THE COMMERCIALIZATION OF SPACE RESOURCES: FINANCING THE NEXT WAVE OF INVESTMENT IN SPACE RESOURCES

by

Adam A. Janikowski

A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Doctor of Philosophy (Space Resources).

Golden, Colorado

Date _____

Signed: _____

Adam A. Janikowski

Signed: _____

Dr. Ian Lange
Thesis Advisor

Golden, Colorado

Date _____

Signed: _____

Dr. Angel Abbud-Madrid
Program Director, Space Resources

ABSTRACT

The opportunity and potential in developing space resources is enormous, with estimates for a medium-term space resources economy in the trillions of dollars. Even now, the world is seeing a dramatic increase in the number of private companies focused on the exploitation of space resources, a trend that will only increase.

This dissertation attempts to bring academic vigor to the study of the financing of space resources, specifically researching the current status of space resources, the financial impact of domestic space resources legislation, and the issue of establishing a multilateral development bank focused on developing space resources.

The findings in these studies indicate that the financing of space resources is a complex and multifaceted issue that demands innovative approaches and collaborations between various stakeholders, including international cooperation. However, given the right approach to innovation and to funding, space resources can be harnessed for the benefit of humanity, ensuring a sustainable and prosperous future for generations to come.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

African Development Bank	AfDB
Asian Development Bank	AsDB
Asian Infrastructure Investment Bank	AIIB
China Great Wall Industry Corporation	CGWIC
China Aerospace Science and Technology Corporation	CASC
Commercial Lunar Payload Services	CLPS
Commercial Space Launch Competitiveness Act	CLCSA
European Bank of Reconstruction and Development	EBRD
European Investment Bank	EIB
European Space Agency	ESA
European Space Resources Innovation Centre	ESRIC
Geosynchronous Earth Orbit	GEO
Gross Domestic Product	GDP
International Futures Program	IFP
Institute for Defense Analyses	IDA
Institutional Review Board	IRB
In-Situ Resource Utilization	ISRU
Inter-American Development Bank	IDB
International Advisory Panel	IAP
International Finance Corporation	IFC
International Space Development Bank	ISDB
Japan Aerospace Exploration Agency	JAXA
Launch Services Program	LSP
Low Earth Orbit	LEO
Luxembourg Space Agency	LSA
Multilateral development banks	MDBs
Organisation for Economic Co-operation and Development	OECD
Purchasing power parity	PPP
Sectoral Adjustment Loans	SECALs
Securities and Exchange Commission	SEC

Science, Technology, Engineering, Mathematics	STEM
Structural Adjustment Loans	SALs
United Nations	UN
United Nations Committee on the Peaceful Uses of Outer Space	UNCOPUOS
United Nations Office for Outer Space Affairs	UNOOSA
United Arab Emirates	UAE

ACKNOWLEDGMENTS

I would like to thank and acknowledge Dr. Ian Lange, for advising me on this thesis, Edwin Janzen for helping edit my research and Blaine Curcio for providing valuable insights on China's involvement in the space resources industry.

CHAPTER 1
INTRODUCTION

The exploration and utilization of space resources have long been topics of fascination and scientific curiosity. Significant attention is increasingly being directed toward the space resources industry, which people are calling the next frontier for mineral exploration. This dissertation aims to provide an analysis of the funding aspects of the space resources industry, focusing on the state of funding for the sector as well as the challenges and opportunities faced by stakeholders.

The opportunity and potential in developing space resources is enormous, with estimates for a medium-term space resources economy in the trillions of dollars. Even now, the world is seeing a dramatic increase in the number of private companies focused on the exploitation of space resources, a trend that will only increase.

Despite this considerable economic opportunity, most academic papers address the current space resources industry on the basis of a specific domain (technical innovation, infrastructure needs, etc.) or of the legal ramifications and considerations of space resource laws vis-à-vis international treaties. However, little academic research currently addresses the funding aspect of the new space economy, even as we are seeing the inevitable transition of a maturing industry from substantial public funding for space to private funding. Given the significant amounts of capital that will be required to develop the space resources industry, this dissertation seeks to begin to examine the various aspects of space resources industry funding.

This dissertation aims to make significant contributions to both academia and industry. By providing a comprehensive analysis of the funding aspects of the space resources industry, it will enhance understanding of current practices, as well as the challenges and potential rewards for the stakeholders involved. It is hoped that the findings of this research will also guide policymakers, investors, and industry players in formulating strategies and policies to foster the industry's growth and sustainability. Each of the three chapters in this dissertation was written as a standalone paper to be submitted for publication in a relevant peer reviewed journal. As such, the research contained in these three chapters consists of:

- A qualitative analysis of a broad set of interviews with individuals representing different aspects of the space resources funding ecosystem (including entrepreneurs, corporate employees, brokers, academics, government and agency personnel, investors, and advisors) aimed at examining and reporting on the current state of funding for the space resources

sector, including identification of key partners and an examination of current regulation and legislation;

- A quantitative analysis that examines the enactment, in various countries, of space resources legislation and its impact upon investment in those countries' domestic commercial space sectors; and
- A policy analysis examining terrestrial multilateral development banks and assessing the suitability of, and proposing a structure for, a multilateral development bank focused on the space resources sector.

As research for this dissertation progressed, it became apparent that even among professionals who are active in the space resources sector, there exists a lack of a coherent definition of space resources. This absence of a basic definition presents a potential barrier to investment by the wider private sector, as non-industry professionals are very likely to be deterred by uncertainty and a lack of clarity as to what the sector actually represents.

To that end, it is important when considering this research that the reader has a basic framework for understanding what space resources are. As mentioned above, each chapter was written as a standalone research effort, to fit into a wider "story arc"; as such, it was necessary to define space resources in each chapter for those readers who were not reading the dissertation in its entirety.

In United States law, space resources are defined as "any tangible or intangible benefit which can be realized only from (A) aeronautical and space activities; or (B) advancements in any field related to space," [3] and are often cited as a crucial component in current plans to develop a new space economy and unlock the commercial potential of space. Additionally, the U.S. Commercial Space Launch Competitiveness Act of 2015 defines a space resource as "an abiotic resource in situ in outer space"; while the "Building Blocks" adopted by the Hague International Space Resources Governance Working Group define it as "an extractable and/or recoverable abiotic resource in situ in outer Space" that includes mineral and volatile materials, including water, but excludes a) satellite orbits; b) the radio spectrum; and c) energy from the Sun, except when collected from unique and scarce locations.

To help the reader situate and understand the context for this dissertation, the author defines a space resource as a material or commodity located in space that is exploitable and has a value to humankind.

It is also important to note that this research focuses primarily on the funding aspects of the space resources sector, examining the opportunities and challenges it presents. However, it is equally important to acknowledge that the space resources industry is evolving rapidly, with new developments emerging

during the course of this research or shortly thereafter. Therefore, the reader should consider the findings and recommendations in this dissertation in the context of the industry's dynamic nature.

This dissertation delves into various aspects of funding for the space resources industry, with the aim of providing an analysis of the industry as well as of the opportunities and challenges faced by stakeholders. By exploring the industry's financial ecosystem, it is hoped that this research may contribute to a broader understanding of space resources and to the development of sustainable financing mechanisms to support the industry and help realize its ambitious space exploration and utilization goals.

CHAPTER 2

THE STATE OF FUNDING OF THE SPACE RESOURCE SECTOR

A COMPOSITE VIEW OF SPACE RESOURCES FUNDING FROM MARKET RESPONDENTS

Published in NewSpace

2.1 Abstract

Given the significant volume of capital that will be required to develop the space resources industry, it is important to understand the fundamentals and drivers of funding in this growing industry. This paper distills a series of 30 interviews with individuals representing different aspects of the space resources funding ecosystem—including entrepreneurs, corporate employees, brokers, academics, government and agency personnel, investors, and advisors—to examine and report on the current state of space resources sector funding, including identifying key partners and examining current regulation and legislation. The results of this research are intended to be used as a lens through which to understand the current state of funding within the space resources sector and to help observers interpret certain actions on the parts of individuals and companies operating in the industry.

2.1 Introduction

Outer space, with its many unique features, serves as an ideal incubator for the development of diversified commercial activities such as space launching, space tourism, remote sensing, telecommunications, small satellites and, importantly, space mining and the development of space resources [1], whether it be on asteroids or the surface of the Moon.

Furthermore, resources from the Moon, Mars, and certain asteroids have been proposed for use in human space exploration to produce propellants, water for life support, structural materials, and radiation and heat shielding [2]. These asteroids in particular present the possibility of a vast source of minerals, free from environmental or land use restrictions. A dream of science fiction for decades, recent developments in the areas of robotics, autonomy, artificial intelligence and, most notably, reduced launch vehicle costs, now place space resources development within technological and cost-effective reach.

This research examines the current state of funding of space resources industries, including a summary of the current international and national space resources legislation that is in place.

The scale of this opportunity is enormous. The Space Project Team of the Organisation for Economic Co-operation and Development International Futures Program (IFP) determined that future demand for

commercial space applications is likely to be substantial. They presented three likely scenarios, with different geopolitical, socioeconomic, and energy and environment characteristics. Using the three IFP scenarios for Space 2030 and the presented cost of access to space, this research determines the potential impact, for the U.S. economy, of the change in final demand of the space value chain. The IFP estimates encompassed an 18–40% growth for the industry from 2004 to 2030 [3]. This estimate is a conservative one, as Morgan Stanley estimates that the industry will be worth more than USD $1 trillion by 2040 [4,5]; and, in 2021, the Space Foundation found that by 2020, the global space economy had risen to USD $447 billion, an increase of 4.4% from $428 billion in 2019, and of 55% from a decade ago. Commercial space activity grew 6.6% to nearly $357 billion in 2020, representing close to 80% of the total space economy [6].

Historically, funding for space projects has come at the expense of the public purse, whether in the United States, Russia, China, or any other country involved in space activities. However, the funding model for space projects is changing, with increased participation by the private sector.

As illustrated in the figure below, investment in start-up space companies has increased significantly since 2012, through a variety of investment types.

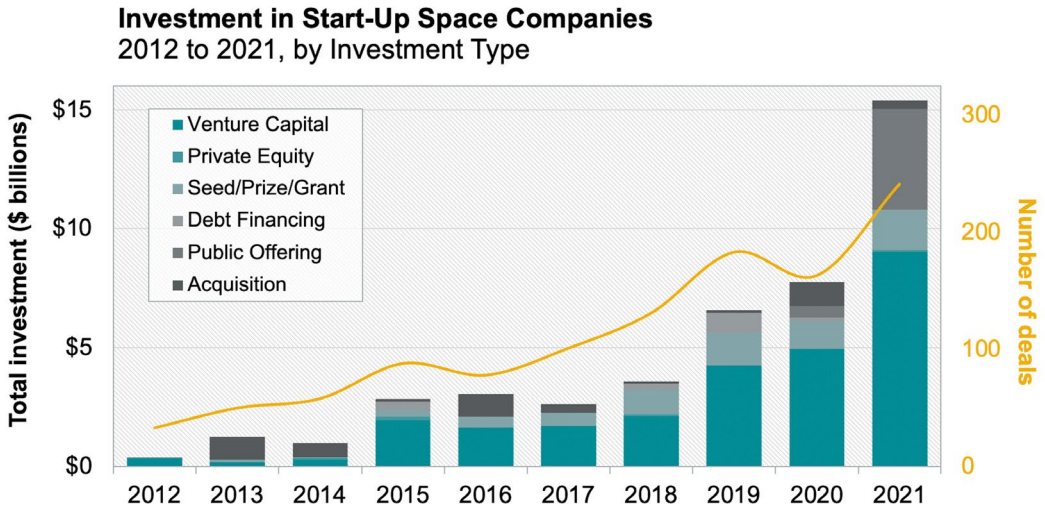


Figure 2.1: Investment in start-up space companies [7]

Following a literature review, the author concluded that there is a dearth of research regarding the sources and effects of, and a general lack of understanding regarding, the funding ecosystem that is currently developing to support the exploitation of space resources. Relevant research includes studies by Atkins [8], DePagter [9], Foster [10], George [5], and Masson-Zwaan and Richards [11]; however, these papers tend to focus more on the international and legal ramifications of space resource activities rather than how the industry is funded. Information on funding of space resources is more often found outside of academic research journals and is reported, rather, by commercial parties such as the Space Capital

investment fund and consulting contractors such as BryceTech, Euroconsult, and others.

This lack of relevant academic research is understandable due to the relative newness of the industry. However, given the significant amounts of capital that will be required to develop the space resources industry, it is important that researchers begin to examine drivers of funding for space resources.

This research focuses on examining and reporting on the state of the space resources industry, in general, and how it is funded, in particular. It includes a review of the funding partners involved and the effectiveness of the regulation and legislation currently in place. Questions such as "What are the biggest opportunities in the space resources sector?", "What are the biggest challenges in terms of funding in the space resources sector?", and "Who should regulate funding in the space resources sector?" do not lend themselves easily to experimental or statistical analysis, particularly when the number of studies on the subject is still small. To this end, it was decided to approach expert respondents in the space resources industry to aggregate an understanding of the state of funding within the sector.

Although a significant sampling of experts was selected for this research, it is by no means exhaustive. This paper is intended to highlight key themes, pinpoint differences, and identify shortfalls that may exist within the current funding structure of the space resources sector. Following from this research are various further opportunities to build on these findings, such as conducting additional interviews within a specific subcategory of expertise, or using the findings to augment a study of empirical data.

2.1 Methodology

The findings discussed in this paper are derived from an interview-based study of space resources industry funding. As such, it is informed by the knowledge and expertise of individuals identified due to their involvement within some aspect of the industry. In developing the methodology for this research, the author leaned heavily on the framework published by Dejonckheere [12].

An interview structure was chosen for this research, as interviews are an accessible, affordable, and effective method to understand the socially situated world of the research participants [13]. All interviews were semi-structured, typically consisting of a dialogue between researcher and participant, guided by a flexible interview protocol and supplemented by follow-up questions, probes, and comments [12]. Interviews were conducted using standardized questions. A semi-structured interview style was chosen, as qualitative, semi-structured interviews use verbal communication, mostly in face-to-face interactions, to collect data on participants' attitudes, beliefs, and experiences [13].

Out of the total 30 interviews, 27 were conducted via Zoom, allowing the author also to observe respondents' facial expressions and body language. Interviews were recorded and transcribed for

reference while compiling data. Each interview was scheduled for one hour, during which the interview sought to keep the discussion to the allotted time; however, respondents who wished to elaborate further were allowed extra time to complete the discussion and convey their responses appropriately. No follow-up questions or sessions were used with any of the respondents. Each respondent was asked to reconfirm their willingness to be acknowledged in this paper and, if interested, to review a draft. No revisions were requested following this review.

The remaining three interviews were submitted as written responses, as no convenient time slot could be found to connect via videoconference. Each respondent was provided in advance with a list of standardized questions, so that the interview could be carried out most efficiently; however, the interviewer was permitted some leeway to expand further on relevant topics and viewpoints. In addition, respondents were asked to provide their qualitative views and opinions, consistent with the approach of a semi-structured interview.

Interviews were conducted over a period of approximately one month, during February 2023, such that all respondents shared a comparable frame of reference with regard to time when commenting on the state of funding for space resources.

It was originally planned to interview more than 50 relevant individuals and requests for interviews were sent to more than 90 potential participants. This target number was set to ensure that the number of people interviewed in each category and professional role was sufficient, such that reserves would be in place should any individual decline to participate or be prevented from taking part [14].

As expected, in several instances potential respondents declined due to time constraints or work restrictions and in one instance, because the author was based in Hong Kong, for which the individual's employer declined to approve the individual to participate.

After successfully carrying out thirty interviews, the author concluded that the data set had reached theoretical saturation—or, as Glaser and Strauss [15] put it, "the point in grounded theory analysis where collecting and analyzing additional data does not teach you more about your topic".

2.2 Data Collection

The sampling strategy used in this research was selected to identify relevant individuals within the author's personal network, as well as key companies from which relevant individuals within those companies might be identified and contacted. In addition, following the formal interview, each respondent was asked "if there was anyone else I should speak further to on this topic?" This created a snowball effect, a popular sampling method whereby researchers begin with a small number of initial

contacts (seeds) who fit the research criteria and are invited to become research participants [16]. This snowball sampling strategy helped maximize the pool of interview candidates for this study, both in quantity and in quality.

In total, 30 people were interviewed, representing different aspects of the space resources funding ecosystem. These included entrepreneurs, corporate employees, brokers, academics, government and agency personnel, investors, and advisors. Within these categories, interview subjects held a wide range of positions, including CEO, department head, consultancy partner, law firm partner, head of business development, professor, etc.

This sampling strategy was designed to capture a range of different organizational contexts, and to pinpoint similarities and differences between the study respondents' answers. Respondents were thus categorized in five broad categories: Academic and Legal; Consulting and Finance; Corporate and Late-Stage Entrepreneur; Investor and Early-Stage Entrepreneur; and Government, Policy, and Agency, with the common thread being active participation in the space resources industry. The wide range of respondents helped to ameliorate the problems of information gaps and personal biases, as expert testimony is inherently personal and not necessarily representative or replicable [17].

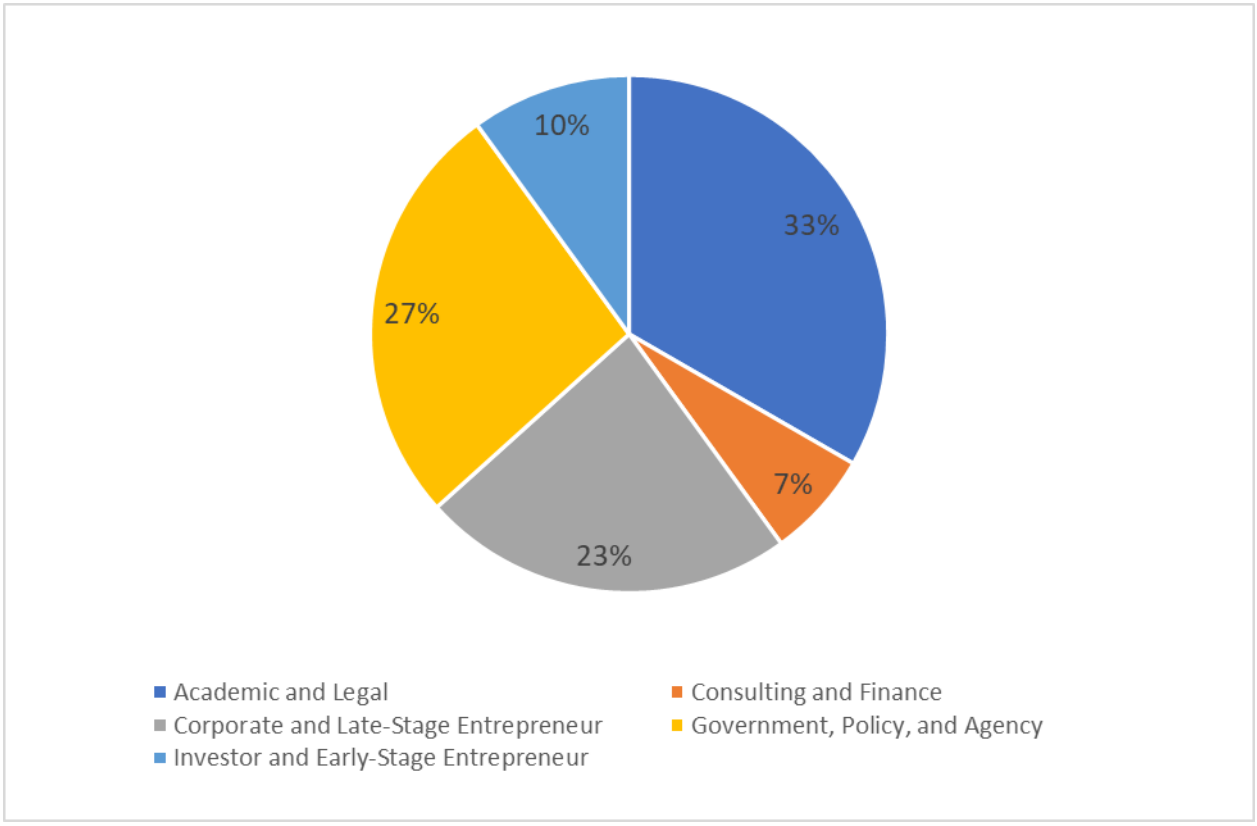


Figure 2.2: Professional breakdown of respondents

The Academic and Legal category was comprised of professors and lawyers; in certain cases,

respondents occupied both roles. The Consulting and Finance category was comprised of respondents actively involved in providing advisory services to space resources industry companies and agencies. The Corporate and Late-Stage Entrepreneurs classification was comprised of respondents who worked in companies with recurring cash flow and/or funding beyond "Series A"; while Investor and Early-Stage Entrepreneur respondents were either active investors in the space resources industry, typically investing in early-stage companies, or entrepreneurs active in the industry but at an early stage of company development. Placing respondents into one of these two categories entailed a degree of subjectivity. The Government, Policy, and Agency category was comprised of politicians and civil servants directly involved in formulating space resources policy, individuals employed by a country's sovereign space agency, and/or individuals involved in the development of a government's space resources policy, either nationally or internationally.

Geographic profiles of respondents were dispersed globally, with approximately 50 percent of respondents based in North America, 25 percent in Europe, and 25 percent in the Indo-Pacific region (including Australia). This breakdown is also reflective of the dispersion of space resources funding (more about this below).

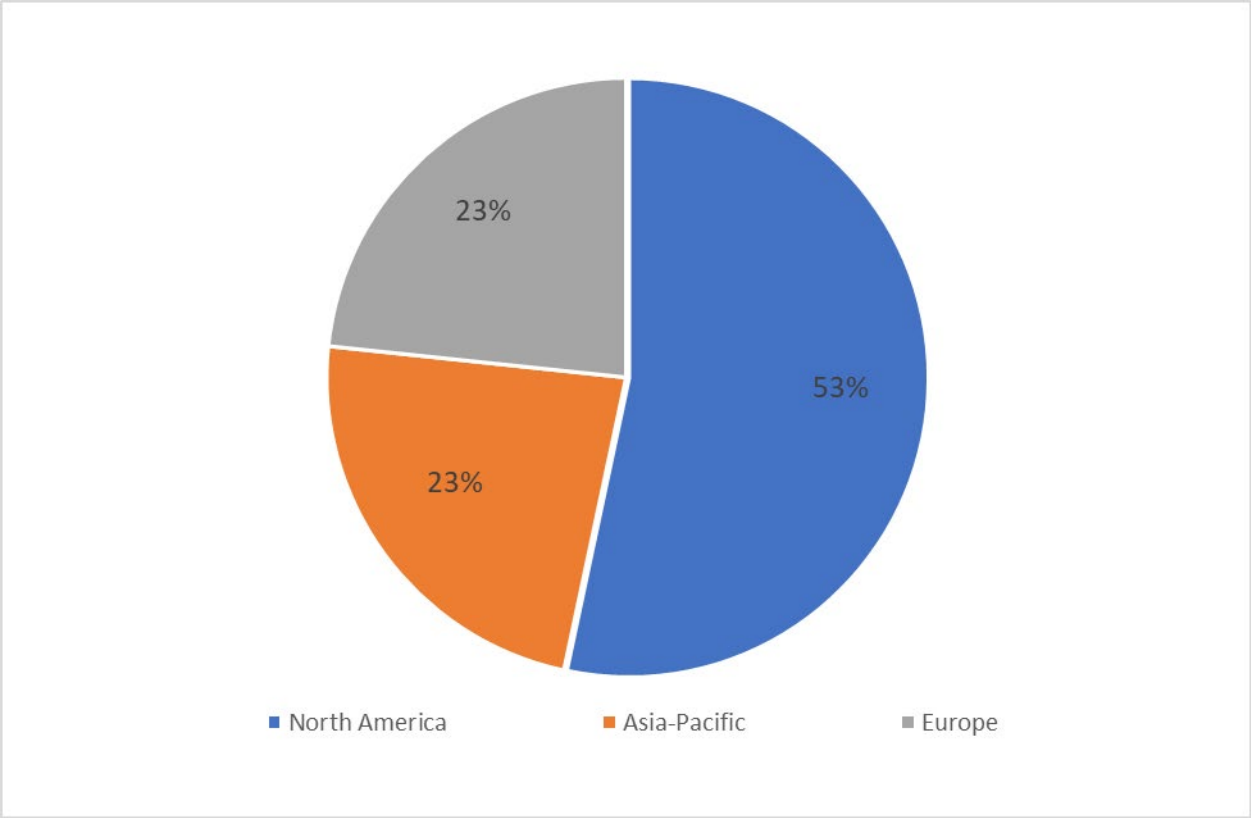


Figure 2.3: Geographic breakdown of respondents

It is important to note that certain prospective respondents associated with multinational banks

declined to participate in this study due to restrictive compliance regulations and concerns around proprietary strategy. In addition, certain other prospective respondents declined to participate citing security concerns related to the author's physical location in Hong Kong.

All the respondents agreed to speak in the understanding that although they are associated with organizations that are relevant to the development of space resources, the opinions they expressed are their own and do not reflect the positions of the organizations that they work for.

Table 2.1: List of research participants

Role	Organization Type
Director, In-Space Infrastructure & Logistics	Corporate
Former Federal Minister, Responsible for Space Agency	Government
Chief Technologist	Space Agency
Director, Private Sector Programs	Foundation
Co-Founder and Managing Partner	Capital Provider
Founder	Consulting
Editor-in-Chief	Scientific Journal
Founder and Managing Partner	Corporate
President	Robotics Corporation
Space Exploration Scientist	Satellite Corporation
CEO	Space Start-Up
Emeritus Professor of International Law	University Law Faculty
Specialist, Operations	Multinational Mining Corporation
Co-Founder and Vice President for Science and Research	Space Start-Up
Lead, Space	Global Economic Think Tank
Partner focusing on Space Industry	Consultant
Associate Professor, Economics and Business	University Business Faculty
Founding Director, President, and Executive Director	Think Tank
Director and Member, Executive Committee	Space Agency
Assistant Professor	University, Law Faculty
Head of Geoscience	Multinational Mining Corporation
Chairman	Small-Cap Mining Corporation
Senior Policy Advisor	Federal Government
Founder, CEO, and former astronaut	Space Start-up
Director, Laboratory for Space Research	University Physics Department
Researcher	University Law Faculty
Executive Chairman	Space Start-Up
Partner and Global Space Practice Leader	Consultant
CEO	University
President	Corporation

All respondents consented to the listing of their names in the publication. This research was deemed to be exempted from Human Subjects Research Approval by the Institutional Review Board (IRB) of the Colorado School of Mines.

2.3 Defining Space Resources

Given Under United States law, space resources are defined as "any tangible or intangible benefit which can be realized only from (A) aeronautical and space activities; or (B) advancements in any field related to space" [18]; and by the Hague Working Group as "extractable and/or recoverable abiotic resource[s] in situ in outer space" [19]. However, as interviews progressed, it became apparent that respondents in the space resources industry are not just heterogeneous in terms of background but also in how they approach the industry. The third question posed to respondents, following those regarding name and occupation, was: "How do you define space resources?" The basis of the respondent's answer to this question set the direction for the rest of the interview. However, in the responses to this question, there was but little repetition. As one respondent observed, "the scope can be quite large!" The broadest similarity observed in the respondents' answers was in the use of key terms: e.g., value, use/usability, consumable, extracted/extraction, minerals/materials/metals, and capture.

Over half of the respondents conflated space resources with In-Situ Resource Utilization (ISRU). When asked to elaborate and, if necessary, expand their definition, most respondents expressed the belief that space resources are focused on usable minerals and materials of value that are extracted from celestial bodies. There was limited consensus among respondents as to whether the definition of space resources includes resources returned to Earth for terrestrial consumption or resources consumed exclusively in space or both.

The second-most common definition of space resources was sufficiently expansive to include power beaming, data, and gravitational resources such as Low Earth Orbit (LEO), Geosynchronous Earth Orbit (GEO), and space debris. Significantly, one respondent specifically excluded space debris from a broader definition because, in his view, space debris should be regulated differently than space resources development and exploitation.

Of significant note were the definitions posited by respondents associated with large terrestrial mining interests. Such companies are making significant investments in space resources, but for purposes of definition, these respondents characterized space resources as a research and development opportunity, whereby space and research on space resources might be adapted and exploited to advance terrestrial mining.

Additionally, certain respondents preferred to direct me to published definitions such as the U.S. Commercial Space Launch Competitiveness Act, of 2015, in which a space resource is defined as "an abiotic resource in situ in outer space" [20]; or to the Hague Building Blocks, in which it is defined as "an extractable and/or recoverable abiotic resource in situ in outer Space" that includes mineral and volatile

materials, including water, but excludes a) satellite orbits; b) the radio spectrum; and c) energy from the Sun, except when collected from unique and scarce locations [19].

Respondents' definitions also reflected professional biases: economists looked at the economics of space resources, mining professionals considered the mining potential, and lawyers focused on the legal aspects and ramifications of defining space resources. Although, among this broad selection of industry respondents, there was little coherence as to a single definition of space resources, this result is likely reflective of the nascence of the industry and the opportunity it entails—a sentiment that was universally shared by respondents.

A similar ambiguity in the definition of space resources is reflected in a series of articles and editorials in the journal New Space that seeks to define new space and commercial space, of which space resources are a subset. An author's note in one editorial states succinctly: "The definition of space market 'segments,' 'sectors,' or 'domains' is somewhat arbitrary, and could include Earth observation, satellite communications, space science, security, satellite navigation, human spaceflight, space manufacturing, and debris removal' [21].

As noted earlier, survey respondents' definitions of space resources influenced their responses to the subsequent questions. In addition to recognizing the significant fact that there is little consensus on how to define space resources, for the purposes of this article we will define a space resource broadly, as *a material or commodity located in space that is exploitable and has a value to humankind.*

2.4 Current State of the Space Resources Industry

Initially, respondents were asked for their impressions of the space resources industry via these three questions:

i. *What do think are the greatest opportunities in the development of the space resources sector?*

ii. *What do you think are the biggest challenges in the development of the space resources sector?*

iii. *Which countries do you think are doing a good job promoting the development of the space resources sector?*

Unlike the previous question on definition, here the responses exhibited significant similarity or conformity, across all the respondents' associated industries.

2.4.1 Greatest Opportunities in the Space Resources Industry

The As seen in Figure 4, below, respondents leaned heavily toward the view that water extraction and energy production represent the greatest near-term opportunity in space resources. This includes energy collection for beaming power back to Earth (as highlighted by three respondents) as well as creating energy, propellant, and fuel primarily from the extraction and hydrolysis of water.

After water and energy, the next-most popular space resources opportunity was split between human habitation in space (primarily on the Moon but also in cislunar space) and telecommunications.

Environmental opportunities included: “using space resources and ISRU to lessen the impact of launches on Earth”; mining and disposing of space debris; and “lessening environmental degradation on Earth through mining in space.” These answers, like the others, tended to reflect the respondents’ various biases and roles.

In the author’s view, the category of knowledge transfer was perhaps the least expected and the most interesting. This category was raised by respondents associated with large terrestrial mining corporations, as representing not only a near-term opportunity but one that is, in fact, currently being exploited. These mining companies are looking to their activities in space to provide greater knowledge and efficiency for their terrestrial mining operations. It is this capture of value through knowledge transfer that helps maintain these companies’ interest in developing space resources.

The final categories were manufacturing, which many respondents saw as a longer-term opportunity (as compared to water and energy, for example); and other, the choice of respondents who saw the greatest opportunity in space resources as a means for inspiring interest among young people in STEM (science, technology, engineering, mathematics) education.

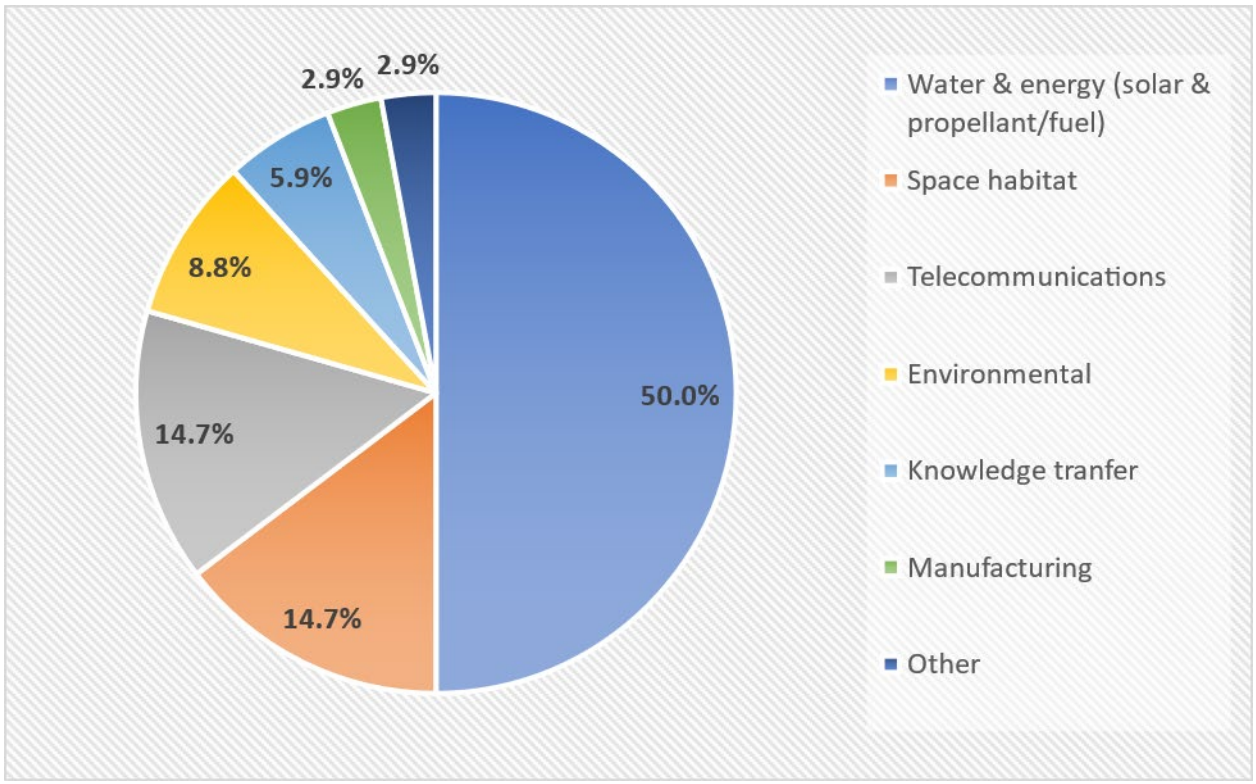


Figure 2.4: Opportunities in the space resources industry

2.4.2 Greatest Challenges in the Space Resources Industry

When asked to describe the greatest challenges facing the space resources sector, participants responded with a dominant theme: financing. Primarily, respondents expressed the feeling that the sector faces a dearth of capital investment, but they also noted misalignment in the funding cycle (i.e., investors expect return before the sector can realistically deliver economic results), the inability of investors to understand and price risk, the lack of an established commercial market, and a perceived lack of commerciality.

After finance, respondents identified legal and regulatory challenges, including the perceived lack or inadequacy of both, and expressed concern that the space resources industry cannot be enjoyed and exploited by all countries—not just the "rich" countries—evenly and equitably.

The current geopolitical environment was also raised as a concern, as were two unique responses under the other category: the viability of development in LEO due to space debris and the viability of returning resources to Earth.

It is worth noting that no respondent mentioned technology as one of the space resources industry's greatest challenges.

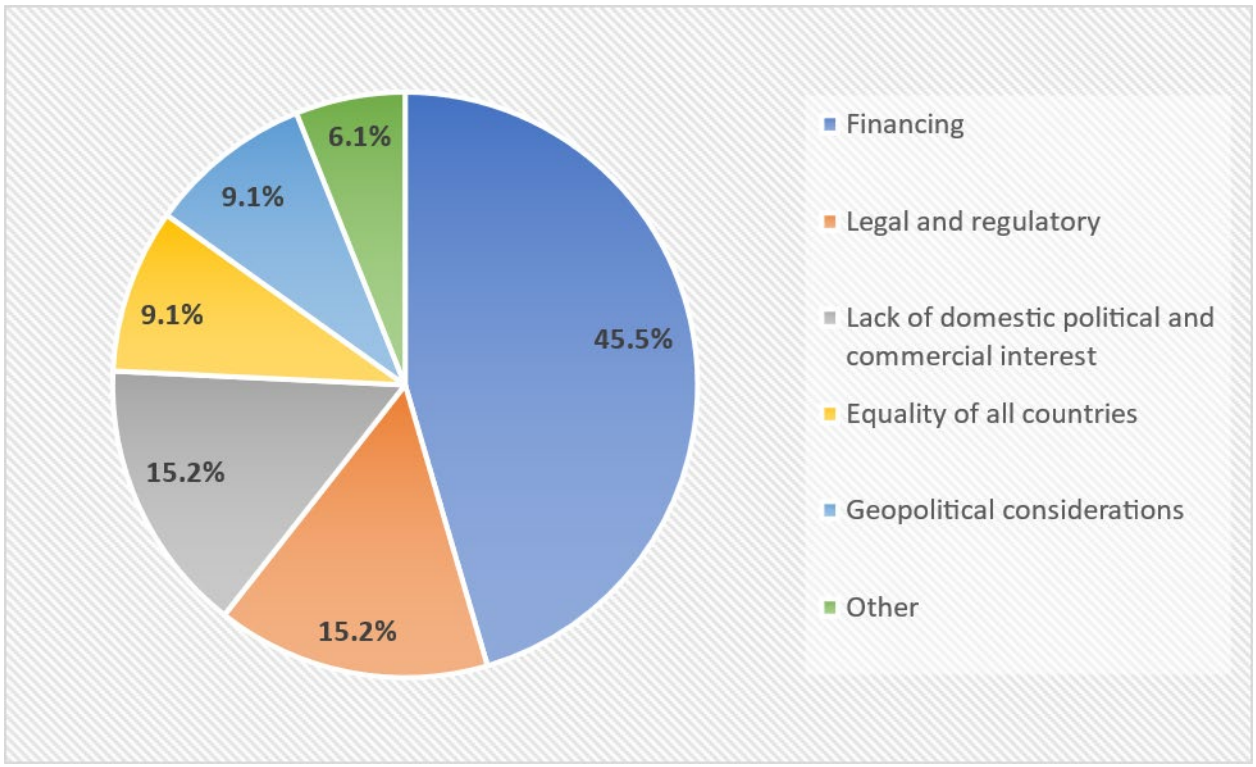


Figure 2.5: Challenges in the space resources industry

2.4.3 Countries Actively Supporting the Space Resources Sector

The figure below records the number of mentions by respondents when asked which countries were the most supportive of the space resources industry. Each respondent was allowed to name however many countries they believed were supportive; in most cases, respondents would mention two or three. The United States, Luxembourg, the United Arab Emirates, and Japan are marked with red dashes, as these countries have enacted legislation and/or legal frameworks related to space resources in some form or another.

It is evident that, in the opinion of the respondents, the United States is clearly the country that is the most supportive of space resources. When asked to elaborate, many respondents replied that this is because of the sheer size of the U.S. economy, but also because of its Commercial Space Launch Competitiveness Act, of 2015.

Following the United States was Luxembourg. In 2016, Luxembourg enacted a draft law to create a legal framework for space resources companies to operate in that country. Shortly thereafter, in July 2017, Luxembourg became the first European nation to provide a legal framework for utilization of space resources. Many respondents also believed Luxembourg was the best promoter, among the world's nations, of space resources as an investable industry.

Rather than name individual European countries, respondents often identified the European Space

Agency (ESA) as a supportive entity. Also, quite interestingly, Canada and Australia were also mentioned often. These mentions were always made in the context of strong crossover and support on the part of both countries' significant terrestrial mining industries.

Another key observation was the location bias inherent in these answers. Respondents would invariably mention the country or region in which they resided as being one of the countries most supportive of the space resources industry; but it also became apparent that many Western-based respondents would not mention China, or would mention it only as an afterthought. When pressed on this, respondents suggested that they had limited exposure to China's activities in the space resources sector, outside of what appeared in the media, and, as such, did not think of China as a particularly active supporter of space resources.

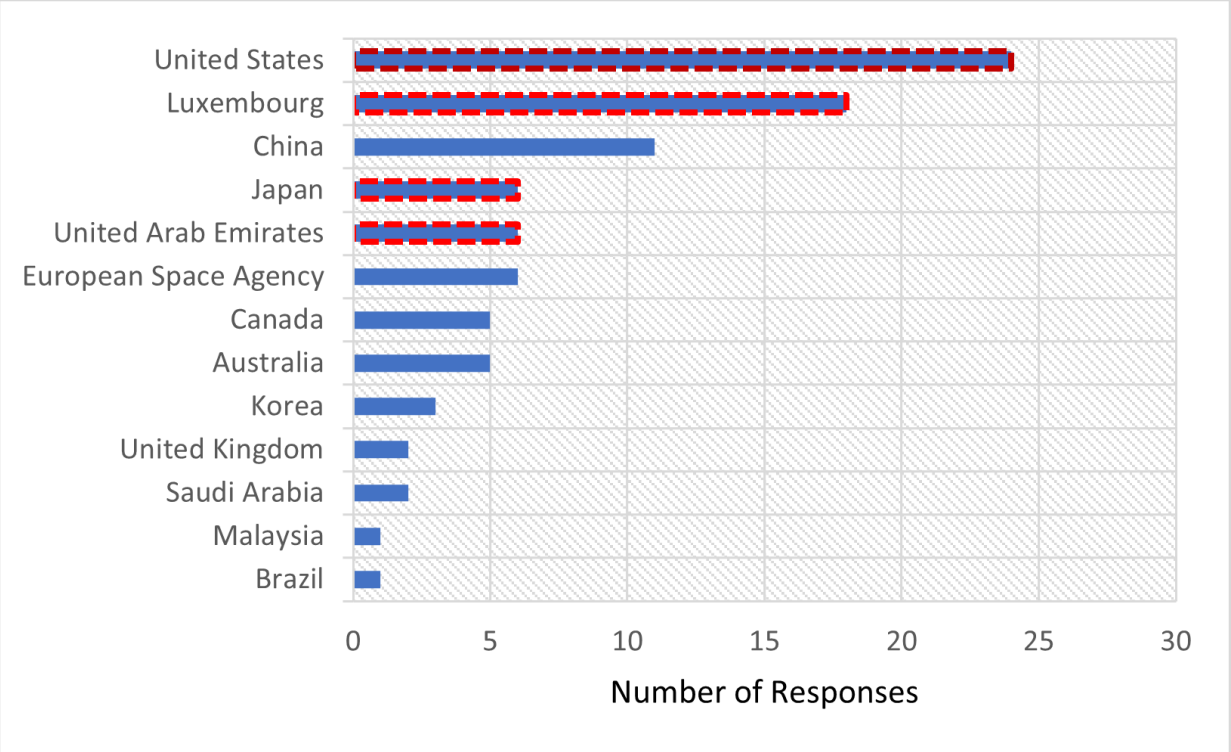


Figure 2.6: Respondents' attitudes regarding countries supporting the space resources industry

2.5 Funding of the Space Resources Industry

Following these general questions on the state of the space resources industry, respondents were asked to share their opinions and insights on the state of funding for the space resources industry. Specifically, they were asked:

i. *What is your current position on whether or not the sector is adequately funded and the state of the ecosystem at present?*

ii. *Where do you think the majority of funding for the space resources sector is currently coming from (private sector, public sector, etc.)?*

iii. *Where do you think the primary funding for the development of space resources should come from in the future?*

iv. *Where are the biggest opportunities for funding the space resources sector?*

v. *Where are the biggest challenges for funding the space resources sector?*

vi. *Which country or geography do you think is the most supportive financially of the space resources sector? Does that change if separating private versus public support?*

Respondents were also asked their views on success stories in regard to space resources sector funding, but it was found that respondents were unable or unwilling to answer this question or that there was no learnings or theme that could be extracted from the respondents' answers, and it was decided that those responses were not relevant to the findings of this paper.

As the interviews progressed, it became apparent that respondents were quite comfortable discussing the space resources sector in general; however, when questioned more granularly on funding, respondents' answers were (perhaps intentionally) vague, or else they chose not to answer due to a lack of familiarity with the topic. The quality and insight value were significantly lower for these more specific responses than for the respondents' observations about the industry in general. This supports the thesis that although funding is an integral part of any commercial industry, in the nascent space resources industry, it is not yet well understood.

2.5.1 Funding Level and State of the Ecosystem

Asking respondents' opinions on whether the space resources sector is adequately funded did not elicit simple yes or no responses. The answers generally fell into four categories—an emphatic "no," a soft "yes," or "it depends," or "don't know." A respondent declining to answer was also noted.

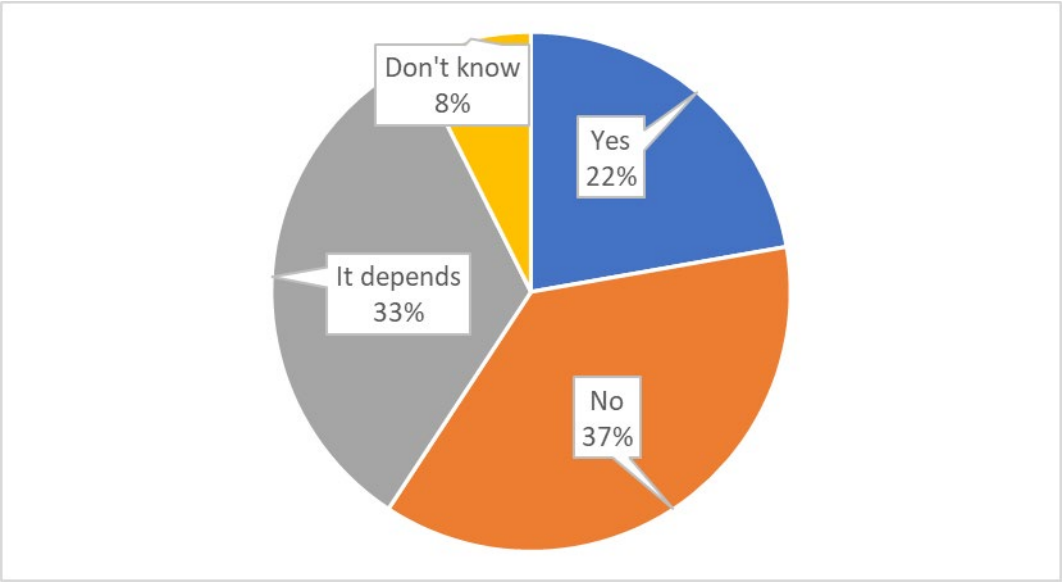


Figure 2.7: Respondents' opinions on whether the space resources sector is adequately funded

The true value of these responses was to be found not so much in the initial answer as in the nuance and insight that accompanied that answer. Asked why they arrived at their conclusion, respondents' answers were entirely distinct; as such, when taken as a whole, the responses amount to an impressive mosaic of knowledge regarding space resources industry funding and underline the nascent and disorganized state of the industry. Table 2, below, details the various elements of this insight.

Table 2.1: Summary of responses regarding funding level and state of space resources ecosystem

"Yes"	"No"	"It Depends"
▪ Well-funded for the current stage of the industry's development ▪ Well-funded for the current stage of the industry's development ▪ "There are a lot of bad ideas getting funded ▪ Adequately funded, both privately and publicly ▪ Adequately funded, both privately and publicly ▪ Funding is there, in some form or another ▪ The sector is nascent but there is money there for people with a decent idea	▪ Very specific funding for discrete projects, but an ecosystem is needed ▪ Public sector has some money but not a priority ▪ Slight funding compared to other aspects of space ▪ Sector is immature ▪ Policy is not sufficiently developed to attract funding ▪ We underestimate some of the technical challenges and therefore underestimate the funding ▪ Too many competing public and private funding priorities and space is not prioritized ▪ It's a question of time; investors will start approaching the sector more systematically ▪ Governments should be funding this but are leaving it to the private sector, which is not picking up the slack	▪ Funding support varies from country to country ▪ Certain aspects of space resources are funded ▪ There is funding for space resources innovation but not space resources infrastructure ▪ Depends on how you define the various buckets into which the public spending is going ▪ Depends on subsector: energy capture is underfunded but robotics is overfunded ▪ Depends on funders' priorities (e.g., U.S. Space Force) ▪ Currently, there is money around but not enough of it, and what there is won't be around long unless something changes ▪ Spending is not focused appropriately ▪ Ample funding for specific niche needs but not enough to grow a commercial industry

2.5.2 Funding Sources for the Space Resources Sector

Respondents were then asked their opinion on where the majority of space resources sector funding is currently coming from (e.g., public sources, private sources, other) and where it should come from in the future.

Regarding current funding, respondents replied overwhelmingly that most funding comes from public sources, with NASA and the Chinese government cited most often as the biggest space resources sector funders. Some outlier respondents, who believe that most funding for space resources currently comes from the private sector, admitted that their opinions were based on trade shows and media exposure, and not grounded in research.

An interesting consideration raised by one respondent was how space resources funding from military sources today compares to military sponsorship of resource exploration during the Age of Discovery. Although such research is outside the scope of this paper, it is perhaps worth mentioning that this would be a relevant and related subject for further research.

When asked about future funding sources, respondents were almost evenly split, with half believing that the space resources sector will in the future be mostly privately funded and the other half believing that it will be supported through a mix of public and private funds, including the model, widely used, of public-private partnerships, and accompanied by heavy government regulation and/or incentives to stimulate private investment. A small minority (two) believed that in the future, most of the funding for space resources will continue to come from the public purse.

2.5.3 Opportunities and Challenges in Funding the Space Resources Sector

Unlike the respondents' unified focus regarding the greatest opportunity in space resources (water and propellant), when asked about the greatest opportunities in funding for the space resources sector, the answers were more varied.

Approximately 30 percent of respondents believed that developing programs and services to contract with publicly funded entities and government programs was the greatest opportunity. This was primarily the view of Western respondents, who often cited NASA as the public entity that represents the greatest opportunity for funding.

The second-most common response was creating infrastructure to support the space resources industry. More than once, respondents who cited this as the top opportunity made an analogy to the California Gold Rush of the mid-1800s and the role of hardware suppliers and general stores in

supporting the speculating miners. These respondents often referred to the sale of "picks and shovels" to the space resources industry as the top opportunity. When respondents were asked for more detail, one theme that emerged was the development and commercialization of geological data on asteroids and planets, which can be sold to companies planning on engaging in resource extraction.

The third-most common response was technology transfer for terrestrial resources. It is worth noting that this answer was given by respondents associated with large terrestrial corporations such as mining companies, as well as by politicians and policymakers.

Similarly, respondents also saw data and data transfer as an opportunity in space resources sector funding. Further answers included lowering environmental impact through a reduced number of space launches and the ability to scale operations.

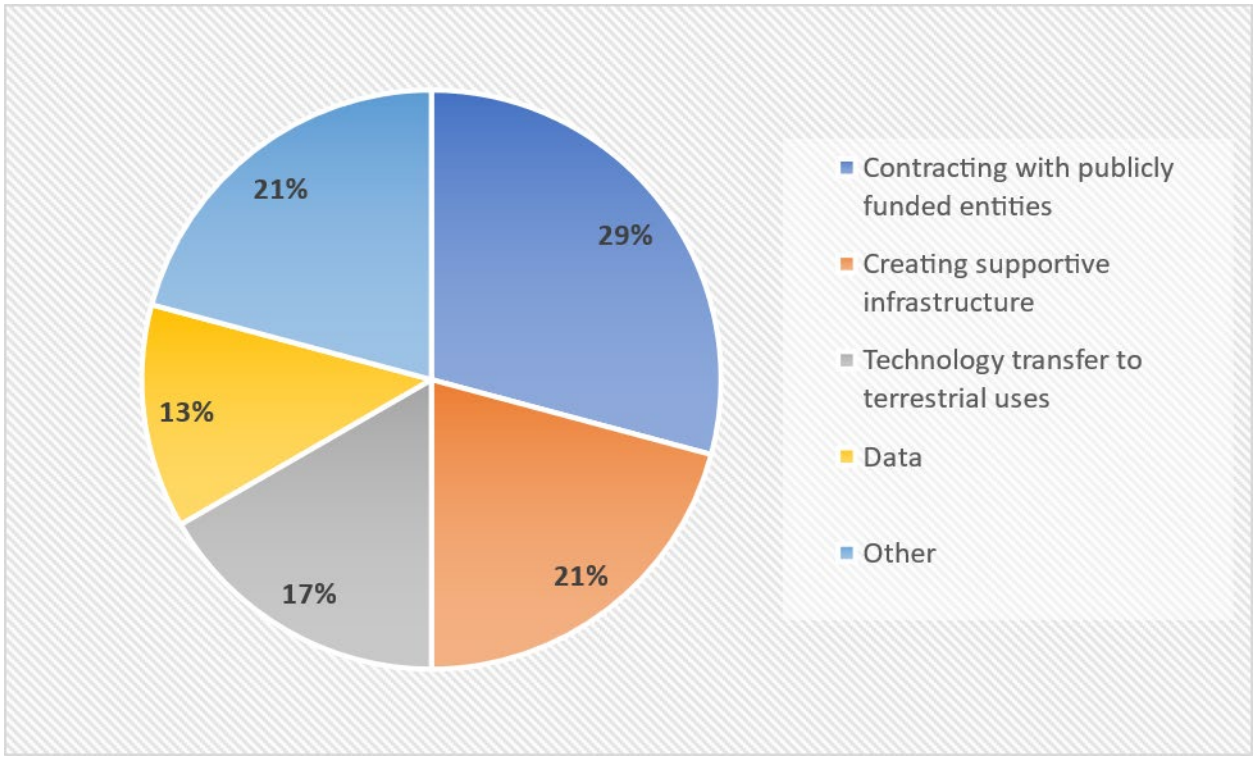


Figure 2.8: Opportunities in funding the space resources industry

When asked about funding challenges facing the space resources industry, responses generally fell into four categories: the financial return is uncertain, the legal and/or regulatory regime is unclear, the market opportunity is uncertain, and the risk and/or understanding of risk is too high. It could be argued that all these challenges are interrelated, reflective of a nascent market, and may well be addressed as the sector matures and its players gain experience. Indeed, when questioned on this point, the general feeling among the respondents was that such challenges will be ameliorated over time, as the industry grows.

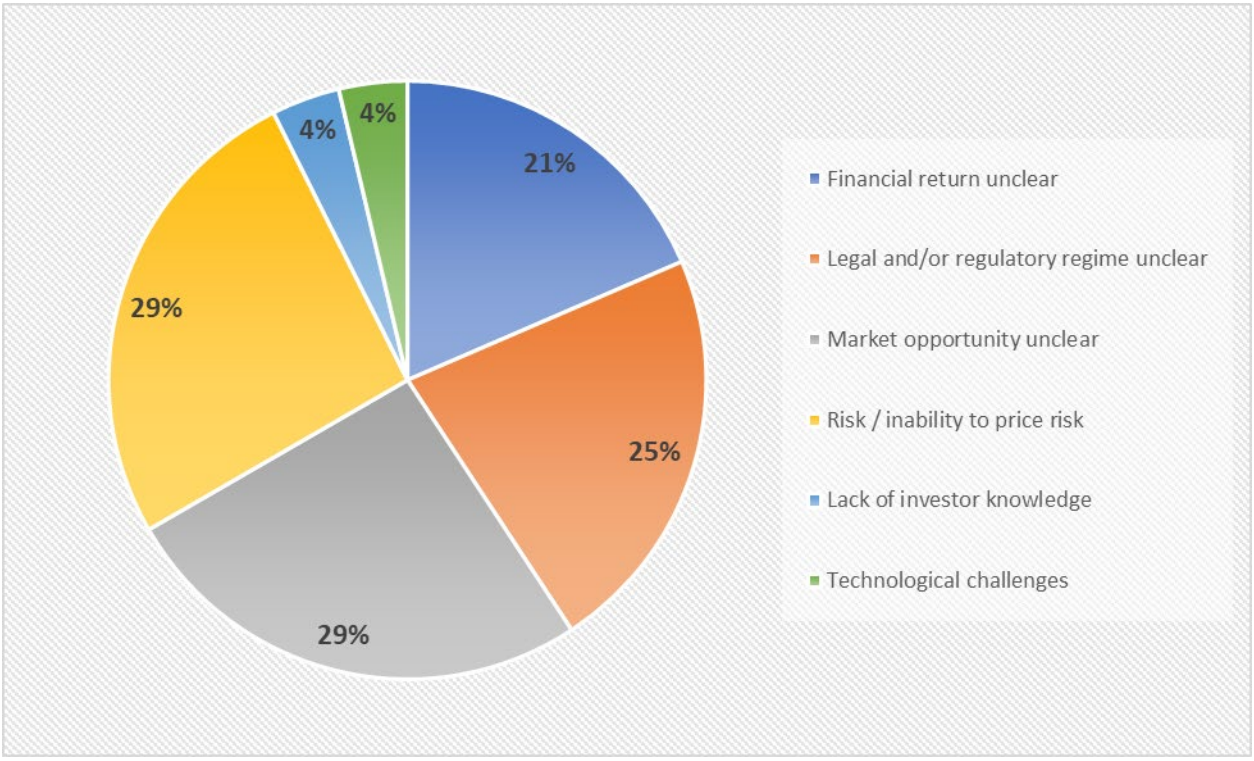


Figure 2.9: Challenges in funding the space resources industry

Following the above questions regarding opportunities and challenges for space resources industry funding, respondents were asked to identify a success story in the space resources industry. However, as stated earlier, due to the inability to distill learnings or themes, the responses to this question were deemed insufficiently relevant to include in this report.

2.5.4 Supportive Geographies

Next, respondents were asked to share their views on which countries or regions were the most supportive of the space resource sector financially. The respondents were given clear instruction that their answers were to focus on the financial aspect of the industry—in contrast to Question 5 (discussed above), concerning countries successfully promoting the development of the sector.

As illustrated in Figure 10, respondents believed that the primary country supporting the space resources sector financially is the United States. Two answers, from respondents who replied "the Middle East" rather than naming individual countries, were added to the tallies for both the United Arab Emirates and Saudi Arabia (rather than creating a new category).

A key insight gleaned from this discussion was that although the respondents almost invariably believed that the United States is the sector's primary financial supporter, they also felt that this is a function of the size of the U.S. economy. Table 3, below, illustrates the size of the economy of select countries as represented by gross domestic product in 2022 [22]. These countries have been selected as

they have passed or are expected to pass national space resources legislation.

Table 2.2: 2022 GDPs (in millions of USD) of selected economies

Country	2022 GDP
United States	25,464,475
China	18,100,044
Japan	4,233,538
Saudi Arabia	1,108,149
United Arab Emirates	507,535
Luxembourg	82,340

Although no respondent provided numerical evidence, many did suggest that the European Union or individual countries such as Luxembourg were in fact more financially supportive of the sector than the U.S. inasmuch as their respective commitments represented a greater proportion of their economies.

In addition, when pressed on this point, respondents suggested that in the United States, financial support derived primarily from public sources of capital, while other countries and regions had a larger proportion of private funding.

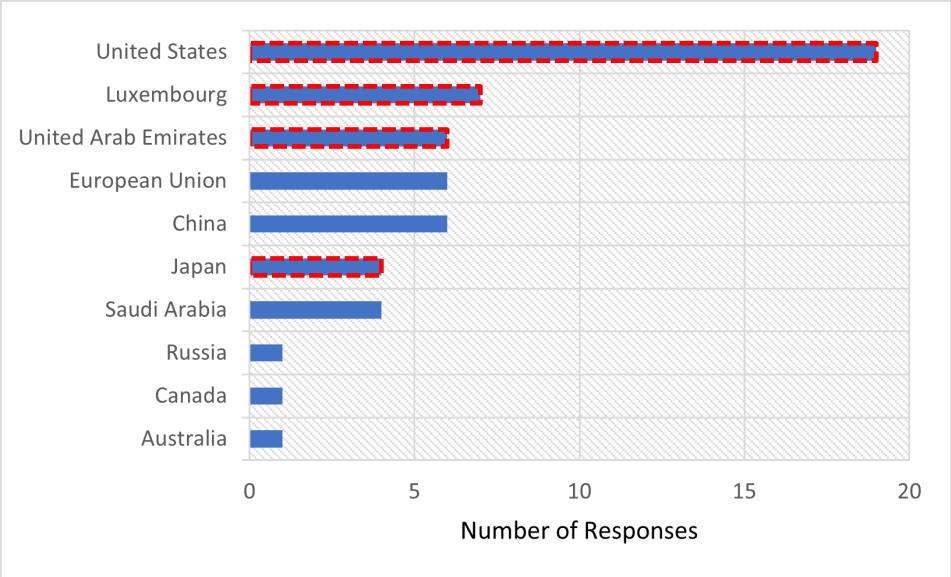


Figure 2.10: Respondents' attitudes regarding countries financially supportive of the space resources industry

As in Figure 6, the United States, Luxembourg, the United Arab Emirates, and Japan are all identified with a dashed red border, as these countries have enacted legislation and/or legal frameworks related to space resources in some form or another.

Respondents' views of the U.S. as the dominant funder of the space resources sector are reinforced by data compiled by Space Capital, a seed-stage venture capital firm that invests in the space economy and produces quarterly reports of investment data. As illustrated in Figure 11, between January 1, 2014, and

March 31, 2023, the United States was the dominant investor with regard to all aspects of the space economy.

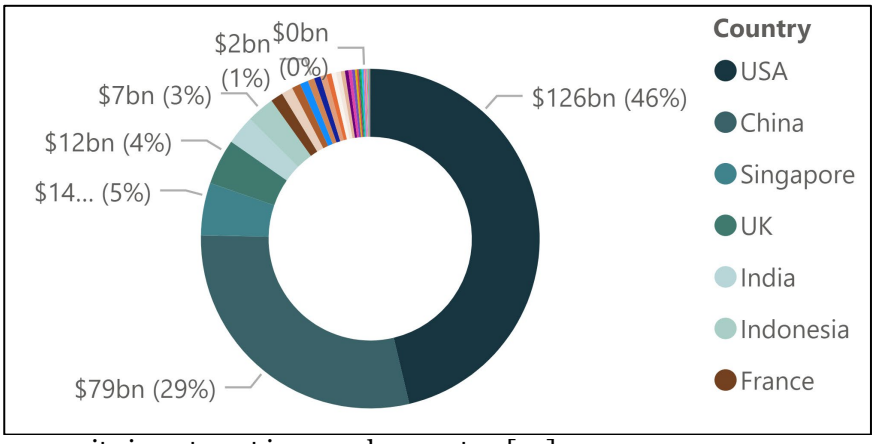


Figure 2.11: Ten-year equity investment in space by country. [23]

2.6 Key Funding Partners and Supporters

In the next section of the research, respondents were asked to share their views on partnerships and support for the space resources sector. Specifically, they were asked:

i. *Do you think that there is sufficient communication and understanding between providers of capital in the space resources sector and users of capital?*

ii. *How well are national governments doing in regard to support for the space resources sector around the world?*

iii. *How effective is the private sector in supporting the space resources sector?*

This section is important for understanding the quality of financial support for the space resources sector and where that support is coming from. In response to the first question, in general the participants believed that currently there is not sufficient communication and understanding between providers of capital and users of capital in the space resources sector. With the exception of two respondents, who said that communication and understanding are adequate and/or improving, it was apparent that the respondents in these interviews were frustrated by a lack of communication and understanding.

Several respondents noted that they believe there is significant information available on the space resources sector—in the form of conferences such as Investing in Space or FT Live, academic journals like Space Policy, New Space, or Acta Astronautica, and popular media articles such as "The Space Industry Is Taking Off. Space Law Is Still a Mystery," in the New York Times [24], or "Space Companies Struggle to Meet Lofty Goals," in the Wall Street Journal [25]. But respondents also reported a lack of education on the part of investors and providers of capital, or simply a lack of interest in educating themselves.

A further theme in the responses to this question was a perceived lack of professionals who properly understand the opportunities and risks inherent in space resources and who can communicate appropriately with the investment community. This shortfall of interlocution extends to a lack of understanding of risk and the inability, on the part of the space resources community, to provide the financial community with the necessary risk education and due diligence materials.

When asked how well national governments are performing in regard to supporting the space resources sector, the dominant theme from respondents was that such performance is mixed and that only a few governments are truly engaged in the industry at this point. Not surprisingly, the United States, China, and Luxembourg, and to a lesser extent Japan and the United Arab Emirates, were cited as being the most supportive countries and possessing the political will to continue to support the sector. Few other governments were mentioned as being engaged in a meaningful way. One respondent posited that governments are having a hard time defining and distinguishing between commercial space activities over against government space activities, and that, because of this difficulty, governments are having a difficult time nurturing a private, commercial space resources sector.

One response to highlight was that the governments that are currently committed to space resources are doing quite well in supporting the industry, with strong interest and open communications; but, because of the way in which public funding is deployed (grants, competitions, etc.), governments are excluding partnerships and collaborations with companies beyond their domestic borders, thereby stunting global advancement of the industry and creating less efficient domestic market ecosystems.

When asked about support for space resources on the part of the private sector, as with the responses to the question about government support, the dominant theme here was that performance is mixed. Many respondents pointed to strong support from the venture capital market, but added that support from the larger, more traditional sources of private funding, including debt capital providers, was limited. Additionally, most respondents were optimistic that support from the private sector is growing, a phenomenon being stimulated by the success of launch companies such as SpaceX and manufacturers of CubeSats.

The respondents also clearly believed that for private-sector players to become stronger partners and meaningful funders of the space resources industry, a significant amount of education about the sector, its commensurate risks, and the return timeline will be required. One respondent also observed that a country's level of private-sector support is directly commensurate with the degree of support provided by the public sector in the same country.

2.7 Regulations and Legislation in Funding Space Resources

As humankind's activities in space are no longer limited to exploration and research, and now include commercial activities, including through the exploitation and development of space resources, in 2017, the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) encouraged members to start national space legislation [1].

The basic international space treaties—the Outer Space Treaty (1967), the Rescue Agreement (1967), the Liability Convention (1972), the Registration Convention (1974), and the Moon Agreement (1979)—were executed at relatively early stages in the development of space exploration and exploitation, and, as such, may require updating to address the needs of the growing space resources industry.

2.7.1.1 International Space Treaty Summary

The Outer Space Treaty was considered by the UN Legal Subcommittee in 1966 and agreement was reached in the General Assembly the same year (Resolution 2222 [XXI]). The Treaty was largely based on the Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space, which had been adopted by the General Assembly in Resolution 1962 (XVIII) in 1963, but added a few new provisions. The Treaty was opened for signature by the three depository governments (the Soviet Union, the United Kingdom, and the United States) in January 1967, and entered into force in October 1967. The Outer Space Treaty provides the basic framework for international space law [26]. It has been ratified by more than 100 countries and remains the most important and foundational source of space law [27].

The Rescue Agreement was considered and negotiated by the UN Legal Subcommittee between 1962 and 1967. Consensus was reached in the General Assembly in 1967, in the form of Resolution 2345 (XXII), and the Agreement entered into force in December 1968. Elaborating on elements of articles 5 and 8 of the Outer Space Treaty, the Rescue Agreement provides that "States shall take all possible steps to rescue and assist astronauts in distress and promptly return them to the launching State, and that States shall, upon request, provide assistance to launching States in recovering space objects that return to Earth outside the territory of the Launching State" [28].

The Liability Convention was considered and negotiated by the UN Legal Subcommittee between 1963 and 1972. Agreement was reached in the General Assembly in 1971—Resolution 2777 (XXVI)—and the Convention entered into force in September 1972. Elaborating on Article 7 of the Outer Space Treaty, the Liability Convention provides that "a launching State shall be absolutely liable to pay compensation for damage caused by its space objects on the surface of the Earth or to aircraft, and liable for damage due to

its faults in space. The Convention also provides for procedures for the settlement of claims for damages" [29].

The Registration Convention was considered and negotiated by the UN Legal Subcommittee from 1962 onward, until its adoption by the General Assembly in 1974 as Resolution 3235 (XXIX). It was opened for signature on 14 January 1975 and entered into force on 15 September 1976. Responding to a desire expressed by states party to the Outer Space Treaty, the Rescue Agreement, and the Liability Convention for a mechanism that would provide states with "a means to assist in the identification of space objects," the Registration Convention expanded the scope of the United Nations Register of Objects Launched into Outer Space, which had been established by Resolution 1721B (XVI) in December 1961, addressing issues relating to state parties' responsibilities concerning their space objects [30].

The Moon Agreement was considered and elaborated by the UN Legal Subcommittee between 1972 and 1979, and was adopted by the General Assembly in 1979 as Resolution 34/68. It was not until June 1984, however, that a fifth signatory country, Austria, ratified the Agreement, allowing it to enter into force in July the same year. The Agreement reaffirms and elaborates on many of the provisions of the Outer Space Treaty as applied to the Moon and other celestial bodies, providing that those bodies should be used exclusively for peaceful purposes, that their environments should not be disrupted, and that the United Nations should be informed of the location and purpose of any station established on those bodies. In addition, the Agreement provides that the Moon and its natural resources are the common heritage of mankind and that an international regime should be established to govern the exploitation of such resources when exploitation is about to become feasible [31].

2.7.1.2 National Space Resource Legislation

Today, individual states are beginning to regulate an industry that did not exist when the basic space treaties were originally signed. In addition, some believe that nontraditional space activities (such as in-situ resource utilization) lack clear and dedicated international rules to govern them [32].

To address this, countries are beginning to develop their own frameworks and legislation, under which space resource companies can operate. Commercial space activities, like other commercial activities, are governed by their respective states' national laws [33]. These include contract, property, tort, creditors' rights, bankruptcy, insolvency and reorganization, and other laws.

Currently, four countries have actively developed frameworks for the development of space resources: the United States, Luxembourg, the United Arab Emirates, and Japan. Certain other countries, such as Saudi Arabia, are actively working on developing their own frameworks.

2.7.2 Respondents Views

With this background, the following questions were asked of respondents, focusing on regulation and legislation in funding the space resources sector:

i. *Who should regulate funding in the space resources sector and why?*

ii. *If there was one piece of regulation you would enact or change to help develop a stronger funding ecosystem for space resources, what would that be?*

iii. *Describe which country has the strongest legislation to support space resources. Are there any shortcomings or obviously missing regulation?*

Respondents cited a lack of in-depth knowledge or insight when answering questions in this category, particularly when asked about specific pieces of regulation and legislation.

On the matter of who should regulate funding of the space resources sector, answers fell into four categories: let existing mechanisms such as securities regulators (i.e., the SEC in the United States, the Ontario Securities Commission in the Canadian province of Ontario, etc.) oversee this type of funding; create a multilateral organization to provide regulatory oversight; leave regulation to national governments and their bureaucrats; or (the most common response) no one should regulate the sector, i.e., let funding be subject to market forces. Nonetheless, several respondents who gave the latter answer added the caveat that some kind of oversight would be necessary to prevent the emergence of monopolies and ensure companies are not acting illegally.

Interestingly, when comparing respondents' views on appropriate regulation with the same respondents' backgrounds, a correlation became apparent. Respondents who were entrepreneurs typically advocated for no regulation, multinational lawyers called for creating a multilateral organization, and so on.

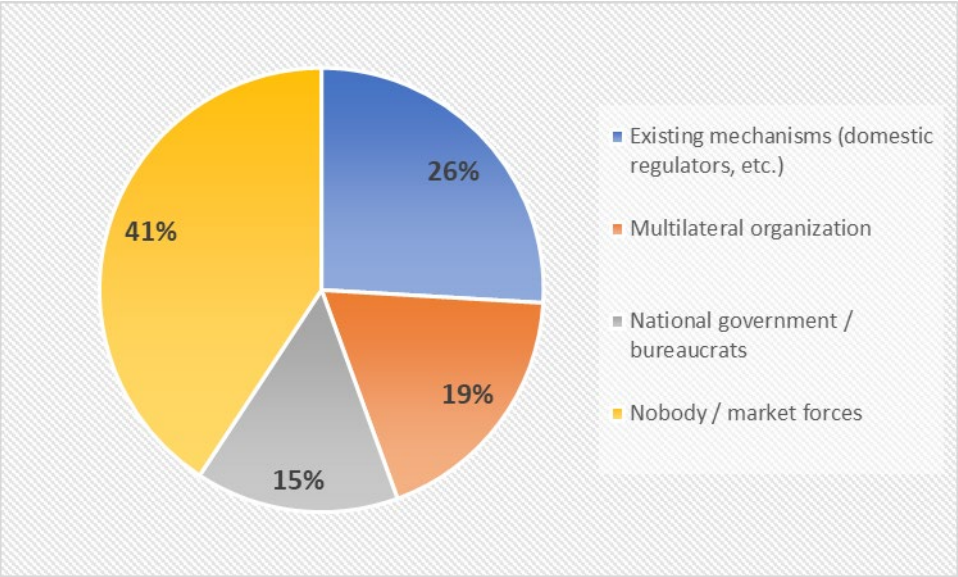


Figure 2.12: Who should regulate funding in the space resources industry?

As noted earlier, respondents were hesitant to comment on the final three questions. However, when asked to name a single piece of regulation that they would enact, or amend, to help develop a stronger funding ecosystem for space resources, participants who were sufficiently comfortable to respond invariably pointed toward ensuring clarity regarding property rights and providing assurance that such rights will be applied and respected internationally. The sole deviations from this position came from two respondents, who proposed tax credits or tax breaks for space resource activities. One of these two respondents also suggested that policy should be adapted to provide for limitation and removal of space debris.

2.7.3 Countries with Strong Legislation to Support the Space Resources Sector

When asked to describe which country has the strongest legislation to support space resources, respondents identified the four countries that have enacted such legislation. Additionally, the United Kingdom, due to the strength of its aviation regulation, as well as China and Russia, were mentioned. As with government support for the industry, regulatory and legislative support varies from country to country.

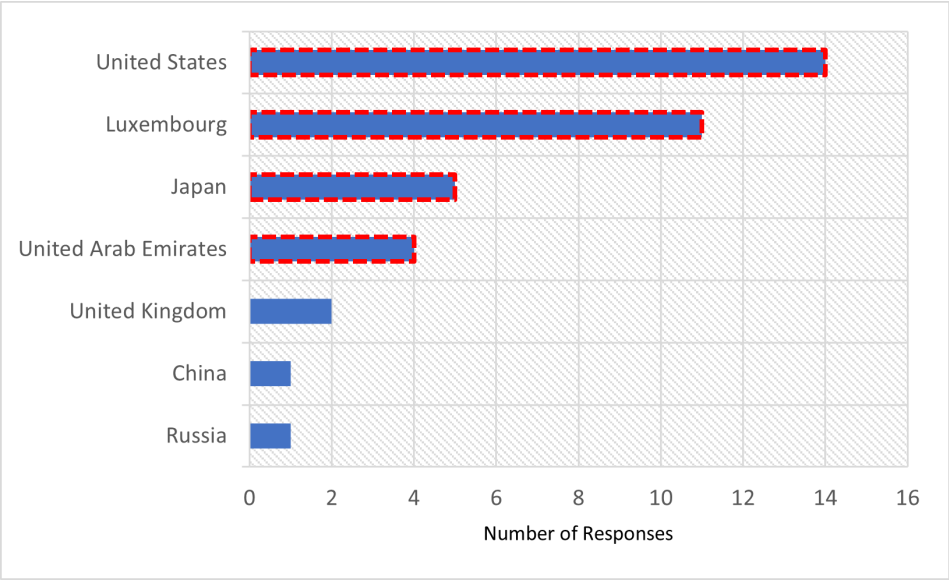


Figure 2.13: Respondents' attitudes regarding countries with strong space resources legislation

Interestingly, no respondent was willing to describe any given country's specific shortcomings or obviously missing regulation, but many felt that no single country's regulatory measures were currently sufficient to support and develop a space resources sector. One respondent mentioned that political science, as a discipline, lacks the patience necessary to project the potential future impact of the development of a space resources industry due to a limited ability to demonstrate impact in the near term. In this respondent's opinion, this inability is a key factor underpinning the insufficiency of current legislative and regulatory efforts regarding the space resources sector.

2.8 Discussions and Findings

Additional themes, which respondents shared outright, or which emerged over the course of the interviews, were also revealing as to the state of space resources industry funding.

2.8.1 Key Findings

Table 2.4: Summary of key findings

Section	Key Findings
Defining Space Resources	• Survey respondents' definitions of space resources were varied and inconsistent ○ Likely reflective of the nascence of the industry and the opportunity it entails • Survey respondents' definitions of space resources influenced their responses to the subsequent questions
Current State of the Space Resources Industry	• Water and energy are believed to be the biggest opportunities in the development of the space resources sector, followed by habitat and telecommunications • Financing is believed to be the biggest challenge to the development of the space resources sector, followed by the lack of domestic

Table 2.4: Summary of key findings continued

Current State of the Space Resources Industry (cont'd)	political and commercial interest • Out of the five top countries considered to be actively supporting the space resources sector, four have passed national space resources legislation (the United States, Luxemburg, the United Arab Emirates, and Japan), with the fifth country being China
Funding of the Space Resources Industry	• Respondents were generally split in their belief that the space resources sector is adequately funded, not adequately funded, or "don't know"/ "it depends" • Respondents were almost evenly split in believing that the space resources sector will, in the future, be mostly privately funded versus supported through a mix of public and private funds • Contracting with publicly funded entities was believed to be the biggest opportunity in terms of developing funding for the space resources sector, with creating infrastructure, technology transfer, and data being reported as other key opportunities • The two biggest challenges in developing funding for the space resources sector were that the financial return is unclear and that the legal and/or regulatory return is unclear o These were followed by the beliefs that the market opportunity is unclear, that there is risk and/or an inability to price risk, and then lack of investor knowledge and lack of technical knowledge • The five geographies most supportive of funding for space resources were given as the United States, Luxembourg, the United Arab Emirates, the European Union, and China o Three of those geographies have passed national space resources legislation o Many respondents felt that the size of the U.S. economy in general contributed to its lead as a geography supportive of funding space resources
Key Funding Partners and Supporters	• Respondents believed that communication and understanding between providers of capital and users of capital in the space resources sector was insufficient • There is a perceived lack of professionals who properly understand the opportunities and risks inherent in space resources and who can communicate appropriately with the investment community • Support by governments for the space resources sector is varied and dependent on the government and geography • There is strong support for space resources from the venture capital market, but support from the larger, more traditional sources of private funding, including debt capital providers, is limited • A significant amount of education is necessary for the private sector to understand and begin investing meaningfully in space resources
Regulation and Legislation in Funding Space Resources	• 41% of respondents stated that market forces should regulate the space resources industry, with the remainder saying that existing mechanisms are sufficient (26%), that a multilateral organization should provide regulation (19%), or that national governments/bureaucrats should do it (15%) • Out of the five top countries considered to have strong legislation supporting the space resources sector, four have passed national space resources legislation (the United States, Luxemburg, Japan, and the United Arab Emirates), with the fifth being the United Kingdom

2.8.2 Biases

Certain biases became apparent when examining the respondents' answers collectively. Interviewees were selected to include a wide range of industries—law, entrepreneurship, corporations, finance—and, as such, each respondent spoke to whatever they were knowledgeable and comfortable speaking about. The differences in the answers returned by respondents operating in different sub-industries call attention to the need for increased communication and education between industry actors. Conversely, the fact that all the respondents are active in the space resources industry may bias them toward the view that this industry is of greater importance than what society or governments currently accord it.

Another bias that emerged pertained to geography. In their answers, respondents based in North America tended to focus on Western countries and companies, whereas respondents based in Europe and, especially, the Indo-Pacific region tended to mention China more often. When asked directly about this discrepancy, following the formal questions, one respondent pointed to the fact that actors in these two groups (North America versus Europe and the Indo-Pacific) exhibit little overlap in the conferences they attend or the research they undertake; and that a lack of exposure to one another affects the importance they accord to the contributions to the sector from their respective spheres.

It is also important to acknowledge the author's bias. The information presented in this paper is the distillation of thirty hours of conversation. Using transcripts, the author collated and interpreted the information to present a coherent, collective view of thirty individuals from disparate professions as to how they view the state of space resources funding. As such, the author needed to make certain assumptions and generalizations, such as inferring context while categorizing responses, in order to present this data as succinctly and accurately as possible.

2.8.3 Other Thematics

Several respondents made references to space resources companies that were very active and successful in raising money, but less successful in executing their business plans. Among these respondents, there was a general feeling that these companies have harmed the industry's funding prospects and even tainted governments' views on providing support for the industry. Some respondents identified a need to educate government personnel, as well as both the investing and the non-investing public, to win broader acceptance for the industry.

Respondents also drew analogies to the California Gold Rush of the late nineteenth century. The space resources sector, these respondents observed, is similarly a nascent industry—a "wild west"—but they also noted that there is room in the industry for a wide variety of players, from active leaders to providers of

infrastructure, such as markets or “pick and shovel” providers.

The issue of debris arose quite often as a topic of conversation, not as a space resource but as a potential impediment to the industry’s development. There was a consensus among these respondents that space debris is a genuine problem, which will need to be tackled and does not currently receive sufficient attention from the industry.

When asked about other relevant themes and issues that had not yet been discussed, responses ranged from the value of public-private partnerships to the need to educate the investing community about space resources, to potential inequalities between wealthy countries and poor countries. Each interview suggested avenues for further research; however, for the purposes of this paper, we remain focused on the state of the space resources industry, the state of funding for the industry, partnerships in the ecosystem, and regulation and legislation. Advancing this research, the author believes, promises significant potential for the industry

2.9 Conclusion

The pool of respondents for this research was comprised of individuals from significantly varied backgrounds (law, business, education, etc.) and the resulting discussions and responses reflected these differences. As such, the author may have imbedded unconscious biases into the responses, simply through processing and distilling the responses, and seeking to identify commonalities and unique differences among the respondents. However, because all of the respondents are active participants in the space resources sector, significant thematic similarities emerged, which contributed greater certainty and confidence in presenting the responses. As the interview process progressed, it was interesting to be able to identify certain unique differences and to try to discern the reasons for them. Perhaps future research may explore these differences further, yielding new insights and understanding, and thereby helping to develop the industry.

In addition, the interview findings suggest that due to the industry-wide lack of a universally accepted definition of space resources, it is difficult for the supporting financial infrastructure to gain a foothold in the wider business community and become recognized as a legitimate funding branch. Interview evidence suggests that apart from R&D funding aimed at the development of terrestrial mining technologies, funding for space resources will continue to be either an afterthought in the wider market, a derivative of technology and start-up funding, or simply be linked to and constrained by the public purse.

It was also found (although it is perhaps also intuitively obvious) that more developed countries, particularly those that have enacted laws supporting space resources exploitation, such as the United

States, China, Japan, and Luxembourg, tend to be the most active in funding space resources and supporting space resources development in general. Following these countries are other countries that have well-established markets for funding terrestrial resource development, such as Canada and the Scandinavian countries.

A significant difference was also observed with regard to the understanding of funding sources between individuals focused solely on the space resources industry and individuals involved with larger companies where space resources represent but one aspect of their operations among many. Further research could and should be focused on a better understanding of the latter type of company, and how they make capital allocation decisions.

2.10 References

[1] Y. Zhoa, Space commercialization and the development of space law, Oxford Research Encyclopedia: Planetary Science, 30 July 2018. https://doi.org/10.1093/acrefore/9780190647926.013.42

[2] M.S. Saletta, K. Orrman-Rossiter, Can space mining benefit all of humanity? The resource fund and citizen's dividend model of Alaska, the "last frontier," Space Policy 43 (2018) 1–6.

[3] Organisation for Economic Co-operation and Development. Space 2030: Exploring the future of space applications. OECD Publishing, 2004.

[4] Morgan Stanley. Space: Investing in the final frontier. https://www.morganstanley.com/ideas/investing-in-space, New York, 2017.

[5] K. George, The economic impacts of the commercial space industry, Space Policy 47:3 (2019) 181–186.

[6] Space Foundation, The Space Report 2021 Q2. https://www.spacefoundation.org/2021/07/15/global-space-economy-rose-to-447b-in-2020-continuingfive-year-growth/

[7] BryceTech, B. (2022). Update on investment in commercial space ventures. 2022. https://brycetech.com/reports/report-documents/Bryce_Start_Up_Space_2022.pdf, 2021.

[8] S. Atkins, The commercialization of outer space: How an international securities framework can be the launching pad for a global space economy, International Corporate Rescue 19:3 (2022).

[9] M. DePagter, "Who dares, wins": How property rights in space could be dictated by the countries willing to make the first move, Chic. J. Int. Law 1:2 (2023) 116–133.

[10] C. Foster, Excuse me, you're mining my asteroid: Space property rights and the U.S. Space Resource Exploration and Utilization Act of 2015, U. Ill. J.L. Tech. & Pol'y 407 (2016).

[11] T.R. Masson-Zwaan, B. Richards, International perspectives on space resources rights, SpaceNews, 8 December 2015. https://spacenews.com/op-ed-international-perspectives-on-space-resource-rights/.

[12] M.V. Dejonckheere, Semistructured interviewing in primary care research: A balance of relationship and vigor. Family Medicine and Communal Health, 7(2), e000057. 2019. DOI: http://dx.doi.org/10.1136/fmch-2018-000057

[13] H. Alshenqeeti, Interviewing as a data collection method: A critical review. English Linguistics Research, 3(1). 2014. doi: 10.5430/elr.v3n1p39

[14] O.T. Hargie, Auditing organizational communication: A handbook of research theory and practice. Routledge. 2009

[15] B. Glaser, A.L. Strauss. The discovery of grounded theory: Strategies for qualitative research. Aldine De Gruyter. 1967

[16] C. Parker, S. Scott, A. Geddes. Snowball sampling. SAGE Research Methods Foundations. https://methods.sagepub.com/foundations/snowball-sampling, 2019.

[17] C. von Soest. Why do we speak to experts? Reviving the strength of the expert interview method. Perspectives on Politics, 21(1), 277–287. 2022. DOI: 10.1017/S1537592722001116

[18] U.S. Congress. National and Commercial Space Programs. Public Law 111–314. 111th Congress.

2010

[19] Hague Working Group. Building Blocks for the Development of an International Framework on Space Resource Activities. Leiden: The Hague International Space Resources Governance Working Group, 2019 Available at: https://www.universiteitleiden.nl/binaries/content/assets/rechtsgeleerdheid/instituut-voor-publiekrecht/lucht--en-ruimterecht/space-resources/final-bb.pdf

[20] United States Congress, H.R.2262 – U.S. Commercial Space Launch Competitiveness Act, 25 Public Law 114–90, 114th Congress, November 2015. https://www.congress.gov/bill/114th-congress/house-bill/2262.

[21] K. Davidian. The beginning of new markets. New Space, 7(3), 117–119. 2019.

[22] International Monetary Fund. 2023. Retrieved from: https://www.imf.org/en/Publications/WEO/weo-database/2023/April/weo-report?c=924,158,137,456,466,111,&s=NGDPD,&sy=2022&ey=2022&ssm=0&scsm=1&scc=0&ssd=1&ssc=0&sic=0&sort=country&ds=.&br=1

[23] Space Capital, www.spacecapital.com. Accessed 12 May 2022.

[24] E.K. Livni. The space industry is taking off. Space law is still a mystery. New York Times. June 17, 2023.

[25] M. Maidenberg, Space companies struggle to meet lofty goals. Wall Street Journal. August 5, 2023

[26] United Nations. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies. United Nations Office for Outer Space Affairs (UNOOSA). 1966

[27] C.D. Johnson, C. D. The Outer Space Treaty. In Oxford research encyclopedia of planetary science. 2018. DOI: 10.1093/acrefore/9780190647926.013.43

[28] United Nations. Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space. United Nations Office for Outer Space Affairs (UNOOSA). 1967. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introrescueagreement.html

[29] United Nations. Convention on International Liability for Damage Caused by Space Objects. United Nations Office for Outer Space Affairs (UNOOSA). 1971. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html
https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introliability-convention.html

[30] United Nations. Convention on Registration of Objects Launched into Outer Space. United Nations Office for Outer Space Affairs (UNOOSA). 1974. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introregistration-convention.html

[31] United Nations. (1979). Agreement Governing the Activities of States on the Moon and Other Celestial Bodies. United Nations Office for Outer Space Affairs (UNOOSA). 1979. https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/intromoon-agreement.html

[32] L.T. Hao, F. Tronchetti, The American Space Commerce Free Enterprise Act of 2017: The latest step in regulating the space resources utilization industry or something more?, Space Policy 47 (2018) 1–6. DOI:10.1016/j.spacepol.2018.02.004

[33] B.M. Cahan, Outer frontiers of banking: Financing space explorers and safeguarding terrestrial finance, New Space 4:4 (2016) 253–286. DOI: 10.1089/space.2016.0010.

CHAPTER 3

THE INVESTMENT IMPACT OF ENACTING SPACE RESOURCES LEGISLATION

Submitted to Space Policy.

3.1 Abstract

Significant attention is now being directed toward the space resources industry in what people are calling the next frontier of mineral exploration. The basic space treaties were proposed and executed at relatively early stages in the development of space exploration and exploitation, and, as such, were drafted to be ambiguous as new technologies were developed. To that end, individual states are beginning to propose domestic legislation to regulate space property rights. To date, the United States, Luxembourg, Japan, and the United Arab Emirates have succeeded in enacting such laws, with other countries currently drafting similar legislation.

This paper does not attempt to discuss the suitability of or to interpret domestic law and how it fits within the framework of the basic space treaties; rather, it reflects upon the domestic space property rights legislation that has been enacted and examines the impact that those laws have had upon investment into the country in which they were passed.

3.2 Introduction

Outer space, with its unique features, serves as an ideal incubator for the development of diversified commercial activities, including space launching, space tourism, remote sensing, telecommunications, small satellites and, importantly, space mining and the development of space resources [1], whether it be on asteroids or the surface of the Moon.

Space resources, which are defined in United States law as “any tangible or intangible benefit which can be realized only from (A) aeronautical and space activities; or (B) advancements in any field related to space,” [2] and by The Hague Working Group as “extractable and/or recoverable abiotic resource[s] in situ in outer space” [3], are often cited as a crucial component in current plans to develop a new space economy and unlock the commercial potential of space. Some of these plans, to be carried out in the coming decades and championed by both the public and private sectors, include orbital outposts and hotels, space-based solar power stations, and manned and/or robotic missions to the Moon and Mars.

Furthermore, resources from the Moon, Mars, and certain asteroids have been proposed for use in human space exploration to produce propellants, water for life support, structural materials, and radiation and heat shielding [4]. These asteroids in particular present the possibility of a vast source of

minerals, free from environmental or land use restrictions. A dream of science fiction for decades, recent developments in the areas of robotics, autonomy, artificial intelligence and, most notably, reduced launch vehicle costs, now place space resources development within technological and cost-effective reach.

The scale of this opportunity is enormous. The Space Project Team of the Organisation for Economic Co-operation and Development International Futures Program (IFP) determined that the future demand for commercial space applications is likely to be substantial. They presented three likely scenarios, with different geopolitical, socioeconomic, and energy and environment characteristics. Using the three IFP scenarios for Space 2030 and the presented cost of access to space, this research determines the potential impact, for the US economy, of the change in final demand of the space value chain. The IFP estimates encompassed an 18–40% growth range for the industry from 2004 to 2030 [5]. This estimate is a conservative one, as Morgan Stanley estimates that the industry will be worth more than USD $1 trillion by 2040 [6,7]; and, in 2021, the Space Foundation found that by 2020, the global space economy had risen to USD $447 billion, an increase of 4.4% from $428 billion in 2019, and of 55% from a decade ago. Commercial space activity grew 6.6% to nearly $357 billion in 2020, representing close to 80% of the total space economy [8].

In an op-ed published in SpaceNews, prominent professionals in the field of space law opined that, “with the promise of property rights comes confidence for investors, which invariably leads to more money and technology” [9]; and, building on this, in providing confidence for investors, companies can move forward with their plans to extract resources [10]. Conversely, the lack of a comprehensive legal framework and the consequent uncertainty surrounding legality and the conditions under which space resources can be utilized represent a significant barrier to private investment [11].

Therefore, in order to access this emerging market opportunity, a growing number of countries have already begun to implement policy facilitating space resource development, including in-situ resource utilization, the term used to refer to the generation of consumables, for purposes of supporting robotic or human activities, from raw materials found in situ on the Moon or other planetary bodies [12]. These countries have seen increased investment in their commercial space sectors, with a growing number of companies (and thus of employment) as well as improved technology development.

Half a century ago, the United States and the USSR were the major space players; however, more than 90 countries are now involved in space-based activities. Currently, about 35 countries have their own national space research institutions, while 13 countries and one international organization (the European Space Agency) have independent space launch capability [13].

Out of all of these countries involved in the exploration and discovery of outer space, four have actively

developed frameworks and enacted legislation for the development of space resources: the United States, Luxembourg, the United Arab Emirates, and Japan. Certain other countries, such as Saudi Arabia, are actively working on developing their own frameworks.

The rationale behind the adoption of these laws is twofold: 1) to establish, under domestic law, the right of private entities to recover, own, and use space resources; and 2) to set up procedures to authorize private companies to carry out space mining activities. The latter point is directly connected with Article VI of the Outer Space Treaty, which requires private entities to be authorized and continuously supervised by an "appropriate State" before being entitled to carry out space activities [14].

In addition, it is worth noting that China, a significant sovereign participant in space activities, has enacted legislation that has allowed the proliferation of private companies focused on the space industry. Further, China recently outlined a plan for the development of space resources looking toward the year 2100 [15].

There is a significant amount of research considering the ramifications, legal or otherwise, of passing such space resource laws vis-à-vis international treaties. Comment on these issues is beyond the scope of this paper; rather, this paper focuses on the statistically significant effect of increased investment into jurisdictions that have enacted domestic space resource laws.

3.3 Background on National Frameworks for Space Participation and Space Resources Legislation

Interestingly, the commercialization of space is an example of a field of radical innovation that supports additive rather than displacement entrepreneurship. For example, jobs related to asteroid mining or space tourism do not displace existing mining or tourism jobs [16]. This aspect of additive economic and job creation creates an incentive for states to capture investment at the expense of other countries.

Recognizing this, in 2013, NASA's Office of Strategy Formulation released a report promoting public-private partnerships for developing economic growth and promoting NASA's mission of exploring the unknown in air and space [17]. However, humankind's activities in space are no longer limited to exploration and research; we are rapidly seeking to commercialize space, including through the exploitation and development of space resources. In addition, in 2017, the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) encouraged members to develop national space legislation [1].

As such, individual states are now looking to regulate an industry that did not exist when the basic

space treaties were originally signed. In fact, the basic treaties—the Outer Space Treaty (1967), the Rescue Agreement (1967), the Space Liability Convention (1972), the Registration Convention (1974), and the Moon Agreement (1979)—were executed at relatively early stages in the development of space exploration and exploitation, and, as such, may require updating to address the needs of the growing space resources industry.

In an article discussing the commercialization of outer space, a lawyer with the international law firm Norton Rose Fulbright opined that the Outer Space Treaty does not extend explicitly to the regulation of the ownership rights of private entities in outer space. Although a notion of "common ownership" of resources acquired in outer space (relevant particularly for space mining and engineering activities) is embodied in the Moon Agreement, this is limited to resources acquired from the Moon and does not extend to those acquired from other celestial bodies. A framework for the creation, recognition, priority, and enforcement of ownership interests in outer space therefore remains outside the scope of any current international instrument [18]. In addition, some believe that non-traditional space activities (such as in-situ resource utilization, or ISRU) lack clear and dedicated international rules to govern them [19].

To address this, countries are beginning to develop their own frameworks and legislation under which space resource companies can operate. Commercial space activities, like other commercial activities, are governed by their respective states' national laws [20]. These include contract, property, tort, creditors' rights, bankruptcy, insolvency and reorganization, and other laws.

A common denominator for all these countries that have established or are soon to establish Space Resources Legislation is that they are advanced, well capitalized economies, with the capacity and sophistication to fund markets and to accurately price risk and expect a commensurate return—especially as the public purse, which has historically funded space activities, has been withdrawn in the expectation that private capital will fill the gap.

3.4 United States

The United States was one of the first countries to ratify the Outer Space Treaty in 1967, and is thus bound by its articles. In 1979, several countries signed the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies. This agreement stipulates that any activities in space should conform to international law and provides a framework of laws (Article 11.5) to establish an international cooperation regime, including appropriate procedures, to govern the responsible exploitation of natural resources of the Moon. The United States, however, was not a signatory to this agreement (nor were China or the former USSR). In 2015, the Obama administration enacted the Commercial Space Launch Competitiveness Act (CLCSA), which made the United States the first country to establish space resources

policy [21].

Pursuant to Title IV of the CLCSA, US companies were granted, under US law, the right to possess, own, transport, use, and sell asteroid and space resources. This provision was complemented by the so-called "disclaimer of sovereignty," which clarified that private space mining activities could not result in the appropriation of the celestial body where resources were recovered [21].

Also included in the CLCSA is the provision that outer space is not a global commons and that not all of the rights and entitlements of the United States are imputable to nongovernmental entities [19]. Some claim this policy violates the tenets of the Outer Space Treaty [22]; more recently, however, NASA has gone so far as to offer to purchase lunar samples from commercial entities [23]. As then NASA administrator Jim Bridenstein elucidated: "What we're trying to do is make sure that there is a norm of behavior that says that resources can be extracted and that we're doing it in a way that is in compliance with the Outer Space Treaty."

The CLCSA recognizes the ability of private entities to acquire ownership rights over resources in outer space via its provision that "a United States citizen engaged in commercial recovery of an asteroid resource or a space resource … 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" [21,18].

In 2020, two additional policy measures were enacted by the Trump administration. The first is the Artemis Accords, which include NASA's global legal framework for mining on the Moon. This policy "include[s] an agreement that extraction and utilization of space resources should be conducted in a manner that complies with the Outer Space Treaty and in support of safe and sustainable activities. The signatories affirm that this does not inherently constitute national appropriation, which is prohibited by the Outer Space Treaty. They also express an intent to contribute to multilateral efforts to further develop international practices and rules on this subject" [24].

The second was an executive order—Encouraging International Support for the Recovery and Use of Space Resources [25]—which reaffirmed the Commercial Space Launch Competitiveness Act and stated that the United States is not bound by the abovementioned 1979 Moon Agreement. Most importantly, the executive order is relevant when considered in connection with the fundamental question of how new rules governing the recovery and use of space resources should be developed.

Importantly, Title IV of the CLCSA did not set up a procedure to authorize private space mining activities but, rather, simply required the president to submit to Congress a report suggesting the federal

agency that should be in charge of licensing such activities [26]. However, with the enactment of the 2020 US National Space Policy, the Secretary of Commerce was formally given the task to develop authorization and supervision processes for those activities that fall outside the scope of existing authorization and supervision procedures [27].

It is evident, therefore, that the main priority for US legislators in 2015 was to establish the right of US companies to collect and own space resources [14].

The United States has also provided investment for the development of infrastructure that could be deployed for the purpose of space resources development. Estimated to be in excess of USD $100 billion, NASA has funded space resources development adjacent initiatives such as: Commercial Lunar Payload Services (CLPS); the Launch Services Program (LSP), from which companies such as SpaceX have received funding; and the Artemis Program, which includes plans for both landed assets on the lunar surface and Gateway, a lunar-orbiting space station. Future endeavors include a Moon base and accompanying ISRU-related activities.

3.4.1 Luxembourg

Since 2017, Luxembourg has made a concentrated effort to become a global hub for the development of in-situ resource utilization. It has done this through legislation and financial incentives for companies. As a result, Luxembourg is clearly the leading country for incorporating companies focused on ISRU or various support capacities for such companies.

Luxembourg ratified the 1967 Outer Space Treaty [28] in 2006. The treaty states that nations must use space for peaceful purposes and can neither occupy nor own territory. However, the treaty lacks clarity about the ownership of metals, minerals, and other resources that may be found in space.

In 2016, Luxembourg launched its SpaceResources.lu initiative, which sought to position Luxembourg as a pioneer in the exploration and utilization of space resources. As the Agency's homepage explains, the initiative's goal "is to ensure that space resources explored under its jurisdiction serve a peaceful purpose [and] are gathered and used in a sustainable manner compatible with international law and for the benefit of humankind. Luxembourg's vision is built on support for advanced research activities and technological capabilities, drawing on the country's existing expertise in the space sector and its ongoing strategy of economic diversification into future-oriented high-tech industries" [29].

The SpaceResources.lu initiative is built on five pillars:

i. Political support: ensure national political support and promote international cooperation

ii. Legal framework: build a clear legal framework and engage internationally

iii. Research and education: provide long-term public support and workforce engagement

iv. Innovation, R&D: provide dedicated support for industrial R&D activities

v. Funding instruments: develop long-term funding instruments

With reference to the last point, the country also announced the opening of a €200 million (~USD $215 million) line of credit for entrepreneurial space companies to set up their European headquarters within its borders [30].

In 2017, The Space Resources Law [31] was enacted, which states that private companies can be entitled to the resources they mine in outer space, but they cannot own celestial bodies. Other portions of the Act set up a system for the government to authorize and supervise resource extraction and other space activities. Luxembourg's law also aims at providing a cheap legal regime by ensuring only moderate fees and low tax rates [32].

Luxembourg's 2017 Law on the Exploration and Use of Space Resources states in its first article that "space resources are capable of being appropriated," thereby giving private entities a pathway to acquire ownership of the resources they extract from outer space [18]. This grant of resource ownership applies only after resources have been extracted, thereby avoiding potential conflicts with the Outer Space Treaty, which prohibits companies from claiming territory on celestial bodies.

One difference between the CLCSA and the Luxembourg law is that the latter contains a detailed procedure to license private space mining operations while, as currently written, the American one does not. The Luxembourg law obliges a company to have its registered office in Luxembourg and requires that it prove its stability from financial, technical, and governance standpoints [14].

In an effort to cooperate on space activities, including the exploration and utilization of space resources, Luxembourg has signed memorandums of understanding with: the United Arab Emirates (2017); Japan (2017); China (2018); the Czech Republic (2018); Poland (2018); the United States (2019); Belgium (2019) [33]; South Korea (2022) [34]; and Canada (2022) [35].

In 2018, Luxembourg established its own space agency, the Luxembourg Space Agency (LSA), and, in 2020, launched the European Space Resources Innovation Centre (ESRIC) in collaboration with the European Space Agency. The goal of the Centre is to "create an internationally recognized entity of expertise for scientific, technical, business and economic aspects related to the use of space resources, including water on the moon, and metals and minerals in asteroids." Luxembourg has sought to

"contribute to economic growth by supporting commercial initiatives and start-ups, offering a business incubation component and enabling technology transfer between space and non-space industries" [36].

Luxembourg has allocated €16 million to the human and robotics exploration program at ESRIC for the period 2020–24, with a ~20% increase expected for the 2023–27 timeframe [37].

3.4.2 United Arab Emirates

The United Arab Emirates (UAE) signed onto the Outer Space Treaty [28] in 2000, and became the third country to sign the Artemis Accords. In 2014, the UAE initiated a domestic space agency, followed quickly by a domestic space policy in 2016, with the stated goal of "becoming an integral international partner in the study and exploration of the Solar System in particular, and outer space in general, including exploration of available resources there" [38].

The UAE's National Space Law, which came into effect in December 2019, provides a legal framework that supports the exploitation and utilization of space resources (upon obtaining a permit from the UAE Space Agency), operating in conjunction with the UAE's National Space Policy and National Space Strategy 2030. One of the express objectives of the National Space Law is to stimulate investment and encourage private sector participation in space sector activities [18]. In addition, the insertion of space mining-related provisions in the UAE National Space Law is to be understood in connection with the country's plan to become a major space player in the Middle East and to attract all kinds of space-related ventures, including those related to space mining [14].

In 2017, the UAE signed a memorandum of understanding with Luxembourg that included language on space resource utilization [39]. This is relevant, as the memorandum allows for companies based in the UAE to operate in Luxembourg and thereby access that country's regulatory framework as well as its system of grants specific to space resource utilization. This also facilitates the exchange of technical and research information relating to space resources development, thereby bolstering Luxembourg's position as a hub for space resources development. The UAE enacted a domestic space resource utilization policy in 2020 [40], becoming the third country to do so.

In September of 2019, a UAE astronaut visited the International Space Station, becoming the first Emirati launched into space [41].

To date, the UAE has launched seven telecommunication and Earth observation satellites [42]. In 2022, the Emirates earmarked USD $820 million over six years for the development of a variety of space programs [43], including planetary missions to the Moon, Mars, and Venus. Most recently, it outlined plans for an asteroid mission to be conducted in 2028, a necessary first step in any future asteroid-mining

endeavors [42].

3.4.3 Japan

Japan ratified the Outer Space Treaty in 1967, did not sign on to the Moon Treaty, and signed a five-year memorandum of understanding with Luxembourg in 2017. The terms of the Luxembourg agreement support exchange of information and expertise on the exploration and commercial utilization of space resources, as well as enhancement of further cooperation in the field of space activities, most notably on legal, regulatory, technological, economic, and other aspects of exploration [44]. Japan was among the initial seven countries to sign the Artemis Accords, in 2020 (there are 23 signatories at the time of writing).

In 2021, Japan became the fourth country to enact a domestic space resources development policy. Passed by the National Diet (Japan's legislature), the Law Concerning the Promotion of Business Activities Related to the Exploration and Development of Space Resources (Act No. 83) provides similar provisions to those of legislation in Luxembourg and the United States, inasmuch as Japanese private business operators are permitted to engage in the exploration and development of space resources. Resources are defined as "water, minerals, and other non-living resources in outer space, on the Moon and other celestial bodies." Again, similar to other nations' domestic laws, Japan's space resources act provides that the person who obtained the permit owns the space resources [45].

Further, under the Law Concerning the Promotion of Business Activities Related to the Exploration and Development of Space Resources, Japanese entities may prospect for, extract, and use various space resources if the Japanese government approves their stated objectives, timing, and research methods [32].

In January 2023, Japan and the United States signed a space partnership agreement [46]. Details regarding the Framework Agreement for Cooperation in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, for Peaceful Purposes have yet to be released, but it is believed that the agreement will reaffirm elements of the Artemis Accords and may potentially contain specific language on the use of space resources.

Japan has similarly invested in ISRU-related developments, with an estimated 120 joint research projects being undertaken to date [47]. The Japan Aerospace Exploration Agency (JAXA) also inaugurated an innovation Hub Centre, with a total budget of nearly ¥300 million (approximately USD $2.1 million in 2023 dollars), and this includes an ISRU component [48]. This is in line with Space Industry Vision 2030, Japan's 2017 strategic plan, which sets out the nation's aim of doubling the market

size of its space industry to ¥2.4 trillion (approximately USD $17 billion in 2023 dollars) by 2030 [49].

Table 3.1: Comparison of states' domestic space resources laws [32]

	United States	Luxembourg	United Arab Emirates	Japan
Legality of appropriations	Activities in law are not claims of ownership or sovereignty over the celestial body	Explicitly states that resources can be appropriated	States desire to comply with international law	States desire to comply with international law
International obligations	President must discourage barriers and promote right to exploit	No requirements on national government	Emirates Space Agency must support conclusion of international agreements that help the objectives of their law	Government must facilitate international system that allows development of space resources
Space resources definition	Abiotic resources in or on celestial body	Acknowledges US definition as the common definition	Non-living resources	Water, mineral, and natural resources
Who can have property rights	Citizen, national, or organized in the country	Citizen, national, or organized in the country	Citizen, national, or organized in the country	Launch and control must be within their borders

3.4.4 China

Although it is difficult to quantify the impact of legislation in a centrally controlled economy such as China's, the progress they have made in promoting their commercial space industry and establishing laws allowing for privatization is worthy of note. China has had a space program in development since the 1950s, one that generally coincided with the development of NASA [50]. At the time, similar to the early Soviet space program, China's space-related companies and funding were focused on military technologies. Since the 1970s, in conjunction with China's economic rise through state-directed intervention and policy, China has developed an increasingly sophisticated space ecosystem that includes military, robotic, and human spaceflight. In 1980, Deng Xiaoping created the China Great Wall Industry Corporation (CGWIC), a division of the China Aerospace Science and Technology Corporation (CASC), to be the country's sole exporter of satellites and launch services. CGWIC was the only Chinese space company permitted to engage in international trade and, although CGWIC was marketed as a private company, in reality it was state controlled and effectively a state-owned corporation.

Beginning in 2000, when China issued its first White Paper on the subject of space, the country began to regard space as an important part of its comprehensive development plan. This led to growing government support for space-related activities, including China's first manned space mission in October

2003.

As its interest in space grew, China issued increased national policy guidance on how the sector ought to be developed, the most important examples being the five-year plans issued by the State Council (commonly known as the State Council White Papers on Space Activities, or simply the "Space White Papers"); the 2015–25 medium- and long-term development plan for the National Civil Space Infrastructure; and national policies regarding private investment in the space industry. In forwarding such guidance, policymakers made it clear that "they cannot continuously leapfrog technologies because this means they will have to follow foreign strategies in the global space community. China does not want to follow and play science and technology catch up, but is striving to learn to innovate and choose its own path to space" [51].

The Chinese State Council has issued five Space White Papers, in 2000, 2006, 2011, 2016, and 2022, to provide explicit policies and guidelines for the development of the space sector, including both public and private actors. The 2011 White Paper, though designating lunar exploration as a major target, made no reference to the need to enact domestic legislation regulating the use of space resources [52].

In addition, much of China's private commercial growth may be directly attributed to the issuance, by the Chinese government, of a national policy commonly referred to as Document 60, or, more formally, "Guiding Opinions of the State Council on Innovating the Investment and Financing Mechanisms in Key Areas and Encouraging Social Investment" (国务院关于创新重点领域投融资机制鼓励社会投资的指导意见). Document 60 was formally issued in 2014 by the State Council, the chief administrative authority of the People's Republic of China, which suggests that at the very highest levels, China's political decision makers support the development of a robust private space resources economy.

Policy documents that focus, broadly or specifically, on science and technology, such as Document 60 and the Space White Papers, are critical for understanding the development of the private space resources ecosystem, as they set out the state-approved framework within which start-up companies must operate. Document 60 has been critical in fostering investment into the Chinese space industry by private corporations, and helped proliferate a Chinese start-up culture focused on the space industry. In 2020, according to Xinhua, the official government news agency, the number of enterprises in China's commercial aerospace industries exceeded 140 [53]. As seen in Figure 14, the publication in 2014 of Document 60 helped encourage a boom of space-focused private start-ups within China's space industry.

Figure 14: Number of Chinese commercial aerospace companies by year [54]

China neither reacted to the US and Luxembourg passing of space resources laws nor officially commented on the lawfulness of domestic space mining laws [52]. However, on August 19, 2023, Wang Wei, the lead scientist at the CASC, addressed the Chinese Society of Astronautics and laid out plans to boost the global space economy and build a space resources system spanning the Solar System by 2100. This initiative, named Tiangong Kaiwu after an encyclopedic work compiled by Ming-dynasty scientist Song Yingxing (Tiangong Kaiwu means "The Exploitation of the Works of Nature"), sets out plans for constructing facilities to exploit water ice on the Moon, near-Earth asteroids, Mars, main-belt asteroids, and the moons of Jupiter, and eventually create a resupply system reaching across the Solar System [15].

3.5 Investment Impact of Enacting Space Resources Legislation

3.5.1 Terrestrial Impacts of Enacting Property Rights Legislation

As countries develop national space policy on space property rights, they attract investment, which is lured by the certainty of economic and regulatory protections, and of returns.

In 2021, the Trump administration released a study examining the beneficial impacts of enacting space legislation at a country level, including: diminishing the risks of short-term decision making, support for the ability of humans to receive benefits from space, enhanced investment and asset value, and protection against expropriation, among others [55].

These beneficial impacts have also been identified in terrestrial analogues. Numerous studies show that greater security for property rights increases both investment and economic activity in the terrestrial activities studied. Selected illustrative results are highlighted in table 6 below [55].

Table 3.2: Selected studies highlighting the beneficial impacts of enacting property rights legislation

Study	Industry	Cause	Effect	Timing of Impact
Acemoglu, 2001 [56]	All	Expropriation risk	GDP per capita increased 100%	10 years
Alston, 2020 [57]	Land	Tenure uncertainty	Investment delayed	5–10 years
Bohn, 2000 [58]	Oil	Expropriation risk	GDP per capita increased 100%	Immediate
Cust, 2020 [59]	Oil	Expropriation risk	Investment increased 200%	Immediate
Galiani, 2010 [60]	Housing	Tenure uncertainty	Investment increased 40%	15 years
Grainger, 2014 [61]	Fisheries	Tenure uncertainty	Asset value increased 50%	Immediate
Hornbeck, 2010 [62]	Agriculture	Enforcement	Productivity increased 23%	5–10 years
Johnson, 2002 [63]	Land	Tenure uncertainty	Investment Discouragement	5-10 years
Leonard, 2019 [64]	Water	Tenure uncertainty	Income increased 16%	40 years

3.5.2 Regression Analysis Source Data and Methodology

To understand the quantifiable impacts of enacting domestic space utilization policies, the authors began with data provided by Space Capital, a venture capital firm tracking investment in the space industry. Space Capital reports investment in companies focused on the space economy by the country in which they are registered. This proprietary data was collected through various sources: public announcements, confidential sources (diligence processes, management discussions, co-investor disclosure, investment partnerships, etc.), public news reports, investment databases, and crowd platforms, such as social media.

In Space Capital's methodology, no piece of data may be added to the databases until it is confirmed by multiple sources. Space Capital provided data for the period from the beginning of 2009 to the end of Q1 2023. This data was provided in Q2 2023. The data can be subject to change over time, as previously undisclosed deals are added to Space Capital's database.

Investments were deemed investments in the space economy if the core business relies on orbital access to deliver its values. This includes three primary industries: 1) applications: specialized hardware and software that utilizes data from space-based assets; 2) distribution: hardware and software to connect, process, and manage data from space-based assets; and 3) infrastructure: hardware and software to build, launch, and operate space-based assets.

3.5.3 Results

All of the investment data provided by Space Capital was evaluated using a fixed effects model—a statistical model used to analyze panel data or longitudinal data, wherein observations are collected across several time periods or on multiple individuals or entities. Using this model, we accounted for country and time-period effects, controlling for unobserved heterogeneity that may occur, allowing for estimation of the effects of the enactment of space resources legislation upon the volume of investment into the country examined. The software package used for this model was Stata, a general-purpose statistical software package developed by StataCorp LLC.

The aggregate annual private investment data into the space sector was regressed against a trend (refer to Table 7, below).

Unfortunately, upon reviewing the source data, we discovered that there are currently not enough data points for space investment in Luxembourg and the United Arab Emirates to provide a statistically significant value of investment increase. However, we were able to review data for the United States and for Japan.

Following the regression analysis, it was calculated that following the enactment of space resource legislation in Japan in 2021 and in the US in 2015, there was an increase in investment into the space resources sector of USD $6.7 billion when controlling for time as a trend, and USD$7.2 billion when for controlling for time with year dummies. This investment increase is found to be statistically different than zero, based on the available data.

Given Japan passed space resources legislation in 2021 and the data set used examined the years 2009 to 2022, a similar regression analysis using only the US data and excluding the Japan data revealed that the effect of passing space resources legislation in the US in 2015 led to an increase of USD $8.7 billion into the sector. This investment increase is also found to be statistically different than zero, based on the available data.

Table 3.3: Regression analysis

Outcome Variable: Private Investment into Space Sector			
	US & JAPAN	US & JAPAN	US
Property rights protection ($mm)	7,157*** (1,743)	6,713*** (1,754)	8,677***(2,000)
Time specification	Year dummies	Trend	Trend
Observations (n)	94	94	83
Notes: Data indicate annual private investment from 2009 to December 2022 in millions of dollars. Country fixed effects included. **** Represents statistical significance at the 1% level*			

Further analysis performed across all the countries represented in the data found average investment of $3.1 billion with a cumulative annual growth rate of 18.1%.

Table 3.4: Aggregate investment in space industry across select countries

Year	Number of Countries	Mean Aggregate Investment	Standard Deviation	Minimum Aggregate Investment	Maximum Aggregate Investment
2012	6	$ 0.4	$ 0.7	$ 0.0	$ 1.7
2013	6	$ 0.5	$ 0.8	$ 0.0	$ 2.0
2014	7	$ 2.8	$ 5.9	$ 0.0	$ 15.9
2015	7	$ 2.5	$ 3.2	$ 0.0	$ 7.7
2016	7	$ 4.8	$ 7.4	$ 0.0	$ 18.5
2017	7	$ 3.4	$ 4.4	$ 0.1	$ 10.4
2018	7	$ 5.7	$ 9.3	$ 0.2	$ 22.5
2019	7	$ 2.5	$ 4.3	$ 0.1	$ 12.0
2020	7	$ 3.5	$ 6.1	$ 0.2	$ 16.7
2021	7	$ 5.5	$ 8.6	$ 0.2	$ 23.7
2022	7	$ 2.3	$ 4.5	$ 0.0	$ 12.5

As the regression analysis indicates, after taking account for country and time effects, there is a statistically meaningful increase in investment in a country's space industry following that country's enactment of space property rights.

It is worth highlighting that the reliance of this paper's analysis on a single proprietary database, which can be subject to change retroactively as new information becomes available, may cause concern regarding the quality of the data. However, it is the author's belief that, due to Space Capital's leading position within the space investment community and its long history of tracking space economy investments, there is no better database available with which to study the impact of enacting space property rights legislation.

3.6 Conclusion and Recommendations

As noted earlier, it is worth repeating that this paper does not aim to address the legal complications that arise from the enactment of national space resource legislation but, rather, to identify that passing such legislation creates incremental investment in that nation.

As space moves ever closer to our daily lives, the commercialization of space presents itself as an irreversible trend toward further development of space activities [1]. As such, the passage of domestic space resource legislation has shown to be important for increasing investment in the space resources industry of the country that passed it.

Greater clarity is needed regarding the application of the principle of non-appropriation to space resource activities. The absence of such clarity creates uncertainty around the legal right to engage in commercial space resource utilization activities. This, in turn, may stifle innovation and dissuade private actors from investing in and undertaking such activities [65].

Based on the data set provided by Space Capital, it has been found that passing national space resource legislation helps to create the clarity required to attract investment, as countries that have passed such laws have seen statistically significant increases in investment in their domestic space industries.

It is worth revisiting the regression analysis of this data set regularly, as more investment information becomes available for the United Arab Emirates and Luxembourg, and as deeper data sets develop for Japan and the United States. Given both the current trend in investment into space resources, and industry size forecasts by large, globally recognized banks, it is apparent that further data of this kind will be forthcoming.

3.7 References

[1] Y. Zhoa, Space commercialization and the development of space law, Oxford Research Encyclopedia: Planetary Science, 30 July 2018. https://oxfordre.com/planetaryscience/display/10.1093/acrefore/9780190647926.001.0001/acrefore-9780190647926-e-42.

[2] United States, Public Law 111–314, 2010, Enactment of Title 51 – National and Commercial Space Programs, United States Government Printing Office, Washington, DC, 2010.

[3] Hague Working Group. Building Blocks for the Development of an International Framework on Space Resource Activities. Leiden: The Hague International Space Resources Governance Working Group, 2019

[4] M.S. Saletta, K. Orrman-Rossiter, Can space mining benefit all of humanity? The resource fund and citizen's dividend model of Alaska, the "last frontier," Space Policy 43 (2018) 1–6.

[5] Organisation for Economic Co-operation and Development, Space 2030: Exploring the Future of Space Applications, OECD Publishing, Paris, 2004.

[6] Morgan Stanley. (2017). Space: Investing in the final frontier. https://www.morganstanley.com/ideas/investing-in-space, New York, 2017

[7] K. George, The economic impacts of the commercial space industry, Space Policy 47:3 (2019) 181–186.

[8] Space Foundation, The Space Report 2021 Q2. https://www.spacefoundation.org/2021/07/15/global-space-economy-rose-to-447b-in-2020-continuingfive-year-growth/

[9] T.R. Masson-Zwaan, B. Richards, International perspectives on space resources rights, SpaceNews, 8 December 2015. https://spacenews.com/op-ed-international-perspectives-on-space-resource-rights/.

[10] C. Foster, Excuse me, you're mining my asteroid: Space property rights and the U.S. Space Resource Exploration and Utilization Act of 2015, U. Ill. J.L. Tech. & Pol'y 407 (2016).

[11] M. Svec, Outer space, an area recognized as res communis omnium: Limits of national space mining law, Space Policy 60 (2022) 101473. https://doi.org/10.1016/j.spacepol.2021.101473

[12] T. Spohn, D.J. Breue, Encyclopedia of the Solar System, third ed., Elsevier, Amsterdam, 2014.

[13] S.S. Hussain, India's Quest for "global space and influence" through the "outer space" domain, J. Space Saf. Eng. 10:3 (2023) 351–365.

[14] F.L. Tronchetti, The White House Executive Order on the Recovery and Use of Space Resources: Pushing the boundaries of international space law?, Space Policy 57 (2021) 101448.

[15] L. Xin, China launches road map to explore solar system, including steps towards creating space-age tech to mine and use water ice, South China Morning Post, 1 September 2023. https://www.scmp.com/news/china/science/article/3233067/china-launches-road-map-explore-solar-system-including-steps-towards-creating-space-age-tech-mine.

[16] W.P. Carter, A. Pezeshkan, The complexity of entrepreneurial ecosystem evolution and new venture policy: The case of the U.S. commercial space ecosystem, Technol. Forecast. Soc. 192 (2023) 122568.

[17] National Aeronautics and Space Administration, Public-private partnerships for space capability

development: Driving economic growth and NASA's mission, NASA, Washington, DC, 2014. https://www.nasa.gov/sites/default/files/files/NASA_Partnership_Report_LR_20140429.pdf.

[18] S. Atkins, The commercialization of outer space: How an international securities framework can be the launching pad for a global space economy, International Corporate Rescue 19:3 (2022).

[19] L.T. Hao, F. Tronchetti, The American Space Commerce Free Enterprise Act of 2017: The latest step in regulating the space resources utilization industry or something more?, Space Policy 47 (2019) 1–6.

[20] B.M. Cahan, Outer frontiers of banking: Financing space explorers and safeguarding terrestrial finance, New Space 4:4 (2016) 253–286. DOI: 10.1089/space.2016.0010.

[21] United States Congress, H.R.2262 – U.S. Commercial Space Launch Competitiveness Act, 25 November 2015. https://www.congress.gov/bill/114th-congress/house-bill/2262.

[22] R. Ridderhof, Space mining and (U.S.) space law, Carnegie Foundation Peace Palace Library, 18 December 2015. https://peacepalacelibrary.nl/blog/2015/space-mining-and-us-space-law.

[23] J. Foust, NASA offers to buy lunar samples to set space resources precedent, SpaceNews, 10 September 2020. https://spacenews.com/nasa-offers-to-buy-lunar-samples-to-set-space-resources-precedent/.

[24] The Artemis Accords: Principles for cooperation in the civil exploration and use of the Moon, Mars, comets, and asteroids for peaceful purposes, 13 October 2020. https://www.nasa.gov/wp-content/uploads/2022/11/Artemis-Accords-signed-13Oct2020.pdf.

[25] United States, Executive Office of the President, Encouraging international support for the recovery and use of space resources, Federal Register, 6 April 2020. https://www.federalregister.gov/documents/2020/04/10/2020-07800/encouraging-international-support-for-the-recovery-and-use-of-space-resources.

[26] P.R. Blunt, One small step: The impact of the U.S. Commercial Space Launch Competitiveness Act of 2015 on the exploration of resources in outer space, N.C. J.L. & Tech. 18:2 (2016).

[27] National Space Policy of the United States of America, 9 December 2020. https://history.nasa.gov/NationalSpacePolicy12-9-20.pdf.

[28] United Nations, Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, UN Office for Disarmament Affairs Treaties Database, 27 January 1967. https://treaties.unoda.org/t/outer_space.

[29] Luxembourg Space Agency, Spaceresources.lu initiative: Pioneers in space, last updated: 18 November 2019. https://space-agency.public.lu/en/space-resources/the-initiative.html (accessed 30 August 2023).

[30] M. Smith, Luxembourg stakes initial 200 million euros to become Silicon Valley of space resources, spacepolicyonline.com, 5 June 2016. https://spacepolicyonline.com/news/luxembourg-stakes-200-millio-euros-to-become-silicon-valley-of-space-resources/.

[31] Luxembourg Space Agency, Legal framework: International space law, last updated: 11 August 2023. https://space-agency.public.lu/en/agency/legal-framework.html (accessed 28 November 2023).

[32] M. DePagter, "Who dares, wins": How property rights in space could be dictated by the countries willing to make the first move, Chic. J. Int. Law 1:2 (2023) 116–133.

[33] D. Osville, T. Bovier, Luxembourg, a rising star in the space industry, Deloitte, 2023. https://www2.deloitte.com/lu/en/pages/technology/articles/luxembourg-space-industry-companies.html (accessed 28 November 2023).

[34] N.A. Gerhardstein, Luxembourg signs space MoU with South Korea, as latter announces new roadmap, Delano, 28 November 2022. https://delano.lu/article/luxembourg-signs-space-mou-wit.

[35] J. Bauldry, Luxembourg & Canada ink space MoU, Silicon Luxembourg, 25 June 2022. https://www.siliconluxembourg.lu/luxembourg-canada-ink-space-mou/.

[36] Luxembourg Space Agency, European space resources innovation center, 4 April 2022. https://space-agency.public.lu/en/space-resources/the-initiative1.html.

[37] Luxembourg's new €256m space strategy to focus on sustainability, Chronicle.lu, 14 December 2022. https://chronicle.lu/category/space/43709-luxembourgs-new-eur256m-space-strategy-to-focus-on-sustainability.

[38] United Arab Emirates, UAE National Space Policy (English), September 2016. https://space.gov.ae/Documents/PublicationPDFFiles/UAE_National_Space_Policy_English.pdf.

[39] UAE Space Agency signs MoU with Luxembourg, Times Aerospace, 10 November 2017. https://www.timesaerospace.aero/news/space/uae-space-agency-signs-mou-with-luxembourg.

[40] K. Warner, UAE looks to regulate asteroid mining as it aims to lure private space sector, The National UAE, 27 November 2019. https://www.thenationalnews.com/uae/science/uae-looks-to-regulate-asteroid-mining-as-it-aims-to-lure-private-space-sector-1.943028.

[41] Mohammed Bin Rashid Space Centre, UAE astronaut programme, 2023. https://www.mbrsc.ae/service/astronaut_prog/ (accessed 28 November 2023).

[42] United Arab Emirates, Space science and technology, 23 February 2023. https://u.ae/en/about-the-uae/science-and-technology/key-sectors-in-science-and-technology/space-science-and-technology.

[43] A. Nair, UAE earmarks $820 million to build satellites, fund space plan, Bloomberg, 17 July 2022. https://www.bloomberg.com/news/articles/2022-07-17/uae-earmarks-820-million-to-build-satellites-fund-space-plan#xj4y7vzkg

[44] Luxembourg and Japan agree to explore space resources, Mining Technology, 30 November 2017. https://www.mining-technology.com/news/luxembourg-japan-agree-explore-space-resources/.

[45] Japan, Law Concerning the Promotion of Business Activities Related to the Exploration and Development of Space Resources (Act No. 83), article 5.

[46] A. Blinken, The United States and Japan sign framework agreement on space cooperation, United States Department of State, 13 January 2023. https://www.state.gov/the-united-states-and-japan-sign-framework-agreement-on-space-cooperation/

[47] H. Yamakawa, JAXA and European partners and space industry, EU-Japan EPA Forum, 2021. https://www.eujapanforum.com/insightssss/jaxa-and-european-partners-and-space-industry (accessed 28 November 2023).

[48] Japan Aerospace Exploration Agency, Space Exploration Innovation Hub Center, 2023. https://www.ihub-tansa.jaxa.jp/english/files/JAXA_inb_brochurer.pdf (accessed 28 November 2023).

[49] H. Takakura, Recent trends in Japan's space policy – Centered on promoting the space industry, Japan Spotlight, July/August 2019, pp. 24–28.

[50] E. Solem, The emergence of China's commercial space companies and start-ups, China Aerospace Studies Institute, September 2020.

[51] M. Aliberti, When China Goes to the Moon, Springer, New York, 2015.

[52] L.T. Hao, Should the red dragon arise? Assessing China's options vis-à-vis the enactment of a domestic space resource utilization law, Space Policy 39–40 (2017) 9–13.

[53] China sees robust growth in commercial aerospace industries, Xinhua, 24 November 2020. http://www.xinhuanet.com/english/2020-11/24/c_139540343.htm.

[54] I. Liu, E. Linck, B. Lal, K.W. Crane, X. Han, T.J. Colvin, Evaluation of China's commercial space sector, IDA Science & Technology Policy Institute, Institute for Defense Analyses, Washington, DC, September 2019, pp. iv–v.

[55] United States, Executive Office of the President, Council of Economic Advisers, Chapter 8: Exploring new frontiers in space policy and property rights, in: Economic Report of the President, pp. 225–250, U.S. Government Publishing Office, Washington, DC, 2021.

[56] D.S. Acemoglu, The colonial origins of comparative development, Am. Econ. Rev. 91:5 (2001) 1369–1401.

[57] E. Alston, S. Smith, Development derailed: Uncertain property rights and asset-specific investment, Mountain West Economic History Conference, 2020.

[58] H.A. Bohn, Ownership risk, investment, and the use of natural resources, Am. Econ. Rev. 90:3 (2000) 526–549.

[59] J. Cust, T. Harding, Institutions and the location of oil exploration, J. Eur. Econ. Assoc. 18:3 (2020) 1321–1350.

[60] S. Galiani, Property rights for the poor: Effects of land titling, J. Public Econ. 94:9–10 (2010) 700–729.

[61] C. Grainger, Capitalizing property rights insecurity in natural resource assets, J. Environ. Econ. Manag. 67:2 (2014) 224–240.

[62] R. Hornbeck, Barbed wire: Property rights and agricultural development, Q. J. Econ. 125:2 (2010) 767–810.

[63] S. Johnson, J. McMillan, C. Woodruff, Property Rights and Finance, Am. Econ. Rev. 92:5 (2002) 1335-1356.

[64] B. Leonard, Collective action by contract: Prior appropriation and the development of irrigation in the western United States, J. Law Econ. 62:1 (2019) 67–115.

[65] M. de Zwart, S. Henderson, M. Neumann, Space resource activities and the evolution of international space law, Acta Astronaut. 211 (2023) 155–162.

CHAPTER 4

A FRAMEWORK FOR THE CREATION OF AN INTERNATIONAL SPACE DEVELOPMENT BANK

Modified from a paper to be published in NewSpace

4.1 Abstract

Many papers address the current space industry on the basis of a specific domain (technical innovation, infrastructure needs, etc.) but few address the funding aspect of the new space economy, particularly as we transition from substantial public funding for space to private funding. Even now, the world is seeing a dramatic increase in the number of private companies focused on the exploitation of space resources, a trend that will only continue to advance. Accompanying this development has been a transition from generous public funding for space initiatives to private funding. Both of these trends will also increase, significantly, as time moves on.

As all of the private actors require external funding to achieve their commercial aims, the need has developed for a bold new source of funding for higher-risk private ventures related to the space resources industry. This paper argues for the creation of an International Space Development Bank that would be structured, owned, and governed in a manner similar to analogous terrestrial multilateral development banks (MDBs), but with a focused mandate to fund space- and space resource–related development projects and thereby help the space economy to achieve faster growth and reinforce best practices in regard to financing, cooperation, and oversight.

4.2 Introduction

Historically, funding for space projects has come at the expense of the public purse, whether in the United States, Russia, China, or any other country involved in space activities. However, the funding model for space projects has changed, with significantly increased participation on the part of the private sector.

The global space industry is currently valued at about USD $360–380 billion and is projected to grow, at a CAGR of 5.6 percent, to USD $558 billion by 2026 [1].

As activity in space begins to pivot from exploratory activities and projects of national pride (such as the moon landing) to commercial activities and the development of space resources, we are beginning to see a rapid increase in the number of private companies focused on space, including companies focused on the development of space resources. In addition, there has been a commensurate increase in the complexity, and cost, of space- and space resource–focused ventures. Business estimates for commercial

activities in space, including those involving space resources, are optimistic, suggesting market growth projections for all aspects of space activity of 18–40 percent by 2030, for an overall volume of over $1 trillion by 2040 [2].

Space resources, which are defined in United States law as “any tangible or intangible benefit which can be realized only from (A) aeronautical and space activities; or (B) advancements in any field related to space,” are often cited as a crucial component in current plans to develop a new space economy and unlock the commercial potential of space. Some of these plans, to be carried out in the coming decades and championed by both the public and private sectors, include orbital outposts and hotels, space-based solar power stations, and manned and/or robotic missions to the Moon and Mars.

Furthermore, resources from the Moon, Mars, and certain asteroids have been proposed for use in human space exploration to produce propellants, water for life support, structural materials, and radiation and heat shielding [4].

Development of space resources entails considerable risk and financial capacity; this has led to different funding models, as a financial support ecosystem develops for the space resources industry. Funding solutions now include such traditional funding sources as angel investment, public capital markets, traditional venture capital funds, traditional private equity, and public-private partnerships. Each of these funding solutions has a long tradition of valuing risk and requires a return commensurate with that risk.

In addition, the traditional market, characterized by government or other institutional customers, is shifting toward a “mixed” space market not limited to superpowers and multinationals, but also open to new national players [5]. As a result of this evolution, private funding sources are also becoming transnational. As such, there is a growing need for a funding entity that can bridge the roles of the public purse and private investment, and can use public funding to directly encourage the development of space resources projects while exacting an economic return for the use of those funds.

Many examples of this kind of funding entity currently exist terrestrially and are used to develop infrastructure projects. These include various national and international multilateral organizations such as the Asian Development Bank, the World Bank’s International Finance Corporation, and the European Investment Bank, among others. It is a natural progression that both spacefaring and non-spacefaring companies should work together to develop a similar multilateral organization to help fund and develop space resources projects.

4.3 A Funding Model for Space Resources

All independent commercial endeavors are reliant upon external funding in their venture and initial stages. This funding can come from several sources, including private or public sources. Prevalently, however—particularly for industries and other endeavors of national importance—such funding is originally publicly sourced.

As shown in Figure 16, currently, the United States has both the highest government space budget share of GDP and per capita space expenditure (0.25 percent and USD $147 purchasing power parity (PPP) in 2017, respectively), followed by the Russian Federation (0.17 percent and approximately USD $30) and China (0.08 percent and USD $7) [6].

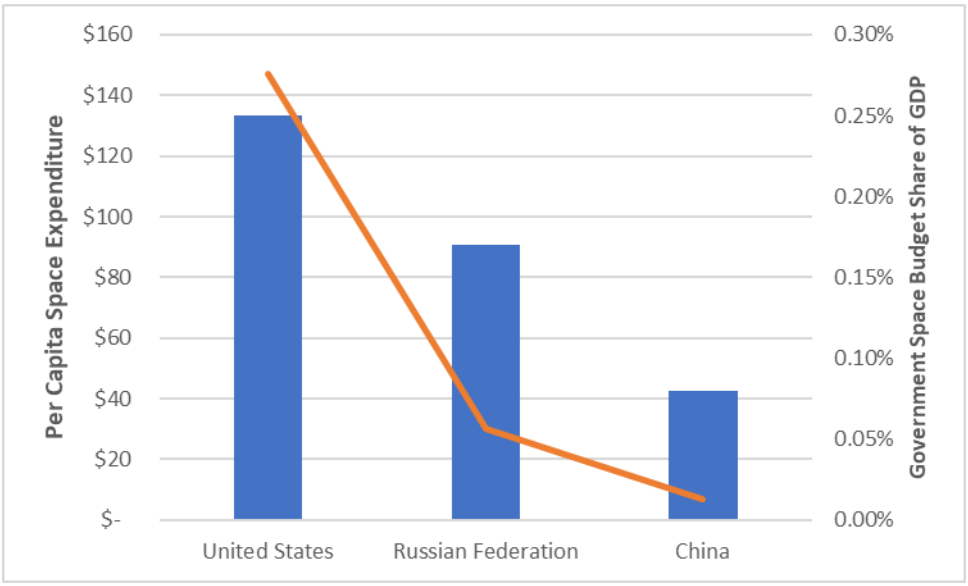


Figure 4.1: Current expenditures on space

The United States has sustained a level of public investment averaging of almost USD $20 billion per year (adjusted for 2020 values) since 1959, which has allowed this country to gain significant comparative advantages in terms of experience, knowledge, and industrial networks [1].

However, government funding for space programs has decreased as have the grants that have traditionally bolstered space research [8]. Furthermore, public funding is more appropriate at the initial stage of research and development of space resources projects, which tend to be extremely risky and cannot produce the commercial return expected by a traditional financial investor. Whether public or private, it has been found that long-term finance plays a significant role in promoting long-term economic growth and financial stability [9].

As an industry develops and matures, there is often a blending of funding sources, as the venture's ability to yield a commercial return increases—especially if public funding remains available in the form of grants to

private companies or public-private sponsorships. Increasingly, however, there is trend toward private, rather than public, investment to fund space resources.

Even for publicly funded missions, research has shown that there appear to be significant savings in costs, as well as improved service, when publicly funded space agencies purchase services from private suppliers [10].

Access to financing for private space resources companies is an important consideration for space commercialization, with private start-up and scale-up funding available mostly in the United States, and for risk-heavy, early-stage ventures. Such financing methods include: seed funding, prizes and grants, angel investing, venture capital, private equity, debt financing, and even crowdfunding.

Due to the nature of the industry's funding stream, the most efficient business model for many start-up space resources companies involves provision of asset-light and added-value downstream services, such as in-orbit computing, information relay, and power transfer. This is because these kinds of activities require lighter up-front investment than that required for hardware-based, asset-heavy businesses.

Comparisons are often made between the development of space resources as a commercial industry and the construction of railroads in the nineteenth century, particularly for technology and asset-heavy space resources projects such as lunar water mining.

This is due in part to similarities such as high start-up costs associated with new, more efficient technologies, a highly regulated sector environment, and the high risk/return potential of the endeavor [11]. In general, government support for private development of railroads came in several forms:

i. Land grants as a means of ensuring potential future revenue, a key component of success in creating the railroad system.

ii. Direct government appropriations to companies involved in the endeavor.

iii. Waivers/modifications to taxes and other regulatory requirements.

iv. Contracts for services once capability is demonstrated.

v. Government endorsement and backing of corporate bonds/assets.

vi. Indirect support for related but supplemental elements of the railroad transportation system.

In every case, these government initiatives were intended to leverage (not replace) existing private funding, especially additional industry, and venture capital [11].

This railway analogy is historical and, in many ways, superficial, and does not hold up to significant scrutiny as the terrestrial, land-focused requirements of the railroad are not applicable to space resources, particularly under the current legal regime governing outer space. Where we are seeing relevant comparisons is in the evolution of governments into promoters of commercial development through regulation, government contracts, and public-private partnerships (items 3, 4, and 6 in the list above). Currently, such support on the part of governments is limited to supporting their countries' domestic space industries rather than promoting the financing of space resources development in a coordinated international manner.

A better historical precedent for government involvement to develop a specific industry is that of development banks with clearly defined missions and lending-sector targets, such as the reconstruction of Europe following the Second World War or developing Africa's social infrastructure.

4.4 National Regulatory Frameworks for Development of Space Resources

In 2013, NASA's Office of Strategy Formulation released a report promoting public-private partnerships for developing economic growth and promoting NASA's mission of exploring the unknown in air and space [12]. However, humankind's activities in space are no longer limited to exploration and research; we are rapidly seeking to commercialize space, including through the exploitation and development of space resources.

As such, individual states are now looking to regulate an industry that did not exist when the basic space treaties were originally signed. In fact, the basic space treaties—the Outer Space Treaty (1967), the Rescue Agreement (1967), the Space Liability Convention (1972), the Registration Convention (1974), and the Moon Agreement (1979)—were executed at relatively early stages in the development of space exploration and exploitation, and, as such, may require updating to address the needs of the growing space resources industry.

To address this, countries are beginning to develop their own frameworks and legislation, under which space resource companies can operate. Commercial space activities, like other commercial activities, are governed by their respective states' national laws [13]. These include contract, property, tort, creditors' rights, bankruptcy, insolvency and reorganization, and other laws.

Currently, four countries have actively developed frameworks for the development of space resources: the United States, Luxembourg, the United Arab Emirates, and Japan. Certain other countries, such as Saudi Arabia, are actively working on developing their own frameworks.

A common denominator of all these countries is that they are well capitalized, advanced economies, with the capacity and sophistication to fund markets and to accurately price risk and expect a

commensurate return—especially as the public purse, which has historically funded space activities, has been withdrawn in the expectation that private capital will fill the gap.

These countries' efforts to develop a domestic legal framework to regulate the exploitation of space resources are at varying stages. In the United States, the Commercial Space Launch Competitiveness Act was adopted and signed into law in 2015. This Act stipulates that that the

United States does not assert sovereignty, exclusive rights, or jurisdiction over, or ownership of, any celestial bodies, but includes provisions to protect the property rights of private companies that will mine asteroids for minerals.

In Luxembourg in 2016, a draft law was enacted to create a legal framework for space resources companies to operate in that country. Shortly thereafter, in July 2017, Luxembourg became the first European nation to offer a framework for utilization of space resources.

A few years later, in 2020, the United Arab Emirates announced the UAE Space Law, consisting of nine chapters and fifty-four articles that regulate space activities across the country and govern the United Arab Emirates Space Agency's role in this regard. This law helps clarify the mechanism for issuing space activity permits and registering space objects and vehicles; responsibility and insurance regulations for space activities; space accident and risk regulations; the transitional period for current operators' regulations; and provisions for regulating the construction of facilities on other planets, utilization of space resources, and development of space-debris mitigation measures.

In June 2021, Japan became the fourth country to pass dedicated legislation on exploration and exploitation of space resources in the form of the Law Concerning the Promotion of Business Activities Related to the Exploration and Development of Space Resources. This legislation grants Japanese companies permission to prospect for, extract, and use various space resources. Companies wishing to do so must first obtain permission from the Japanese government.

As capital is global and fungible, space resources companies will seek out the jurisdiction with the strongest legal framework to protect their space interests terrestrially and allow them access to the greatest amounts of capital at the least cost. To this end, developed countries are actively creating legal frameworks to attract space-focused capital via passage of domestic legislation. There is a need, however, for a framework that includes not only the four countries that have already developed their own space resources frameworks, but all countries with an interest in participating in the broader space economy. One means of identifying such countries is by their status as signatories to the Artemis Accords, a series of bilateral agreements between the United States and other world governments participating in the Artemis

Program, an American-led effort to return humans to the Moon by 2025, with the ultimate goal of expanding space exploration to Mars and beyond [14].

On Earth, there is developing not just a technological space race but also a space resources funding race, with the weapons in this contest being legal frameworks, regulatory protections, and financial markets. The complexity and cost of this kind of competition, both in terms of public funding and bureaucratic resources, heavily favors developed nations. Therefore, a funding mechanism must be implemented to ensure fair access to investment opportunities for developing countries. Such a funding mechanism could be a multilateral development bank, with a very clear and specific mission to focus on funding space resources development opportunities. A multilateral development bank, if developed similarly to analogous terrestrial development banks, would be able to support the space and space resources sector through a variety of funding mechanisms, including various kinds of loans, sovereign-backed financing, direct equity investing, and credit guarantees, not to mention providing advisory services and guidance.

4.5 Proposal for a Space-Focused Multilateral Development Bank: The International Space Development Bank (ISDB)

By their nature, space resources development activities present issues of cross-border jurisdiction; yet it is generally agreed that space ought to be developed for the good of humanity (per the terms of the Outer Space Treaty). There is also a widespread belief that many space applications will eventually become profitable [10]. It is important, therefore, that individual countries work together to develop space resources and establish a structure to share equally the risks and rewards that come with the development of this industry.

Given the current, early stage in the evolution of the space resources industry, as well as the industry's transnational nature, there is currently an opportunity to develop a global, multilateral development bank—an International Space Development Bank (ISDB)—to assist in building private sector capacity and to help support and finance projects of international importance within the space resources community.

A multilateral organization is an organization founded by three or more nations to work on issues relevant to each of them. Precedents for multilateral partnerships abound, throughout the development of the space industry. A strong example of such a partnership is the cooperation and joint operations between the United States, Russia, and other nations on the International Space Station, including transport services for each other's materials and personnel. Similarly, Canada, a spacefaring nation through its partnership with the United States, contributed the versatile CanadArm to NASA's shuttle program, enabling significant advancements in knowledge.

A multilateral development bank (MDB) is typically created with a specific mandate, such as a sectoral or geographical focus, to support the deployment of economically and socially important projects. Quite often, MDBs are referred to as infrastructure banks, given their focus on developing infrastructure.

Historically, these kinds of organizations were developed to rebuild infrastructure destroyed in the wars of the twentieth century. However, lately these infrastructure banks, both national and international/multilateral, have been addressing infrastructure financing challenges using different policy contexts like the mobilization of private finance or project preparation [15]. The success of these organizations relies on low-cost financing, typically sourced either from participating governments or directly from capital markets [16].

In addition to providing debt capital, these organizations can help create investment-worthy projects in several ways. These include: setting bankability standards, so that a project's proponents know what investors require; providing technical assistance; offering competitive project development grants; working with government to create a list of suitable projects; allocating below-market cost equity to improve the risk-adjusted returns on a project; and partnerships on high-priority projects [17].

Although not technically regarded as infrastructure, the space resources industry has many infrastructure-like qualities: long project lead time, heavy initial investment, significant investment requirements, the need to coordinate efforts to create conditions for success, and utility for a broad range of market participants, among others. Because of their clear mandate to invest in developing countries, with the explicit aim of promoting economic and social development, banks and infrastructure banks alike often participate in syndicate loans, when the private sector is less able, or less willing, to provide funding because of high borrower risk (perceived or actual) [18]. The same set of circumstances that require the creation of an infrastructure bank are present in the space resources industry, and thus require the development of an International Space Development Bank.

4.6 Financing ISDB Operations

It is anticipated that the International Space Development Bank would provide financing in a variety of ways including, inter alia, making loans; investing in the equity capital of an enterprise; and guaranteeing, whether as primary or secondary obligor, in whole or in part, loans for economic development. In addition, the ISDB would underwrite, or participate in the underwriting of, securities issued by any entity or enterprise for purposes consistent with the bank's mandate. The financing mechanism for each project would be determined on a case-by-case basis, subject to the ISDB's investment policies; however, it is to be expected that ISDB participation would occur once there is a clear sight to commercial return on a given project.

Given its unique mission, this new, space oriented MDB could help regulate and manage the government scrutiny that is inevitably put in place in projects of transnational importance. This bank could be instrumental in attracting private sector finance to the industry; focusing development on critically important industry infrastructure or projects to spur further advancement of the industry; securing investment and participation opportunities for smaller countries with less developed space resources industries; securing financing for important projects which nonetheless are sub-investment grade and might otherwise struggle to obtain financial support; and serving as a center of expertise for finance within the industry. Expanded roles for the ISDB could also include taxation and revenue distribution between participant countries, corporate oversight, IP transfer, and influence on terrestrial infrastructure development.

In addition, funding could be structured to include requirements to adhere to good governance and practice around space activities. Where relevant to the funded project, this could include self-regulation of space traffic, minimization and elimination of space debris, and promotion of practices that would maximize the utility of space as a shared resource.

In addition to mobilizing private capital to invest into space resources projects, an International Space Development Bank could also assist both the government and the private sector in developing their respective roles in project pipeline development through the coordinated and directed use of capital. This activity would benefit the industry, as development timelines would be well understood and managed.

Given that the risk rating of MDBs is typically sovereign or close to sovereign, and is assigned based on the risk rating of the bank's constituent members, an MDB—and thus also an ISDB—can borrow at advantageous rates and lend out senior-ranked debt at competitive rates.

In addition, there is a perceived benefit in dealing with an MDB as the bank's underlying constituent membership provides assurance to private sector lenders that credit risks are backstopped.

4.7 Analogous Terrestrial Multilateral Development Banks

There currently exist several non-space MDBs that exert a tremendous impact on financing development projects of transnational importance. For the purpose of providing guidance in the structuring and development of an International Space Development Bank, it is useful to consider some of the largest and best funded of these. These include the African Development Bank (AfDB), the Asian Development Bank (AsDB), the Asian Infrastructure Investment Bank (AIIB); the European Bank of Reconstruction and Development (EBRD); the European Investment Bank (EIB); and the International Finance Corporation (IFC), a division of the World Bank.

Except for the IFC, the terrestrial development banks referred to in this paper are primarily regionally focused and typically reflect the regional makeup of their founding countries. In the case of the ISDB—sectorally rather than regionally focused—these non-space MDBs are here considered homologically, as examples of viable structures that might be used to expedite the development of space and space resources through proven methods of financial support.

4.7.1 African Development Bank

The African Development Bank (AfDB) was founded in 1964 with a mandate to promote sustainable economic growth and reduce poverty in Africa. Its shareholders are 54 African countries (also known as *regional member countries*) as well as 27 non-African member countries (or *non-regional member countries*). The AfDB is part of the African Development Bank Group, which also includes the African Development Fund and the Nigeria Trust Fund.

The AfDB has subscribed capital of USD $253 billion, of which USD $13.95 billion is paid up. Since 1967, the AfDB has approved USD $175.5 billion in projects. In order to fulfill its mandate, the AfDB uses a variety of lending instruments—mainly project loans, including lines of credit and technical assistance. To ensure faster-disbursing and policy-based loans, the AfDB also issues Structural Adjustment Loans (SALs) and Sectoral Adjustment Loans (SECALs) [1].

Over time, the AfDB determined that its constituent regional member countries lacked institutional capacity, including in the formulation of macroeconomic and microeconomic policies as well as in project preparation and appraisal; as a result, many of these companies could not take full advantage their participation in the AfDB. The AfDB has committed to providing strong and reliable information technology support and to developing a knowledge base of social and economic data to enable its constituent countries to reduce the costs of doing business and developing appropriate projects.

The AfDB also provides loans to assist the institution's regional member countries in building institutional capacity through training and studies, planning support, and policy guidance.

4.7.2 Asian Development Bank

The Asian Development Bank (AsDB) was established in 1966 with a mandate to be Asian in character and foster economic growth and cooperation within Asia. Originally comprised of 31 member nations, the AsDB currently has 68 members, of which 49 are from the Asia-Pacific region and 19 from other regions.

The AsDB has subscribed capital of USD $147.2 billion, of which USD $7.4 billion has been paid up.

[1] A SAL includes a set of economic reforms that a country must carry out in order to secure the loan. SECALs provide flexible support for institutional and policy changes at the sector or subsector level, through fast-disbursing funds.

The bank has USD $22.8 billion deployed in current operations.

The bank finances projects and programs in developing countries from its member nations. Its main instruments comprise loans, equity investments, guarantees, grants, and technical assistance. The AsDB has a broad focus on development issues but keeps its operations within a set of targeted developing nations.

The AsDB also facilitates policy dialogues and provides advisory services, and mobilizes financial resources through co-financing operations. Co-financing is an arrangement under which the AsDB, together with multilateral or bilateral organizations, foundations, and other emerging development partners, finance a project or program in response to the needs of developing member countries.

4.7.3 Asian Infrastructure Investment Bank

The Asian Infrastructure Investment Bank (AIIB) commenced operations in 2016 with 57 founding member states (37 regional and 20 non-regional). It currently has 105 approved members, representing approximately 81 percent of the world's population and 65 percent of global GDP.

The bank's purpose is: 1) to foster sustainable economic development, create wealth, and improve infrastructure connectivity in Asia by investing in infrastructure and other productive sectors; and 2) to promote regional cooperation and partnership in addressing development challenges by working in close cooperation with other multilateral and bilateral development institutions [19].

The AIIB has contributed capital amounting to USD $96.9 billion, of which USD $73.8 billion comes from the region. As of December 21, 2021, the AIIB had approved disbursements of USD $31.9 billion, of which it had disbursed USD $13.8 billion. The AIIB is triple-A rated with preferred creditor status.

Since 2016, the AIIB has invested in 160 projects, the majority of them in energy, transport, finance and, more recently, COVID-19 recovery support. The AIIB is highly active in supporting projects along the themes of green infrastructure, connectivity and regional cooperation, technology-enabled infrastructure, and private capital mobilization.

The AIIB places significant emphasis upon diverse and transparent governance. Its governing structures include a Board of Governors, the bank's highest decision-making body, consisting of one governor and one "alternate" governor appointed by each member country; and a non-resident Board of Directors, comprised of twelve directors and twelve alternate directors, each representing a group of constituent member countries.

4.7.4 European Bank of Reconstruction and Development

The European Bank of Reconstruction and Development (EBRD) was founded in 1991 to spur renewal, following the end of the Cold War, in Central and Eastern Europe.

The EBRD is owned by 71 member countries, as well as the European Union and the European Investment Bank. Membership is comprised of European and non-European countries that are members of the International Monetary Fund and also includes the European Investment Bank [20].

The EBRD was created with a mandate to conduct operations in the countries of Central and Eastern Europe, as they transitioned toward market economies. Since then, the bank has expanded its original area of operations to include new countries such as Mongolia (2006), Türkiye (2009), Egypt, Jordan, Morocco, Tunisia, and Kosovo (in 2012), Cyprus (2014), Greece (2015), and Lebanon (2017) [20].

The bank's purpose is to foster the transition of the Central and Eastern European countries toward open, market-oriented economies. It also promotes private sector and entrepreneurial initiatives and structural and sectoral economic reforms, including de-monopolization, decentralization, and privatization, to help integrate these countries' economies fully into the international economy.

The EBRD fulfills its mandate by mobilizing domestic and foreign capital, providing experienced management for appropriate projects, and supplying technical assistance in project preparation, financing, and implementation. In addition, the EBRD provides business advisory services and promotes trade financing and loan syndication. The bank also fosters political engagement to promote policy reform.

The EBRD's authorized share capital is €30.0 billion, including €29.8 billion in subscribed capital and €6.2 billion in paid-in capital [20]. The EBRD is triple-A rated with a stable outlook.

The EBRD governance structure consists of a Board of Governors, representing the bank's 71 member countries as well as the EU and EIB, which delegates executive powers to the Board of Directors. The Board of Directors is comprised of 23 directors, each of whom represents one or more members, and is chaired by the EBRD's president.

4.7.5 European Investment Bank

The European Investment Bank (EIB) was established in 1958 under the Treaty of Rome, and has become the European Union's long-term lending institution.

Although the EIB is owned by the European Union's 27 member states, it is financially independent.

The EIB raises its funds through issuance of bonds and other debt, with bonds sold on international capital markets. While the management of this MDB must take into consideration the preferences of its constituent countries to ensure a continued source of funds, the EIB's professional staff enjoy a great deal of discretion as to the allocation of funds [21].

As of March 2020, the subscribed capital of the EIB amounts to EUR 248.8 billion]22]. The EIB is triple-A rated with a stable outlook.

The EIB will finance no more than 50 percent of a project's cost, and usually no more than one third, but EIB loans may be combined with EU funds through a blending of grants, guarantees, and other financing instruments. These loans must be in line with stated EU policy objectives, which permit the bank to invest strategically and for the long term. Projects must also meet economic, financial, technical, and environmental criteria, which helps to ensure that funded projects are viable on multiple fronts. To complement its financial support, the EIB offers technical advice from expert economists, engineers, and sectoral specialists to assist in the preparation of projects and advise local authorities on how best to use public resources [23].

4.7.6 International Finance Corporation

The International Finance Corporation (IFC) was established in 1956 as the private-sector arm of the World Bank Group. The purpose of the IFC is to advance economic development by encouraging the growth of productive private enterprise in member countries, particularly in less developed areas. It is one of the largest analogous MDBs and provides a significant suite of services.

The IFC is owned by 186 member countries with an initial authorized stock capital of USD $100 million. The IFC's funding comes primarily from capital markets, where the credit profile of its shareholders allows for attractive cost-of-capital rates. The IFC issues bonds in a variety of markets, formats, and currencies, including global benchmark bonds, green and social bonds, Uridashi notes, private placements, and discount notes. To support its mandate, the IFC conducts business in three pillars: investment (debt, equity, trade and commodity finance, derivatives); advisory; and debt and equity mobilization (syndications and asset management). The IFC has debt and equity exposure in 117 countries and in more than 1,800 companies [24].

4.8 Benefits of an MDB for Space-Based Industries

Empirical research by Gurara et al [18], find that a multilateral development bank is more willing to lend at longer tenure than the private sector and have a propensity to finance riskier projects that may not be financed by the private sector [18]. This is a significant benefit to the space resources industry where

funding needs are present but private capital may not be educated enough to understand the risks and make a necessary, meaningful investment on appropriate terms.

In addition to the funds contributed by its constituent countries, an MDB typically has a credit rating similar to that of a stable government and is thus able to raise funds for selected projects at a lower cost of capital than it otherwise normally would be able to access. Table 9 below illustrates the strength of analogous multilateral development banks.

The savings that result from borrowing at a sovereign credit rating rather than a private credit rating can be passed on to companies and projects approved for MDB support. When private-sector actors participate in funding projects, there is the expectation, implicit or explicit, of a government-imposed risk backstop for their investment activities, which in turn allows them to accept a lower return. Such a "political umbrella," provided by the participating governments, would allow an International Space Development Bank similarly to influence government decisions in a positive manner and help to avoid adverse events that might negatively affect the project's outcome [25].

Table 4.1: Credit rating status of multilateral development banks

Institution	**Credit Rating**					
	Moody's			**S&P Global**		
	Long Term	**Short Term**	**Outlook**	**Long Term**	**Short Term**	**Outlook**
AsDB	Aaa	P-1	Stable	AAA	A-1+	Stable
EIB	Aaa	P-1	Stable	AAA	A-1+	Stable
AIIB	Aaa	P-1	Stable	AAA	A-1+	Stable
EBRD	Aaa	P-1	Stable	AAA	A-1+	Stable
AfDB	Aaa	P-1	Stable	AAA	A-1+	Stable

Sources: Moody's *[28]* and S&P Global Ratings *[29]*

Interestingly, Degl'Innocenti et al. [26] found evidence that loans with a development bank as a participant lender have a more diffuse loan ownership structure [26], leading to stronger review and oversight. Creation and utilization of an MDB can lead to greater coordinated project oversight and ensure high standards in terms of fiduciary control, monitoring capacity, and quantifiable targets, as well as help improve stakeholder engagement and dialogue. An MDB can also help facilitate access to long-term financial flow, as such a bank's specialized expertise comprises an informational advantage [18].

As the governing structures and practices of the ISDB are developed, there is also an opportunity to develop procurement and service contract regulations, which can be preferentially allocated to member countries provided that quality and general competitiveness are not compromised.

4.9 SWOT Analysis

A SWOT analysis is a strategic tool used to identify, compare, and contrast an organization's strengths, weaknesses, opportunities, and threats. Such analyses comprise significant tools that can yield comprehensive results. To conduct a full-scale SWOT analysis is outside the scope of this paper; nonetheless, by way of illustration, table 10 illustrates how such an analysis for the proposed ISDB might touch on the following points:

Table 4.2: SWOT analysis of the creation of an ISDB

STRENGTHS	WEAKNESSES
• Ability to use government credit rating and support to reduce cost of capital • Expertise in project evaluation and subsequent investment support within a specific industry • Strong relationships with multilateral organizations, governments, and other key stakeholders • Opportunity for broad stakeholder participation and amplified impact of investment dollars • MDBs tend to be willing to lend at longer tenure than private sector actors, and often finance riskier projects normally avoided by the private sector	• Possible political influence due to government funding • The dual-use nature (military and scientific) of space activities may preclude certain countries' willingness to participate • Mandate may be too specific and not easily adapted to new technologies or changes in the industry landscape • Project funding criteria and guidelines may be too rigid to identify and support key industry opportunities • Space resources industry is not as well developed as other sectors supported by MDBs
OPPORTUNITIES	**THREATS**
• Rapidly changing and growing space resources market • Governments actively seeking opportunities for involvement in the space resources industry • Possibility to develop procurement and service contract regulations, which can be allocated preferentially to member countries • Smaller countries with fewer financial resources can participate as part of a syndicate/shareholder model • Increasing demand for innovative financing solutions	• Stricter regulatory requirements and higher compliance costs • Present and future geopolitical issues may affect funding decisions and project support • Market may be too fragmented to develop appropriate project pipeline • Key governments and other critical allies may be unwilling to participate in the ISDB • Possible partisan jockeying and sovereign "power grab" within the ISDB • Nascent stage of industry may create increased risk of suboptimal investment

As the ISDB is adopted and created, a much more comprehensive SWOT analysis should be completed.

4.10 Structural and Operational Considerations for the Development of an ISDB

In 2017, the consulting firm McKinsey & Company published a paper outlining the benchmarks for success in creating an infrastructure bank. As mentioned earlier, the ISDB should be developed based on the broad principles of an infrastructure bank but with a focus on the space resource industry and a

multilateral remit. The McKinsey study noted that infrastructure banks can help to direct capital efficiently into certain sectors or regions, in several ways: setting bankability standards, providing technical assistance, working with governments to identify worthwhile projects, and allocating below-market cost equity to improve a project's risk-adjusted returns [17].

4.10.1 Mission and Mandate

Articulating a clear vision is critical to ensuring that a development bank fills a need. In this case, an International Space Development Bank would have a mandate to invest in space resource–related activities across its participant countries, which would in turn help in coordinating the efficient allocation of capital.

In addition to financing space resource–related activities, the mission of the ISDB could be broadened to include complementary activities such as mobilizing more private-sector financing through education and partnership, and develop best practices for researching and promoting space resources.

Table 11 summarizes the missions of the currently existing MDBs mentioned in this paper.

Table 4.3: Missions of analogous MDBs

Institution	Mission
AsDB	"AsDB is committed to achieving a prosperous, inclusive, resilient, and sustainable Asia and the Pacific, while sustaining its efforts to eradicate extreme poverty." *[30]*
EIB	"The mission of the European Investment Bank is to foster sustainable growth within the EU and abroad. We are firmly committed to sustainable development, which is anchored in our strategy and remains the foundation of our business model." *[31]*
AIIB	"The AIIB is a multilateral development bank whose mission is financing the Infrastructure for Tomorrow—infrastructure with sustainability at its core." [19]
EBRD	"The EBRD mission is to develop open and sustainable market economies in countries committed to, and applying, democratic principles." *[20]*
AfDB	"The overarching objective of the AfDB Group is to spur sustainable economic development and social progress in its regional member countries, thus contributing to poverty reduction." *[32]*
IFC	"Advance economic development by encouraging the growth of private enterprise in developing countries." *[33]*

A potential basic framework for a mandate for the ISDB can be found in the Space Resources Exploration and Utilization Act, which states its intention 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." Creating a mandate of this kind would support the proposed bank in carrying out its mission, simply put: "financing space resources development for the good of all."

As the ISDB develops its mission and mandate, it will need to develop an order of priority and subsequently create metrics—tangible and measurable milestones—to measure its progress in achieving that mission and mandate. These metrics are critical in promoting accountability and efficiency [17].

4.10.2 Improving Project Pipeline

In developing an ISDB, it is important that the bank's management identify and nurture projects that will be both commercial in nature and beneficial for the overall development of the space resources industry. Development of this project pipeline will require significant technical and commercial expertise with funding decisions being made on a case-by-case basis, subject to a framework and guidelines for ISDB board approval.

To develop and high-grade the project pipeline, it is imperative that the ISDB hire experts in the field and develop a strong training program. These experts will help to identify promising projects deemed to be generally commercial in nature and would also generate expert analyses to quantify and price risks.

In addition to appropriately trained and experienced staff, there are other ways to improve the project pipeline. Such measures include: setting bankability standards, to help project sponsors better understand project expectations; providing technical assistance; offering competitive project development grants; developing relationships with governments to identify, examine, and appropriately prioritize projects of national or international importance; and allocating below-market equity to improve projects' risk-adjusted returns [17].

4.10.3 Determining Which Financial Products to Offer

Initially, many of today's investment banks began by offering senior debt, primarily for reasons related to risk; but, over time and in accordance with their mission, they also began to offer other products. These have taken the form, variously, of subordinated debt, debt guarantees, mezzanine debt, construction debt, equity, and subordinated equity finance [17] as shown in Table 12. Not only can these additional products help an MDB to fulfill its mission, but, when applied appropriately, they also can de-risk the more senior debt tranches that private-sector investors contribute.

Table4.4: Products offered by analogous MDBs

Institution	Products Offered
AsDB	Financial products: • Flexible loans • Local currency loans • Concessional ordinary capital loans • Currency swaps/interest-rate swaps (debt-management products) These products fall into several modalities: project; sector; financial intermediation (to other financial institutions); emergency assistance; multi-tranche lending
EIB	Loans: • Public-sector loans • Framework loans for the public sector • Private-sector loans

Table 4,4: Products offered by analogous MDBs continued

EIB cont'd	• Intermediated loans for SMEs, mid-caps, and other priorities • Venture debt Loans: • Public-sector loans • Framework loans for the public sector • Private-sector loans • Intermediated loans for SMEs, mid-caps, and other priorities • Venture debt[2] Equity: • Investments in SMEs and mid-caps • Investments in infrastructure and environmental funds Guarantees: • Credit enhancement for project finance • Guarantees in support of SMEs, mid-caps, and other objectives Advisory services: • Strategic development • Project development • Market development
AIIB	Sovereign-backed financing: • A loan to, or guaranteed by, a member of the bank • Guarantees against government defaults • Guarantee using a bank member's indemnity Non-sovereign backed financing (loan products) Equity investment including loan convertible to equity Financial advance to prepare for sovereign-backed financing
EBRD	Loans (differentiated between larger projects [€3–250 million] and small projects [less than €3]) Equity investment Advisory services (for small and medium businesses) Policy reform dialogue services
AfDB	Loans Equity (including quasi-equity) Guarantee products Grants
IFC	Loans Equity Trade and supply-chain finance Loan syndication coordination Treasury client solutions (market hedging activity) Blended finance (structured as debt, equity, risk sharing, or guarantee products with different rates, tenor, security, or rank, tailored to address specific market barriers and failures) Advisory services Asset management

[2] Venture debt refers to a type of loan given to an early-stage company to provide the company with liquidity during the period between equity funding rounds. Venture debt is rarely used as a long-term financing solution. Typically, these loans are repaid within a period of eighteen months, or sometimes up to two to three years. Most often, private venture debt providers (funds or banks) expect to be repaid from the proceeds of the next funding round. However, venture debt providers stay very closely linked to venture capital investors, and it is not unusual to see a beneficiary company being provided with such loans multiple times during its development [31].

4.10.4 Developing a Framework and Criteria for Evaluation of Projects

MDBs typically set out eligibility criteria that projects must meet in order to be considered for financing. Such criteria may include factors such as the project's potential for economic and social development, environmental and social impacts, financial viability, and alignment with the country's development priorities. These criteria also may change, depending on the financial product being utilized by the project and its sponsor. Diverse examples of such product offerings by analogous terrestrial MDBs can be found in Table 12.

Eligibility policies do not necessarily comprise purely financial decisions but also pertain to each individual MDB's policies and guidelines. As MDBs are often region-specific, eligibility criteria too may be quite specific and aligned to the needs of the region.

In addition, MDBs often consult with stakeholders, including governments, civil society organizations, and private sector entities, to help ensure that individual investments are effective in promoting the MDB's aims.

In 2014, the United States Department of the Treasury delivered a report to Congress, following a review of evaluation policies and practices at the five major MDBs in which the United States is a shareholder: the World Bank (including the IFC), the AfDB, the AsDB, the EBRD, and the Inter-American Development Bank (IDB). A key finding of the report was that there is no single "best" standard, type, or system of evaluation; rather, there exists a wide spectrum of evaluation methodologies that employ different degrees of rigor, depending on the objective and subject of the evaluation (e.g., whether it is designed for accountability, learning, or assessing a project, sector, country, program, or approach) [27].

Another key finding from the Treasury report was that given the breadth and diversity of MDB operations, evaluation methods, and knowledge, a strong case may be made for MDBs to use a diverse range of evaluation approaches, depending on each MDB's particular aims, rather than promoting a single approach for all MDBs and for all projects.

Based on the report's findings, the Department of the Treasury identified six priority recommendations to enhance evaluation standards and practices, and, ultimately, the effectiveness and impact of development projects:

i. Adopt a risk-based, strategic portfolio approach to evaluation.

ii. Increase the use of external and peer reviews as part of the overall evaluation process.

iii. Institute regular external evaluations of MDBs' independent evaluation offices.

iv. Create incentives and feedback loops to strengthen monitoring and evaluation and enable generation of, access to, and use of learning and knowledge in MDB programming.

v. Strengthen public disclosure of data in transparent and usable forms.

vi. Bolster inter-MDB collaboration (and peer pressure) on evaluation.

Of these recommendations, the first five are of particular relevance to creating a framework and criteria for evaluation of projects seeking ISDB support. The fifth recommendation is most relevant to banks with similar regional development priorities, rather than specific sectoral criteria.

Furthermore, of these six recommendations, the first is of critical importance for the long-term viability of the ISDB and its capacity to support space resources ecosystem development.

In order to adopt a risk-based, "strategic portfolio" approach to evaluation, an ISDB could consider developing guidelines regarding what is "bankable" for companies at various stages of their development. The ISDB will need guidelines pertaining to which levels of development it will consider for funding, and via what kind of instruments. Examples of such criteria might include questions such as these: "Is the company profitable?" "Is this a research and development project?" "How much and what type of funding has been raised to date?"—and so on.

Guidelines such as these will assist professionals at the ISDB in considering further criteria for expected investment return hurdles, cost of funding, which level and type of support the ISDB is willing to provide, and other details specific to each case. Such guidelines will also enable applicants for ISDB funding to develop "bankable" proposals suitably matched to the ISDB's investment criteria. Overlaying all these investment decisions, of course, is the demand for clear adherence to the ISDB's mission and mandate.

Once these criteria are developed (the "risk-based" approach), the ISDB's professional personnel may then consider market practice and standard economic theory to determine the mix of investments, at various investment stages, that they are comfortable making (the "strategic portfolio").

4.10.5 Determining Membership and Participation

Similar to the AIIB, funding for the ISDB could be based on contributed capital with shareholder voting rights assigned based both on contributed capital and precedence of funding. One option to develop the shareholder base is initially to approach countries that have agreed to the Artemis Accord and invite them to become founding shareholders. A further round could be opened so that non-spacefaring nations can participate in the investment and equity returns of a coordinated space resources

development program.

Equity participation in the ISDB could be determined based upon the percentage of GDP required to fund the initial bank (see Table 13). This would be similar to the NATO model, except on a one-time basis rather than annually.

Table 4.5: 2021 GDPs of Artemis Accord participants

Country	2021 GDP (USD – billions)	Country	2021 GDP (USD – billions)
United States	$22,996.10	Poland	$674.05
Japan	$4,937.42	Israel	$481.59
United Kingdom	$3,186.86	Singapore	$396.99
France	$2,937.47	United Arab Emirates	$358.87
Italy	$2,099.99	Colombia	$314.32
Canada	$1,990.76	Romania	$284.09
South Korea	$1,798.53	New Zealand	$249.99
Brazil	$1,608.98	Ukraine	$200.09
Australia	$1,542.66	Luxembourg	$86.71
Mexico	$1,293.04	Bahrain	$38.87
Saudi Arabia	$833.54		

Sources: World Bank [34]

Furthermore, membership in the ISDB need not be restricted to Artemis Accord participants but could be open to all countries interested in pursuing the bank's mission of developing the space resources ecosystem. As illustrated in Table 14, there is significant precedent for membership growth in each of the analogous MDBs.

Table 4.6: Ownership of MDBs

Institution	Initial Ownership	Current Ownership	Member Growth
AsDB	31 members (1966)	68 members	119%
EIB	6 members (1958)	27 members	350%
AIIB	57 members (2016)	105 members	84%
EBRD	39 members (1991)	71 members	82%
AfDB	23 members (1963)	80 members	248%
IFC	31 members (1956)	185 members	497%

It is also important that the ISDB's headquarters location, leadership, and governance reflect its multijurisdictional aspect (see Table 15). It is likewise vital that leadership be merit based and reflect member country participation.

Table 4.7: MDB headquarters locations and executive nationalities

Institution	Headquarters Location	CEO / Managing Director Nationality
AsDB	Mandaluyong, Philippines	Japanese
EIB	Kirchberg, Luxembourg	German
AIIB	Beijing, China	Chinese
EBRD	London, UK	French
AfDB	Abidjan, Côte d'Ivoire	Nigerian
IFC	Washington, DC, USA	Senegalese

4.10.6 Ensuring Strong Governance

Throughout all the above developments, sound governance is of critical importance, not only to advance the ISDB's mandate but also to ensure that the bank does not crowd out private investment and that it exercises due care in providing financing. In analogous MDBs, boards of directors are generally made up of a representative and an alternate representative from each member country, with an advisory board comprised of a smaller subset of the larger board.

To ensure prudence, the Board of Directors should insist upon compliance with the bank's mission, but delegate investment and corporate decision making to the relevant credit or investment committees.

As shown in Table 16, MDBs take varied approaches to governance.

Table 4.8: MDB governance structures

Institution	Board of Governors	Board of Directors	Other Governance Bodies
AsDB	Highest policy body Comprised of 1 representative from each member nation Each governor is supported by an alternate governor	Twelve-member board, elected by Board of Governors Each director is supported by an alternate director The directors supervise AsDB's financial statements, approve its administrative budget, and review and approve all policy documents and all loan, equity, and technical assistance operations	None
EIB	Consists of ministers designated by each of the 27 member states (usually the finance minister)	Consists of 28 directors and 31 alternate directors appointed for a renewable five-year period One director is nominated by each member state and one by the European Commission (the executive body of the European Union)	The Management Committee is the bank's permanent collegiate executive body, with nine members

Table 4.8: MDB governance structures continued

EIB cont'd		Alternates are nominated by member states depending on their capital share and constituency agreement. One alternate member is also nominated by the European Commission Has sole power to take decisions regarding loans, guarantees, and borrowings, and ensures that the bank is managed in keeping with the provisions of applicable treaties and statutes, and with the general directives set by the governors The Board may co-opt a maximum of six experts (three directors and three alternates) to participate in Board meetings in an advisory capacity, without voting rights	
AIIB	Consists of one governor and one alternate governor appointed by each member country. A governor or alternate serves at the pleasure of the appointing member	Each Board Member is appointed by a constituency group with an alternative director appointed from the same group There are 12 constituency groups resulting in 12 directors Non-resident Board of Directors is responsible for the direction of the bank's general operations, exercising all powers delegated to it by the Board of Governors	An International Advisory Panel (IAP) supports the bank's president and senior management with strategy, policy, and general operational issues. The Panel meets at least twice a year (physically or virtually), including one meeting held in conjunction with the bank's annual Board of Governors meeting The bank's president selects and appoints IAP members to an initial two-year term, renewable upon completion
EBRD	Consists of one governor and one alternate governor appointed by each member country. Each governor and alternate governor serves at the pleasure of the appointing member Solely responsible for determining the bank's membership, changes in capital stock, appointments of directors and the bank president, decisions regarding financial	Consists of 23 directors and is chaired by the bank's president Each director represents one or more shareholders Responsible (subject to the Board of Governors' authority) for the direction of the bank's operations and policies in alignment with the general objectives set by the Board of Governors	None

Table 4.8: MDB governance structures continued

EBRD	statements, and determining reserves and allocation of profits		
AfDB	Consists of one governor and one alternate governor appointed by each member country Each governor represents their country and exercises voting power proportionate to that country's capital subscription	Comprised of 20 members (who cannot be governors or alternate governors): 13 are elected by governors from regional member countries, and 7 by governors from non-regional member countries. Directors are elected for three-year terms, renewable once. Each director appoints an alternate; however, no alternate (except the United States alternate) may be of the same nationality as their corresponding director	None

This author posits that, in line with the above MDBs, the ISDB's CEO and the chair of its Board of Governors both be appointed by member states, but that they be neither sponsored by the same country nor citizens of the same country. In addition, there is merit to exploring various possibilities in terms of sponsorship or oversight—for one example: an ex-officio board member appointed by the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS).

4.11 Conclusion

The development of a multilateral development bank focused on providing finance for space resources development projects—an International Space Development Bank—would help the space economy to attain faster growth and reinforce best practices in regard to funding, oversight, and cooperation. Creation of such a bank would also signal a national commitment to the industry sector and comprise an important investment, in terms of both capital and knowledge, to ensure a strong and healthy space ecosystem.

Further work is needed to develop a proper framework for a multilateral development bank focused on the space sector. Some of this work will likely be driven by the participating states themselves as well as by their various respective priorities. However, if well executed, the creation of an International Space Development Bank will increase aggregate space resource investment, limit the influence of single-state politics on project selection, and facilitate projects that span multiple jurisdictions, allowing for efficiency in the allocation of development funding. It would also allow non-spacefaring nations to participate meaningfully alongside spacefaring nations in the financing and development of space.

4.12 References

[1] Rementeria S. Power dynamics in the age of space commercialisation. Space Policy, 2022; 60:101472; doi: 10.1016/j.spacepol.2021.101472.

[2] Morgan Stanley. (2017). Space: Investing in the final frontier. https://www.morganstanley.com/ideas/investing-in-space, New York, 2017.

[3] Public Law 111–314, 2010, ENACTMENT OF TITLE 51—NATIONAL AND COMMERCIAL SPACE PROGRAMS, United States Government Printing Office, 2010.

[4] M.S. Saletta, K. Orrman-Rossiter, Can space mining benefit all of humanity? The resource fund and citizen's dividend model of Alaska, the "last frontier," Space Policy 43 (2018) 1–6.

[5] Parrella, R., Spirito G., Cirina C., and Falvella, M. The New Space Economy and New Business Models. 10:4, 291-297; doi: 10.1089/space.2021.0020

[6] Organisation for Economic Co-operation and Development. The space economy in figures: How space contributes to the global economy . OECD Publishing: Paris; 2019. Available from: https://www.oecd.org/innovation/the-space-economy-in-figures-c5996201-en.htm [Last accessed: 06/05/2023].

[7] Organisation for Economic Co-operation and Development. The space economy in figures: How space contributes to the global economy . OECD Publishing: Paris; 2019. Available from: https://www.oecd.org/innovation/the-space-economy-in-figures-c5996201-en.htm [Last accessed: 06/05/2023].

[8] Pomeroy C, Calzada-Diaz A, Bielicki D. Fund me to the Moon: Crowdfunding and the new space economy. Space Policy 2019;47:44–50.

[9] Hu B, Schclarek A, Xu J, et al. Long-term finance provision: National development banks vs. commercial banks. World Dev 2022;158:105973.

[10] Elliot C. Funding for space – private finance for public space missions? Space Policy 1997;13(4):315–322.

[11] Launius R. The railroads and the space program revisited: Historical analogues and the stimulation of commercial space operations. Astropolitics 2014;12:2–3.

[12] National Aeronautics and Space Administration. Public-private partnerships for space capability development: Driving economic growth and NASA's mission. NASA: Washington DC; 2014. 46 p. Available from: https://www.nasa.gov/sites/default/files/files/NASA_Partnership_Report_LR_20140429.pdf

[13] B.M. Cahan, Outer frontiers of banking: Financing space explorers and safeguarding terrestrial finance, New Space 4:4 (2016) 253–286. DOI: 10.1089/space.2016.0010. [Last accessed: 06/05/2023].

[14] National Aeronautics and Space Administration. What is Artemis? . NASA: Washington DC; 2019 [cited 2022 Nov 11]. Available from: www.nasa.gov: https://www.nasa.gov/what-is-artemis [Last accessed: 06/05/2023].

[15] Global Infrastructure Hub. Guidance note on national infrastructure banks (NIBs) and similar financing facilities . GIH: Sydney; 2019. Available from: https://www.gihub.org/nibs/ [Last accessed: 06/05/2023].

[16] Uzsoki D. Infrastructure banks: Solutions and best practices . Winnipeg: International Institute for Sustainable Development; 2018. Available from: https://www.iisd.org/publications/report/infrastructure-banks-solutions-and-best-practices [Last accessed: 06/05/2023].

[17] Duvall T, Kerlin M, Palter R. Creating an Infrastructure Bank: Principles of Success. McKinsey & Company: Washington, DC; 2017.

[18] Gurara D, Presbitero AF, Sarmiento M. Borrowing costs and the role of multilateral development banks: Evidence from cross-border syndicated bank lending. J Int Money Finance 2020;100:102090; doi: 10.1016/j.jimonfin.2019.102090.

[19] Asian Infrastructure Investment Bank. Articles of agreement . Beijing: AIIB; 2015. Available from: https://www.aiib.org/en/about-aiib/basic-documents/_download/articles-of-agreement/basic_document_english-bank_articles_of_agreement.pdf [Last accessed: 06/05/2023].

[20] European Bank of Reconstruction and Development. Annual review 2021 . London: EBRD, 2022. Available from: https://www.ebrd.com/news/publications/annual-report/annual-review-2021.html [Last accessed: 06/05/2023].

[21] Birch MH. Institution building: Multilateral development banks and state-owned enterprises. World Dev 1988;16(2):255–270; doi: 10.1016/0305-750X(88)90140-4.

[22] Facts Sheet on the European Union, 2022. Available from https://www.europarl.europa.eu/factsheets/en/sheet/17/the-european-investment-bank [Last accessed: 06/05/2023].

[23] Davis K, Galston WA. (2012). Setting priorities, meeting needs: The case for a national infrastructure bank . Washington, DC: Brookings Institution; 2012. Available from: https://www.brookings.edu/research/setting-priorities-meeting-needs-the-case-for-a-national-infrastructure-bank/ [Last accessed: 06/05/2023].

[24] International Finance Corporation. Investor information . Washington, DC: IFC; 2022. Available from: https://www.ifc.org/wps/wcm/connect/CORP_EXT_Content/IFC_External_Corporate_Site/About+IFC_New/Investor+Relations/ir-info/ [Last accessed: 06/05/2023].

[25] Hainz C, Kleimeier S. (2012). Political risk, project finance, and the participation of development banks in syndicated lending. J Finance Intermed 2012;21(2):287–314; doi: 10.1016/j.jfi.2011.10.002.

[26] Degl'Innocenti M, Frigerio M, Zhou S. Development banks and the syndicate structure: Evidence from a world sample. J Empir Financ 2022;66(C):99–120.

[27] United States Department of the Treasury, Report to Congress on the Evaluation Standards and Practices at the Multilateral Development Banks; September 2014.

[28] Moody's Investors Service . New York: Moody's; 2022 [cited 2022 Nov 8]. Available from: http://www.moodys.com/ [Last accessed: 06/05/2023].

[29] S&P Global Ratings . New York: S&P Global Ratings; 2022 [cited 2022 Nov 8]. Available from: www.disclosure.spglobal.com [Last accessed: 06/05/2023].

[30] Asian Development Bank. Who we are. Mandaluyong (PH): AsDB; 2022 [cited 2022 Nov 7]. Available from: https://www.AsDB.org/who-we-are/main [Last accessed: 06/05/2023].

[31] European Investment Bank. Corporate responsibility.. Kirchberg (LU); 2022 [cited 2022 Nov 7]. Available from: https://www.eib.org/en/about/cr/index.htm [Last accessed: 06/05/2023].

[32] African Development Bank. Mission and strategy.. Abidjan (CI): AfDB; 2022 [cited 2022 Nov 7]. Available from: https://www.afdb.org/en/about/mission-strategy [Last accessed: 06/05/2023].

[33] International Finance Corporation. About IFC. Washington, DC: IFC; 2022 [cited 2022 Nov 7]. Available from: https://www.ifc.org/wps/wcm/connect/corp_ext_content/ifc_external_corporate_site/about+ifc_new [Last accessed: 06/05/2023].

[34] World Bank. The World Bank – data. New York: World Bank; 2022 [cited 2022 Sept 16]. Available from: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?most_recent_value_desc=true [Last accessed: 06/05/2023].

CHAPTER 5
CONCLUSION

Undertaking this research has been a significant journey of discovery through the current landscape of space resources industry financing. Significant opportunities exist, along with considerable challenges, in this rapidly growing sector.

Through the "story arc" comprised by this dissertation's three chapters—on the current status of space resources, the financial impact of domestic space resources legislation, and the issue of establishing a multilateral development bank focused on developing space resources—I have attempted to shed light on the importance of space sector financing.

The findings in these studies indicate that the financing of space resources is a complex and multifaceted issue that demands innovative approaches and collaborations between various stakeholders, including international cooperation.

One of the key challenges identified in this study is the uncertainty that surrounds the legal and regulatory frameworks governing space resource activities. The high costs associated with space exploration and resource extraction pose significant challenges to private companies and governments seeking to invest in this field; without a clear legal and regulatory framework, it will be difficult to attract the private capital required to make the space resources sector self-sustaining vis-à-vis funding. However, as the sector's legal and regulatory regimes evolve, nationally and internationally, the potential returns on investment, both in terms of economic gain and technological advancement, may make it an attractive proposition for those willing to take on the risks.

Another key challenge that became apparent through this research is that conceptions and definitions of space resources vary widely—even among participants in the space resources industry. This presents a further barrier to private investment because, as in all industries, investors in space resources need to understand the underlying asset class in which they choose to invest.

Following the "story arc" of this dissertation, my first chapter, "The State of Funding of the Space Resources Sector," identifies important trends in how the space resources sector is financed. Key findings include: that the sector suffers from the lack of a broadly accepted definition of space resources; that the absence of a universally accepted legal regime has created ambiguity and hindered investment in this sector; and that (perhaps unsurprisingly) the more developed countries—particularly those that have

enacted laws supporting space resources exploitation, such as the United States, China, Japan, and Luxembourg—have tended to be the most active in funding space resources and supporting the industry's general development.

The second chapter, "Impact of Space Resources Legislation," found that the enactment of space resources legislation that grants property rights for resources extracted from celestial bodies, such as the U.S. Commercial Space Launch Competitiveness Act of 2015, has provided some clarity and offered incentives for private companies to engage in space resource activities. Such legislation has also led to significantly increased investment in the domestic space resources sectors of the countries that have enacted it.

Given the significant challenge that the high upfront costs associated with space missions and resource extraction represent, my third chapter, "A Framework for the Creation of an International Space Development Bank," argues that traditional sources of financing, such as government funding and venture capital, which have played a crucial role in enabling space exploration and technological advancement, must be supported by a new financing model capable of attracting private investment. Such a model could consist in the establishment of a multilateral development bank focused on financing space resources and companies involved in their development.

Looking ahead, the financing of space resources will continue to evolve, driven by technological advancement, changing regulatory landscapes, and shifting market dynamics. The emergence of new players, such as private space companies and emerging space-involved nations, will further diversify the financing landscape and inject fresh perspectives into the industry. It is imperative that policymakers, industry stakeholders, and researchers monitor these developments closely and adapt their strategies accordingly.

To help develop this sector appropriately, significant further research is required to better evaluate the milieu of space resources sector financing. Such research ought to include continual monitoring and updating of the findings set out in chapters 2 and 3 of this dissertation.

The successful financing of space resources represents a unique and challenging opportunity for both private and public entities. The potential economic benefits, technological advancements, and scientific discoveries that may be derived from space exploration and resource extraction are immense.

However, realizing this potential will require the development of innovative financing models, the establishment of a robust legal and regulatory framework, and enhanced international cooperation. These

measures are needed to provide certainty and clarity for investors in the space resources industry.

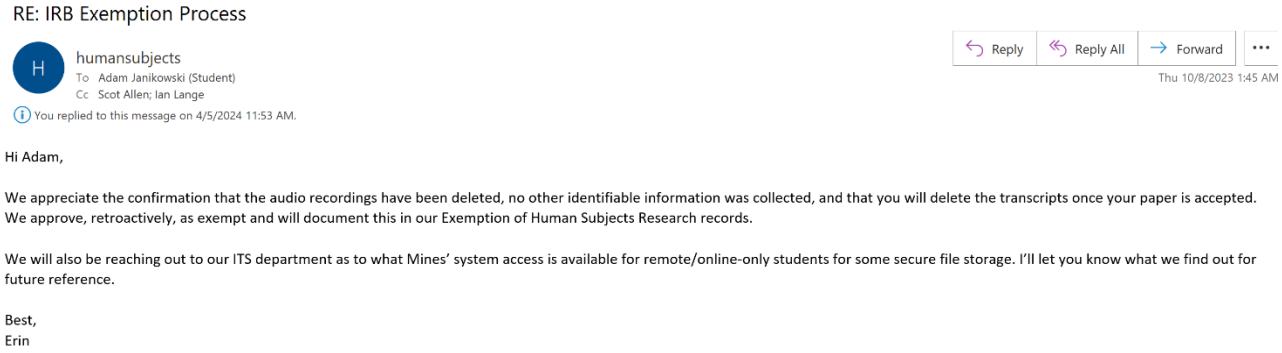
Given the right approach, space resources can be harnessed for the benefit of humanity, ensuring a sustainable and prosperous future for generations to come.

APPENDIX A

COPYRIGHT PERMISSIONS

A.1 Chapter 2: IRB Exemption

"We approve, retroactively, as exempt and will document this in our Exemption of Human Subjects Research records." Humansubjects at Colorado School of Mines via email, October 8, 2023



RE: IRB Exemption Process

H humansubjects
To Adam Janikowski (Student)
Cc Scot Allen; Ian Lange

Reply | Reply All | Forward | ...
Thu 10/8/2023 1:45 AM

You replied to this message on 4/5/2024 11:53 AM.

Hi Adam,

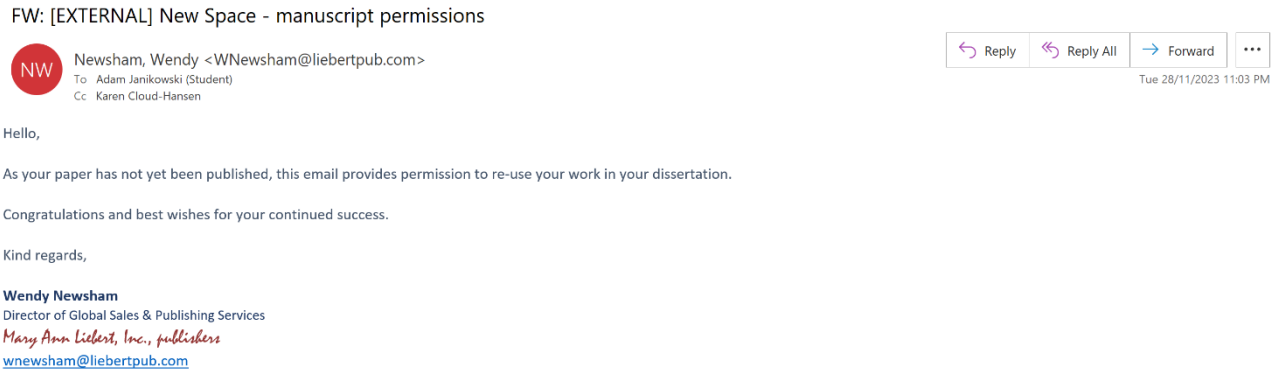
We appreciate the confirmation that the audio recordings have been deleted, no other identifiable information was collected, and that you will delete the transcripts once your paper is accepted. We approve, retroactively, as exempt and will document this in our Exemption of Human Subjects Research records.

We will also be reaching out to our ITS department as to what Mines' system access is available for remote/online-only students for some secure file storage. I'll let you know what we find out for future reference.

Best,
Erin

A.2 Chapter 4: Publisher Permission

"As your paper has not yet been published, this email provides permission to re-use your work in your dissertation." Wendy Newsham via email, November 28, 2023



FW: [EXTERNAL] New Space - manuscript permissions

NW Newsham, Wendy <WNewsham@liebertpub.com>
To Adam Janikowski (Student)
Cc Karen Cloud-Hansen

Reply | Reply All | Forward | ...
Tue 28/11/2023 11:03 PM

Hello,

As your paper has not yet been published, this email provides permission to re-use your work in your dissertation.

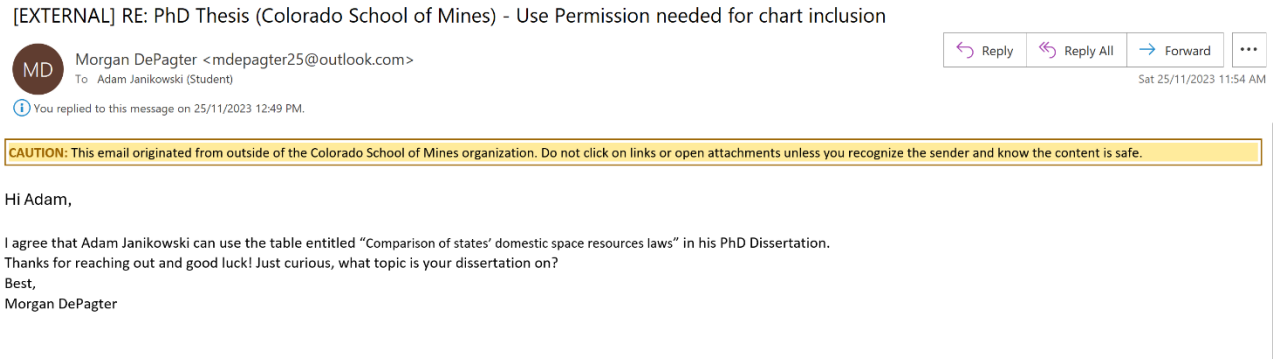
Congratulations and best wishes for your continued success.

Kind regards,

Wendy Newsham
Director of Global Sales & Publishing Services
Mary Ann Liebert, Inc., publishers
wnewsham@liebertpub.com

A.3 Figures and Tables Permissions

Table 3.1: "*I agree that Adam Janikowski can use the table entitled "Comparison of states' domestic space resources laws" in his PhD Dissertation*." Morgan Depagter via email, November 25, 2023



[EXTERNAL] RE: PhD Thesis (Colorado School of Mines) - Use Permission needed for chart inclusion

MD Morgan DePagter <mdepagter25@outlook.com>
To Adam Janikowski (Student)

Reply | Reply All | Forward | ...
Sat 25/11/2023 11:54 AM

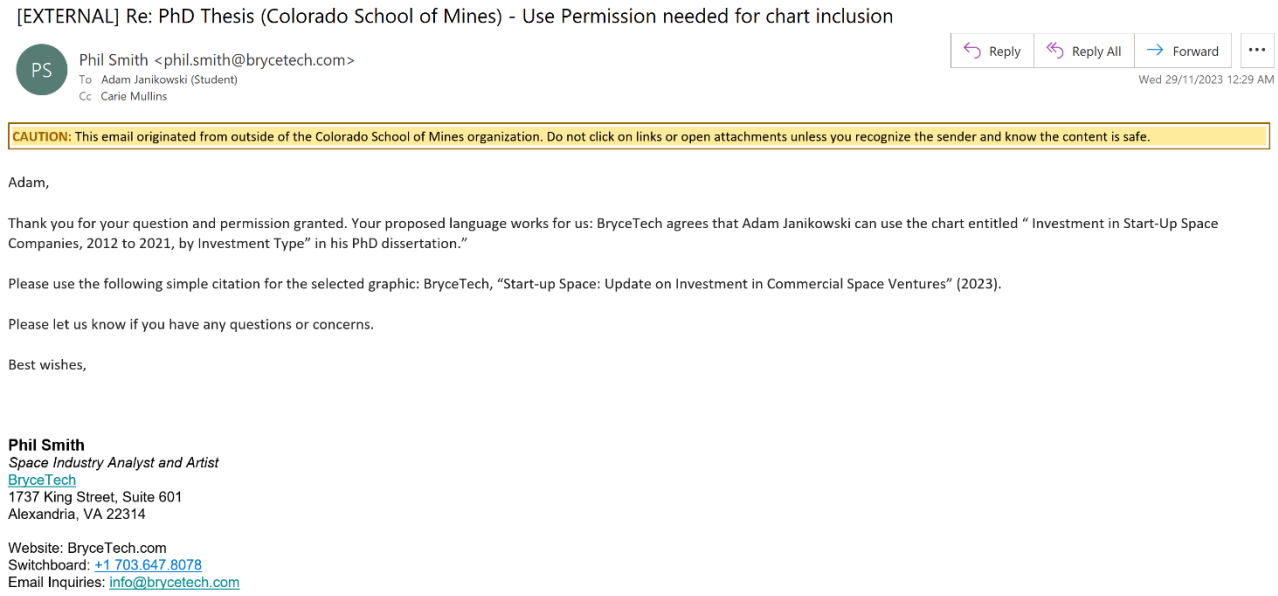
You replied to this message on 25/11/2023 12:49 PM.

CAUTION: This email originated from outside of the Colorado School of Mines organization. Do not click on links or open attachments unless you recognize the sender and know the content is safe.

Hi Adam,

I agree that Adam Janikowski can use the table entitled "Comparison of states' domestic space resources laws" in his PhD Dissertation.
Thanks for reaching out and good luck! Just curious, what topic is your dissertation on?
Best,
Morgan DePagter

Figure 2.1: "*BryceTech agrees that Adam Janikowski can use the chart entitled " Investment in Start-Up Space Companies, 2012 to 2021, by Investment Type" in his PhD dissertation.*" Phil Smith via email, November 28, 2023



[EXTERNAL] Re: PhD Thesis (Colorado School of Mines) - Use Permission needed for chart inclusion

PS Phil Smith <phil.smith@brycetech.com>
To Adam Janikowski (Student)
Cc Carie Mullins

Reply | Reply All | Forward | ...
Wed 29/11/2023 12:29 AM

CAUTION: This email originated from outside of the Colorado School of Mines organization. Do not click on links or open attachments unless you recognize the sender and know the content is safe.

Adam,

Thank you for your question and permission granted. Your proposed language works for us: BryceTech agrees that Adam Janikowski can use the chart entitled " Investment in Start-Up Space Companies, 2012 to 2021, by Investment Type" in his PhD dissertation."

Please use the following simple citation for the selected graphic: BryceTech, "Start-up Space: Update on Investment in Commercial Space Ventures" (2023).

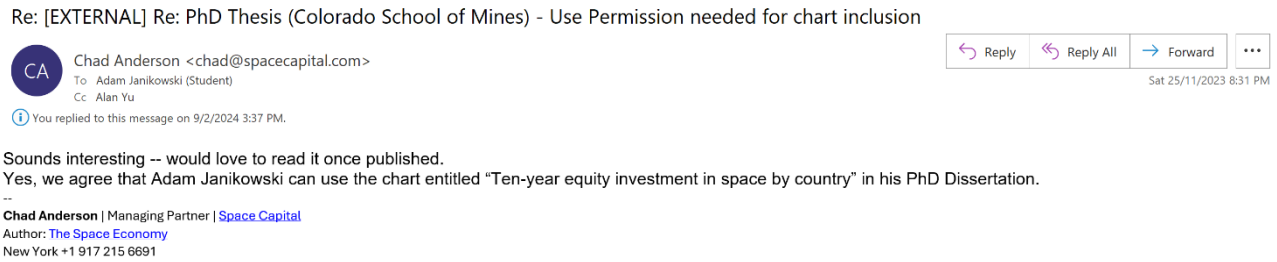
Please let us know if you have any questions or concerns.

Best wishes,

Phil Smith
Space Industry Analyst and Artist
BryceTech
1737 King Street, Suite 601
Alexandria, VA 22314

Website: BryceTech.com
Switchboard: +1 703.647.8078
Email Inquiries: info@brycetech.com

Figure 2.11: *"We agree that Adam Janikowski can use the chart entitled "Ten-year equity investment in space by country" in his PhD Dissertation."* Chad Anderson via email, November 26, 2023



Re: [EXTERNAL] Re: PhD Thesis (Colorado School of Mines) - Use Permission needed for chart inclusion

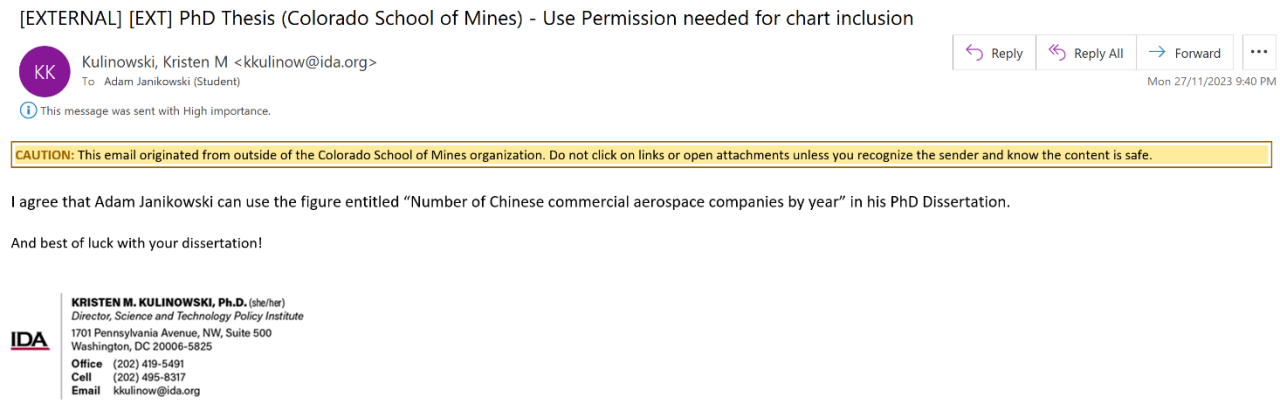
CA Chad Anderson <chad@spacecapital.com>
To Adam Janikowski (Student)
Cc Alan Yu

Reply | Reply All | Forward | ...
Sat 25/11/2023 8:31 PM

You replied to this message on 9/2/2024 3:37 PM.

Sounds interesting -- would love to read it once published.
Yes, we agree that Adam Janikowski can use the chart entitled "Ten-year equity investment in space by country" in his PhD Dissertation.
--
Chad Anderson | Managing Partner | Space Capital
Author: The Space Economy
New York +1 917 215 6691

Figure 3.1: *"I agree that Adam Janikowski can use the figure entitled "Number of Chinese commercial aerospace companies by year" in his PhD Dissertation" IDA via email, November 28, 2023*



[EXTERNAL] [EXT] PhD Thesis (Colorado School of Mines) - Use Permission needed for chart inclusion

KK Kulinowski, Kristen M <kkulinow@ida.org>
To Adam Janikowski (Student)

Reply | Reply All | Forward | ...
Mon 27/11/2023 9:40 PM

This message was sent with High importance.

CAUTION: This email originated from outside of the Colorado School of Mines organization. Do not click on links or open attachments unless you recognize the sender and know the content is safe.

I agree that Adam Janikowski can use the figure entitled "Number of Chinese commercial aerospace companies by year" in his PhD Dissertation.

And best of luck with your dissertation!

IDA
KRISTEN M. KULINOWSKI, Ph.D. (she/her)
Director, Science and Technology Policy Institute
1701 Pennsylvania Avenue, NW, Suite 500
Washington, DC 20006-5825
Office (202) 419-5491
Cell (202) 495-8317
Email kkulinow@ida.org