to the mineral resource exploitation. Leading up to this point, nations were responsible for a majority of the development of space and space resources, such as orbit. There could be a strong urge for government to participate a great deal in the risk sharing programs, by surveying, developing technologies, managing resource infrastructures, and operating full banks, but as seen with Spain and their silver, the tight coupling of all of these factors could be deleterious. However, the success of controlling mining claims and preventing interference while promoting new technology options could lend some insight into how to manage the risk of developing expensive space systems and infrastructure to support it.

3.2.2 American Gold Rush

The New World not only had wealth in silver, but also gold, which wasn't discovered until the 1850's along the West Coast, nearly three hundred years after the first major resource rush of silver in the same regions. The American Gold Rush represents a policy environment that promoted exploitation and eventually laid the foundation for modern mining policies on ownership. It stands as one of the first examples of grassroots policies being developed by private agents and eventually being codified as local, national, and eventually international law.

In 1750, at the time of the original colonization by the British of what would become the East Coast of the United States of America, King George III of England issued a Royal Proclamation forbidding movement westward beyond the sources of the water that flowed into the Atlantic and ownership of any of these lands, but people continued to disregard the King's orders and occupy

and improve these lands.²¹¹ During the first half of the 19th Century, America was gripped by Manifest Destiny to spread westward across the North American continent.

The United States of America Government procured a great deal of land through trades, deals, and military strength and created a variety of policies to help support the steady movement westward.²¹² In 1841, the United States Congress recognized that many squatters had been living in the areas normally forbidden, and passed the Preemption Act, which gave squatters the ability to purchase up to 160 acres of land that they had been using based on *prior appropriation*.²¹³ With this early code, there were some concerns, as coordination between claimants could potentially allow for large tracks of land to be acquired through shell companies,²¹⁴ as well as the concern that the 160 acres being granted typically were less fertile than the Eastern lands, forcing settlers to develop new technologies for resource exploitation including timber and other resources.²¹⁵ Ultimately, these methods of licensing turning into eventual ownership worked well, enabling economic exploitation of the land, coordinating use and preventing interference, laying down the foundation of basic ownership of unclaimed lands, and were expanded upon in the West once gold was discovered, and the value of land could also include its minerals as well.²¹⁶ Eventually, the policies developed for squatters became codified as part of the 1862 Homestead Act,²¹⁷ where they could purchase the land at \$1.25 per acre after six months of residency and improvement of the land,²¹⁸ and unused regions could be used for infrastructure as part of the Railroad Act.

²¹¹ (Pop, Who Owns the Moon, 2009) p 101-102

²¹² (Pratt, 1927)

²¹³ (Pop, Who Owns the Moon, 2009) p 102

²¹⁴ (Gates, 1936) p 657

²¹⁵ (Gates, 1936) p 662-666

²¹⁶ (Shanks) p 30

²¹⁷ (Shanks) p 31

²¹⁸ (Shanks) p31

When gold was discovered by a watermill worker in California nine days before annexation, the word spread quickly across the nation.²¹⁹ At the time, this land was mostly uninhabited, and once annexed by the United States, it was completely unowned, except for a few settlements and military outposts.²²⁰ The technology of previous mineral exploitation allowed for the cheap and easy exploitation of alluvial gold sources,²²¹ and the sudden discovery of gold with no pre-existing *prior appropriation* claims created a new resource rush for the mineral. Here, the American miners took on technology development by themselves, and developed hybrids of old world methods, like the alluvial gold panning process, where gold was sifted through pans to reveal gold,²²²

Transportation infrastructure connecting the east and the west was nonexistent, so many chose to sail through Panama to San Francisco and many lives were lost on disease ridden boats during their long trips.²²³ Some did decide to use overland routes²²⁴ to move to the west after hearing about the boats, and within the year, 60 or more wagons per day set out on the singular overland trail.²²⁴ Later, in recognition of the riches of the West, the Transcontinental Railroad and over land trails were developed as a byproduct of the Homestead and Railroad Act. Eventually, these miners reached the unclaimed lands and started mining but, at the time, there was no way to limit the interference from other mining agents or retain any legal right to a claim.

Just like with the silver mining before, the land belonged to the US government, and there was a public debate to make the mines operate for the public benefit (meaning that all of the resource recovered and land would be owned by the federal government).²²⁵ However, the President and Congress decided against this course of action, and eventually each small mining area

²¹⁹ (Martin L. , 2004) p 119-120

²²⁰ (Lueck, 1995)

²²¹ (Rawls & Orsi, 1999) p 20-25

²²² (Rawls & Orsi, 1999) p 28-29

²²³ (Martin L. , 2004) p 124

²²⁴ (Martin L. , 2004) p 126

²²⁵ (Martin L. , 2004) p 127

made their own rules and procedures for mining claims, knowing that whatever they mined would be their own and used the Preemption Act to secure ownership rights and possession. The Gold Rush of 1849, often seen as a “chaotic scramble for high-profit opportunities in an open-access setting,” was actually quite different than that, with policy being made at the local level and eventually being codified.²²⁶ Despite the lack of common law, the culture of the community made their own set of laws to describe how resources, land and mining rights were to be established. The legal system that eventually developed was based on two fundamental principles each seen up and down the West Coast:²²⁷

- A man could only claim such ground they could work by themselves
- A man must continue to work that land to hold the claim

There had been slight variation in the rules of order, but because they stemmed nearly directly from the social norms set by earlier Spanish silver exploiters on the west coast of North America and the Homestead Act, there was a high level of agreement between individual camps.²²⁸ By the time government caught up with the technological development of the miners, the modern claim system was implemented based on the original work of these miners.²²⁹ The later 1872 Mining Codes kept the same intent and focus of the original mining claim, and made it into law.²³⁰ These mining codes took a culture developed in the west that was derivative of Spanish, squatting culture, and Homestead Act beginnings, and adapted all of these into a hybridized structure that became well accepted and the basis for further laws.

The American Gold Rush can show space mineral resource miners the potential for sustainable resource use policy development by taking initial cultural and legal starting points and

²²⁶ (Clay & Wright, 2005)

²²⁷ (Martin L. , 2004) p 128

²²⁸ (Clay & Wright, 2005)

²²⁹ (Clay & Wright, 2005)

²³⁰ (US Department of the Interior-Bureau of Land Management, 2015)

then developing new policy regimes on ownership on their own. As an extension of this, the modern mining claim system based on licensing appears during the American Gold Rush, and is still the standard on land ownership for resource exploitation today.

3.2.3 Australian Gold Rush

The American Gold Rush was not the only gold rush that happened in the middle of the 19th Century, as gold was discovered in Australia in 1851. One American miner, Edward Hargraves, having failed in the California Gold Rush, went to Australia after hearing about various gold discoveries, bringing techniques and tools for gold mining with him.²³¹ The discovery of large alluvial gold veins and gold ore triggered another Gold Rush, as the necessary technology was already there from the previous American Gold Rush, costs were low to work in Australia, and Australia had no large scale policies on mineral mining and land exploitation.²³²

Australia was fundamentally different in its social and legal structure than the West Coast of America with regards to land exploitation, and land had been historically licensed for the use of animal husbandry or otherwise occupied through *prior appropriation* by indigenous peoples or squatters.²³³ After the discovery of gold in the southern regions, 19,000 British, American, Chinese and South Asians immigrated in 1851, and the year afterwards, more than 75,000 had immigrated.²³⁴ Many miners came from America, bringing the licensing and mining culture from that country, which in combination with the wealth of the gold mined, triggered a 'complete social revolution.'²³⁵ The concept of using land temporarily for mining based on current use was foreign to the federal land coordinators in Australia, who had typically given permanent deeds for land

²³¹ (Cavendish, 2001)

²³² (Sunter, 2003)

²³³ (Martin L. , 2004) p 135-136

²³⁴ (Martin L. , 2004) p 138-139

²³⁵ (Cavendish, 2001)

ownership for agriculture and livestock. There were great conflicts in the perception of the public and private good of mineral mining.

In order to limit economic losses of Australia due to a shifting focus from agriculture to mining, controls were put in place in the form of restrictive licensing for mining which would highly tax miners and limit participation in the act.²³⁶ This tax, equivalent to a few hundred grams of gold (when a miner might only gather a few kilograms over a year) was designed to further strengthen industrial development in Australia and offset the public risk of reallocating land use.²³⁷ However, miners simply avoided paying the tax, causing a great deal of stress for the peoples in Australia and adding to growing tension between the colonial government and the miners.²³⁸ The next few years were fraught with policy reversals, protests and eventually in 1854, the Eureka Stockade rebellions, in which the armed miners and authorities fought.²³⁹ Twenty four miners were killed in the rebellions, and afterwards, reform swept across the country. The license fee was revoked, replaced with an export tax and a Miner's Right, and local governments asked for a more general mining fee for one year.²⁴⁰ Australia eventually did enjoy the economic, social, and infrastructure success that America had, but at a greater economic and social cost over time.

Space mineral resource miners could also potentially go down a similar path to the Australian Gold Rush scenario if there are too high upfront costs arbitrarily imposed to limit participation. Already, there are concerns about the potential to leave lesser developed nations behind by expanding the resource base to include space,²⁴¹ but by imposing harsh fines and fees, which could help develop other nation's space mineral mining capacity, the economic interest in mining greatly decreases. Ultimately, the Australian Gold Rush details the limits of risks that private agents are

²³⁶ (Sunter, 2003)

²³⁷ (Sunter, 2003)

²³⁸ (Martin L. , 2004) p 140-141

²³⁹ (Sunter, 2003)

²⁴⁰ (Martin L. , 2004) p 142-143

²⁴¹ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 17

willing to undertake, and any extra financial risk with the management and use of resources before any profit is earned is highly undesirable as a way to control utilization.

3.2.4 Modern Mining

Since these early gold and silver rushes, the nature of mining has fundamentally changed, focusing on a large variety of ores rather than just precious minerals creating new risks and policy opportunities, but much of the ownership policies have stayed the same. The mental image of a man with a cart pushing ore out of an open mineshaft is less prevalent with the growing use of large and complicated machinery to dig deeply into the Earth.²⁴² Modern mining is highly connected to a global commodity market and banking system, highly connected to local and international environmental monitoring agencies, and organized by investors to maximize efficiency, reduce environmental impact, and ultimately maximize profit.²⁴³ Modern mining is large in scope, expensive in execution, and representative of some of the same investments and technologies that need to be developed for space mineral resource mining.

The ownership of mining sites is primarily done through temporary licenses as part of the 1872 Mining Law, developed from the common laws of the American Gold Rush.²⁴⁴ Since then however, the act of surveying is shared between public and private agents, and more of a focus on ensuring that not only does the mine add value to the region and is profitable,²⁴⁵ but that it is also environmentally friendly.²⁴⁶ To ensure that these lands can also be used in the future, the land is managed by federal governments, such as the Bureau of Land Management for the United States of America.²⁴⁷ The United States of America allows citizens to use federal lands for mineral extraction. Licenses can be requested, and licensees are asked to continue infrastructure development (at least

²⁴² (Sachs & Warner, 2001)

²⁴³ (Sachs & Warner, 2001)

²⁴⁴ (Rohlin, 2011) p 1

²⁴⁵ (Wilson, 1982)

²⁴⁶ (Martin L. , 2004)

²⁴⁷ (Rohlin, 2011) p 2

\$100 worth) and supply information about their operations and materials with smaller filing fees from \$10-\$100.²⁴⁸ Additionally, land is licensed for a period of time in a given region, but in specific cases where land is isolated or uneconomic to manage, or fallen in disarray and disposal would be preferable, individuals can buy this region.²⁴⁹

The development of processes like the Hall-Heroult process by Bayer made aluminum metal mining profitable and took something that was once valuable, like pure aluminum, into a common commodity that is thrown away.²⁵⁰ This kind of advanced metallurgy heralded a new age of materials science being integrated with modern mining and the centralization of large refineries technology with distributed mining networks.²⁵¹ To establish these mines, there is also growing reliance on large financing structures to ensure profitability.²⁵² Financing and economically supporting a startup mine is nearly impossible for an individual to do. The use of international financing and the banking system can help companies start up and by the extensive architectures for mining, safety, and mineral exploitation (drills, refinery equipment, etc.) can also help in preventing competition by supporting one company over another, or forming alliances and partnerships for a common goal.²⁵³ Competition is one of the greatest threats to the modern mineral miner, as most economic deposits have been found, and profitability is determined by process innovation in perfecting the methods and modes of mineral mining.²⁵⁴ Policies are usually developed to help mitigate these competitive risks through altering the ownership process or

²⁴⁸ (US Department of the Interior-Bureau of Land Management, 2015)

²⁴⁹ (Pop, Who Owns the Moon, 2009) p 91-92

²⁵⁰ (Martin L. , 2004) p 281

²⁵¹ (Martin L. , 2004) p 308-310

²⁵² (Rudenno, 2012)

²⁵³ (Hickman, 1999)

²⁵⁴ (Martin L. , 2004) p 279-280

providing subsidies and incentives to promote the development and deployment of mines within nations.²⁵⁵

Mining financing is a growing aspect of the mineral market today. Part of the financing structure is participating in the exploration (\$12 billion industry in 2010 for exploitable minerals and \$440 billion for the development of hydrocarbons), definition and assay, feasibility studies, extraction, processing, and mining.²⁵⁶ Capital is required now more than ever for exploration of mineral resource deposits as returns can only be made with substantial scale earning more profit than the large equipment and machinery required to mine.²⁵⁷ State development banks and even the World Bank get involved for these large scale developments, and they are used often as a borrowing base to help these large scale operations function profitably and develop specific implementations of technology to mine. In some cases, mining financing is also done by the state to promote the development and growth of new industries or for the expansion of a domestic resource base. Chinese mining management focuses on large scale industries being operated by the national government rather than private investors, and they have had success exploiting the mineral deposits of the Gobi Desert.²⁵⁸ However, they have had some issues with the high risk of mining interacting with the interests of the federal government, which typically has a very low risk threshold, causing their mines to be highly conditional.²⁵⁹ Lesser developed nations with high mineral resources tend to have strained relationships with the mineral wealth of their nations, where investment into the short term benefit of natural resources and infrastructure development often prevents sustainable economic development, called a *resource curse*.²⁶⁰

²⁵⁵ (Nelson & Langlois, 1983)

²⁵⁶ (Rudenno, 2012) p 2-3

²⁵⁷ (Rudenno, 2012) p 9-10

²⁵⁸ (Wang, 2012) p 77-80

²⁵⁹ (Global Economic Prospects, 2013) p 104-105

²⁶⁰ (Sachs & Warner, 2001) p 828

Ultimately, modern mineral mining can be done in a variety of ways, with financing coming from private backing, multinational world development banks or the support of nations. For the space mineral resource miner looking to ultimately reduce the risks they might encounter when mining asteroids, these policies might provide some help in promoting the development of new systems and technologies. However, heavy involvement into the development of a few resources by risk-averse investors such as governments or a few private agents might limit overall economic impact and activity.

3.2.5 The Use of Antarctica

Antarctica was another major resource rush triggered by steady technology development, a policy gap that had never been addressed about the ownership of Antarctica, and a large scale surveying done as part of international research. Antarctica was never claimed by any human civilization during the age of imperialism during the 1850's, and the use of Antarctica was primarily limited to short term docks and a few scientific expeditions.²⁶¹ The continent is nearly twice the size of Australia, and covered by ice, which limited the ability of nearly any country from working deep into the continent.²⁶²

However, this all changed during the International Geophysical Year between 1958 and 1959. In Antarctica specifically, thirty thousand scientists from 70 different countries explored this continent to understand more about its geology and past history.²⁶³ Despite its harsh weather, the continent was found to be incredibly rich in resources that were now accessible with modern mining tools. Minerals were found in abundance near the surface, and 50 billion barrels of oil, comparable to the entire reserves of Alaska, were found in the continent.²⁶⁴

²⁶¹ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 204-205

²⁶² (Soucek, The Polar Regions, 2011) p 272

²⁶³ Argentina, Australia, Chile, France, New Zealand, Norway, and the United Kingdom

²⁶⁴ (Soucek, The Polar Regions, 2011) p 272-273

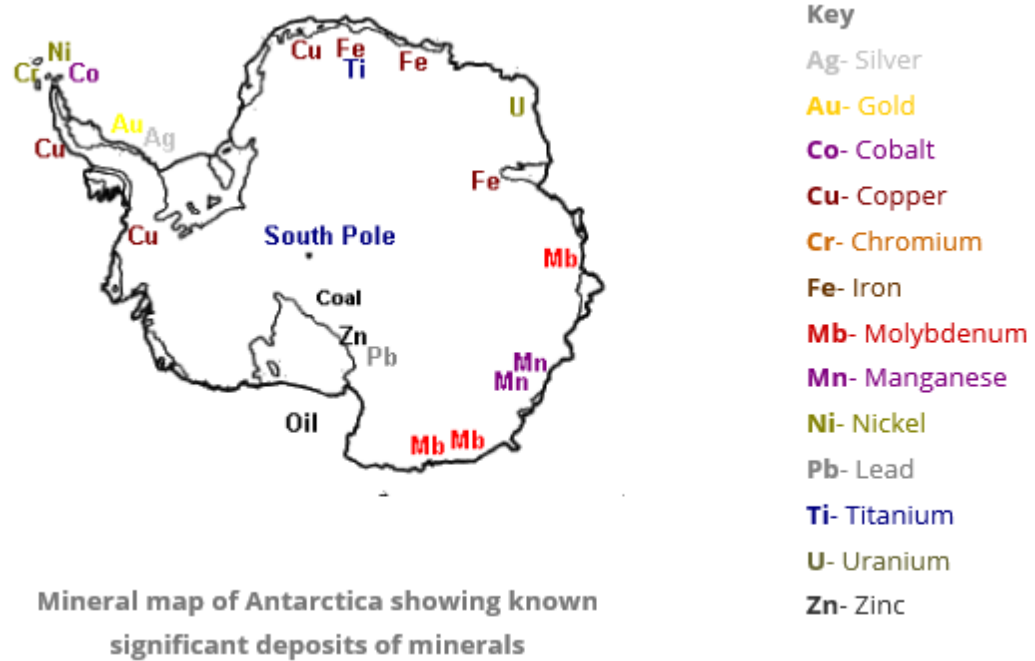


Figure 5: Mineral Resources of Antarctica (Soucek, *The Polar Regions*, 2011)

Because of these numerous mineral riches, many nations used their surveying knowledge to lay claims to Antarctica before any international policy could be put into place. Generally, the intent behind all of these claims was to not only be able to access resources, but to also expand scientific research regions and prevent later interference between nations trying to own the mineral and energy resources of the continent.²⁶⁵ However, fearing larger scale interference and seeking a way to legally support their claims, the international community that had grown on the continent, guided by some of the same principles of equitable and fair use for scientific research over time, developed the first instance of the *Common Heritage of Mankind*. Originally, the mineral resources were of great interest to nations who laid claims, but realizing that the scientific and environmental

²⁶⁵ (Shackelford, 2009) p 113

resources and maintaining their claims were more important than immediate exploitation, industrialized nations were willing to put off economic development for some time.²⁶⁶

The Antarctic Treaty (now called the Antarctic Treaty System, or ATS, reflecting its growth since 1959) was put into place by the United Nations to establish principles for the peaceful use of the Antarctic, prevent powerful industrialized nations potentially overusing the environment and mineral resources of the Antarctic before any other nation could, ensure the freedom of scientific investigation within the region, and protect the unclaimed environment.²⁶⁷ This was the first use of the *Common Heritage of Mankind* to ensure that there was a future use of the continent for all peoples and reduce the potential impacts of industrialized nations.²⁶⁸ Participation in the Treaty System was determined by who had been participating or actively exploring the Antarctic and other provisions were designed to ensure the free sharing of all scientific knowledge derived from the exploration of the continent.²⁶⁹ Unfortunately, there were few tools actually in place to enforce this policy mechanism besides legal action to revoke the land claims that were left in place after CHM was applied to the continent.²⁷⁰

In the regions claimed by their host nations, some economic activity still continued, done by private agents focusing on mining, dock working, and oil exploration for future use under a different policy regime.²⁷¹ The text of the Treaty using the *Common Heritage of Mankind* was not strong enough to prevent exploitation that could damage the environment and there was no discussion about allowing or preventing private ownership of Antarctica-derived mineral

²⁶⁶ (Pop, *Appropriation in outer space: the relationship between land ownership and sovereignty on the celestial bodies*, 2000)

²⁶⁷ (Soucek, *The Polar Regions*, 2011) p 273

²⁶⁸ (Shackelford, 2009) p 128-129

²⁶⁹ (Soucek, *The Polar Regions*, 2011) p 277

²⁷⁰ (Soucek & Brunner, *Outer Space in Society, Politics, and Law*, 2011)

²⁷¹ (Joyner, 1992)

resources. That original language of the ATS only prevented nations from exploiting the minerals,²⁷² but allowed for private agents to exploit mineral resources with no liability as the region was *res communis* to private agents.²⁷³ In response to the economic exploitation (typically by industrialized nations) and the environmental damage that was involved, the *Protocol on Environmental Protection to the Antarctic Treaty*, signed in 1991, declared the Antarctic to be a natural reserve in light of the growing knowledge of the scientific and environmental resources of the continent.²⁷⁴ Claims for scientific and peaceful use were maintained, but no further economic exploitation by any national or private agents was allowed, strengthening the intent of the *Common Heritage of Mankind* by actually undoing it and replacing it with a natural preserve.²⁷⁵

This major reversal of the *Common Heritage of Mankind* came about when social and technological pressures forced the policy systems and mechanisms to break down.²⁷⁶ Through the 1950's, the technological capability of exploitation steadily grew, and eventually began to supersede the environmental argument for preserving the Antarctic.²⁷⁷ However, it was determined by the Antarctic community that the preservation of the scientific and natural resources were more important than the private exploitation argument and the *Common Heritage of Mankind* and the *res communis* policies on private ownership allowed exploitation to happen.²⁷⁸ The potential for runaway environmental degradation and exploitation was too dangerous, and in light of the national activities on the continent, the new protocols prevented any economic exploitation.

Antarctic serves as an example of potentially detrimental application and change of the *Common Heritage of Mankind* principle already in place for space mineral resource mining and the

²⁷² (Shackelford, 2009) p 128-129

²⁷³ (Joyner, 1992)

²⁷⁴ (Shackelford, 2009) p 130-131

²⁷⁵ (Soucek, *The Polar Regions*, 2011) p 280

²⁷⁶ (Shackelford, 2009) p 131

²⁷⁷ (Shackelford, 2009) p 131

²⁷⁸ (Joyner, 1992)

potential future of that regime when economic and social pressures were applied. Additionally, with regards for the coordination of efforts among space mineral resource miners, it does demonstrate coordination coming out of shared communal interest in exploiting the scientific resources of this untouched continent. Ultimately, the change of the use of the *Common Heritage of Mankind* to meet a variety of different needs shows the capabilities and deficits of the CHM, and how it might evolve.

3.2.6 Deep Sea Bed Exploitation

For the same reasons of free and equitable use while trying to preserve the scientific and environmental resources, the deep seabed and high seas (regions far away from the Exclusive Economic Zones operated by coastal nations to be discussed later) were declared to be part of the *Common Heritage of Mankind* shortly after the Antarctic in the early 1960's. The use of this policy regime during UNCLOS I, its reversal to a more open regime in UNCLOS III, and eventual redeployment as part of UNCLOS IV caused several issues for the economic development of deep seabed mineral resources while inhibiting technological growth and steady economic exploitation. Ultimately, by extending the *Common Heritage of Mankind* by forcing the sharing of technology, dissemination of expensive survey knowledge, and reducing the ability for private investors to actually own deep seabed-derived mineral resources across industrialized and non-industrialized nations has inhibited any further development of this resource base. Asteroid and space mineral resource miners should rightfully fear what happened to the deep seabed.

The ocean covers over 70% of the Earth's surface, and just as there are economic mineral deposits on the surface, there are also mineral deposits underneath the water. While undersea mining is more expensive than surface mining, economic resource deposits are seen with rare-earth

metals, some platinum group metals,²⁷⁹ and other ferrophilic metals such as iron, cobalt and nickel locked in nodules and hydrothermal vents that contain heavy metals in large supply, pumped directly up from the core of the Earth.²⁸⁰ Going into the second half of the 21st century, most of these mining activities were held close to shore, and there was no capability to mine the deep seabed which is several times deeper underwater than the continental shelf. Over time, technology capabilities grew in robotics, remote sensing, and autonomous mining, expanding the usable domain of the sea well outside of the local Exclusive Economic Zones and the lands beyond the continental shelf (100 nautical miles out from the shore).²⁸¹

In response to the growth into the deep seabed for mineral miners as well as the incursion of diesel powered fishing vessels venturing into commonly held waters, the first meeting of the United Nations Convention on the Law of the Sea happened in the late 1950's, creating the Convention on the Continental Shelf and the Convention on the Territorial Sea and Contiguous Zone which created a legal framework akin to the *Common Heritage of Mankind*. Under this regime, any natural resources mined or extracted in this region would be available for the common good of all international people with minimal coordination put in place for things beyond the continental shelf extending a few hundred nautical miles from shore.

This policy regime worked for the first few decades of its deployment, but as technology progressed, more nations were looking to access the ocean and fishing regions, UNCLOS I could not be sustained due to the extending ranges of industrialized nations and their powered fishing vessels. This stance was later reversed, as the UNCLOS was nearly completely rewritten as a byproduct of creating Exclusive Economic Zones and other coastal jurisdictions as part of UNCLOS III. The high seas were once again open for all to use under a *res communis* policy regime, with little

²⁷⁹ (Fouquet, 2014) p 10-12

²⁸⁰ (Fouquet, 2014) p 68-72

²⁸¹ (Wilson, 1982) p 5-7

coordination behind it. UNCLOS III, in 1973, gave nations the rights to mineral resource activities in their immediate Exclusive Economic Zones, required nations that used the commonly held zones to preserve the environment, and opened up the deep seabed outside of Exclusive Economic Zones for private operations by removing the original language in UNCLOS I.²⁸² At this point, UNCLOS attempted to balance the needs of industrialized nations and non-industrialized nations as both had rapid technology developments allowing them to access more ocean and potential fishing regions.²⁸³

During the next two decades, until UNCLOS IV in 1994, the field of deep seabed mineral resource exploitation grew rapidly with new opportunities to exploit the mineral resources of the deep seabed. The US Deep Seabed Hard Mineral Resource Act in 1980, which allowed private American agents to apply to the administrator of the National Oceanic and Atmospheric Association for a 10 year license to explore and 20 year permits to mine for mineral resources, marked the beginning of private ownership regimes of lands in the commons.²⁸⁴ During the time of open use under UNCLOS III, licenses were administered to four separate companies to work in an area that would be known as the Clarion-Clipperton Zone between Hawaii and Mexico.²⁸⁵ Other industrialized nations throughout Europe, and some Asiatic countries followed suit, developing their own policies for claiming the international seabed, but also recognizing the claims and licenses of other nations.²⁸⁶ Most of these licenses were only given out to organizations that were financially capable of exploring and recovering resources, and they also abided by international regulations on pollution and environmental protection.²⁸⁷ Just like with gold mining in America, individual private agents and their national representatives developed a mining and ownership

²⁸² (Fouquet, 2014) p 95-96

²⁸³ (Groves, 2012)

²⁸⁴ (Groves, 2012)

²⁸⁵ (Shackelford, 2009) p 117-118

²⁸⁶ (Shackelford, 2009) p 118

²⁸⁷ (Groves, 2012)

paradigm by themselves through a shared interest in maintaining the commons for future exploitation while protecting their own economic interests.²⁸⁸ However, the actions among industrialized nations drew concerns from non-industrialized nations as these large technological and economic super powers were starting to go and exploit the resources of the deep seabed before any other nation had the opportunity to do so.

UNCLOS IV, in 1994, and the Part XI convention were developed primarily as a way to prevent industrialized nations from continuing to mine the deep seabed as an extension of the intent of the *Common Heritage of Mankind*. To normalize the field and ensure that the resource, surveying knowledge, technology development, and infrastructure costs were evenly shared among all nations and their private agents, the *Common Heritage of Mankind* was enhanced to include private agents organized through the International Seabed Authority.²⁸⁹ The International Seabed Authority (ISA) ensured that the use of these resources and Commons is done to its fullest extent and the exploitation of commonly held resources benefits all. Technology development transfer is mandatory among all participating nations (though the only functional technology is owned by the United States who is not a signatory to Part XI and not a part of the ISA).²⁹⁰ Large funds are required to participate in the mining process,²⁹¹ and all data and scientific knowledge about resource deposits must be freely shared. The ISA also has²⁹² *“The right to take at any time any measures...to ensure compliance with its provisions and the exercise of the functions of control and regulation assigned to it thereunder or under any contract.”* The ISA inherently is designed to prevent private or national level exploitation of these resources in order to ensure future and free use of them, but in the process, greatly disenfranchises industrialized nations who could actually be

²⁸⁸ (Groves, 2012)

²⁸⁹ (Managing Impacts of Deep Sea Resource Exploitation)

²⁹⁰ (Groves, 2012)

²⁹¹ (Groves, 2012)

²⁹² (Shackelford, 2009) p 119

mining this region. For example, the United States of America has yet to actually agree to be part of this 1994 Addendum, due to issues with the ISA's environmental regulations, total control over operations and resource areas, the dissemination of knowledge and profit among lesser developed nations.²⁹³

Ultimately, the strengthening of the *Common Heritage of Mankind* principles reduced any and all economic advantage for private mineral exploitation within the region, now evidenced by no nation in the ISA actually mining the deep seabed. There is no way to ensure economic success, little protection against risk, and the new policy regime removes any incentive to mine and sell the derived resources. Additionally, the threat of removing the intellectual property protections through technology transfer further reduces the opportunities for private members to actually make back their investment. In two of the three instances where the Common Heritage of Mankind has been enacted, which was designed to inhibit governmental exploitation of commonly held resources, these policy regimes have failed when economic and social pressures have been introduced. In Antarctica, the *Common Heritage of Mankind* was weakened and replaced to secure scientific resources, while on the Deep Seabed, these policy controls grew in such strength that even social beneficial exploitation was too risky to take on.

For the space mineral resource miner, the outcome of the *Common Heritage of Mankind* to coordinate control of the deep seabed allowed for exploitation, but a sudden reversal of these policies caused several issues despite its intent to better the world. UNCLOS IV forced industrialized nations to share technologies that were costly to develop where these nations were expecting to reclaim some of that investment during the process of mining minerals. Additionally, with no ability to effectively sell minerals exploited or even own them or have an ownership right to a plot or claim, there was no way to secure a region to invest in to develop the mineral resources there.

²⁹³ (Groves, 2012)

Finally, by even forcing surveying data to be freely shared, any chance to reclaim that investment was greatly diminished. Ultimately, by extending and increasing the strength of the *Common Heritage of Mankind*, UNCLOS removed any economic reason or advantage to developing the minerals.

3.2.7 Diamond Mining

The exploitation of a modern precious mineral, diamonds is another interesting pathway for resource exploitation policy development, where the strong privatization was almost completely opposite of the communal nature seen with most mineral resources. Modern diamond mining is another major ownership and policy regime where much can be learned from the interaction of governments and private interests. Diamond mining today represents the end state for an unbridled ownership, technology development and mining process with rare minerals, similar to what could be experienced with asteroidal platinum exploitation if no changes are made from the current state. There are strong similarities between the *res communis* nature of asteroid material and the historical exploitation of diamonds, a high value rush to acquire more of it, a group of very wealthy investors ready to help support the initial profit-makers, and a strong chance to actually close off the mining market to other competitors.

In the second half of the 19th Century, large scale diamond production started within South Africa, attracting numerous veterans of the Australian and American Gold Rushes, as well as European imperialists and industrialists.²⁹⁴ Diamonds could be mined economically, there were technologies already in place to facilitate the mining of these pretty pebbles, and these unowned lands could be claimed and used by nearly anyone.²⁹⁵ Diamonds would eventually become an undeniable source and image of wealth and power to these early miners.

²⁹⁴ (Zoellner, 2006) p 101

²⁹⁵ (Egede, 2011) p 184

Individuals flocked to the continent to try to take advantage of the untapped mineral resources within the region. Individual miners squatted to claim various plots of land, started mining those resources, and traded knowledge of new mine sites and volcanic tubes that contained diamonds. This *res communis*, first come and first serve policy regime for land ownership did not inhibit individuals from participating and promoted exploitation in the most extreme sense, as anyone who wasn't actively mining could lose their investment instantly.²⁹⁶ Exploitation was open to all participants with no protections limiting the number of agents or the ability to buy or invade other claims, while no formal mechanisms were there for technology development, infrastructure building or surveying.²⁹⁷

Individual miners scattered across the country side and would move from place to place as they heard about new mineral deposits.²⁹⁸ For example, John Cecil Rhoades was told about the valuable minerals found at what would eventually become the Kimberly Mine, and started mining and claiming land there.²⁹⁹ Other miners followed him, separating mining claims with pieces of string and only a few inches of dirt. Rhoades was able to get diamonds first, sell them, and then use that to eventually buy out all of the miners and their claims to quickly consolidate the land into the Kimberly Mine. Eventually, several mines consolidated, forming the Diamond Syndicate to help coordinate and establish a diamond market as well as the supply of diamonds, controlling the market value and volatility.³⁰⁰

This focus on rapid economic growth, which disregarded sustainable ownership and infrastructure development policies, turned the diamond mining conglomerates of South Africa into economic powerhouses with little regard for corporate responsibility, sustainable development, or

²⁹⁶ (Bergensstock & Maskulka)

²⁹⁷ (Maconachie & Binns, 2007)

²⁹⁸ (Bergensstock & Maskulka)

²⁹⁹ (Bergensstock & Maskulka)

³⁰⁰ (Bergensstock & Maskulka)

designing economic systems to promote open access.³⁰¹ Throughout World War II, the Diamond Syndicate was threatened with Sherman Anti-trust legislation when it was found that the total control over diamonds allowed this group to inhibit the wartime development for both Allied and Axis powers.³⁰² Additionally, the focus on diamonds and high value natural resources inhibited the development of alternative infrastructure and economic programs, and is thought to be the source of several socio-economic failures and conflict (which would lead to the term “Blood Diamonds”) throughout the regions where diamonds were mined.³⁰³ Other countries, such as Botswana, have a great deal of mineral richness from diamonds alone and could have developed hospitals, schools, and other infrastructure. However, the short term focus on profitable mining of diamonds has increased the death rates, increased the disparity between the poor and rich, and leaves no future pathway for Botswana’s development that doesn’t involve diamonds.³⁰⁴

Sierra Leone is another case example of the growth and eventual resource curse of a strong natural mineral resource economy. Since the 1930’s, diamonds have been a major export of the country at nearly 60% its GDP,³⁰⁵ and a major diamond rush happened in the 1950’s, with the deployment of new mechanical mining technologies. By the middle of the 1970’s, diamonds grew to most of the GDP (approximately 80%) and eventually overtook the use of the rural lands for agriculture, converting them to mining regions. The focus on diamonds took away from the farming of food, and the population steadily decreased as there was a growing reliance on imported goods and foods. Infrastructure for roads, schools, and hospitals was not built, and today as diamond

³⁰¹ (Harris & Cai, 2002)

³⁰² (Bergensstock & Maskulka)

³⁰³ (Zoellner, 2006)

³⁰⁴ (Claasen & Roloff, 2011)

³⁰⁵ (Maconachie & Binns, 2007) p 370

mines are starting to be exhausted, there are few economic prospects for the people of Sierra Leone.³⁰⁶

With very few controls on the exploitation of highly valuable minerals with respect to ownership and infrastructure development, the diamond mining of Africa can serve as an example of a potential path that space mineral resource mining could take, with a short term focus on immediate profit overriding or designing protections against long term changes in the economic environment.³⁰⁷ Policies designed to help ensure sustainable economic development of highly valuable minerals need to be able to recover from sudden shocks and ultimately recover by adapting or rebuilding the previous natural resource base through the development of supporting industries and infrastructure.³⁰⁸ For the exploitation of diamonds and other rare minerals, these controls were never put into place and there was a free and unencumbered exploitation of these mineral resources. In the process, interests became entrenched, leading to resource curses preventing further economic development such as seen with the settlement and colonization of the New World, while also creating a system where no new agents are able to participate. This final outcome flies in the face of the past fifty years of precedent for the utilization of space, and in light of the nearly innumerable resources of space, is a completely unacceptable outcome for space mineral resource mining policy paradigms.

3.3 FRUCTUS STOCKS

Mineral resource exploitation on Earth is the most similar example to mineral resource exploitation in space from a mechanical and geological standpoint, but there might be similarities that can be drawn from the policies managing renewable and replenishing resources. Drawing from

³⁰⁶ (Maconachie & Binns, 2007) p 379

³⁰⁷ (Sachs & Warner, 2001) p 837

³⁰⁸ (Maconachie & Binns, 2007) p 369

the common similarities between the high seas and outer space, and the replenishing nature of asteroids as they orbit the sun in large cycles, much can be learned from biologically reproducing and replenishing stocks of renewable resources or even the fishing of the deep sea. Asteroids, agriculture, and fish might bear many similarities as the market and technology develops to the point where asteroids replenish themselves due to the cyclic nature of the solar system and these ore bodies' orbits.

3.3.1 French and British Renewable Resource Exploitation

The first really long term successful colonies founded by the British and French focused on the development of renewable resources and infrastructure systems that supported future growth of the primary industries. For asteroid miners, this enabling feature of infrastructure forms the basis of an argument to support the development of infrastructure by national governments through policy. Historically, the growth of the primary industries (agriculture and trading) was supported by the growth of secondary industries which eventually allowed the continents to seek eventual economic and political independence.

The Colonies founded by the British and French (which would ultimately become the United States of America and Canada respectively) ultimately would become more successful in the long term than the Spanish colonies (Mexico and South America) that focused on minerals. These colonies, focusing on renewable resources and trading, would have a higher GDP per capita with lower crime rates and higher rate of development, which some argue stem from the development of their original industries and economies.³⁰⁹ The plantations and trading posts that soon became standard in the French and British colonies were many times more scalable than even the most

³⁰⁹ (Sokoloff & Engerman, 2000) p 217-219

profitable mines created by the Spanish in the New World, and large scale agriculture to support the more intense mining markets was very successful.³¹⁰

Reliance on scalable markets that favored the mercantilism approach succeeded with the North American colonies, as they could quickly expand agricultural plantations and develop better trading networks. The mines could only be expanded if local ore veins were found adjacent to the original mine sites, but agriculture could be expanded as long as there was adjacent fertile land. Large plantations to small family owned farms could be expanded on demand and in reaction to market forces, allowing all to participate rather than just an elite class that operated the mines and all of the associated equipment.³¹¹ Anyone could invest and potentially make a return on their investments with agriculture. In North America, many small land plots were opened up for a variety of immigrants with little difficulty in acquiring a plot, in comparison to the Middle and South American viewpoints, where there was a large tax or licensing fee levied.³¹² Elite farmers and their families dominated the agriculture of the Spanish Americas, leading to greater strength and political will, and now, in retrospect, lower capability to generate actual revenue among individuals.³¹³

Ultimately, allowing more participants in the industrial process, promoting the growth of infrastructure, and supporting ownership policies that allowed numerous peoples to participate and provide a variety of services eventually led to the independence of these nations and the economic well-being of these colonies. Asteroid miners might be looking to these policies to form the foundation of their future independence from Earth.³¹⁴ By keeping the possibility for ownership open to a variety of newer agents, the colonies of North America fared much better than the colonies of South and Middle America which focused on rapid profit by any means necessary. Both

³¹⁰ (Sokoloff & Engerman, 2000) p 221

³¹¹ (Sachs & Warner, 2001)

³¹² (Sokoloff & Engerman, 2000) p 224

³¹³ (Pop, Appropriation in outer space: the relationship between land ownership and sovereignty on the celestial bodies, 2000)

³¹⁴ (Lewis & Lewis, Space Resources: Breaking the Bonds of Earth, 1987)

groups had steady economic growth, with the mineral mining focus being much quicker, but in the long run, the steady, natural development that supports further economic and infrastructure development into newer industries helped create economic and social independence faster and enabled greater economic growth into new supporting industries, which only increased the rate of further growth.

3.3.2 Fishing and Exclusive Economic Zones

Ensuring the sea was open for use, and ensuring that there was enough fish to catch have been major elements of international law and policy since the beginning of the concept of government. With the similarities between the seas and space in terms of their use, knowledge of resources, and costs to operate in them, as well as their great value for commerce and trade, there are many parallels that could be drawn, some of which are even codified into the *Common Heritage of Mankind*.³¹⁵ The development of sustainable fishing programs, the development of licensing systems in response to growing technological capabilities to sail the seas, and ultimately the ability to prevent interference while also preventing exclusivity is something very desirable for future space mineral mining programs.

Under the first concepts of *mare liberum*, the seas were open for free use, and fishing was usually kept close to the shore, due to the fact that the technology behind fishing, sailing, and the storage of fishes after catching was heavily limited to sails and salt. Hugo Grotius' *Common Property of All* in the 1600's (which would later form the basis of the *Common Heritage of Mankind*) states that "*The air belongs to this class of things for two reasons. First, it is not susceptible of occupation; and second its common use is destined for all men. For the same reasons the sea is common to all, because it is so limitless that it cannot become a possession of any one, and because it is adapted for the use of all, whether we consider it from the point of view of navigation or of fisheries. Now, the same*

³¹⁵ (Soucek, The Polar Regions, 2011) p 247

right which applies to the sea applies also to the things which the sea has carried away from other uses and made its own, such for example as the sands of the sea, of which the portion adjoining the land is called the coast or shore."³¹⁶

Grotius' original works would be sustained through the industrial era, but begin to falter by the mid twentieth century. When diesel turbines became prevalent after World War II, these ships could now extend their reach into the open ocean, and the governments supervising the ships extended their claims further and further, coming into conflict as their private agents continued to spread.³¹⁷ This expansion was based on the principle that renewable resources and biologically replenishing resources were covered under *res communis* policies on ownership and they were free for open use as a *fructus* stock. In response to the potential for industrialized nations to claim a great deal of coastal waters for their own private industries, the potential Tragedy of Commons with regards to over-fishing, and the problematic status of land-locked nations, the international community came together to update the policies on ownership, territorial claims, and the freedom of the seas.³¹⁸

The first United Nations Convention on the Law of the Sea (UNCLOS I) set the standard for the steady movement of nations into the immediate continental crust around their oceans, forbidding private use of the deep seabed and distant waters.³¹⁹ Private agents quickly developed technology to fish all the way out to the edge of the continental shelf, and in light of the steady changes in the view of the sea as an ecological resource,³²⁰ as well as a source of a *fructus stock*, the original use of the *Common Heritage of Mankind* in these regions was further modified.³²¹

³¹⁶ (Grotius, 1916)

³¹⁷ (Applebaum)

³¹⁸ (Gallo, 1992) p 194

³¹⁹ (Mallory, 2013) p 99

³²⁰ (United Nations Treaty Series, 2005)

³²¹ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 236-238

UNCLOS III allowed nations to extend their claims 200 nautical miles out into the ocean adjacent to their shores and ensured the freedom of the seas and access to land-locked states. Today, these Exclusive Economic Zones are highly successful, covering 30% of the world's oceans and representing 90% of the marine fish catches, the others coming from uniquely licensed fishing expeditions into deep water or fishing in rivers and lakes (Figure 6).³²² The remainder of the land outside of the coastal state jurisdiction was reclassified as *res communis* for use and exploration, which played a major role in the exploitation of the deep seabed discussed earlier.³²³

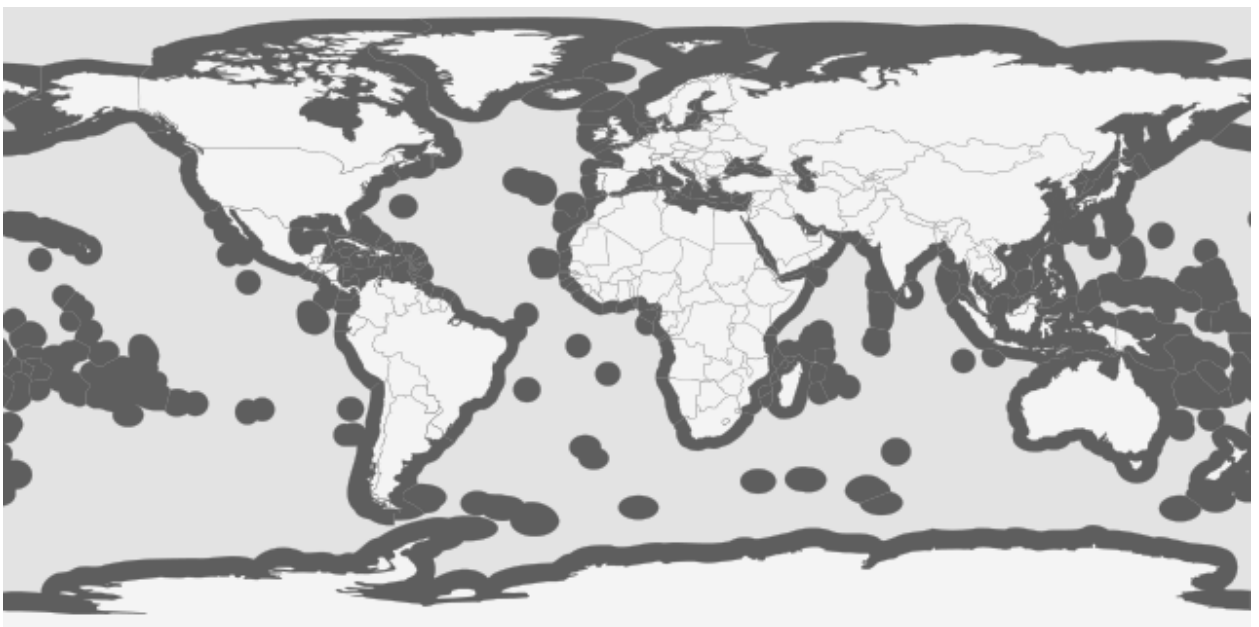


Figure 6: Exclusive Economic Zones

Today, national governments can control some aspects of the fishing business in terms of maximum hauls, and can exert environmental protection protocols on to the ships flying their flags. Prevalent in the United States of America are very formal procedures and accountability, where Canadian regimes are focused on flexibility and centralization of authority.³²⁴ The Canadian

³²² (Eckert, 1979) p 116

³²³ (Applebaum)

³²⁴ (Gallo, 1992) p 178

Authorities uses a Fisheries Act to manage and license the use of their waters while leaving open the specific operations of their fisheries and exact management.³²⁵ They manage and operate total allowable limits through informal means, and publications dictating management structures are sparse.³²⁶ Allowable catches are determined for the entire country based on regions, and the Coastal Fisheries Protection Act allows heavier control over the regions. The United States of America fishing authorities operate in a different way, with a strong management oversight and focus on maintaining the few stocks that still remain in the overfished areas in the United States territories.³²⁷ Optimum yields are defined, organized, and distributed to domestic centers, while regional centers play a role in managing and organizing the stock usage over time. This strategy sometimes falls short and is focused on ensuring profitability rather than conservation.³²⁸

Other authorities, such as the Chinese Fishing programs actually use policies and bilateral agreements to share communal Exclusive Economic Zones.³²⁹ This can be extended to colony and friendly states near the Sea of Japan or around the coast of Africa and the premise has founded the basis of Distant Waters Fishing (DWF).³³⁰ This has allowed organizations and nations to combine efforts and expand their economic zones, increasing their yields of fish.³³¹ Over fishing is still a major issue to be dealt with, as the *res communis* policies put in place are able to provide some controls to states within Exclusive Economic Zones, but the free use of fish outside these regions are hard to control and limit. These policies are still adapting over time, finding new methods to help control and reduce environmental impact.

³²⁵ (Gallo, 1992) p 184

³²⁶ (Gallo, 1992) p 184-185

³²⁷ (Gallo, 1992) p 187-188

³²⁸ (Gallo, 1992) p 190-192

³²⁹ (Mallory, 2013) p 103-105

³³⁰ (Mallory, 2013) p 103-105

³³¹ (Mallory, 2013) p 99

Ultimately, this international treaty system was able to develop a strategy that reduced overfishing to some extent, ensured some degree of protection for investments made into fishing boats, and promoted economic exploitation while still allowing new actors to participate. For the space mineral resource miner, there might be a role for governments to play in the coordination and control of resource markets of asteroid-derived mineral resources as they continually replenish themselves. In these cases, policies put in place to prevent interference also attempted to prevent over exploitation for both economic reasons (market saturation) and environmental reasons (overfishing and ecological degradation). The same kind of policies and controls might be appropriate in light of the nature of space mineral resources.

3.4 DIGITAL AND TELECOMMUNICATIONS RESOURCES

Finally, the use of certain telecommunications resources and the process by which they are allocated can provide a lot of insight into potential future options for the utilization of space resources. The policy regimes of the International Telecommunication Union over seemingly infinite resource stocks are designed to prevent interference, maximize public gain, and ensure equitable access. The regime provides a few great examples of how to potentially handle the near-infinite resources of space, as well as providing the only precedent for the allocation and utilization of a portion of space (specifically geostationary orbit) despite national ownership being expressly forbidden by the Outer Space Treaty.

The ITU was first known as the International Telegraph Union when it was founded in 1865 to create standards for telegraph wiring. Today, the ITU is a mixture of government representatives, private individuals, and multi-national companies and corporations working together to coordinate

the use of seemingly infinite electromagnetic, orbital, and digital resources for communication while preventing interference.³³²

3.4.1 Radio Spectrum

The International Telecommunications Union's first duty was to handle the coordination of telegraph lines, but soon adopted the mantle of coordinating the use of radio frequencies to support telecommunications as the radio was starting to be adopted. At the time, there was interest in using the new invention of the radio for a variety of different reasons, but there was a potential for two or more parties to use the same frequencies, interfere with their communications, and reduce the quality of the market. In light of electromagnetic radiation being a fundamental aspect of the universe, it is not possible to technically own it, but the ITU set the precedent of spectrum coordination to prevent harmful interference.

No one is capable of owning radio spectrum, but it can be allocated to prevent harmful interference and maximize social utility.³³³ The radio frequency spectrum is considered to be a natural resource, but unlike mineral resources, it is completely reusable.³³⁴ Spectrum management prevents the Tragedy of the Commons that often befalls readily available resources, and ensures that every user is capable of making the most of this resource. Many countries allocate some spectrum important to their vital services, but use spectrum auction (and sometimes lotteries) to open up the remainder of the spectrum to private industry. These licenses are temporary in nature, allowing other industries to replace existing ones if they can provide greater utility. In the process, it prevents most agents from "sitting on" spectrum resources, when they could be applied to more

³³² (Allison, 2014) p 12

³³³ (Ryan, *Wireless Communications and Computing at a Crossroads: New Paradigms and Their Impact on Theories Governing the Public's Right to Spectrum Access*, 2005)

³³⁴ (Ryan, *Treating the Wireless Spectrum as a Natural Resource*, 2005) p 10620

beneficial uses for new industries to utilize for new business prospects, to hand them over to first responders for clear and efficient communication, or fit more users into the spectrum.

In America, the Federal Communications Commission handles the specifics of radio spectrum allocation, as charged by the ITU, and allocates usage based on a spectrum auction and licenses for the use of this natural resource. The United States of America Supreme Court has recognized that radio spectrum is a scarce resource, and that it is similar to fisheries, forestry, and mineral extraction in terms of licensing and maintenance.³³⁵ European governments see the “radio spectrum [as] a vital and scarce natural resource,” and that they have full right to control and regulate access to the radio spectrum, allocating sections to companies and private agents when appropriate.³³⁶

This licensing and management regime functions well, but with some criticisms. By limiting total use, it produces an artificial scarcity which undermines the benefit of managing that resource.³³⁷ Additionally, as technology has reduced bandwidth and the amount of radio spectrum necessary to be used, many companies end up holding on to spectrum they don't need, causing inequality. This inequality exerts a great deal of pressure on innovators in the crowded spectrum areas, and gives capital simply through ownership to the larger spectrum holders. The licensing structure and natural monopoly that comes out of it to some extent is no longer fully supporting the original intent of the policy, so restructuring of the licensing system is argued for.³³⁸ However, this is one of the strengths of this ownership paradigm, where there are known limits on holdings, and the system can adapt.

³³⁵ (Ryan, Treating the Wireless Spectrum as a Natural Resource, 2005) p 10622

³³⁶ (Ryan, Wireless Communications and Computing at a Crossroads: New Paradigms and Their Impact on Theories Governing the Public's Right to Spectrum Access, 2005) p243-244

³³⁷ (Ryan, Treating the Wireless Spectrum as a Natural Resource, 2005) p 10628

³³⁸ (Ryan, Wireless Communications and Computing at a Crossroads: New Paradigms and Their Impact on Theories Governing the Public's Right to Spectrum Access, 2005) p 246

Licensing has played a special role in physical resource allocation, and its use in managing and coordinating the use of radio spectrum resources shows that the same concepts can be applied to something that never runs out and is impossible to actually own. Space mineral resources fall under a similar category of being in the international commons, and their ownership by national agents is expressly forbidden.

3.4.2 Geostationary Orbit Allocation

In 1959, the ITU was the first organization to actually coordinate the use of space resources by identifying that there was a policy need for the coordination of activities in geostationary orbit. At the time, the benefits of placing a radio platform in such a distant orbit was that a spacecraft put in place there could maintain a position above a specific place on the Earth, and there was soon to be a major resource rush to use this untapped resource. Initially, the ITU designed a "first come, first served" policy that allowed private agents to place satellites in geostationary orbit above wherever they desired, and forced them to hand over that slot when a nation requested space above their own country.³³⁹

Over the course of the next few decades, interest in using geostationary orbit grew, and space systems technology steadily grew to be able to use this orbital space, which quickly grew very crowded. In light of this, several nations banded together to form the Bogota Declaration,³⁴⁰ which awarded equatorial states (most of which could not achieve spaceflight at that time in 1977) ownership of the space above their nation as an extension of UN Resolution 2692.³⁴¹ The treaty ultimately failed, due to the insistence of owning orbital tracks rather than envelopes³⁴², as well as

³³⁹ (Allison, 2014) p 14

³⁴⁰ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 171-175

³⁴¹ "the right of the peoples and of nations to permanent sovereignty over their wealth and natural resources that must be exercised in the interest of their national development and of the welfare of the people of the nation concerned"

³⁴² Under the Bogota Treaty, individuals could own an orbital track, like a railroad line that their satellite could fly along. However, in reality, due to a variety of orbital perturbation and the relative motions of planets

the national appropriation of a space resource, expressly forbidden by the OST.³⁴³ At the same time, no industrialized nations actually supported this endeavor, as it would limit their private industrial use of the space.³⁴⁴ Most of the drive to put satellites in geostationary orbit was for telecommunications, so the ITU petitioned to be the primary coordinator of these orbits, and could provide licenses for specific orbital envelopes to place satellites there. If a greater or more cost effective service were to take its place, the orbit could be reallocated.³⁴⁵

This process still stands today and is the only instance of controlling and operating orbital envelopes in space. However, installing this policy regime was not easy, and fraught with “paper satellites,” or fillings intended to hold a spot in a legal paralysis that the claimant could then sell for a profit even if there were no satellites installed.³⁴⁶ Policy changes were implemented to move from a first come first serve method to a larger sale planning process with financial commitments to effectively license the use of orbital locations and frequency spectrums.³⁴⁷

Now, the orbits are managed to optimize public and private benefit, and are enjoying a great deal of success, with multiple agents being able to claim envelopes, and when their missions are done, moving to a graveyard orbit. There have been no collisions, a protection from interference, appropriate reactions to technology development and potentially the most reliable method of controlling and operating orbital space.

3.4.3 Internet Allocation

Finally, the ITU is also trying to get involved in the coordination of internet activities and the operating of Domain Name Servers and master lists to ensure websites do not interfere with

to the Sun and other bodies, such a definite track was impossible, with later policies recognizing the more scientifically accurate orbital envelope.

³⁴³ (United Nations Office of Outer Space Affairs, 2016)

³⁴⁴ (Gorove, 1979) p 451-453

³⁴⁵ (Allison, 2014) p 22

³⁴⁶ (Allison, 2014) p 27

³⁴⁷ (Allison, 2014) p 39-41

one another and that the internet remains free for commerce. The internet as it exists today represents an incredible amount of economic, technological, and social development. When the system was first created as ARPANET, Internet Protocol addresses, essentially machine readable codes to tell computers where to connect to receive data, were handed out if someone called up Vint Cerf or Jon Postel at the University of California at Los Angeles.³⁴⁸ In 1988, the Internet Assigned Numbers Authority was formally created to continue and formalize the work of handing out IP addresses. The development and current changes with this operating regime demonstrates how ownership and technology development policies can come out of private agents rather than being organized by a central authority, and eventually lead to an effective way of protecting the Commons.

Mechanically, IP addresses could be handed out in billions of billions of permutations based on the four 255 digit numbers with IPV4, and the newest version of IPv6 could supply humanity with enough IP addresses for thousands of years. To prevent two computers holding the same address, which would cause just as many problems as two people having the same physical address for mail, Internet Assigned Numbers Authority(IANA) worked to prevent the over utilization of the IP address resource.³⁴⁹ Later, the same process would happen with the creation of domain names, short form names that match via a Domain Name Server (DNS) to an IP of choice. In both of these cases, seemingly infinite resources were controlled and harnessed by quasi-governmental agencies, like the IANA, which is supported by the US Department of Commerce to organize and prevent harmful interference. To do this, they collect small fees for operation, and organize servers to be set up for the public good to sustain this system.

³⁴⁸ (Kleinwachter, 2004) p 235

³⁴⁹ (Kleinwachter, 2004) p 235-237

However, the response to IANA being part of the United States of America governmental structure has caused some to be concerned within the international community. First and foremost, the internet is proving to be a critical element of commerce and trade, and to have any nation in control of the ability to assign IP address blocks or redirect entire swaths of the internet is concerning.³⁵⁰ Alternately, the control over the entire internet by one company, and the monopoly through first-actor privilege and, to some extent, *prior appropriation*, seemed unlawful. At the same point, the management of infinite but limited-access resources of the international field has had a pretty diverse economic and social effect on a variety of fields; in some cases allowing everyone to freely access resources or putting in cost and regulation infrastructure so severe that no one wants to partake in the system.³⁵¹ IANA would eventually become part of ICANN, The Internet Corporation for Assigned Names and Numbers and their scope would eventually expand to ensure that the infrastructure of the internet stays stable and open for growth through democratic input and an advisory committee.³⁵²

The International Telecommunications Union is vying to include control of the Internet into their organization and structure. As an international organization looking to manage telecommunications resources, international internet policy is still very much in its infancy, based on earlier codes for telephone communication.³⁵³ Proposals under consideration would bring Domain Name and IP allocation into the ITU structure to control it too, but the current frameworks to organize this change have frightened some. In the World Conference on International Telecommunications 2012, the ITU would tax international communications using the internet, similar to the international taxes they levy on international phone calls based on the sender nation. ICANN and IANA have operated under the principle that the operation of the internet should be free

³⁵⁰ (Kleinwachter, 2004) p 238-239

³⁵¹ (Kleinwachter, 2004) p 242

³⁵² (Mueller, 1999) p 500-501

³⁵³ (Kleinwachter, 2004) p 243-244

from government intervention, and that the model proposed of international governmental control would be against it and over time place an undue economic burden to limit access.³⁵⁴ This new model would actually achieve a diffusion of economic power, taking away from services in the western world and then providing those funds to other nations through infrastructure development and support, just as was done with radio technologies.³⁵⁵

The development of ICANN and IANA are often used as representatives of industrial self-governance when dealing with infinite, but limited access resources. In these cases, there is an understanding of the value and importance of non-interfered internet address numbers and the industry moved to self-regulate. The value is that the transfer of knowledge, economic advantages, and free and open communication is easy and unencumbered by governmental interference.

³⁵⁴ (Mueller, 1999) p 501

³⁵⁵ (Allison, 2014) p 79

4 POLICY ISSUE: TECHNOLOGY DEVELOPMENT POLICY

Hybrid policies for research, which share the risks and responsibilities of technology development among private and public entities, are necessary for the basic and applied research required to support space mineral resource industries.³⁵⁶ Contests for research grants or prizes as well as protection for intellectual property (IP) rights might be the best suited policy mechanisms for these research topics, as the goals of public space programs and private space mining programs overlap and have the potential for great public and private benefit. Public procurement research policies might conflict with the Outer Space Treaty, and private industry tax incentives and subsidies assume an overwhelming benefit for the applied research in business development and implementation which has yet to be substantiated.

4.1 TECHNOLOGY DEVELOPMENT TYPES

Developing new technology innovations are risky; the payoffs are unknown, the upfront costs are unknown, and the time to develop is often unknown, but promised are substantial economic and social value that could be realized in the future.³⁵⁷ Right now, the development of the asteroid redirect mission for scientific exploration (planned to be launched within the decade by NASA along with a small fleet of sample return missions) is expected to cost over \$100 billion USD including research, development, launch, and mission operations³⁵⁸ and the prospective costs of an asteroid mining program would be many times larger.³⁵⁹ Policy can help deal with these risks,³⁶⁰ and a hybrid of basic and applied research (Figure 7: Simplified Linear Model of Technology Development) is required for space mineral resource programs. As identified by Mark Sonter in his

³⁵⁶ (Hickman, 1999)

³⁵⁷ (Neal & Smith, 2008) p 5-10

³⁵⁸ (Keck Institute for Space Studies, 2012)

³⁵⁹ (Sonter M. , 2006)

³⁶⁰ (Bush, 1945)

salient Characteristics of a space mineral mining paradigm, there needs to be feasible concepts for the refinement of asteroid resources, as well as feasible concepts for their storage and potential use on the surface of the Earth (salient characteristics III and IV).³⁶¹

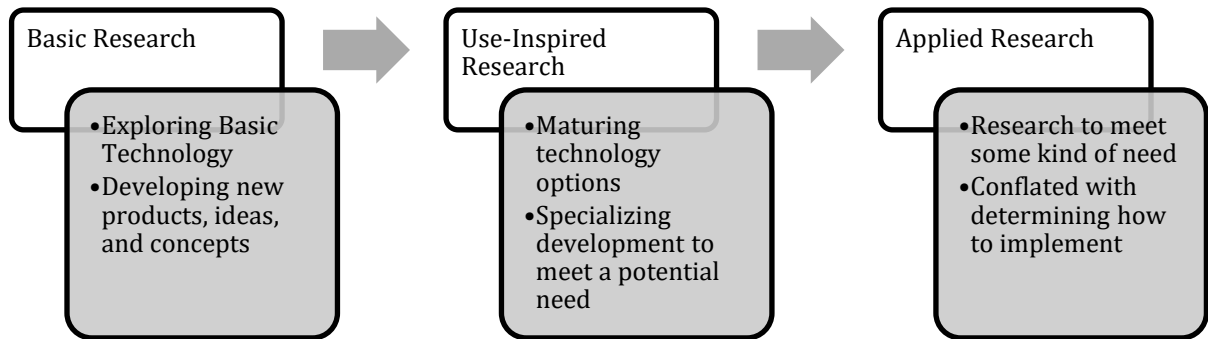


Figure 7: Simplified Linear Model of Technology Development³⁶²

4.1.1 Basic Research Needs

Basic research is focused on creating a new product or mechanism, or exploring the basic elements of technology or scientific field to further develop it into something that could be industrialized or formed into a business opportunity.³⁶³ This kind of research is primarily done by governmental groups or individuals curious about a topic.³⁶⁴ Basic research was seen in mineral mining during the early stages of its development. Individual miners in the 1500's through 1800's did large amounts of basic research to develop their field, such as Georgius Agricola writing on and collecting the techniques of mining in *De re metallica* which inspired silver and gold miners in North and South America.³⁶⁵ In the American and Australian Gold Rushes, sluicing and hydraulic techniques were developed by individuals curious about new ways to exploit the gold in alluvial deposits,³⁶⁶ but as the need and costs for new technologies grew, there was a steady movement

³⁶¹ (Sonter M. J., 1997) p 638

³⁶² (Neal & Smith, 2008) p 7

³⁶³ (Neal & Smith, 2008) p 6

³⁶⁴ (Sarewitz, 1996) p 5-6

³⁶⁵ (Rothwell, 1981)

³⁶⁶ (Clay & Wright, 2005) p 159-160

towards more applied research.³⁶⁷ In the past 50 years, aerospace basic research was done primarily by national civilian space programs and defense programs curious about using space for defense and exploration.³⁶⁸ Over time, this technology development paradigm has moved steadily towards applied research focusing more on the industrial applications of spaceflight, now making space mining a technical possibility.

For space mineral resource exploitation programs, there are a wide variety of basic technologies that need to be developed to support the implementation of these asteroid mineral mining programs based on assessments from those in the field (Table 3).

Field	Description	Implications
Robotics	Mining operations under remote control	Ability to mine without humans at site
Electronics	Lowering cost, improving capabilities and increasing storage	Improved automation and longer, more robust mission architectures
Ballute And Drag Devices	Methods to Slow Reentry Or Reenter Earth's Atmosphere	Delivering larger and larger payloads with less thermal protection system shielding
Advanced Materials	Composites, meta materials and smart materials for spaceflight	Reducing cost, reducing mass, and improving quality
Power Systems	Nuclear, solar and other power systems for spaceflight	Improving power budgets, increasing total capacity, more power to operate
Control And Automation	Improved software and control mechanisms	Ability to self-repair code or adapt naturally
Simulation	Improvements in computer aided design and optimization	Test and simulate more extreme environments
Propulsion	Development of innovative launch and space propulsion	Lower launch costs and reduce transportation costs

Table 3: Potential Technologies to Develop to Support Asteroid resource Exploitation³⁶⁹

4.1.2 Applied Research Needs

Applied research is the other end of the research spectrum, focused on implementing technology developments as a business, focusing on increasing the efficiency of a discovered

³⁶⁷ (Rothwell, 1981)

³⁶⁸ (Sarewitz, 1996) p 5-6

³⁶⁹ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 26

process, or deploying it as part of a technology product or solution.³⁷⁰ Applied research is supported by policy because it provides almost immediate public and private good (compared to the longer time scale implications of basic research).³⁷¹ Currently, exploitation technologies of both *fructus* and mineral stocks has become increasingly more focused on these applied research solutions as the basic research has been done about how to mine and fish.³⁷² In the aerospace field, the applied research of companies such as SpaceX, Blue Origin, United Launch Alliance, and OrbitalATK over the past two decades have driven down launch costs and have expanded the field of potential launch suppliers.³⁷³

4.2 DIMENSIONS OF RESEARCH AGENTS

Basic and applied research can be done by private or public agents, depending on the intended purpose of these developments and the current state of technology.³⁷⁴ The promise of public and private benefit forms a substantial basis of an argument for technology to support hybridized research programs for space mineral mining activities.³⁷⁵

4.2.1 Public Research Policy Support

Technology development to create new products, ideas, or basic technologies is usually handled by public organizations.³⁷⁶ With public research programs, there is some kind of benefit in the future from the development of new technologies, and these programs tend to be able to absorb higher risks upfront because they are sustained by governments and their substantial economic base if the exploration of a new idea is not profitable in the long-term.³⁷⁷ Public benefit for

³⁷⁰ (Neal & Smith, 2008) p 6

³⁷¹ (Neal & Smith, 2008) p 135-137

³⁷² (Rothwell, 1981)

³⁷³ (Martin P. , NASA's Management of hte Commercial Crew Program, 2013) p ii-iii

³⁷⁴ (Neal & Smith, 2008) p 25-47

³⁷⁵ (Mann, 2012)

³⁷⁶ (Neal & Smith, 2008) p 6-7

³⁷⁷ (Neal & Smith, 2008) p 9-10

technology development for space mineral resource exploitation could stem from a lower cost of resources and materials or an increased ability to exploit and access space, but that would not happen until well into the mining process.

Public research policy support can be public procurement buying vehicles and spacecraft, prizes and contests to determine who to award research grants to, and protection of IP rights so that those who are taking the risk of development could sell their technology to others to reclaim the investment.³⁷⁸ Public research programs have been the primary drivers for aerospace systems because the development of these systems are generally for the public good in terms of scientific development or defense applications.³⁷⁹ Driving this has been the high promises of public and private wealth, anywhere from 10% to 40%, for space systems technology in remote sensing and telecommunications (which may be higher for systems that can generate mineral wealth).³⁸⁰

To coordinate efforts, the United State of America (through NASA) and other industrialized nations develop a technology roadmap of technologies they are developing that year based off of their National Space Policies.³⁸¹ Under the current revision for the United States of America, civilian science programs in the United States of America are charged to increase space access, promote industry, and strengthen national leadership in space systems through public research (Table 4). Private industry is encouraged to participate, and in some cases, the similarities between technology goals encourage partnerships. NASA is currently focused on crewed Mars exploration, the development of the Space Launch System, and an Asteroid Redirect Mission to bring back asteroid material to lunar orbit to develop impact mitigation and even in situ resource utilization basic technology.³⁸² Some of the relevant technologies areas for this asteroid mission (and eventual

³⁷⁸ (Takalo, 2012)

³⁷⁹ (Neal & Smith, 2008) p 137-138

³⁸⁰ (Salter & Martin, 2001) p 514

³⁸¹ (National Space Policy of the United States of America, 2010)

³⁸² (Handberg, 2014) p 32-33

space mineral resource exploitation) are listed below while irrelevant topics are grayed out (Table 4: NASA Technology Areas).

Field	Description	Applications
TA 1: Launch Propulsion	Achieving spaceflight	Liquid Propulsion Systems, Unconventional Propulsion Systems
TA 2: In Space Propulsion	Maintaining spaceflight and moving to location	Chemical, Non-Chemical, Advanced Propulsion
TA 3: Space Power And Energy Storage	Gathering and storing electrical energy	Power Generation, Energy Storage, Distribution
TA 4: Robotics And Autonomous Systems	Using autonomous systems to explore and use the space environment	Sensing, Mobility, System Level Autonomy, Autonomous Rendezvous, Systems Engineering
TA 5: Communications, Navigation	Designing robust communication systems	Communications, Inertial Guidance Systems
TA 6: Human Life	Ensuring crew safety	Environmental Controls
TA 7: Human Exploration Destination Systems	Supporting human habitation and exploration by gathering water, propellant, and life support materials	In Situ Resource Utilization
TA 8: Science Instruments	Using sensors to gather data about the world	Remote Sensing, Observatories
TA 9: Entry, Descent, And Landing Systems	Landing and returning material from space to a surface	Descent And Targeting
TA 10: Nanotechnology	Improving materials science	Enhanced structures
TA 11: Modeling and Simulation	Improving model fidelity for better analysis	Computational Fluid Dynamics
TA 12: Materials, Structures, Mechanical Systems And Manufacturing	Designing a structure and mechanisms to support space exploration	Materials, Structures, Mechanical Systems, Manufacturing
TA 13: Ground and Launch	Developing ground support	Launch Complex 39A
TA 14: Thermal Management	Heat rejection for crew safety	Radiator systems and thermal sinks
TA 15: Aeronautics	Better aeronautic systems	Quiet Supersonic Cruise

Table 4: NASA Technology Areas³⁸³

4.2.2 Private Research Programs

Private research typically is used to deal with applied research, such as designing business plans to sell a technology, or increasing the efficiency of implementing a technology (if that is selling it, using it, or improving it) but it requires basic technology to be developed first.³⁸⁴ This support usually takes the form of IP right protection, subsidies for development of better business

³⁸³ (National Aeronautics and Space Administration, 2015)

³⁸⁴ (Neal & Smith, 2008) p 134-135

operations or tax subsidies for the risk of the activity or implementing a new technology.³⁸⁵ The private benefits for space mineral resource exploitation stem from Planetary Resources' objective "to be the first to harness potentially trillions of dollars of minerals including platinum group metals."³⁸⁶ If they are successful, they might not need the help of an industrialized and wealthy nation to absorb the costs and risks of their technology development.

In the past, private technology development was readily seen, especially with mineral mining innovations. Typically, when mines were shut down to enhance their technology, tax exemptions and subsidies were provided by the national governments monitoring their claims, happening as early as the Spanish silver mines in the 1500's.³⁸⁷ Subsidies are provided to develop and implement technologies to reduce environmental impact during PGM and REM mining, as these actions have an overwhelming good associated.³⁸⁸ Private research programs have been less prevalent with spaceflight because it is such a new field.

4.3 POLICY MECHANISMS

Consistently, these research policy mechanisms fall along a line, with more socially beneficial and basic research happening by public agents, and as industrial agents become interested in deploying these technologies for a profit, their research becomes more privatized and applied.³⁸⁹ The policies to support technology development tend to be the following along a spectrum of options (Figure 8):³⁹⁰

- Tax Incentives: Indirectly reducing cost for innovation by reducing the taxes that private agents would have to pay while they also invest in development

³⁸⁵ (Takalo, 2012)

³⁸⁶ (Farrell, 2013)

³⁸⁷ (Brading & Cross, 1972) p 545

³⁸⁸ (Takalo, 2012)

³⁸⁹ (Bloch, Kaminski, Mowery, Tellep, & Walker, 1999)

³⁹⁰ (Takalo, 2012)

- Subsidies: Providing a grant for the development of a specific technology or process improvement
- Intellectual Property Rights: Developing a technology and supporting initial development for a funding reclamation
- Prizes and Contests: Allowing private or public research groups to compete to develop in a challenge for a prize, which could vary from a competitive contract to a cash payout
- Public Procurement: Contracting the development of a new technology to serve some kind of public good

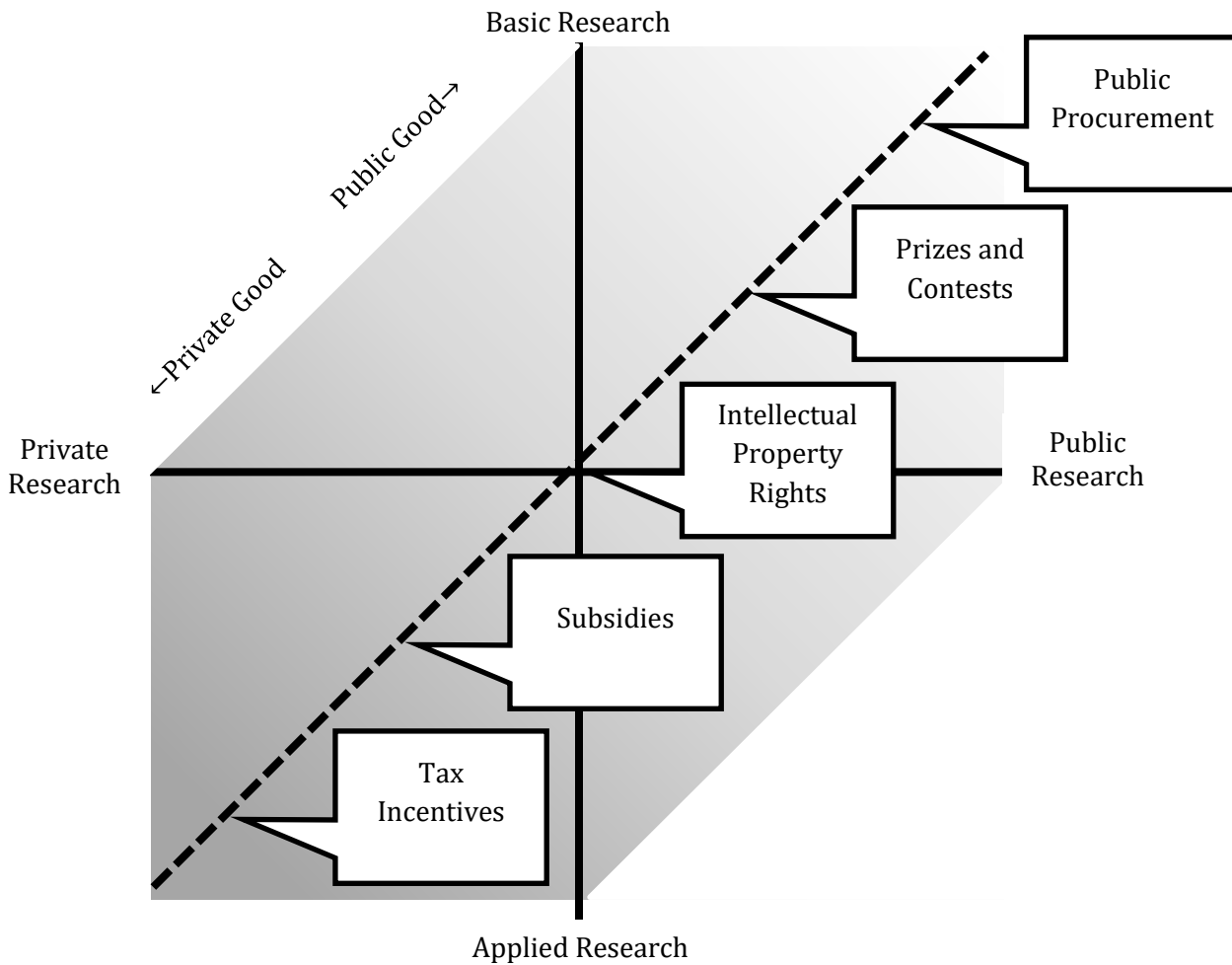


Figure 8: Technology Policy Support Spectrum

4.4 HYBRID RESEARCH POLICY FOR SPACE MINERAL RESOURCE ACTIVITIES

When dealing with a problem as large as space mineral resource exploitation, hybrid research programs are ideal to promote further development of the field (Figure 9: Technology Breakdown for Space Mineral Resource Activities). Technology policy would most likely be prizes and contests and IP protection, which has been very successful in other mineral mining activities and in spaceflight (Table 5: Technology Development Regimes) because neither totally public (procurement) nor private research regimes (tax incentives and subsidies) alone are suitable for this current high risk state of development and in some cases are not acceptable at all.

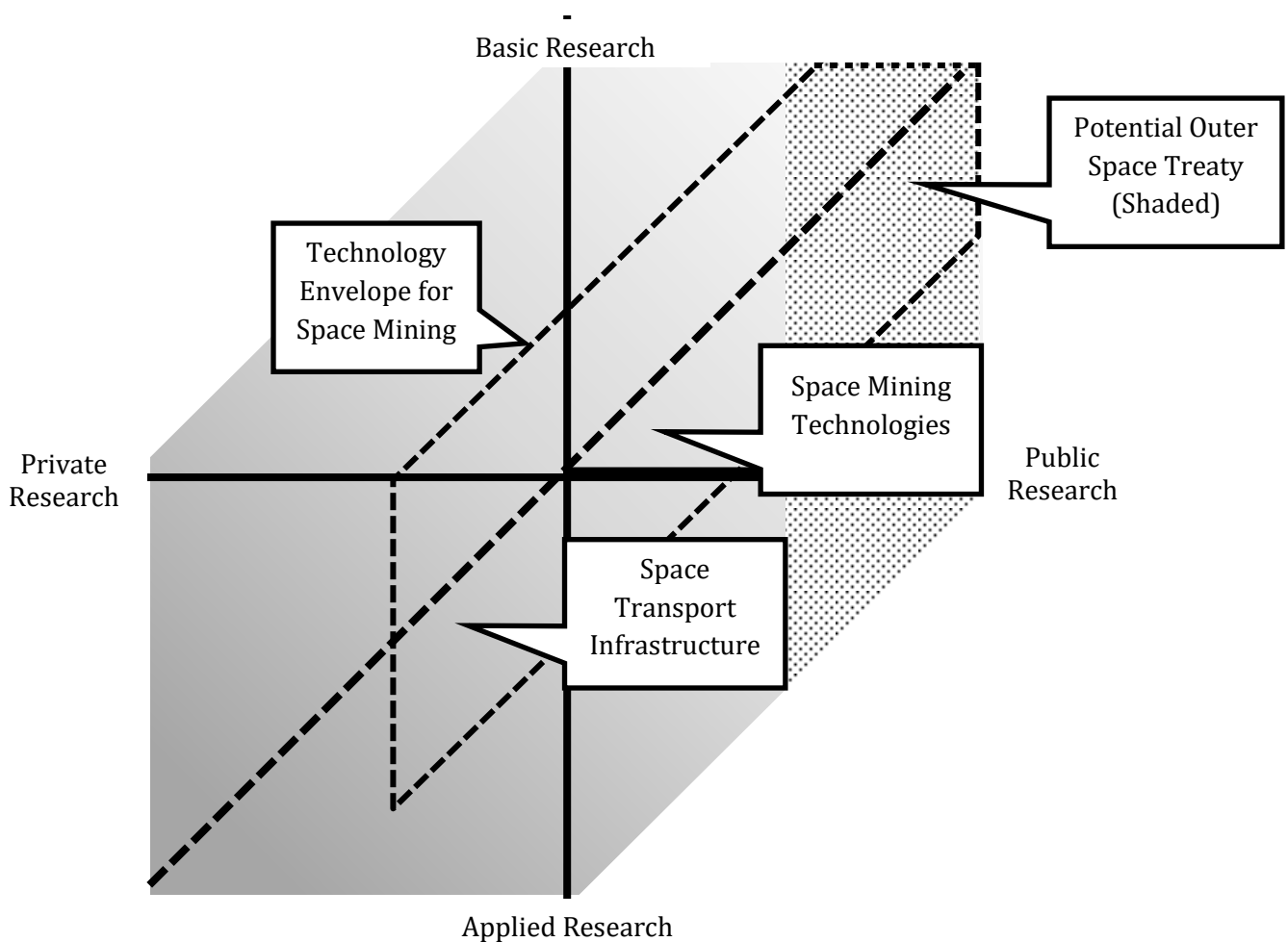


Figure 9: Technology Breakdown for Space Mineral Resource Activities

Policy Regime	Resource	Actor	Mechanisms	Outcomes
Mineral	Gold/American	Basic Research	Private Research	Development new process technologies (sluicing)
	Silver/New World	Basic Research	Private Research (Tax Incentives)	De Me Metallica book bound and disseminated, Mining processes improved
	Metals/Modern	Applied Research	Private Research (Subsidies, Tax Incentives)	Decreasing environmental costs, Development of new process technologies
	Metals/Deep Sea (UNCLOS III)	Applied Research	Hybrid Research (Subsidies, IP Rights, Prizes And Contests)	Growth of competing agents, four agents begin process
	Metals/Deep Sea (UNCLOS IV)	Applied Research	Public Research (Procurement, Mandatory Tech Transfer)	Failure of industry, (withdrawal of participating private agents, and other nations)
Space Policy/ Space Technology	Commercial Crew Development	Applied Research	Hybrid Research (Public Procurement, Contests, IP Rights, Subsidies)	New launch suppliers and decreasing launch costs
	Centennial Challenges	Applied Research	Public Research (Contests, IP Rights, Public Procurement)	General Success with some technologies (Power beaming, Glove, vertical landing), failure of other competitions (mineral extraction, unmanned flight)
	Small Satellites	Applied Research	Hybrid Research (Subsidies, Tax Incentives)	Growth of CubeSat field through and industry
	Science Vehicle Design	Basic Research	Public Research (Procurement)	Space Shuttle, Apollo, Remote Sensing (etc.)
Free Market Space Competition	Ansari X PRIZE	Applied Research	Private Research (Contests)	No growth of the suborbital spaceflight market
	Google Lunar X PRIZE	Applied Research	Private Research (Contests)	Steady monopolization and potential cancellation of the contest

Table 5: Technology Development Regimes

4.4.1 Public Procurement Might Be Forbidden

Public procurement to support research primarily focuses on buying or contracting companies to develop new technologies to use for the public good³⁹¹ and normally require a customer like the government to pay for expensive satellites and vehicles to form the basis of a

³⁹¹ (Nelson & Langlois, 1983)

civilian space exploration program when no major profits are foreseeable in the near future.³⁹² One could argue that the risks of technology development for asteroid mining could be absorbed by national governments to start these space mineral mining programs, but in light of the OST obligations, this may not be acceptable.³⁹³ Ownership of space resources is in direct conflict with the prohibition of nations owning space resources without freely sharing the benefit for all mankind.³⁹⁴ Public programs might end up buying technology components to assist shared space goals to explore more distant places (such as using automation and propulsion technology designed for asteroid missions to fly to other locations to collect scientific data), but the procurement-based development and operation of a full asteroid mining system architecture (and all of its basic and applied research developments) is not acceptable.

4.4.2 Public Prizes and Contests to Develop Shared Technology Interests

Prizes and contests are uniquely suited to support the development of the technologies for space mineral resource operations. Public prizes and contests usually revolve around promoting individuals, research agencies, and private companies to compete in a public research competition either for a prize or a potential to fill a procurement contract later.³⁹⁵ Public research contests and prizes can provide an economic incentive to develop new technologies that meet certain performance requirements, as well as create relationships between technology developers and suppliers to support future business plans³⁹⁶ and both public and private groups benefit.³⁹⁷ The National Academies Press in 1999 identified these “Open Innovation” competition programs as a

³⁹² (Neal & Smith, 2008) p 17-19

³⁹³ (United Nations Office of Outer Space Affairs, 2016)

³⁹⁴ (United Nations Office of Outer Space Affairs, 2016)

³⁹⁵ (Takalo, 2012)

³⁹⁶ (Salter & Martin, 2001)p 529

³⁹⁷ (Neal & Smith, 2008) p 134-135

beneficial supplement to basic research programs in the public sphere³⁹⁸ as well as sharing the risk and benefit between both public and private agents.³⁹⁹

Technology development competitions are partially responsible for the current steady privatization of the aerospace field and its successes.⁴⁰⁰ Early in the history of space systems, competitions formed the basis of a lot of the developments, from spacesuits to lunar landers, as they excite people, propose next steps for applied research, and provide simple challenges to be met.⁴⁰¹ In the field of space systems, these challenges have become increasingly more formalized, through the Centennial Challenges to address a wide variety of basic public research goals (Table 6: NASA Centennial Challenges).⁴⁰² Other competitions, such as the Commercial Crew Development Program, create new launch providers such as SpaceX, OrbitalATK, and Blue Origin.⁴⁰³

The private sector has been able to develop their own challenges like the XPRIZE for a variety of basic technology developments such as reusable suborbital spaceflight for tourism which was won in 2004 and currently the Google Lunar XPRIZE for landing on the Moon.⁴⁰⁴ These competitions are generally unable to provide support for basic research, as they do not have the capacity to deal with the high risks usually incurred by public basic research programs.⁴⁰⁵ Additionally, they have insufficient support for the next steps of development that public research can provide, as seen with the experience of the Ansari X-Prize for suborbital spaceflight and its inability to come to market.⁴⁰⁶

³⁹⁸ (Bloch, Kaminski, Mowery, Tellep, & Walker, 1999) p 14

³⁹⁹ (Johannsson, Wen, Kraetzig, & al., 2015) p 179-182

⁴⁰⁰ (Johannsson, Wen, Kraetzig, & al., 2015)

⁴⁰¹ (Davidian, 2005) p 3-5

⁴⁰² (Davidian, 2005) p 3

⁴⁰³ (National Space Society, 2011)

⁴⁰⁴ (Neal & Smith, 2008) p 137

⁴⁰⁵ (Seetharaman, Lahkotia, & Blasch, 2006)

⁴⁰⁶ (Messier, 2015)

Challenge	Focus	Outcome
Sample Return Robot Challenge	Develop A Robot To Collect A Sample And Load It Into A Rocket	Ongoing
Mars Ascent Vehicle Prize	Insert A Sample Into A Rocket, Launch From The Surface And Deploy The Container	Ongoing
Cube Quest Challenge	Design A CubeSat To Fly Onboard The Space Launch System Exploration Mission For A Lunar Flyby	Ongoing
Green Flight Challenge	Fly 200 Miles In 2 Hours With A Gallon Per Gasoline Per Passenger	Pipistrel USA Won In 2011
Strong Tether Challenge	Develop High Strength Tether Systems	Ongoing/Postponed 2011
Power Beam Challenge	Direct Energy To A Robot Climbing Within A Limited Time Frame	Completed 2009
Moon Regolith Oxygen Challenge	Extract Oxygen From Lunar Regolith	No Winner 2009
Astronaut Glove Challenge	Develop A Better Astronaut Glove	2009
Vertical Lunar Lander Challenge	Vertical Take Off And Vertical Landing With A Given Flight Time	Armadillo Aerospace (Now A Part Of A Lunar Landing Company) Won In 2009
Regolith Excavation Challenge	Excavate Lunar Regolith	Won In 2009
Night Rover Challenge	Long Duration Night Rover	Closed In 2013

Table 6: NASA Centennial Challenges⁴⁰⁷

When there are overlapping goals between public and private research, competitions are uniquely suited to promote private individuals to find the “best” solutions, whether that be performance or cost-based.⁴⁰⁸ With publicly run competitions, there are clear next steps in terms of implementation and often these competitions are successful in involving a wide variety of participants and finding a wide variety of possible solutions.⁴⁰⁹ Prizes and contests for technology development that supports private space mineral exploitation activities as well as public civilian science programs could be done for asteroid characterization and sample return missions, automation and robotics, re-entry for high mass payloads or even in situ resource utilization that would also be in line with the developments required for national space programs (Figure 10: Overlap of Technology Goals). These would fall in line with previously publically run programs

⁴⁰⁷ (Davidian, 2005) p 1-2

⁴⁰⁸ (Martin P. , House Committee on Science, 2011) p 4-6

⁴⁰⁹ (Bloch, Kaminski, Mowery, Tellep, & Walker, 1999) p 7-9

dealing with space flight technologies, seen below, but could potentially have greater success in light of increased demand for these technologies and the potential immediate application of the products developed in space mineral business applications. Creating more Centennial Challenges could be the key for future technology development for space mineral mining and supporting public space programs at the same time.

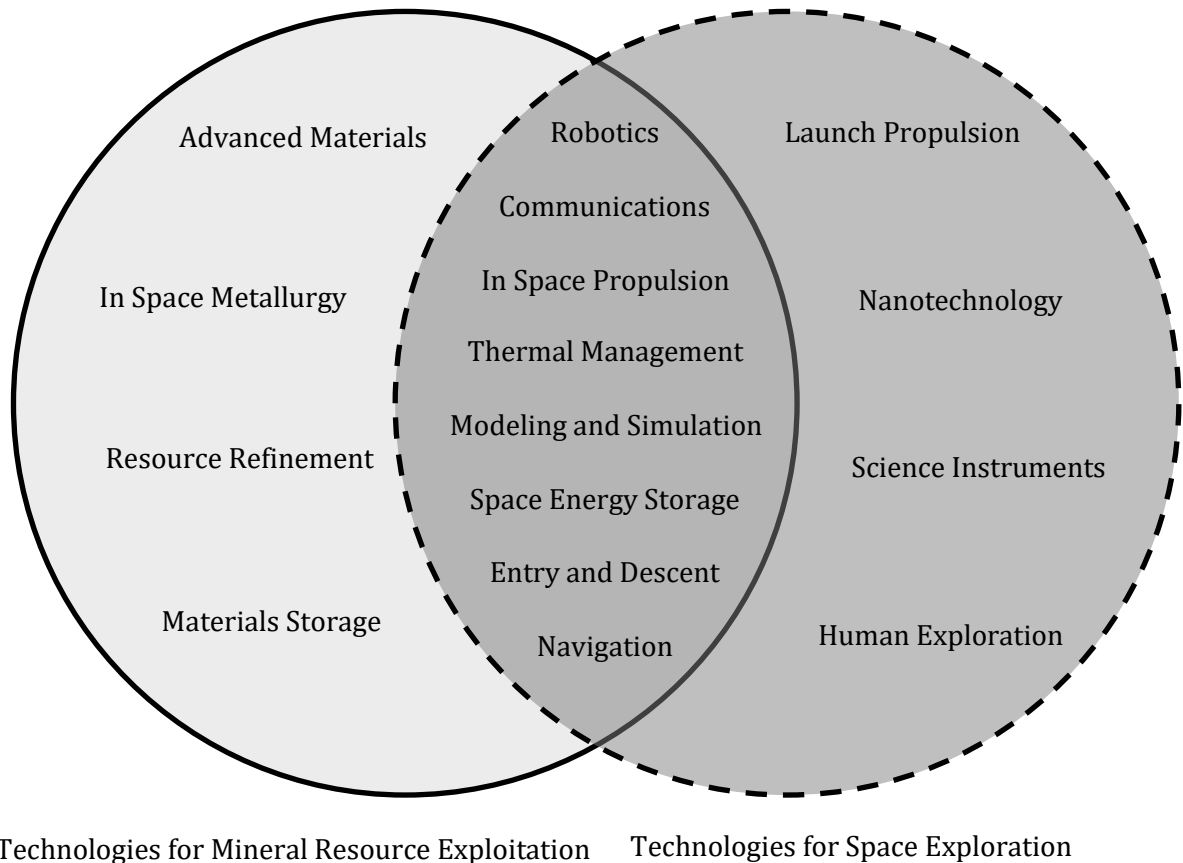


Figure 10: Overlap of Technology Goals

4.4.3 Intellectual Property (IP) as a Resource

Aerospace technology is a highly valuable resource in and of itself due to the time and energy required to develop it as well as the performance standards that must be met for spaceflight. Risking time, energy, and money on developing these technologies is dangerous, but allowing

private agents to maintain their control of this intangible resource could help promote the development of the necessary basic and applied technologies for space mineral exploitation programs and produce a market for the future trading of these technologies.

Intellectual property is the byproduct of the research process, and representative of the investment into making that new technology.⁴¹⁰ In the modern era, intellectual property has become an economic resource of its own, with numerous companies brokering and trading IP rights to different pieces of technology that has come out of basic and applied research.⁴¹¹ The technologies developed in the pursuit of a spaceflight or mining goal can be reapplied in a variety of situations, as they often have high performance characteristics.

In some cases, after developing a new basic technology, that technology can then be licensed or sold to another company for that original research to recuperate the cost.⁴¹² When the ability to maintain and control IP rights has been threatened in the past, such as with mandatory technology transfer with the International Seabed Authority, private agents are less willing to participate in the technology development process.⁴¹³

4.4.4 Tax Subsidies and Incentives are Not Appropriate Now

Subsidies and tax incentives are some of the strongest policies to support technology development, but usually are provided only if there is an overwhelming social or economic good for the technologies developed or implemented.⁴¹⁴ It is usually reserved for applied research outcomes rather than basic research.⁴¹⁵ In light of the basic research needs now and the unknown benefit of

⁴¹⁰ (Neal & Smith, 2008) p 14-145

⁴¹¹ (Neal & Smith, 2008) p 230

⁴¹² (Eckert, 1979)

⁴¹³ (Neal & Smith, 2008) p144-145

⁴¹⁴ (Takalo, 2012)

⁴¹⁵ (Neal & Smith, 2008) p 6-8

unknown business applications and potential market implementations, using tax subsidy or incentive policy is not warranted.

4.5 CONCLUSIONS AND FUTURE EVOLUTIONARY PATHWAYS

The basic research innovations for new technology developments to support space mineral resource exploitation are well supported by policy mechanisms and by typical policy development regimes. These basic research goals share commonalities with national research goals, could be well maintained through mechanisms such as prizes, contests, and IP protection and would be undertaken by both public and private agents as has been done in the past. Some of the applied research innovations, which would benefit the private the most are still incredibly high risk, and due a lack of definition in the field, subsidies and further incentives are not appropriate right now, but rather policy should be focused on the development of common public science goals.

As the field matures, there is a strong argument to steadily support less of the basic research goals and increase support of the applied research. The hybrid approach is currently supported due to the fact that many technologies have already started being developed under public and basic research paradigms and the needs of future development lies more in the applied and private research domain.

5 POLICY ISSUE: SURVEYING

The detection and characterization of mineral resources before exploitation is a crucial step in the business process for any kind of mining operation and policy should be written such that identification and tracking of asteroids by private industries is encouraged, but the characterization data collected should be protected as intellectual property. Space mineral mining groups should supplement the work already being done and improve the quality of sky watch programs for all. At the same time, improving the economic advantage to undertaking these programs would be beneficial and restore some of the intent of the surveying process, while still retaining and recording the potential scientific value of asteroid mineral resources.

The International Astronomical Union organizes surveys to find Near Earth Asteroids (NEA) and in the process, it has developed a considerable international community of observers gathering data on the night sky trying to identify potential Earth impactors and add to the body of knowledge about our solar system.⁴¹⁶ Freely sharing the knowledge of asteroid location and basic compositional data of over 750,000 asteroids helped create the asteroid mineral resource mining industry seen today, and now these mining agents are looking to increase their data on the composition of asteroids as economic resources and could assist in the public good of further NEA identification.⁴¹⁷ By allowing the characterization data these mineral mining agents collect along the way to be kept private like intellectual property (IP, see 4.4.3 Intellectual Property (IP) as a Resource), the economic risk and investment into detection is protected by the promise of future exclusive knowledge of where economic resource stocks are and what asteroids to license (see Chapter 6 Policy Issue: Ownership).

⁴¹⁶ (Martin P. , NASA's Efforts to Identify Near-Earth Objects and Mitigate Hazards, 2014) p 5-6

⁴¹⁷ (Sonter M. , 2006)

5.1 SURVEYING AS PART OF THE CLAIM PROCESS, AND CHANGES FROM TRADITION

For nearly any major mining program, there needs to be explicit knowledge of where resources are to direct future investments to ensure that private investors and miners make the most profit.⁴¹⁸ Functionally, the act of surveying and the intent of these historical policies were to demonstrate that individuals wishing to mine a region:⁴¹⁹

- Knew of the economic value of the region
- Could access the region of economic interest
- Could access the sources of economic interest

From this information collected and the investment made into this process, the act of surveying could substantiate a further claim and start the process of mining, as seen in numerous mineral resource surveying scenarios on Earth.⁴²⁰

As a policy, surveying was designed to ensure that there is some degree of upfront interest and potential investment into the land as well as a capability to use it, which would include transportation infrastructure, market knowledge, technology capability and the ability to own the resource stock while preventing exclusive ownership and still allowing free use until it was claimed.⁴²¹ Silver was one of the first formalized instances of this surveying leading to ownership and fulfilling the needs listed above,⁴²² as the knowledge collected by early imperial explorers would eventually constitute the Crown's ownership of all lands they discovered (which they would later license to individual mines).⁴²³ With gold, individual miners used the time they invested in

⁴¹⁸ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 28-30

⁴¹⁹ (US Department of the Interior-Bureau of Land Management, 2015)

⁴²⁰ (McAllister & Alexander, 1997) p 5-8

⁴²¹ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 31

⁴²² (Brading & Cross, 1972) p 548

⁴²³ (Brading & Cross, 1972) p 562-563

finding alluvial gold deposits to form the basis of their claims.⁴²⁴ The knowledge of diamond tubes was bought and sold among business partners,⁴²⁵ who sometimes found it more economic to broker surveying knowledge than mine themselves, such as with John Cecil Rhoades who used his knowledge to exploit the Kimberly Mines first and use those first actor funds to take over the mines of the people who followed him.⁴²⁶ The 1872 Mining Code included policies to promote the surveying of land and then used the claim itself almost like a modern patent disclosure to publically release that data at the same time a license was given for someone to temporarily own the land and exploit its resources.⁴²⁷ In the modern era in regions outside of their control, such as with the deep seabed, nations still did recognize the importance of surveying regions that they could not survey themselves. For every license given to deep seabed mineral exploiters, there was a ten year grace period for survey before the actual mining claim came into effect.⁴²⁸ Surveying done by private agents leading to ownership or claiming the land was prevalent in the past, but as the nature of surveying changed in terms of the requisite technology requirements and upfront investments, the policies surrounding surveying changed as well.

The International Geophysical Year in 1958-1959 fundamentally altered who did surveying and made the surveying process more scientifically-oriented.⁴²⁹ Claims in Antarctica were made based on the location of resource sites discovered during this year by national explorers, and throughout the world other nations developed their internal geological survey programs to reassess the natural resources within their countries for scientific, preservation, and potential economic use.⁴³⁰

⁴²⁴ (Martin L. , 2004)p 30-32

⁴²⁵ (Zoellner, 2006) p 106-108

⁴²⁶ (Zoellner, 2006) p 116-118

⁴²⁷ (US Department of the Interior-Bureau of Land Management, 2015)

⁴²⁸ (Groves, 2012)

⁴²⁹ (Joyner, 1992)

⁴³⁰ (Pop, Who Owns the Moon, 2009) p 272-273

When national space programs started to develop at the same time, there was a great deal of interest in better understanding the space environment and local neighborhood.⁴³¹ Through the 1960's to the 1990's, rudimentary telescope and detector combinations with resolutions as low as 200 by 200 pixels observed the night sky to gather data about the solar system, asteroids, potential threats to the Earth, and some basic compositional data.⁴³² Early policies, such as HR 4489 in 1994,⁴³³ created the first asteroid detection programs to formally search for asteroids and in 1998, rates of asteroid detection and basic characterization increased with more funding and technology upgrades (Figure 11: NEA Discovery by Survey).⁴³⁴ These programs have identified more than 750,000 asteroids from the original thousand known about in the 1980's, and have identified more than 15,000 potential NEA's,⁴³⁵ with ten potentially being very valuable (over \$1 billion in platinum alone), more than 100 meters in size, and requiring less energy than the Moon landing to visit, refine, and return.⁴³⁶

⁴³¹ (European Space Agency)

⁴³² (Martin P. , NASA's Efforts to Identify Near-Earth Objects and Mitigate Hazards, 2014)

⁴³³ (Evans, Shell, & Stokes, 2003)

⁴³⁴ (Martin P. , NASA's Efforts to Identify Near-Earth Objects and Mitigate Hazards, 2014) p 2

⁴³⁵ (Lewis, Mining the Sky, 1997) p 80-81

⁴³⁶ (Elvis, 2014)

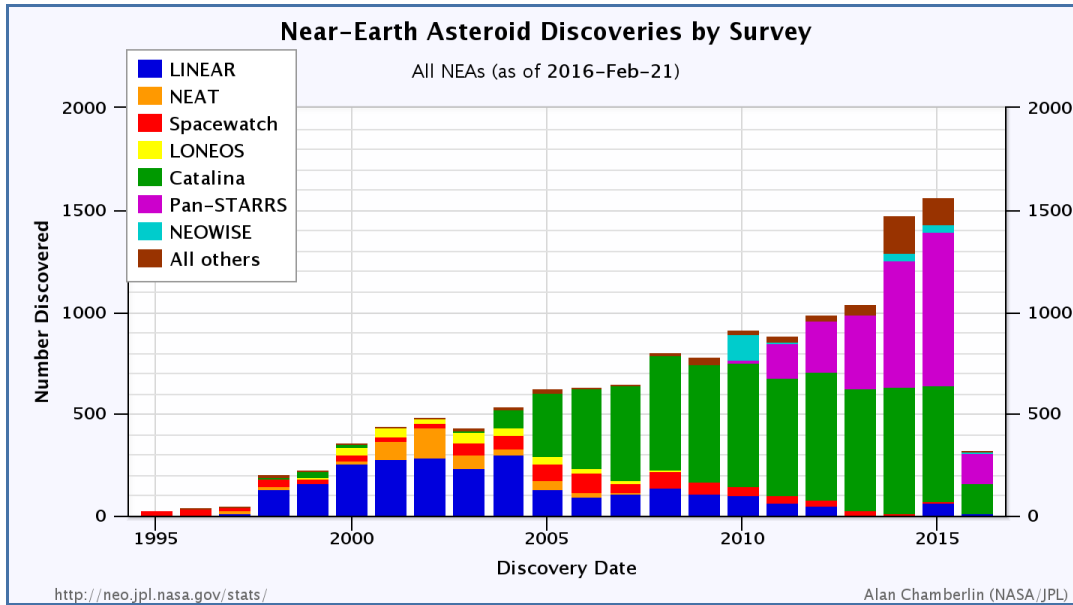


Figure 11: NEA Discovery by Survey⁴³⁷

This characterization and location data collected by these national and international programs had to be freely shared as outlined in the Outer Space Treaty, as outlined in Article I (“There shall be freedom of scientific investigation in outer space, including the moon and other celestial bodies, and States shall facilitate and encourage international co-operation in such investigation”), in Article X (“the States Parties to the Treaty shall consider on a basis of equality any requests by other States Parties to the Treaty to be afforded an opportunity to observe the flight of space objects launched by those States”) and in Article XI (“States Parties to the Treaty conducting activities in outer space, including the moon and other celestial bodies, agree to inform the Secretary-General of the United Nations as well as the public and the international scientific community, to the greatest extent feasible and practicable, of the nature, conduct, locations and results of such activities.”).⁴³⁸ This language set a strong precedent in the policy for the free sharing

⁴³⁷ (JPL Near Earth Object Program, 2016)

⁴³⁸ (United Nations Office of Outer Space Affairs, 2016)

of all knowledge acquired by national resources in the pursuit of space exploration, including the spectral and location data of potential space resource stocks.⁴³⁹

Fundamentally, the act of surveying was to demonstrate knowledge, capability to mine, and the capability to access and mine, and typically all three had been done simultaneously. Mark Sonter in 2000 identified that launch costs and the lack of knowledge were the primary drivers of increasing cost with space mineral resource mining⁴⁴⁰ and substantial prospecting is necessary in advance.⁴⁴¹ However, the nature of public asteroid discovery (which satisfies Sonter's Characteristic III of a successful asteroid mining paradigm, knowing where the resource is) is lacking for economic projects and has changed some of the intent and outcomes of the asteroid surveying process with regards to understanding what resources are there (salient characteristic II).⁴⁴² The public interest in finding asteroids that could threaten Earth, and then expanding that capacity to do basic characterization of these bodies fragmented the typical surveying process and also fragmented its intent. Additionally, the data collected now is inherently decoupled, as in the location (the knowledge of its orbit around the sun), characterization (the knowledge of the chemical composition of the asteroid derived from either spectroscopy or physical characterization and assay), and identification (determining the location, size and movement for the first time of an asteroid) can be separated and recombined as necessary. Surveying asteroids is no longer a single process, but rather multiple dissimilar processes including remote sensing and eventual physical assay (i.e. a probe or spacecraft sent to sample in situ).

The body of knowledge about asteroid mineral composition at this time is insufficient, adding greatly to the already large amount of risk of mining minerals in space.⁴⁴³ To confirm mining sites,

⁴³⁹ (National Space Policy of the United States of America, 2010)

⁴⁴⁰ (Sonter M. J., 1997) p 29-30

⁴⁴¹ (Sonter M. J., 1997) p 638

⁴⁴² (Sonter M. J., 1997) p 638

⁴⁴³ (Crawford, Gump, Lewicki, & Seager, 2013)

Sonter⁴⁴⁴ and Lewis⁴⁴⁵ both originally recommended spectral data, but it appears that actual sample assay might also help the operations of space mineral miners,⁴⁴⁶ and is increasingly becoming cheaper.⁴⁴⁷ Current plans typically focus on telescope observations followed by physical assay probes to return samples to Earth for further characterization, as the location of resources (Sonter's Characteristic II) is already known. Planetary Resources plans on using an Earth-orbiting telescope, and then follow up with more extensive surveying from an interceptor spacecraft and a prospector spacecraft that would gather shape, rotation, density and composition data.⁴⁴⁸ Deep Space Industries will start with picosatellite scale platforms (bricked sized satellites) first to flyby several asteroids to collect data rapidly and inexpensively, and then send out a secondary mothership with more picosatellites on board to go and gather more data of asteroids of interest and essentially place a buoy on them for more accurate tracking.⁴⁴⁹ Ultimately, is the data collected by these individuals for their use only, or can it be shared, and can it be supported by policy in any way?

At the current time, there is a debate about whether or not private characterization data collected by private agents would have to be freely shared among the public because of the OST.⁴⁵⁰ If there is, it would reduce the economic reasons for private agents to survey, but would contribute to the public good.⁴⁵¹ However, the norm currently favors the private ownership of information gathered from space by private agents, and space mineral resource miners should be allowed to use this surveying data to help secure an asteroid claim and prevent interference.⁴⁵² Ultimately for space mineral mining characterization, it is proposed that private agents participate in the public identification programs and receive the benefits derived from contributing to planetary defense,

⁴⁴⁴ (Sonter M. J., 1997)

⁴⁴⁵ (Lewis, *Mining the Sky*, 1997) p 101-102

⁴⁴⁶ (Lewis, *Asteroid Mining 101*, 2014) p 26-30

⁴⁴⁷ (Planetary Resources, 2016)

⁴⁴⁸ (Planetary Resources, 2016)

⁴⁴⁹ (Deep Space Industries, 2016)

⁴⁵⁰ (Abundant Planet, 2009)

⁴⁵¹ (Simberg, 2012)

⁴⁵² (Lee, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, 2012) p 297

such as telescope time and funding. This encourages participation and potentially increases the quality of our knowledge of Near Earth Asteroids while providing private agents the foundation to explore asteroids in more depth to find economic deposits.⁴⁵³

5.2 IDENTIFYING ASTEROIDS FOR THE PUBLIC GOOD

In light of the potential to cover the same parts of the sky and potentially detect new asteroids that could threaten the public safety or provide to the public scientific benefit, asteroid mineral resource exploiters should be included in the sky survey regime (identification of new asteroids as well as collecting their location data) alongside other sky watch programs and be partially funded as they hunt for asteroids that could provide them with economic benefit. These mining agents can increase the detection rate because they will be reviewing the same parts of the sky; help develop the field of asteroid detection, and not lose the economic advantage associated with identifying resource deposits that could be exploited, encouraging them to participate in the identification duty while they characterize ore bodies.

There is a simple correlation about finding asteroids; the more telescopes watching the sky, the greater the detection rate of these bodies, and consequently, more public benefit can be gained as finding asteroids is beneficial as evidenced by the purpose and language of HR4489 and the intent to identify possible Earth impacting NEA's.⁴⁵⁴ Mechanically, the sky survey programs that these asteroid miners will perform leading up to physical survey and assay⁴⁵⁵ will be reviewing large sections of the sky trying to detect new asteroids or increase the fidelity of previous location assessments.⁴⁵⁶ In the process, they will most likely be capturing or indexing hundreds of asteroids at a single time in a single patch of the sky while other sky survey programs are happening at the

⁴⁵³ (NASA Goddard Spaceflight Center, 2016)

⁴⁵⁴ (Gov Track, 2016)

⁴⁵⁵ (Planetary Resources, 2016)

⁴⁵⁶ (Martin P. , NASA's Efforts to Identify Near-Earth Objects and Mitigate Hazards, 2014)

same time (Figure 12: Current Sky Coverage of Various Programs Surveying the Sky).⁴⁵⁷ Associated with this is also the potential for funding and support for these activities, which asteroid miners could use to help reduce the financial risk of some of their activities,⁴⁵⁸ and the potential for the technology developments associated with private research to decrease costs while increasing the performance of the basic research already done by sky watch programs.⁴⁵⁹

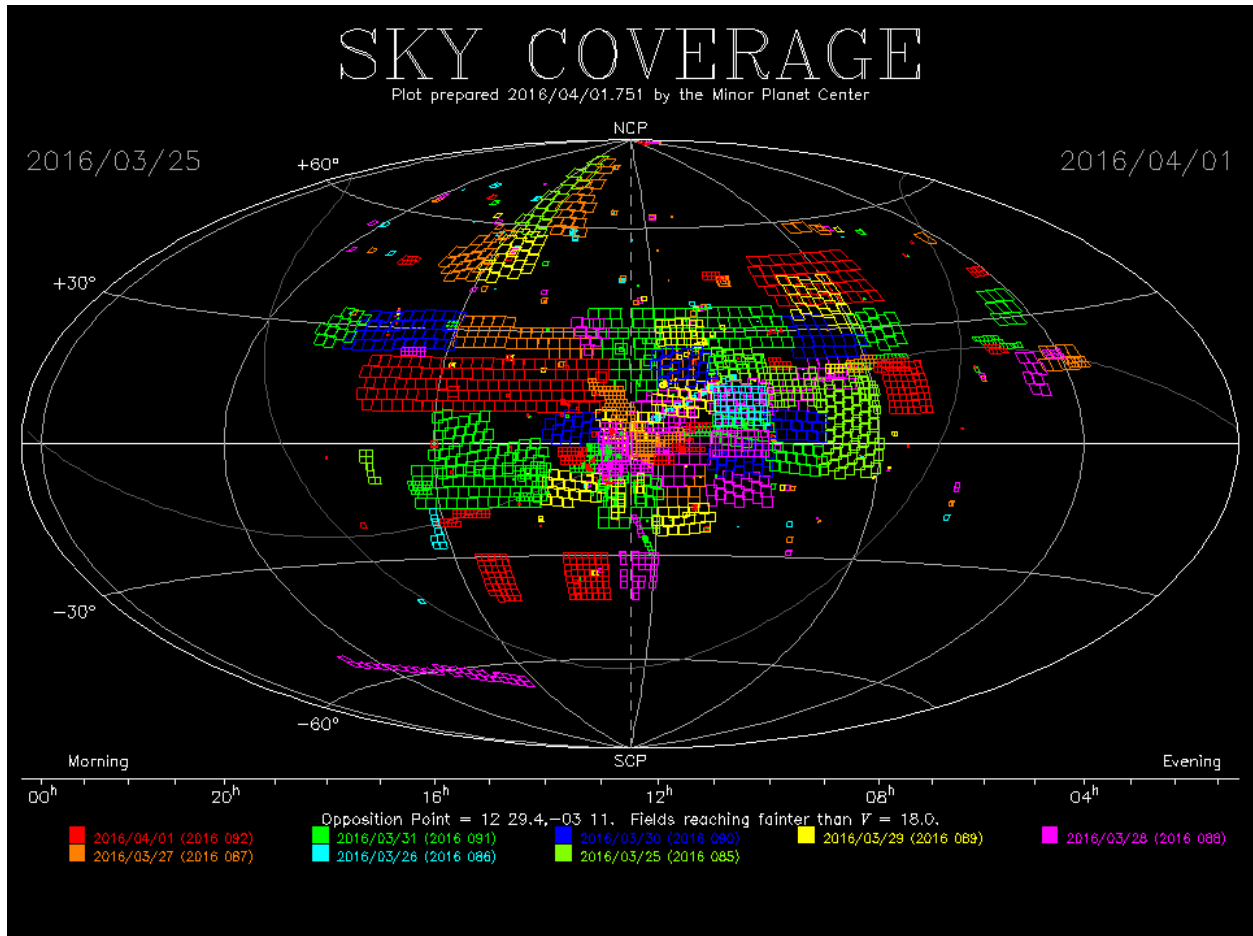


Figure 12: Current Sky Coverage of Various Programs Surveying the Sky⁴⁶⁰

The identification, location, and characterization data is inherently separate and not directly coupled together, and further characterization only comes out of actually visiting or heavily

⁴⁵⁷ (Planetary Resources, July)

⁴⁵⁸ (NASA Near Earth Object Program, 2013)

⁴⁵⁹ (Evans, Shell, & Stokes, 2003)

⁴⁶⁰ (Minor Planet Center, 2016)

analyzing via telescope these potential orebodies. The knowledge and identification of a potential NEA as well as tracking the location of this body only provides half of the salient characteristics necessary for a space mineral mining program and is not economic alone. Consequently, the free sharing of this knowledge for public good will, and potential private benefit through public funding to perform this activity to identify and release location data of newly found NEA's is proposed.

5.3 CHARACTERIZING ASTEROIDS FOR PRIVATE BENEFIT

As sharing the knowledge of potential ore body asteroids, as nearly all asteroids could be considered economic resource deposits, is recommended for the public benefit, the data collected from assay missions using a physical probe or enhanced surveying telescopes could be handled as private intellectual property (IP). The value of the space mineral mining activity directly derives itself from the knowledge of the resources that could be found at a location and the location of those resources, referring back to the original salient Characteristics identified by Sonter in his analysis (Characteristic II and Characteristic III).⁴⁶¹ Above it is argued that there is an overwhelming public benefit for the identification of asteroid bodies, including their location (characteristic III), and it is the knowledge of the ore body composition that provides the economic value.

Gathering this character and compositional data is a fundamental final step in the process of ownership, which has otherwise been disrupted with the rise and analysis of the modern sky survey program. The intent of surveying is to not only know of the economic value, but to demonstrate access of the region, the resources, and ultimately form a basis of an ownership claim through the investment of time into owning that region.

⁴⁶¹ (Sonter M. J., 1997) p 638

In order to return value to the concept of mining in an increasingly remote sensing based paradigm, two actions should be mandated as part of the surveying process that eventually leads to the claiming and licensing process (explained later): compositional data should be collected via remote sensing to identify a small set of bodies of interest, and a physical assay probe (or sample return) should be sent to the surface to collect a minimum amount of sample that would reflect the mineral composition of the asteroid. The data collected during this operation, as described above, could be handled privately, or traded between agents as part of a secondary market.

With respect to the original intent of the survey to find, access the region and access the resource of interest, this proposal does mandate that access of the resource is a critical step in the process to later license resources. Characterization via telescopes is still well encouraged to expand the knowledge of potential economic ore bodies, but to confirm, that physical assay mission is necessary to these business endeavors. The physical assay and the knowledge of the mineral and economic resources of an asteroid would fulfill some of Sonter's original recommendations for a successful space mineral mining program.⁴⁶²

By providing some intellectual property protection, companies are encouraged to collect this knowledge by remote sensing and physical assay; even if they themselves might not be asteroid miners because the data could be sold and handled to give others large competitive advantages by knowing which resource deposits are valuable earlier than others. That intellectual property right produces value, which increases economic advantage to doing this kind of privately valuable research, which could then be used to help manage the risks of launching a physical assay mission, building a better telescope, or launching that mining expedition.

Completely public surveying operations to characterize asteroids through telescope survey or sample return is a socially, but not economically, beneficial outcome. The National Space Policy

⁴⁶² (Pop, Who Owns the Moon, 2009) p 275-278

does call for the United States of America to “...pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize near-Earth objects to reduce the risk of harm to humans from an unexpected impact on our planet and to identify potentially resource-rich planetary objects,”⁴⁶³ but in the context of this document, it is primarily to support national and international space exploration programs and not industry. Additionally, as discussed in Articles I, II, and III of the OST, national appropriation for private gain, unlike national appropriation for public gain like Moon rocks which contribute to the scientific good, are expressly forbidden, so to do this observation with the intent of private gain is not allowable.⁴⁶⁴ Finally, by being forced to freely share the information, the reaction is the same as yelling the location of the next big gold deposit to a large group of miners. It encourages a massive resource rush when policy issues have not yet been addressed, it creates first actor problems if the resource in question is *res communis* in nature, and it does not help prevent exclusivity of exploiting a resource.

Completely surveying data privately also completely disregards the fact that there might be potential scientific value in the space environment. Arguably, it could be said that if a resource of great scientific interest were found, or a potential NEA that could impact the Earth, no matter how large or small, there would be no incentive to keep this data or convey it to national survey programs. At the same time, completely private survey programs receive no assistance with technology development or funding, and provide no technology development or new data to other programs that are functionally doing the same things. It represents a serious duplication of efforts in both the observation and physical assay.

⁴⁶³ (National Space Policy of the United States of America, 2010)

⁴⁶⁴ (NASA Goddard Spaceflight Center, 2016)

The fundamental argument that government should do the remote sensing and physical assays of asteroids is well grounded in some historical fact, but it seems more along the line of a major applied research and private undertaking. There are some technologies that would need to be further developed from the basic research already done and the actual deployment and operation of this technology would not be for the public good, but rather private benefit. If this activity is done for the private interest, using applied research, and collecting data on characteristics of asteroids that have only some scientific benefit, then they are certainly not entirely for the public good, and responsibilities have to be shared or handed off to private interests (as national activities would have to reveal the knowledge of economic deposit location under the OST).

5.4 CONCLUSIONS AND FUTURE EVOLUTIONARY PATHWAYS

Ultimately, more knowledge about the character and composition of asteroid resources is needed, which could be achieved with telescopes and remote sensing as well as with physical assays of these places. The proposed policy argues that public sky watch programs should continue and be supplemented in their location and identification duties (with physical scientific assays being performed for the scientific and public good) while further analysis and physical assay of space mineral resources be treated as intellectual property developed by the private space mineral resource agents.

Nations will continue to identify location and base character of asteroids as a public service and are uninterested in more in depth compositional analysis due to the already present strain on telescope time and sky coverage needs. Gathering this really in depth and economic in nature data is simply not a goal right now, and also potentially conflicts with the Outer Space Treaty to some extent. Companies need to develop their own detection and surveying infrastructure to fill this need that policy cannot cover. In the process, when developing telescope technology, they can contribute

back to the field, and potentially recuperate their costs in the process, by enhancing detector process efficiency or sharing identification and location data, which has some economic interest to them.

Eventually, once they have base composition data, these private space miners will be sending physical survey probes to collect more data. This is a technology development issue, primarily focused on furthering applied research in the field (which makes it more of a private issue), and this policy mandated physical assay will strengthen a later license for that region. This is a reversion to the typical surveying process and intent, where the survey acts not only demonstrated the location of an ore body, but the ability to access the location and resource in question. In the process, it encourages more technology development, more risk assumption upfront by actually surveying the site before a mining license is provided, economic encouragement and investing into the survey process and potentially creates a new market for both scientific and industrial researchers to sell their characterization data.

Mechanically, the protection for space mineral resource miners would not be an incursion or request to share this data unless it serves an overwhelming public good to do so. In line with the SPACE Act, if biological or scientifically valuable samples were found, they should be shared under that policy regime. This would mimic the model currently seen with mineral resource exploitation and allow these actors to help the public good in identification, but also protect their investments into finding the perfect asteroid to mine.

6 POLICY ISSUE: OWNERSHIP

Ownership of space mineral resources by national agents was forbidden under the *Common Heritage of Mankind* policy regime (also known as CHM, which asks for resources and benefit gained from the exploitation of unclaimed lands to be shared equally among all, prohibiting national ownership) set in the Outer Space Treaty (OST),⁴⁶⁵ but never recognized the actions of private agents.⁴⁶⁶ Now, with the growth of private agents, this policy gap is being examined because of the SPACE Act in the United States of America, which confers the right for private agents (specifically US Citizens) to possess space resources under a *res communis* policy regime.⁴⁶⁷

However, the previous history on mineral ownership and management, as well as the utilization of space resources (namely geostationary orbit), indicates that this ownership regime is insufficient to promote the development of resources while also protecting exploiting agents from harmful interference. With a *res communis* and the opportunity to potentially exhaust resources because the high value of the mineral resources in question, along with no upper limits on ownership, this ownership policy regime has failed consistently in protecting others from harmful interference in light of the great cost of operating in space.⁴⁶⁸ Total ownership of space resources as proposed by many would create potential issues with exclusive ownership and the ability to own all of the resource of the *Common Heritage of Mankind*. One cannot assume that the *Common Heritage of Mankind* in its current form will succeed as a ownership policy regime, as it has been overturned

⁴⁶⁵ (United Nations Office of Outer Space Affairs, 2016)

⁴⁶⁶ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 15-16

⁴⁶⁷ (Tronchetti, The Space Resource Exploration and Utilization Act: A move forward or a step back?, 2015) p 6-7

⁴⁶⁸ (Tronchetti, The Space Resource Exploration and Utilization Act: A move forward or a step back?, 2015) p 6-7

in two of the three resource domains it was originally used in once pressure was applied (Antarctica and seabed, with space resources being the third unchanged domain).⁴⁶⁹

The use of a licensing regime from mineral mining to geostationary orbit means that of all the potential policy proposals, this one has been used the most, with the greatest amount of success in encouraging use, preventing interference, and preventing exclusivity, all while maximizing public and private gain (Table 7). There has been a long history of this method being used to optimize the use of public and private mineral, *fructus*, and even telecommunications resources.

Legal Paradigm	Definition	Benefits	Costs
<i>Common Heritage of Mankind</i>	Resources derived must be shared the benefit of all mankind	Prevents militarization and national claims	Provides no economic incentive for use
<i>Res Communis</i>	First come, first serve	Free use of all resources without reservation	Tragedy of the Commons overuse scenario
Licensing	Provisional use based on squatting, use, public benefit, etc.	Protections from interference while temporary exclusivity	Temporary in nature
Total Ownership	Owning the land, and mineral resources contained within for the rest of time	Full use and control of all resources, present or future	High opportunities for exclusivity and first actor monopolies

Table 7: Legal and Policy Paradigms for Resource Rushes

6.1 THE FAILURES OF THE *COMMON HERITAGE OF MANKIND*

Unfortunately, the uses of the CHM as an ownership regime, where resources gained from the exploitation of a resource body must be freely shared among all mankind at no cost,⁴⁷⁰ have consistently failed in promoting economic exploitation of resources by disenfranchising industrialized nations who are the only ones who can fund and develop these resource stocks.⁴⁷¹ CHM has consistently succeeded in preventing any nation from claiming resources, whether

⁴⁶⁹ (Egede, 2011) p 15-17

⁴⁷⁰ (Shackelford, 2009) p 106

⁴⁷¹ (Egede, 2011), p 56-57

mineral, scientific, or industrial for a period of time,⁴⁷² but in the process this policy regime has changed when any economic or social pressures were applied for the use of these resources.⁴⁷³ Developed nations look to use materials freely, where developing nations are interested in managing the resources of the Commons, and these differing viewpoints inhibit economic exploitation and cause instability as seen in the Antarctic and deep seabed.⁴⁷⁴ Within the OST and a slightly modified CHM policy regime that focused on militaristic expansion by nations, very little language actually affects private agents, leaving a substantial policy gap regarding the private ownership of space resources as well as threatening that the adoption of CHM would remove any economic reason to exploit the resources of space.⁴⁷⁵

The *Common Heritage of Mankind* policy regime on ownership is a policy developed in response to the imperialism and militarization that was part of the Cold War⁴⁷⁶ as a byproduct of growing social awareness of the disparity between industrialized and non-industrialized states⁴⁷⁷ and an interest to preserve the environment from rampant industrialization.⁴⁷⁸ Previously, many regions of the world lay “beyond the limits of national jurisdiction,” and the very existence of these regions “created a ‘basic political problem’ that could no longer be avoided” as new technologies allowed for expansion and use.⁴⁷⁹ These technologies are typically developed by richer, developed nations,⁴⁸⁰ creating a regime where the rich became richer, and the poor became

⁴⁷² (Lee, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, 2012) p 15-16

⁴⁷³ (Shackelford, 2009) p 156

⁴⁷⁴ (Shackelford, 2009) p 110

⁴⁷⁵ (Shackelford, 2009) p 106

⁴⁷⁶ (Lee, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, 2012) p 218-219

⁴⁷⁷ (Angelo, 2007) p 18-20

⁴⁷⁸ (Ramakrishna, 1990) p 429

⁴⁷⁹ (Ramakrishna, 1990) p 434

⁴⁸⁰ (Egede, 2011) p 30

poorer.⁴⁸¹ This issue was faced early on with the operations in Antarctica and the Deep Seabed, and are now being seen today again with Outer Space.

Functionally, there are five components to the *Common Heritage of Mankind* which have been formalized through the three major applications of this policy:⁴⁸²

- I. Can be no public or private appropriation of the Commons
- II. Representatives from all nations must manage the Commons area
- III. Must actively share in the benefits acquired from exploitation of resources within a region
- IV. Can be no weaponry or military installations established
- V. The Commons must be preserved for future generations

However, as technological competencies grew to allow for the mining of the mineral resources locked away in the ice continent of Antarctica, diesel power expanded the reach of fishing trawlers, and now space systems may allow for economic mining of space mineral resources, the CHM might not be able to resist the economic and social pressures (element III above).

CHM was first applied in Antarctica as a reaction to the territorial claiming of the land and discovery of a wide variety of resources on the previously uninhabited continent during the International Geophysical Year (1958-1959).⁴⁸³ Through the 1960's to the 1990's, there was overwhelming interest in using the continent for scientific research, but also growing interest in using the mineral resources and expanding territorial claims for a variety of nations.⁴⁸⁴ Eventually, the overwhelming scientific and environmental importance of the Antarctic outweighed the

⁴⁸¹ (Ramakrishna, 1990) p 435

⁴⁸² (Shackelford, 2009) p 103

⁴⁸³ (Soucek, The Polar Regions, 2011) p 271-273

⁴⁸⁴ (Soucek & Brunner, Outer Space in Society, Politics, and Law, 2011) p 277-280

exploitation argument⁴⁸⁵ and in 1991, the region was reclassified as a nature preserve.⁴⁸⁶ Leading up to this change, private agents were interested in mining the resources of Antarctica and exploiting energy and mineral resources,⁴⁸⁷ but the CHM policy regime was not enforceable in the private sphere and did not fully protect the environmental resources of the continent.⁴⁸⁸ The territorial claims nations had made at the beginning could stay, but heavier environmental controls further reduced the capacity for exploitation of mineral resources.⁴⁸⁹ Today, economic activity in Antarctica is focused on technology development and ecological tourism, while many scientists still live in the region exploring the mineral deposits and scientific resources, such as ice-cores, bacteria, and meteorite falls (which were also used to characterize the asteroids that many want to mine).⁴⁹⁰

More alarming was the impact of the reversion from CHM to a *res communis* policy regime and then back to the CHM for deep seabed mineral resources.⁴⁹¹ These changes severely impacted economic development of these resource stocks on the deep seabed and has placed the exploitation of these resources into a policy limbo where no one is sure about the future state of ownership.⁴⁹² Originally, UNCLOS I in the 1950's used CHM because there was no economic interest in mining the region. In the 1970's after exploration of the seabed and after new technologies were developed to operate there, UNCLOS III changed the use of the deep seabed to *res communis*,⁴⁹³ which allowed states to implement a license structure to use the deep seabed for mineral mining through a policy gap on ownership similar to what is seen now with the OST and Space Act.⁴⁹⁴ This license protected surveying for 10 years and then exploitation for 20 years after that. The United States of America

⁴⁸⁵ (Shackelford, 2009) p 128

⁴⁸⁶ (Shackelford, 2009) p 130

⁴⁸⁷ (Wright, 1974) p 16-17

⁴⁸⁸ (Soucek & Brunner, *Outer Space in Society, Politics, and Law*, 2011) p 696-698

⁴⁸⁹ (Lee, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, 2012) p213-215

⁴⁹⁰ (Lee, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, 2012) p213-215

⁴⁹¹ (Groves, 2012)

⁴⁹² (Shackelford, 2009) p 139

⁴⁹³ (Soucek & Brunner, *Outer Space in Society, Politics, and Law*, 2011) p 283

⁴⁹⁴ (Soucek & Brunner, *Outer Space in Society, Politics, and Law*, 2011) p 248-249

issued four licenses to potential miners for a ten year exploration and twenty year exploitation within the Clarion-Clipperton Zone (CCZ), and other nations recognized these claims and made their own through a series of independent treaties.⁴⁹⁵ By 1994, at the drafting of UNCLOS IV and Part XI, the deep seabed was reclassified to the CHM and control was placed in a central coordinating authority, the International Seabed Authority (ISA), in charge of all mineral activities to coordinate resource use, freely share the resources, and protect the environment.⁴⁹⁶ Ultimately, “These limits are designed to protect developing land-based producer countries against overabundant world mineral suppliers which would reduce price and result in lower export earnings”⁴⁹⁷ Under the Part XI policy regime, ISA took control from independent states and licensed miners, and was to control all claims, most notably redistributing wealth gained through deep seabed mineral mining activities to all nations participating in the ISA (including mineral resources and the \$500,000 fee for a mining license).⁴⁹⁸ In protest, two of the four original American miners withdrew their claims before the United States of America considered recognizing Part XI (which it never has) because of the threat to redistribute the wealth that they had exploited and technology they had developed.⁴⁹⁹ Functionally, the application of CHM here did prevent exclusivity from mining the seabed among agents participating in the International Seabed Authority (save for the United States of America which still recognizes two deep seabed miners and has not accepted UNCLOS IV Part XI in order to protect their activities)⁵⁰⁰ but caused much interference to mining operations, increasing the already high risk of their activities.⁵⁰¹ The potential economic elements of mining the deep seabed, from investing in technology development to developing infrastructure,

⁴⁹⁵ (Fouquet, 2014) p 95-96

⁴⁹⁶ (Groves, 2012)

⁴⁹⁷ (Ramakrishna, 1990) p 440

⁴⁹⁸ (Fouquet, 2014) p 99-100

⁴⁹⁹ (Groves, 2012)

⁵⁰⁰ (Groves, 2012)

⁵⁰¹ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 197-198

has prevented the complete acceptance of the UNCLOS IV treaties for sharing the deep seabed.⁵⁰² The industrial viewpoint is to protect the maximum freedom to exploit while also maintain the environment and preventing interference among private agents.⁵⁰³ Functionally, the changes demonstrated that the CHM has no capacity to encourage economic development or prevent interference, leaving the deep seabed in a very undesirable state.

Interestingly, the current use of the CHM in controlling the space resource and regions only applies to national agents, and not private agents.⁵⁰⁴ The actions of nations are heavily controlled due to the potential of militarization in space, but at the time of the drafting the OST, there was no recognition of the private agent participating in space flight.⁵⁰⁵ With no policy regime in place, space was generally considered to be *res communis* and as the number of vehicles and nations participating grew, coordination programs and regimes took over, such as the ITU's licensing and coordination scheme or Committee on Space Research (COSPAR) and National Space Science Data Center.⁵⁰⁶ The passing of the SPACE Act formally recognized this policy gap and provided a way to prevent interference without modifying the *res communis* nature of private space resource activities.⁵⁰⁷

CHM does succeed in preventing exclusivity, but fails terribly in protecting mineral exploiters from interference, who are already dealing with the risks of mining, and simply adding more risk in the name of mankind's development. Ultimately, one could only expect that the Outer Space Treaty's (OST) application of the CHM will be replaced as CHM provides no economic incentive to utilize new resource stocks if these resources will be redistributed equally at price (or

⁵⁰² (Ramakrishna, 1990) p 438

⁵⁰³ (Ramakrishna, 1990) p 438

⁵⁰⁴ (International Institute of Space Law)

⁵⁰⁵ (Pop, Appropriation in outer space: the relationship between land ownership and sovereignty on the celestial bodies, 2000)

⁵⁰⁶ (Bell, 2016)

⁵⁰⁷ (United States Congress)

through the paying of a general fee to participate in the ISA) to all of mankind and the profit will be undercut.⁵⁰⁸ Economic and social pressures have already been applied, and the passing of the SPACE Act represents the first of probably many changes.⁵⁰⁹ The International Institute of Space Law and a variety of other space policy and space law groups argue that the SPACE Act and others can function in the same regime of OST⁵¹⁰ and the CHM and that only national ownership is truly forbidden currently.⁵¹¹

6.2 RES COMMUNIS POLICIES ARE ALSO INSUFFICIENT

Res communis is a way to make a region of land “immune from appropriation by any state, but open to the use of all states on a ‘first come, first serve basis.’”⁵¹² *Res communis* was seen with early unmanaged lands, where anyone could use any resource derived from the use of that region. The general mentality of a *res communis* policy regime is to promote the exploitation and use of a resource that is commonly shared, difficult ways to divide the resource, or previously unowned.⁵¹³ *Res communis* is used to describe the use of open fields, the open sea before the rise of Convention on the Law of the Sea, and the Antarctic before the Antarctic Treaty System. Any person could own and come to possess resources as they saw fit, and no further guidance, coordination, or deeds could be created to control access to these Commons

Functionally, *res communis* ownership policies lack protections to prevent high degrees of exclusive ownership, lack methods to prevent the interference between agents doing space resources activities, and establish a strong potential for the overuse and interference of the exploitation of mineral resources as there are no limits to use, in a typical Tragedy of the Commons

⁵⁰⁸ (Endsor, 2014)

⁵⁰⁹ (Tronchetti, The Space Resource Exploration and Utilization Act: A move forward or a step back?, 2015) p 3-4

⁵¹⁰ (International Institute of Space Law)

⁵¹¹ (United Nations Office of Outer Space Affairs, 2016)

⁵¹² (Joyner, 1992) p 90

⁵¹³ (Shackelford, 2009) p107-108

fashion.⁵¹⁴ Fundamentally, the *res communis* policies proposed by a variety of space mineral resource miners make it highly valuable for them to mine now, but takes away from others in the future.

Res communis policies are placed on any unowned land where all agents are roughly equal in stature or exploitation power and there is a common interest in the use of the resource.⁵¹⁵ *Res communis* has been seen in a variety of frameworks from early gold mining⁵¹⁶ or use of orbital space for satellites.⁵¹⁷ Prior appropriation typically takes a primary role in determining who can use what resource and when,⁵¹⁸ and over time, *res communis* policies adapt and modify to meet the needs of the policy, economic, and social environment. ⁵¹⁹ Ultimately a resource is open to first come and first use basis.⁵²⁰

Res communis policies are typically overwritten quickly, due to the potential of creating a Tragedy of the Commons situation, where first agents acting through prior appropriation can exploit and utilize an entire resource stock quicker than it can be replenished or recovered.⁵²¹ Today, no resources are truly *res communis*, as policy and coordination is put into effect to prevent over use or exclusivity. The Preemption Act recognized the prior appropriation⁵²² of the unowned lands of the West and allowed these individuals to own their squatted land before it was opened up through the Homestead Act preventing further interference between land claims.⁵²³ Gold miners in America valued the concept of a mining claim and license to prevent another miner from taking all

⁵¹⁴ (Andrews, et al., 2015)

⁵¹⁵ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012)p 218

⁵¹⁶ (Laver, 1986) p 359

⁵¹⁷ (Shackelford, 2009) p 108-109

⁵¹⁸ (Laver, 1986) p 360-361

⁵¹⁹ (Shackelford, 2009) p 109-110

⁵²⁰ (Ryan, Treating the Wireless Spectrum as a Natural Resource, 2005)

⁵²¹ (Laver, 1986) p360-361

⁵²² (Lueck, 1995) p 393

⁵²³ (US Department of the Interior-Bureau of Land Management, 2015)

of their gold resources⁵²⁴ before they could mine and with the radio spectrum where two radios operating on the same channel could interfere with each other,⁵²⁵ coordination policies were made to prevent this.⁵²⁶ Satellites colliding with or interfering with each other's operations is actually prohibited by elements of the Outer Space Treaty (Liability Convention) and coordination is done by the International Telecommunications Union to ensure that people have orbital slots that are theirs that they can invest in.⁵²⁷

Additionally, *res communis* policy regimes do not prevent the overuse of resources. For example, *fructus* stocks of reproducing resources have generally been *res communis* in nature,⁵²⁸ such as with the trawling of fish or the use of public lands.⁵²⁹ In these cases, overfishing and overutilization of these resources is very dangerous and possible⁵³⁰ so controls were placed on the use of these stocks as technology capability to exploit to exhaustion became possible.⁵³¹ There might only be a limited number of asteroids right now that are economically beneficial to exploit, and the timescale to cycle through the set of asteroids to a "fresh stock" is measured on the scale of years.⁵³² Consequently, overuse is very possible, as well as over exploitation of various resource stocks, and one can only expect that an ownership policy will be put into place.

As an extension of this, *res communis* policies allow for the possibility of high exclusivity in owning the entirety of a resource stock,⁵³³ as a resource stock cannot be appropriated by any state to coordinate usage, and unilateral exploitation allows a first agent to gain a serious economic

⁵²⁴ (Clay & Wright, 2005)

⁵²⁵ (Soucek & Brunner, *Outer Space in Society, Politics, and Law*, 2011) p 47-49

⁵²⁶ (Ryan, *Treating the Wireless Spectrum as a Natural Resource*, 2005)

⁵²⁷ (Allison, 2014) p 5-7

⁵²⁸ (Black's Law Dictionary)

⁵²⁹ (Laver, 1986) p 362

⁵³⁰ (Applebaum)

⁵³¹ (Pop, *Who Owns the Moon*, 2009) p 96-97

⁵³² (Elvis, 2014)

⁵³³ (Lee, *Law and Regulation of Commercial Mining of Minerals in Outer Space*, 2012) p 218

advantage over others.⁵³⁴ Despite no actor actively owning an asteroid or its constituent components, *res communis* promotes the free and uninhibited use of asteroid material.⁵³⁵ This regime can be initially privately and publically beneficial, such as seen with the exploitation of gold in America,⁵³⁶ but unless a regime is put into place (such as the 1872 Mining Code, which limited and coordinated usage⁵³⁷) this regime often turns into a heavily entrenched total ownership regime, such as with diamond mining.⁵³⁸

Finally, *res communis* policies do not provide frameworks to prevent interference between actors. Because everything is considered free for use, it is intended that agents interfere with each other's resources by using or exploiting resources first.⁵³⁹ In the field of space systems engineering, where there are large timescales for these activities to get to location and return (on the scale of decades), there is a high cost of participation and an even higher cost for failure.⁵⁴⁰ For example, one could use a series of energy intensive maneuvers to access a high value asteroid before another refinery arrives, wasting the time, energy, and funds of another mining agent, potentially losing them upwards of billions of dollars in the launch, coordination, and operations.⁵⁴¹ *Res Communis* interference has not happened often in actual history, as most of the time, policies are put in place beforehand to prevent these potential outcomes, or private ownership laws take precedent.⁵⁴² As seen in the next section, with diamonds, the first few large mines were able to further conglomerate supply⁵⁴³ and demand elements of their market, and create a situation where they own nearly all resources as well as their dissemination of diamonds. Later, they would convert this first come, first

⁵³⁴ (Egede, 2011) p 57

⁵³⁵ (Shackelford, 2009) p 107-108

⁵³⁶ (Rawls & Orsi, 1999)

⁵³⁷ (US Department of the Interior-Bureau of Land Management, 2015)

⁵³⁸ (Maconachie & Binns, 2007)

⁵³⁹ (Lueck, 1995)

⁵⁴⁰ (Sonter M. J., 1997) p 646-647

⁵⁴¹ (Blair, The Role of Near Earth Asteroids in Long Term Platinum Supply, 2000)

⁵⁴² (Laver, 1986) p 370

⁵⁴³ (Lueck, 1995)

serve ownership into a Total Ownership policy regime where their entrenched interests protected and supported.⁵⁴⁴

Currently, private ownership of space resources under the SPACE Act is fundamentally based in *res communis* ownership of resources,⁵⁴⁵ and this current state is highly undesirable due to the lack of interference protections and great opportunity for exclusivity.⁵⁴⁶ The mineral resources of a single asteroid have been promised to bring back enough resources to pay for the development and operation of a space mineral mining business.⁵⁴⁷ However, this requires no limits on ownership or exploitation, which are not favored right now as part of current legislation.⁵⁴⁸ Consistently, *res communis* policies are constantly replaced, and in the few situations where they were not replaced after a short period of time, they developed into very exclusive ownership regimes. *Res communis* does not protect exploiters from interference, does not prevent exclusivity and does not ensure the maximum public and private benefit.

6.3 TOTAL OWNERSHIP POLICIES PROPOSE A FRIGHTENING FUTURE

Total ownership policies, where someone is allowed to own the entirety of a resource stock for an indefinite period of time, usually is a byproduct of *res communis* policies becoming formalized and heavily entrenched to favor a few actors, or as an extension of a single ruler over a region to ensure an ultimate protection from interference.⁵⁴⁹ This would include the permanent owning of land and the resources contained within, and it ultimately generate a great deal of influence and economic pressure to keep it that way.⁵⁵⁰ The land claim is often more economically beneficial to trade rather than exploitation, and development is put off into the far future because

⁵⁴⁴ (Zoellner, 2006) p 105-106

⁵⁴⁵ (International Institute of Space Law)

⁵⁴⁶ (Tronchetti, The Space Resource Exploration and Utilization Act: A move forward or a step back?, 2015)

⁵⁴⁷ (Planetary Resources, 2016)

⁵⁴⁸ (International Institute of Space Law)

⁵⁴⁹ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 261-262

⁵⁵⁰ (Shackelford, 2009) p 122

there is no impetus to exploit the resources contained now, leading to an unexploited resource.⁵⁵¹ As asteroid mineral resource exploiters would argue, total ownership is necessary because they are the tried and true method of mineral resource ownership, but in reality these policies are not seen in many situations in the modern mining landscape.⁵⁵² The potential to own the entirety of asteroid mineral resources that might be in multiples of the mass of the planet Earth would most likely cause exclusive ownership and monopolization of the space resources for an indefinite period of time.⁵⁵³ This would be a highly undesirable state where nearly all of the resource stock available to humanity could be controlled by a small exclusive group.

Total ownership of mineral resources does not happen often, with many preferring licensed based structures to control resource rights. There are some provisions, though highly limited in the 1872 Mining Code⁵⁵⁴ or with diamond mining in South Africa where first actors and their entrenched interests have prevented any limits on their monopolization.⁵⁵⁵ Today, the Diamond Syndicate is the focus of several corporate responsibility studies due to social failures⁵⁵⁶ (wars, systemic oppression, lack of socially valuable infrastructure, paramilitary states) throughout South Africa (their primary mining location), the target of criticism for creating demand through artificial scarcity of their mineral resources,⁵⁵⁷ and generally thought to be the worst possible outcome for a *res communis* policy regime.⁵⁵⁸

⁵⁵¹ (Maconachie & Binns, 2007)

⁵⁵² (Tronchetti, The Space Resource Exploration and Utilization Act: A move forward or a step back?, 2015)

⁵⁵³ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 260

⁵⁵⁴ (US Department of the Interior-Bureau of Land Management, 2015)

⁵⁵⁵ (Maconachie & Binns, 2007)

⁵⁵⁶ (Maconachie & Binns, 2007)

⁵⁵⁷ (Claasen & Roloff, 2011)

⁵⁵⁸ (Lueck, 1995)

6.4 COORDINATING ASTEROID USE THROUGH LICENSES

To manage the use of future space mineral resources, a license structure managed by some form of coordinating entity at the international scale is ideal because it promotes industrial and economic growth, protects investments from interference, prevents exclusivity, and has a long history of success with mineral, *fructus* (biologically reproducing), and telecommunications resources including geostationary orbit, the only precedent for ownership of resources in space. The license structure is a method of managing common spaces that was developed over the past few hundred years as governments took on more of a land management role.⁵⁵⁹ The concept behind licensing took some of the features from the other three major ownership domains, allowing open use, preventing interference, providing a maximum time limit for use, and ultimately encourages economic exploitation of the resource in question, while still managing and protecting the environment.⁵⁶⁰ The general concept behind the license structure is that total ownership is granted for some period of time with general terms and conditions for use, environmental protection and exploitation, with a government acting as a coordinating and oversight body.⁵⁶¹ Licenses can also ensure that interaction between private agents doesn't prevent operations, while also providing legal protections from governmental interference, ultimately leading to controlled *res communis* that also protects just as a total ownership regime would.⁵⁶² This license claim and auctioning process has been widely accepted, and analysis shows that licensing:⁵⁶³

- Extends the usage lifetime of the stock being licensed and rent to use
- Allows for new agents to enter or to disseminate valuable access to resource stocks during the lifetime of a resource

⁵⁵⁹ (Shackelford, 2009) p 113-114

⁵⁶⁰ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 246

⁵⁶¹ (Tronchetti, Fundamentals of Space Law and Policy, 2013) p 22

⁵⁶² (Tronchetti, Fundamentals of Space Law and Policy, 2013) p 37-38

⁵⁶³ (Lueck, 1995) p 429-431

- Mitigates price and ownership issues by insulating the risk and high costs of long term ownership in favor for short term payments for the short term use of the stock
- Allows for economic and social values to change and affect the public/private use of the stock

Ultimately, licensing specifically for space mineral resource mining operations have a long history of being successful, they prevent interference between private agents of the already high risk activity and they also prevent exclusivity of the potential near-infinite wealth of asteroid mineral resources.

6.4.1 History of Success

There has been a long history of using licensing where the usage of a resource stock is metered over time among private agents by some national public program, and in recent history is becoming more popular and more successful in promoting the exploitation of a resource while also preventing interference and exclusivity at the same time. (Table 8: Ownership Policy Effects and History). With mineral resources, mining licenses are a way to provide a legal backing to their claims, and with *fructus* stocks, a way to prevent overuse.

Policy Regime	Resource	Initial State	Ownership Regime	Intent	Outcomes
Mineral Mining	Silver/New World (1500's-1700's)	<i>Res Communis</i> , highly profitable lands controlled by a King	Licensing	Optimize use of public resources (economically)	Acceptance and Growth
	Gold/America (1850's)	<i>Res Communis</i> , highly profitable lands	Licensing	Prevent interference	Acceptance and Growth
	Gold/Australia (1850's)	<i>Res Communis</i> , highly profitable lands	Licensing	Prevent interference, Prevent exclusivity	Disagreements, reversal to pure licensing
	1872 Mining Code (1880's-Today)	<i>Res Communis</i> , highly profitable lands	Licensing	Optimize use of public resources (economically), Prevent exclusivity	Acceptance and Growth
	Deep Seabed UNCLOS III (1980's)	<i>Res Communis</i> , hard to access resource stocks	Licensing	Prevent interference	Acceptance and Growth see below)
	Deep Seabed UNCLOS IV (1990's-Today)	Licensing paradigm reversed to benefit mankind	<i>Common Heritage of Mankind</i>	Optimize use of public resources (economically, access))	Disagreements, unrecognized policy states
	Modern Diamond Mining (1850's-Today)	<i>Res Communis</i> , highly profitable lands	Total Ownership	Prevent interference	Monopolization
	Antarctic Treaty System (1950's)	<i>Res Communis</i> , scientific resources	<i>Common Heritage of Mankind</i>	Optimize use of public resources	Acceptance
Fructus Stocks	Fishing UNCLOS I (1960's)	<i>Res Communis (mare liberum)</i>	<i>Res Communis</i>	Optimize use of public resources (economically)	Acceptance and Growth (see below)
	Fishing UNCLOS III (1980's-Today)	Overfishing and environmental degradation	Licensing	Optimize use of public resources (environmentally), Prevent exclusivity	Acceptance and Growth
Digital/Comm. Resources	Geostationary Orbit (1980's-Today)	<i>Res Communis</i> , hard to access resource stocks	Licensing	Optimize use of public resources, Prevent Interference, Prevent exclusivity	Acceptance and Growth
	Radio Frequency	<i>Res Communis</i>	Licensing	Prevent interference, Prevent exclusivity	Acceptance and Growth
Space Resources	Outer Space Treaty (1967)	<i>Res Communis</i> , hard to access resource stocks	<i>Common Heritage of Mankind</i>	Prevent interference (environmentally, militarily), Prevent exclusivity	Acceptance and Growth, but changing status quo

Table 8: Ownership Policy Effects and History

With early mineral miners, total ownership was heavily favored, but usually was operated through a rudimentary license structure where they were expected to meet specific terms and

provide certain tariffs on their work to maintain their claim on the land.⁵⁶⁴ This precedent was then carried over to the American Gold Rush,⁵⁶⁵ where gold miners and panners valued the ability to keep their land and prevent interference and quickly designed a license regime system to protect their operations.⁵⁶⁶ Their policy mechanisms, where ownership was based on meeting specific terms and not interfering with each other was later put into legal code⁵⁶⁷ and became standard among most western nations, as this method ensured certain protections from other private agents, provided a public legal claim, and ultimately maximized both the public and private utilization of the resource.⁵⁶⁸

Licensing was also developed heavily in the middle of the 20th Century as a way to solve the age old problem of managing the Commons and preventing the Tragedy of the Commons.⁵⁶⁹ *Fructus* stocks, those that replenish themselves such as fish, became less predominant over the course of the 20th Century, leaving only really the fish of the sea and certain land animals still hunted for game.⁵⁷⁰ With rapid technology improvements after World War II, the capability of trawlers to gather more fish grew causing conflicts between nations about overexploitation of fish resources and incursions into national territory.⁵⁷¹ UNCLOS took the original concepts of the freedom of the seas (*mare liberus*, developed by Grotius in the 1400's⁵⁷²) and codified it, with specific protections to use fishing resources.⁵⁷³ Under UNCLOS III, countries developed their own fishing policies to prevent mismanagement, with the American regime focusing on licensing with

⁵⁶⁴ (Brading & Cross, 1972) p 562

⁵⁶⁵ (Clay & Wright, 2005) p 159-160

⁵⁶⁶ (Clay & Wright, 2005) p 165-167

⁵⁶⁷ (US Department of the Interior-Bureau of Land Management, 2015)

⁵⁶⁸ (Lueck, 1995) p 429-431

⁵⁶⁹ (Fouquet, 2014) p 96

⁵⁷⁰ (Fouquet, 2014) p 103-105

⁵⁷¹ (Soucek & Brunner, *Outer Space in Society, Politics, and Law*, 2011) p 251-252

⁵⁷² (Grotius, 1916) *translated text*

⁵⁷³ (Egede, 2011) p 58-59

public feedback and public controls on the amount of fish exploited,⁵⁷⁴ the Canadian regime focusing on total internal management of all fishing duties,⁵⁷⁵ or even a more radical Chinese regime that uses Distant Waters Fishing (DWF) to maintain their supply through coordinating fishing with allies.⁵⁷⁶ All of these license regimes have demonstrated that they can prevent overfishing, encourage economic exploitation, and protect the use of these resources for both current and future use.⁵⁷⁷

Finally, the latter half of the 20th century shows that licensing works incredibly well with not only digital resources, but also provides the only instance of a policy on ownership being instantiated in space by an international body. Licensing is used to help coordinate the use of the Internet Numbers and the machine addresses for every webpage and databases as part of the internet,⁵⁷⁸ as well as ensuring that radio spectrum⁵⁷⁹ is not interfered with for public, private, and individual use.⁵⁷⁹ The ITU manages elements of both of these, but also provides the singular precedent for ownership of space, with the coordination and licensing of geostationary orbits.⁵⁸⁰ The ITU is actually able to own geostationary orbit envelopes and give licenses for use under the premise of providing a public benefit,⁵⁸¹ and their operations have encouraged use of the space while also preventing interference among private agents.⁵⁸²

By putting this policy regime into place, it would not be too far from any precedent already set here on Earth. In fact, that adds to its strength from a historical perspective and supports the adoption of this regime over any other. Adoption would bring the exploitation of space mineral

⁵⁷⁴ (Gallo, 1992) p 194

⁵⁷⁵ (Gallo, 1992) p 207-208

⁵⁷⁶ (Mallory, 2013) p 99

⁵⁷⁷ (Mallory, 2013) p 102-103

⁵⁷⁸ (Mueller, 1999)

⁵⁷⁹ (Allison, 2014) p 14-16

⁵⁸⁰ (Allison, 2014) p 14-17

⁵⁸¹ (Shackelford, 2009) p 149

⁵⁸² (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012) p 162

resources in line with both mineral management and geostationary orbit management and coordination precedents.

6.4.2 Preventing Exclusivity

Through the use of license, the potential for a single or small group of exclusive actors is kept low, as public organizations and private agents can lobby and design license mechanisms to promote large scale involvement, something commonly accepted to be important with these resource utilization policy regimes.⁵⁸³ Unlike Total Ownership and *res communis* policy regimes, there are methods available to policy makers to prevent the total amount of claimed resources as well as ensure that there is free access to resources with respect to the original intentions of the Outer Space Treaty.⁵⁸⁴

Previous ownership license structures were primarily focused on preventing interference, but in the process did prevent exclusivity of ownership by imposing ultimate limits in the space for resource exploitation, the time to do so, or placing terms and conditions that must be met. For example, Spanish silver miners were allowed to maintain their claims as long as they continued to mine and or improve their mines,⁵⁸⁵ while American gold miners maintained their claim as long as they were present on the claim nearly every day⁵⁸⁶ and Australians had to pay heavily for that permission (which was not accepted widely).⁵⁸⁷ The modern mining claim (1872 Mining Act) is based on continual ownership and infrastructure improvement (at least \$100 per year)⁵⁸⁸ and even

⁵⁸³ (Lee, Law and Regulation of Commercial Mining of Minerals in Outer Space, 2012)

⁵⁸⁴ (Endsor, 2014)

⁵⁸⁵ (Brading & Cross, 1972) p 561-563

⁵⁸⁶ (Lueck, 1995) p 393-395

⁵⁸⁷ (Sunter, 2003)

⁵⁸⁸ (US Department of the Interior-Bureau of Land Management, 2015) p 3-5

with *fructus* stocks, coordination of activities prevents overfishing, which could damage the environment and revoke one's ability to fish within that nation's Exclusive Economic Zone.⁵⁸⁹

Licenses for the use of geostationary orbit are on the scale of a few decades based on efficient and equitable use principles,⁵⁹⁰ where after that period, satellites must be moved to a graveyard orbit to open up new space (literally) to avoid collision with newer, better satellites that can more effectively use that orbital slot.⁵⁹¹ Internet assigned numbers and IP addresses are being reissued and coordinated to ensure that new internet users and service providers can participate in the larger framework,⁵⁹² and the temporary nature of domain names allow unused domains that can no longer sustain themselves to be reissued and recycled.⁵⁹³ Radio spectrum is also being reallocated to new users,⁵⁹⁴ especially when technology improvements allow less spectrum to be used for preexisting services (such as the switch from commercial analog to digital television seen in the Americas through 2000's-2010's)⁵⁹⁵ allowing for more agents to use the previously claimed resources.⁵⁹⁶

Preventing exclusivity has always been a very valuable aspect of using space as a resource, and it is a commonly held belief that the free use of space is crucial.⁵⁹⁷ Using a license structure allows time limits to be built into policy to prevent ownership indefinitely. Ownership could pass from agent to agent ensuring constant use, and at the same time encouraging the exploitation and

⁵⁸⁹ (Applebaum)

⁵⁹⁰ (Gorove, 1979)

⁵⁹¹ (Allison, 2014) p 6-8

⁵⁹² (Kleinwachter, 2004) p 235-237

⁵⁹³ (Mueller, 1999)

⁵⁹⁴ (Ryan, Treating the Wireless Spectrum as a Natural Resource, 2005) p 10620

⁵⁹⁵ (Ryan, Wireless Communications and Computing at a Crossroads: New Paradigms and Their Impact on Theories Governing the Public's Right to Spectrum Access, 2005)

⁵⁹⁶ (Ryan, Wireless Communications and Computing at a Crossroads: New Paradigms and Their Impact on Theories Governing the Public's Right to Spectrum Access, 2005) p 243-244

⁵⁹⁷ (Tronchetti, The Space Resource Exploration and Utilization Act: A move forward or a step back?, 2015)

development of infrastructure immediately, rather than putting it off, which is common in situations where the right of ownership is too protective.⁵⁹⁸

Licensing also provides a way to monitor and limit the total number of claims. This would prevent a single individual or agent from claiming the entirety of space resources before a single mission is sent and virtually preventing anyone from using space mineral resource deposits. Nearly all mining claims throughout history have eventually had some ultimate size imposed on them over time to prevent uncontrolled expansion, save for diamond mining which continued to grow with the economic strength of the Diamond Syndicate.⁵⁹⁹ Even with digital resources, the early allocation process of geostationary orbit was filled with actors filing for “paper satellites,” which never occupied the orbit envelope, but their slots could be shared and traded for profit, impeding other’s access to the resource.⁶⁰⁰ Ultimately, fees and safety deposits were imposed to prevent the use of paper satellites, and mining claims tend to allow a single organization to only mine one claim at a time.⁶⁰¹ If those fees are too restrictive and intended to prevent participation, these policies generally are not accepted by the resource exploitation community, as seen by the Eureka Stockade rebellions in protest to high mining fees during the Australian Gold Rush.⁶⁰² Ultimately, in ensuring that space mineral resources are constantly in use, and multiple agents to participate, the licensing structure if executed properly provides all of the protections necessary.

6.4.3 Protection from Interference

Licenses can also provide protection against interference, which can be crippling in light of the already risky nature of mining activities on Earth, let alone in space.⁶⁰³ The ability for a miner to find a resource and then develop technology and infrastructure to exploit those resources without

⁵⁹⁸ (Martin L. , 2004) p 29-33

⁵⁹⁹ (Maconachie & Binns, 2007)

⁶⁰⁰ (Gorove, 1979)

⁶⁰¹ (Allison, 2014) p 39-41

⁶⁰² (Sunter, 2003)

⁶⁰³ (Mann, 2012)

the threat of interference is very important.⁶⁰⁴ The license provides incentive for private agents to invest into their mining claim early to exploit those resources, prevents others from taking away from their investment, and promotes the development of associated infrastructure almost immediately to support the exploitation of a resource while the claim is active.⁶⁰⁵ Applying for and possessing a license to mine and operate a region awards that kind of protection to a potential miner, and they can operate with confidence within that space.⁶⁰⁶

Fundamentally, the concept of a license is temporary ownership given by some larger organization in charge of operating and coordinating the use of a region. In typical mining claims, these licenses are designed with terms and conditions to ensure continual use of the land, steady improvement, infrastructure building, and ultimately economic exploitation.⁶⁰⁷ It is seen with nearly every coordination and ownership policy used for digital/telecommunications resources,⁶⁰⁸ Originally developed as part of early mining claims throughout Europe⁶⁰⁹ which eventually came to the Americas,⁶¹⁰ the concept of preventing interference between two competing mineral miners is simple, and without it, we could see espionage, unallowable usage, and an environment that doesn't support or promote economic encouragement because of the risk of others.⁶¹¹ Gold miners in Australia and America valued the mining claim to prevent interference⁶¹² and diamond miners kept claims separate by thin strips of dirt in between their individual claims, because they wanted to guarantee they received the economic benefit of their investment in mining.⁶¹³ UNCLOS uses licenses to design and designate Exclusive Economic Zones and ensure free use of the sea for

⁶⁰⁴ (Sonter M. , 2006)

⁶⁰⁵ (Martin L. , 2004)

⁶⁰⁶ (Gertsch & Gertsch, 2005)

⁶⁰⁷ (US Department of the Interior-Bureau of Land Management, 2015)

⁶⁰⁸ (Allison, 2014) p 39-41

⁶⁰⁹ (Martin L. , 2004)

⁶¹⁰ (Brading & Cross, 1972)

⁶¹¹ (Clay & Wright, 2005)

⁶¹² (Clay & Wright, 2005)

⁶¹³ (Maconachie & Binns, 2007)

fishers.⁶¹⁴ UNLOS III by allowing the deep seabed to be *res communis* actually ended up allowing individual nations to repeat what they did before, and develop their own independent licensing and claim system that was successfully managed among ten plus western states.⁶¹⁵

As an extension of this, the safety provided by not having to deal with the risks of interference promotes the development of supporting infrastructure and technology development.⁶¹⁶ This could be for transportation infrastructure development,⁶¹⁷ which is sorely needed for asteroid mineral resource mining.⁶¹⁸ Because there wouldn't be direct competition, it would be easier to develop and deploy large scale refinery platforms without the potential to reduce the return on their investments.

6.5 CONCLUSIONS AND FUTURE EVOLUTIONARY PATHWAYS

The *res communis* policies that currently support private exploitation of space mineral resources will undoubtedly not hold, and the extension of the *Common Heritage of Mankind* to private industry has not succeeded before. Left with only a few options, the optimal remaining choice would be to use a license regime to maximize public and private value, protect from interference, prevent exclusive ownership and promote other fringe beneficial programs such as constant usage and infrastructure development.

To provide and produce the licenses for public use, the methodology of the International Telecommunications Union⁶¹⁹ and the precedents set by the United States Mining Codes⁶²⁰ which grew out of a long history of mining management (including the old European codes on usage of the

⁶¹⁴ (Applebaum)

⁶¹⁵ (Groves, 2012)

⁶¹⁶ (Martin L. , 2004)

⁶¹⁷ (Martin L. , 2004)

⁶¹⁸ (Sonter M. , 2006)

⁶¹⁹ (Allison, 2014) p 17-19

⁶²⁰ (US Department of the Interior-Bureau of Land Management, 2015) p 1-2

land guaranteeing a protection from interference) could be combined. To organize claims of mineral resources, there is a long process to ensure that claims are made with the intent to perform mineral exploitation, which includes:⁶²¹

- 1) Discovery of the deposit: Where someone surveying the land or being led by other geological survey data discovers some potential site
- 2) Locating the mining claim: Also known as staking the claim, miners drive posts to indicate their desired ownership and then review previously made claims and other ownership of land in the area.
- 3) Recordation of the mining claims: Analysis of the land and recording the mineral deposit locations to be released to the public as the mining process starts to add to the geological survey data for the region
- 4) Recording the maintenance and performance: Mines need to record the infrastructure developments to the land and the revenue generated once they start mining to show that the land is being used properly and environmental impact is in accordance with local laws.

The completion of these four activities along with ongoing fees (usually on the scale of \$10 to \$100 USD per claim) provides a license to work the land for the resource stock approved for exploitation and can be done within a year.⁶²² Individuals and companies are allowed up to 10 claims without incurring extra fees and oversight but generally, these claims are active as long as the land continues to be worked, infrastructure (more than \$100 USD per claim) is done, and the mines operate profitably without damaging the local environment. Mineral patenting, where someone might be able to own land and has been heavily restricted since 1994 in light of exclusivity

⁶²¹ (US Department of the Interior-Bureau of Land Management, 2015)

⁶²² (US Department of the Interior-Bureau of Land Management, 2015) p 19

concerns, has become possible only if the land is already owned at this point.⁶²³ This system also heavily inspired the Deep Seabed Mineral Resource Act, which granted miners under UNCLOS III licensed use of the deep seabed for mineral utilization and these claims were also recognized and enforced by other participating agents.⁶²⁴

The International Telecommunications Union uses a similar process to manage the use and coordination of geostationary orbit. Orbital slots are highly limited due to the needed orbital parameters to keep a satellite above the surface of the Earth. It takes a lot longer for these processes to go through, usually on the time scale of seven years, but requires coordination, notifications, and more to actually pull off.⁶²⁵ The ITU prioritizes the most efficient use of space, either for profit, or services provided, as well as equitable access for all states.⁶²⁶ Originally, the ITU functioned on a *res communis* basis, which “restricts and sometimes prevents access of certain frequency bands and orbit positions,” created “a relative disadvantage to developing countries,” and allowed for “the submitting of paper satellites that restrict access options.”⁶²⁷ Ultimately, the ITU created a “due diligence” application solution, where a several fees at the \$10,000-\$20,000 range as well as recordation of the country, private operator, spacecraft design, operation intent, delivery window, operational window, and more data detailing the business operations of the proposed satellite needed to happen to progress an application to use an orbital slot.⁶²⁸ When a satellite reaches its operational lifespan (which happens after it runs out of fuel or is no longer able to work) after about 20-25 years, the ITU forces these satellites to move to a graveyard orbit to open up a new slot for further use which is then auctioned.⁶²⁹

⁶²³ (US Department of the Interior-Bureau of Land Management, 2015) p 27

⁶²⁴ (Soucek & Brunner, *Outer Space in Society, Politics, and Law*, 2011) p 283

⁶²⁵ (Allison, 2014) p 19-20

⁶²⁶ (Allison, 2014) p 21-22

⁶²⁷ (Allison, 2014) p 23

⁶²⁸ (Allison, 2014) p 33-37

⁶²⁹ (Allison, 2014) p 38-42

From these two examples, a new license paradigm could be conceived. As stated at the beginning of this chapter, the goal of any ownership policy is to prevent interference for the deployment of time and cost intensive mining platforms, prevent exclusion, and promote economic exploitation and infrastructure development through their protections provided. Using the basis of terrestrial mining codes and the policies of the International Telecommunications Union to manage geostationary orbit, the following license terms are recommended:

- 1) The recordation of a space mineral deposit, most likely done through a surveying process (outlined in Chapter 5 Policy Issue: Surveying)
 - a. The data gathered would include spectral data included with physical assay data
 - b. Demonstration of access and retrieval
- 2) The recordation of the vehicle, company, and mineral or interest at that resource site
- 3) A time-based claim to protect from interference during that time for transit, operation, and return to Earth on the scale of a few decades (30-40) with the opportunity to renew during the coordination process with some terms and conditions to be met
 - a. They use the entirety of the claim period to exploit resources
 - b. They release any scientific or compositional data of great note to the community discovered in the process
 - c. They act to preserve the original space environment, either reconstituting the grains into a new asteroid or not exploiting biologically derived resources
 - d. They develop infrastructure to support more exploitation activities or alternative exploitation pathways for themselves

In the process, the site would be protected for a period of time, and the mineral and scientific resources of the asteroid would be catalogued for the public record (section 1). This policy would provide protection of the activity for a period of time necessary to get to an asteroid site (section 3),

would prevent rapid exclusive ownership by limiting or recognizing the amount of infrastructure being deployed to refine the asteroid and not allowing for more or less infrastructure to be deployed without licensing (Section 2).

Licenses are not totally perfect for this application though. Many would argue that very long term protections must be awarded to protect the sizeable investments of operating in space and that anything besides temporary ownership is acceptable.⁶³⁰ However, these terms and conditions can be extended to allow for the steady development of infrastructure and the deployment of large scale systems⁶³¹ just as they have with the development of deep seabed mineral⁶³² mining programs and the use of mineral resources here on Earth.⁶³³ Additionally, as argued by several policy advisers, the role of licensing inherently prevents companies from making profit rapidly, but in light of the high value of platinum, and the potential for these industries to also control the supply and demand characteristics of their resources, they will not be as beholden to these kinds of pressures as much.⁶³⁴ Finally, the use of licensing does require the development and operation of some kind of policy coordinating group.⁶³⁵ The operations of these groups can be highly contested, especially when limitations are placed on preventing the free access of previously *res communis* resources.⁶³⁶ In light of this, it makes it even more necessary to put these mechanisms in place now. It has been shown that if these policies can naturally grow from a basic starting point, such as with the mining of gold in America using Spanish mining policies as a starting point,⁶³⁷ or with the use of Internet Assigned Numbers,⁶³⁸ these systems can grow and adapt due to the partial impermanence

⁶³⁰ (Gerlach, 2005)

⁶³¹ (Tronchetti, Fundamentals of Space Law and Policy, 2013)

⁶³² (Groves, 2012)

⁶³³ (Gorove, 1979)

⁶³⁴ (Pop, Appropriation in outer space: the relationship between land ownership and sovereignty on the celestial bodies, 2000)

⁶³⁵ (Kleinwachter, 2004)

⁶³⁶ (Mueller, 1999)

⁶³⁷ (Brading & Cross, 1972)

⁶³⁸ (Ryan, Treating the Wireless Spectrum as a Natural Resource, 2005)

of the license.⁶³⁹ As long as these changes fundamentally do not affect the general regime type, incremental changes can be accepted.⁶⁴⁰

In the near future as technology develops, and the ability to own and process new resources grows, coordination policy through the use of licensing asteroids for temporary ownership is necessary to prevent interference while still maintain enough ownership privileges to allow agents to invest in their asteroid claim. Total ownership might be a possibility in the far future, when mining larger asteroids that require larger upfront investments and larger timescales that must be protected from interference, but the technology, funding, and infrastructure is not yet there to support it.

⁶³⁹ (Soucek & Brunner, *Outer Space in Society, Politics, and Law*, 2011)

⁶⁴⁰ (Shackelford, 2009) p 113

7 POLICY ISSUE: INFRASTRUCTURE DEVELOPMENT

Infrastructure development is needed at some point to connect space mineral resources to where they are needed or ensure that there are markets for these resources when the materials arrive, but should not be the focus of policy at this time, despite the arguments of space mineral resource agents and their advocates. Currently, this argument makes sense in light of the early state of technology development as it is a substantial risk for business operations and previously this kind of work has fallen under the realm of infrastructure development policy on Earth. However, asking national or international governments to develop this transportation infrastructure (compared to laying railroad tracks and telephone lines to support other mining efforts) or developing markets for the asteroid derived resources, is not a reasonable expectation at the current time and at the current level of risk. Despite the promises of public and private good, there are too many uncertainties to substantiate this claim, as well as potential conflicts with the Outer Space Treaty (OST), and it requires further development by private individuals to determine the best business operations for later support.

7.1 THE PURPOSE OF SPACE MINING INFRASTRUCTURE

Infrastructure can be described as major technical or organizational structures that facilitate the development of industries and other systems. There are two major needs argued for infrastructure development; developing the transportation infrastructure to connect Earth-space and space-space markets and creating a market for asteroid-derived resources.⁶⁴¹ Both are labeled infrastructure, as they are mechanisms and processes that operate concurrently to a mineral mining operation not directly developing value, but serve a public good and increase the

⁶⁴¹ (Lewis, Asteroid Mining 101, 2014) p 131-133

capabilities of interconnected private systems that use that infrastructure for economic growth. Broadly put, Sonter outlined the two major needs of space mineral resource mining architecture; Characteristic I, a known market for the resources, and Characteristic V focusing on a resource return architecture.⁶⁴²

As it stands right now, the materials gathered from asteroids, refined to constituent minerals and resources, and brought back to Earth will simply float in the sky, staying where they were left based on the current technological state. In order to make a profit, they actually need to be brought to the place where there is demand for them and that could be on the surface of the Earth or at some kind of orbital depot and factory.⁶⁴³ At the same time, there is no available data on the demand for asteroid derived space mineral resources on the surface or in orbit. If anything, there might be a demand for water, which is flown on every resupply mission (300 kg on the last Progress resupply to the International Space Station at \$10,000 USD/kilogram leading to a cost of \$3 million USD every few months⁶⁴⁴), but there are many unknowns that are plaguing the backend of business plans of space mineral resource exploiters regardless of the timescale.⁶⁴⁵

Infrastructure systems are a focus of the current National Space Policy, where developments in securing space access and transportation are mandated.⁶⁴⁶ Infrastructure development for transportation has been a common piece of proposed policies for asteroid mining success, including, but not limited to having private companies only receive ownership after they develop a human transportation infrastructure,⁶⁴⁷ having an asteroid mining bank develop the infrastructure,⁶⁴⁸ or directing a heavily modified NASA to develop the infrastructure for Earth-

⁶⁴² (Sonter M. J., 1997) p 638

⁶⁴³ (Blair, The Role of Near Earth Asteroids in Long Term Platinum Supply, 2000)

⁶⁴⁴ (National Space Society)

⁶⁴⁵ (Coffee, 2002)

⁶⁴⁶ (National Space Policy of the United States of America, 2010)

⁶⁴⁷ (Simberg, 2012)

⁶⁴⁸ (Beldavs, 2013)

Space interconnects.⁶⁴⁹ Transportation is needed that is cheap, designed to carry high mass and protects the mass of mineral resources all the way back down to the surface, or potentially allows for the docking and physical transfer in space.

To illustrate the current transportation issues, very few vehicles can bring back the most precious resource, platinum, at a large scale economically. A SpaceX Dragon cargo variant, one of the more inexpensive vehicles to launch and then potentially reuse, can be launched for approximately \$60 million USD (though reusability might be able to reduce future costs to \$20 million USD) and return 2.5 metric tons of cargo in its 10 cubic meter berth to the surface.⁶⁵⁰ This limitation is based on the mass of the vehicle to decelerate using the atmosphere and the Thermal Protection System's (TPS) ability to deal with the total heating loads and the maximum heating rate from deceleration and re-entry. Adding more payload (mineral or resource) mass is not possible without altering the amount of the vehicle that is expendable TPS, forcing a redesign of the entire vehicle and potential reselection of the booster stage and rocket. If 2.5 metric tons of platinum were returned to LEO by a tug ship coming from an asteroid refinery, and docked with the Dragon cargo capsule in LEO, 120 liters of platinum (about 1/100th of the usable internal volume of the Dragon) could be returned,⁶⁵¹ netting approximately \$80 million USD at current rates (approximately \$32,000 USD/kilogram).⁶⁵² This would yield only \$20 million USD in net profits (assuming the \$60 million USD launch price), disregarding the launches and costs for the vehicle to return the material to LEO, the refinery to refine pure platinum out of the surface of the asteroid, the surveying and assay costs, and the mission operations to run and organize everything. Now, in all seriousness, the Dragon was intended for lightweight cargo and eventually people, but it shows that current vehicles are not designed for returning large amounts of highly profitable materials to Earth cheaply. Some

⁶⁴⁹ (Abundant Planet, 2009)

⁶⁵⁰ (National Space Society, 2011)

⁶⁵¹ (National Space Society, 2011)

⁶⁵² (United States Geological Service, 2014)

sample return missions have been designed and flown, with varying amounts of success, but these are all one-off scientific missions and not an economic industry.⁶⁵³ Developing this new infrastructure which would require designing new technology, coordinating activities in space, and operating landing locations while gathering the required licenses, clearances and more to do so is a business in and of itself, or usually headed up by some coordination body. Not knowing how to get resources back down to the surface or even connecting it to other space systems is as much as a problem as getting off the launch-pad.⁶⁵⁴

Compounding the uncertainty in developing the space mineral mining business plan is the unknown demand on the surface or in Low Earth Orbit for the materials derived from asteroids. Cheap platinum, rare-Earths, and radioactive materials have never been an option on the surface of the planet, and there are unknown effects on global commodity markets if suddenly these valuable minerals were to become suddenly very cheap.⁶⁵⁵ Would prices remain high as demand for super-high tech innovations come into being as the supply of platinum increased, or would prices respond in the same way as when the Hall-Heroult process increased the total supply of aluminum and caused plummeting prices? Some argue that it would herald the future of materials science, with platinum finding a use in jet engines and fuel cells to solve our energy problems,⁶⁵⁶ but these claims are speculative at best and based on projections of current usage regimes.⁶⁵⁷

Additionally, there is very little knowledge about the demand for various resources in an in-space market as well. Consistently, water has been on every cargo flight going to the space station, as it is very useful for spaceflight and crewed exploration, but there is no knowledge about whether or not it would be more economical to harvest water and bring it right to the International Space

⁶⁵³ (NASA Goddard Spaceflight Center, 2016)

⁶⁵⁴ (Sonter M. , 2006)

⁶⁵⁵ (Simberg, 2012)

⁶⁵⁶ (Msimang & Makhuvela, 2014)

⁶⁵⁷ (Blair, The Role of Near Earth Asteroids in Long Term Platinum Supply, 2000)

Station after it has been filtered and purified.⁶⁵⁸ The use of and demand for space minerals in situ to build and fabricate new vehicles is also unknown, as that technology is slowly coming into being so business plans are hard to write,⁶⁵⁹ with most development now focusing on early technology innovations.

7.2 CALLS FOR GOVERNMENT TRANSPORTATION INFRASTRUCTURE ARE UNSUBSTANTIATED

Transportation architecture is severely lacking at the current point and does not satisfy the need of the community to have a reliable way to transport asteroid-derived resources from orbit to Earth's surface or between space-faring entities. However, the issues of infrastructure development are more aligned with general applied research goals than with national infrastructure policies, and would be more privately and publically beneficial to be implemented by private industry. Additionally, infrastructure typically comes after private industries take the first risks, and not before. Ultimately, the arguments to develop infrastructure before this system is possible comes off more as a way to offset the technology and development costs for a critical part of the business plan.

National space policy does call for the creation of infrastructure development, but it focuses primarily on the development of launch systems, tracking, and communication.⁶⁶⁰ This is generally seen as development in launch pads and radio dishes, whereas the development of commercial crew and cargo systems has been handed off nearly entirely to commercial and private organizations doing private and applied research through a variety of hybrid research policies. The development of the basic systems of spaceflight was under the purview of national programs, when

⁶⁵⁸ (Ross, 2001)

⁶⁵⁹ Planetary Resources just demonstrated additive manufacturing through material deposition using asteroidal material reclaimed from a meteorite fall (Planetary, 2016)

⁶⁶⁰ (National Space Policy of the United States of America, 2010)

there were high risks, but also high potential good to be had for science, industry, and defense.⁶⁶¹

The type of transportation architecture being asked for in many proposals to support space mineral resource exploitation is more along the lines of developing new vehicles to meet specific private needs, which should be handled by a hybrid public and private applied research policy in the near future.

As to the second goal to develop infrastructure to allow space systems to grow, there is simply nothing to grow at the moment. It is easy to draw the parallels between roads and railways to launch pads and rockets, but fundamentally, the costs, risks, policies, and engineering requirements of the two are fundamentally different. History has shown that infrastructure development typically comes after the business and industrial interests have demonstrated profitability in the public and private sphere. Silver miners used boats and shipping lanes that were developed with the profitability of the mines.⁶⁶² Gold mining happened first followed by infrastructure development to support them.⁶⁶³ Telecommunications resources and their infrastructure was a response to the growth of the fields and after the demonstration of their usability and public and private benefit.⁶⁶⁴ To develop infrastructure to reduce the risk of a venture right now would be tantamount to automatically assuming that a program will be highly beneficial to both public and private sectors and it will succeed. However, in all of these cases there was a clear and demonstrated public and private benefit to establishing infrastructure, and that development came after the mining activity was underway.

Infrastructure development primarily reacts to a growth of public or private good that could be enhanced by the development of infrastructure. Those supporting space mineral resource activities argue that their services would provide a great deal of public benefit through cheaper

⁶⁶¹ (Neal & Smith, 2008) p 136

⁶⁶² (Flynn & Giraldez, Born with a Silver Spoon: The Origin of World Trade of 1571)

⁶⁶³ (Abundant Planet, 2009)

⁶⁶⁴ (Kleinwachter, 2004)

materials and reduction of resource scarcity,⁶⁶⁵ while they also argue for private benefit under the “Trillions Await” motto referring to the mineral riches of asteroids.⁶⁶⁶ Driving this argument is also the assertion that infrastructure development and vehicle design would be cheaper for governments to undertake publically, which is in direct conflict with the experiences seen in chapter four. There are no grounds to support any of these assumptions yet, and no clear benefit to be gained publically (usually a driving factor in infrastructure development) from the exploitation of space mineral resources.

This work on developing a transportation infrastructure is necessary applied research, and should be handled by increasingly private interests as asteroid mining comes into being, but at the current time, the lack of understanding or valuation of the public and private benefits to develop this infrastructure, and with the current high risks of developing another suite of spacecraft to fulfil a specific private need, is not appropriate for a government policy to handle. It is an understandable response to hand off the risks of technology development to someone else, but the risks involved are not appropriate for government to undertake.

7.3 MARKET CREATION AND SUBSIDIES POSE DANGEROUS OST RISKS

With platinum and other minerals, there are many unknowns about demand and valuation that interfere with business prospects and the creation of governmental based markets for these resources is not the way to solve this issue. Most importantly, there might actually be direct conflicts with the current policy of the Outer Space Treaty if nations were to get involved in the

⁶⁶⁵ (Lewis, Mining the Sky, 1997)

⁶⁶⁶ (Planetary Resources, July)

brokering and management of space mineral resources exploited by private agents.⁶⁶⁷ This would constitute ownership and appropriation of these resources, which is expressly forbidden.⁶⁶⁸

Disregarding issues with the OST and their conflicts with national ownership of space resources, financing these projects is very dangerous and creating potential markets for development even more so.⁶⁶⁹ Gold wasn't mined because it was there; it was mined because it was found in large supply, unowned, and profitable. Silver was mandated by Spain looking to strengthen its mints and there has always been a demand for *fructus* stocks like fish and agriculture because people need to eat.⁶⁷⁰

The volatility seen within the previous years with platinum prices fluctuating from \$70,000 USD/kilogram to now \$30,000 USD/kilogram further erode the confidence in platinum as a good commodity for government to invest in (using the SpaceX Dragon platinum return example above, the profitability could be anywhere from \$15 million USD to \$115 million USD using these prices).⁶⁷¹ Trying to control and manage these spaces mineral resources, if it is allowable under OST, might not help the price volatility either. Governmental controls are partially responsible for the prices of platinum to fluctuate between \$70,000 USD/kg (2014) and \$30,000 USD/kg between 2008 and 2010 as Chinese⁶⁷² and South African⁶⁷³ mining depots turned on and off in response to demand.

Planetary Resources is specifically targeting asteroids containing \$20-\$50 billion USD in modern terms (with no analysis of the effects of returning these materials into a commodity market

⁶⁶⁷ (United Nations Office of Outer Space Affairs, 2016)

⁶⁶⁸ (International Institute of Space Law)

⁶⁶⁹ (Adams, 2012)

⁶⁷⁰ (Walker, Breaking the Rare-Earth Monopoly, 2010)

⁶⁷¹ (United States Geological Service, 2014)

⁶⁷² (Park, Hu, Gao, Campbell, & Gong, 2012)

⁶⁷³ (Coffee, 2002)

supply) at 30 meters in size.⁶⁷⁴ Bringing back large amounts of platinum in the near future might disrupt the supply and demand curves, but potentially internal market policies might be better suited for the management of demand and resource supply.⁶⁷⁵ Essentially, these private agents would need to manage and determine how to operate their markets at maximum efficiency for greatest profit and not rely on governmental control of markets to make their business stay afloat. This course of action is usually withheld for organizations that have demonstrated providing a substantial public and private good, such as natural monopolies or defense programs, and asteroid mining programs and businesses have not reached that level yet.

7.4 CONCLUSIONS AND FUTURE EVOLUTIONARY PATHWAYS

At this point, there are a large variety of risks that space mineral exploiters are advocating that national policies deal with by developing transportation and market infrastructure. The costs of implementation, coupled with price volatility of these resources make developing markets to support asteroid miners difficult as well as potentially create issues with the OST. Additionally, the development of Earth-space and space-space interconnects through policy charges disregard the fact these are large risks and technological risks that should be shared by private and public industries and that transportation comes after profitability demonstration. Ultimately, it is recommended that in the near future, after some of the initial expeditions demonstrate space mineral resource mining to be an economic success, that policy is drafted to potentially help with the cost reductions through infrastructure development to harness that economic and social good that comes with asteroid resource mining under an applied technology research regime. However, at this point, it is premature to recommend these policies.

⁶⁷⁴ (Endsor, 2014)

⁶⁷⁵ (Global Economic Prospects, 2013)

8 CONCLUSIONS

Ultimately, as evidenced through this thesis, space mineral resource exploitation has the potential to alter how humanity acquires key minerals and other resources, but requires certain policy considerations to be made in advance to ensure that is as economically and socially valuable as possible. By looking through the annals of history, much can be learned about what policies promote exploitation, surveying, and technology development while also encouraging responsible and sustainable resource use. There is little past history to draw on that mimics the potential of a space mineral resource mining environment exactly, but a lot of parallels can be drawn.

Looking into these historical examples, there are a few clear policy stances that should be made at the current time to potentially sustain the future development of space mineral resources. For the development of technology, the current state of technology development should support the current basic and use-inspired cases that are required to further develop the field. Fully procurement-based strategies, where the basic research is acquired by a sponsor nation could be problematic in light of the Outer Space Treaty's requirements on national appropriation. Methods that support the later applied research, such as subsidies and incentives are also heavily discouraged, as they assume a benefit to the space mineral resource mining act not yet found. Methods that support the early stages of development, such as Intellectual Property (IP) right protections and the use of prizes and contests, where the development of common technologies between asteroid miners and space explorers could be shared and developed in conjunction are the most ideal technology support that can be provided.

Surveying has been a fundamental element of the traditional mining process and with space mineral resource mining; it still needs to be considered, despite the influence of the public surveying process weakening this tradition of mining. In light of the public value of detecting

asteroids, space mineral mining companies could be included in this system and receive funding for their surveying activities and potentially technology development that could better the public service of Near Earth Asteroid detection. The work that they do in characterizing the content of asteroids, through spectroscopy and physical assay, which is mandated to be part of the ownership process, can be kept privately as a form of intellectual property, providing another economic reason to do the activity and making it fundamentally part of the international community of asteroid identification.

Ownership policies currently are not satisfactory in preventing harmful interference between competing agents, and lead to a potential of total ownership which is not desirable as well because of the negative social and economic impacts of exclusivity. For this, a license structure is recommended with long term protections to support industrial growth and infrastructure development as well as preventing exclusivity through the use of terms, conditions, and temporary nature. There is also a long history of licenses being successfully employed in several different ownership regimes, including the development of mineral resource on the Earth's surface, the management of fishing stocks, and the management of telecommunications resources such as internet protocol addresses and the radio spectrum. Licensing is also the only and most successful ownership regime for the coordination of space resources, namely geostationary orbit.

Finally, the call for government mandated infrastructure development and market creation falls totally under the realm of applied research, and consequently, in light of the unknown public and private benefits of space mineral mining activities, to provide large scale tax incentives or have governments get involved in the use and appropriation of space mineral resources (which is partially forbidden by the Outer Space Treaty) is far too risky. These organizations should continue to develop technologies and systems. Once the benefits are beginning to be actualized, then they can request this kind of assistance.

Ultimately, this is an exciting time to be involved with the development of a brand new industry, and the potential to change the basic functions and methods of resource utilization here on Earth. Being able to “live off the land” in nearly any place is a necessary step in colonization and expansion, and space might be the next frontier of migration. There has been a steady movement towards this point and the first policies have been written. To continue an economically and socially valuable development of the space mineral mining field, policy written now must think of the future and learn from the past.

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