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Research paper

Sustainable space exploration and its relevance to the privatization of space ventures

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ABSTRACT

Although the majority of humanity's current space programs are currently limited to the operation of the international space station and the deployment of probes to analyze distant planets, visions for future space exploration have long-duration missions in sight (such as manned missions to Mars and asteroid mining). According to contemporary literature these missions have the potential to provide tangible and intangible benefits, but they are also subject to public criticism given that increased awareness for environmental protection and preservation has ignited debates surrounding the socio-environmental and financial sustainability of space exploration. In hindsight of past advancements in outer space exploration, the authors follow the assumption that the commercial development will flourish and will provide auxiliary opportunities to overcome existing challenges. However, it is clear that the germination of private investment in the field of space exploration is contingent on the existence of unequivocal international space laws that permit and stimulate profit decision making. Following this line of thought, this paper will explore the divergent definitions of sustainability that exist in the rhetoric of space exploration and will additionally expound on the privatization of space exploration and its relevance to the controversial legal rationales of international space laws.

1. Introduction

As a result of the increased societal benefits acquired from human activities in space such as those derived from the use of unmanned satellites for telecommunications, defense or weather monitoring [1], the vision for future space exploration missions is no longer "*merely looking back at planted flags*" [2]. Upon realizing the untapped potential of space, a growing number of nations and private entities have included exploration in their agenda, framing it as a potentially fruitful technological adventure (even though it entails considerable risk which can be partially alleviated through international cooperation) [1,3]. Although space exploration is currently limited to the operation of the International Space Station and the deployment of probes to analyze distant planets, some of the visions for the next twenty years are promising and include the establishment of self-sufficient lunar bases, manned missions to Mars and asteroid mining [4]. Despite the technological advances and high economic returns that space exploration promises[1] [5], such long-term projects inevitably undergo governmental scrutiny and must overcome a myriad of challenges, including budget shortfalls, technical challenges, environmental degradation and social alterations which can affect political and public support [6].

Public support in particular could be characterized as a dichotomous case as even though civilians have initially little incentive to become directly involved in the political process of space exploration, their consensus is highly dependent on the extent to which tax money is allocated towards space related activities [7]. For instance, while one study from the U.S estimated that approximately 60% of Americans believed that NASA was doing a good job [8], another showed that only 33% of those surveyed thought that space programs, and the Apollo missions in particular, were worth the cost [9]. Similarly, financial concerns may arise amongst citizens of other spacefaring nations such

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[1] For instance, Norwegian space sector companies (which play only a small role in the programs of the European Space Agency) produced a turnover of 4.7 million NOK for every 1 million invested in activities pertaining to the European Space Agency and other related programs in 2009 [5].

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as Japan,[2] which could potentially trigger public opposition to government funded space programs in the future.

These hurdles have compelled the agencies working on such programs to develop standards designed to minimize costs and maximize operational efficiency in order to perform all the tasks they have been entrusted with in a timely, cost-effective manner [10,11], while providing the crew involved in these missions with a good quality of life [12]. These types of solutions, although capable of meeting the top priorities of space agencies, tackle only a fraction of the sustainability concerns pertaining to space activities. In essence, a sustainable space exploration program should be relevant to societal needs by bridging concepts such as space development and discovery [13,14]. Hence, the definition for space exploration utilized in this paper merges the concepts of "development" and "discovery", as employed in NASA's Strategic Plan 2018[3] [15]. Further, the cross-boundary sharing of information amongst earth and space-centric scientists which is required to make such programs succeed, can only be made possible through the broad participation of many stakeholders at the worldwide level, both in the private and public sectors [16,17]. Such collaboration is conditional upon the ability of space agencies to operate within the boundaries of sustainability and the existence of international space laws that unify, enhance and incentivize future attempts at space exploration. However, so far space exploration through private investments has been significantly hampered by the lack of a clearly defined legal regime for recognizing property rights in the boundaries of outer space under current international laws [1], thus limiting the potential growth of space exploration.

Until now, the latter issues were considered inconsequential and limited effort has been explicitly dedicated towards the clarification of the ethical rationales that underlie the sustainability of space exploration. Under the assumption that the commercial development of space will flourish and provide auxiliary opportunities to overcome global challenges (such as environmental degradation and resource shortages), this paper will explore three different domains of space exploration; namely the concept of sustainability in the context of space exploration, the private commercialization of space and international space laws.

Consequently, section two of this paper is dedicated to the different dimensions of sustainability that can be found in discourses pertinent to space exploration. These are centered predominantly around discussions related to the long-term survival of the human race, the alleviation of environmental damage caused by the mining of resources, or the advancement of technology. Section three examines the role of private space organizations in space exploration. As a collection of stakeholders that is currently greatly influencing the sustainability factors mentioned above, it is critical to scrutinize the elements which drive or inhibit private investments in space. We then indicate how this growing trend in the private commercialization of space has created new challenges to space law, which need to be addressed. Finally, to paint an integral picture of the concerns and thoughts surrounding international space laws and their relevance to space privatization, a brief historical overview of international space legislation is provided in section four. Further, this section provides remarks leading to the conclusion that, although the current international laws do not explicitly inhibit space enterprises from exploiting outer space per se, light revisions should be undertaken (particularly with regards to the regime of property rights in outer space) to encourage the private sustainable commercialization of space.

[2] Japan has contributed, as of 2016, the equivalent of 900 billion dollars to the operation of the International Space Station; approximately 100 billion dollars for each Japanese astronaut sent to the space station [113].

[3] "Development" refers to a space mission's attempt to address international challenges and expediate economic growth, whereas "discovery", in the context of space exploration, refers to the expansion of human knowledge through human presence in outer space.

2. Concepts of sustainability

The growing concerns over socio-environmental issues in the 20th and 21st centuries, such as climate change, poverty and social inequality, among others, have heighted the need for the development of policies, regulatory frameworks and other practices that encourage the adoption of principles of environmental and social responsibility [18]. The need for such fundamental social change has led to the emergence of the concept of sustainable development, which was widely discussed during the early 1980s and was finally integrated into the international agenda in 1987 with the publication of the report "Our Common Future" by the World Commission on the Environment and Development (also known as the Brundland's Commission) [19]. Although the notion of sustainability which is multi-dimensional and ambiguous in nature has brought to life a number of divergent discourses over time [20], the very definition of sustainable development remains similar to the one given by the Brundland's Commission [21]. Essentially, it is defined as:

> "Meeting the needs of the present without compromising the ability of future generations to meet their own" [22].

The key principle of this sustainable development is the holistic unification of environmental, social and economic concerns into all aspects of decision making [23], thus incorporating issues such as land development, economic stability, human development (including education and public health) into a global perspective.

Although these principles of sustainable development do not explicitly mention outer space, this does not necessarily exclude their application to this emerging field. Nevertheless, sustainability in the context of outer space is considered to be ill-defined and underdeveloped, potentially because of the perceived vastness of outer space and the limited number of stakeholders involved in space missions. However, given the environmental and social issues that emerged following the industrial revolution, the international community proposed to include the "Long-term Sustainability of Outer Space Activities" as a new agenda item on the report of the Committee on the Peaceful Uses of Outer space in 2010 [24]. This agenda was meant to ensure the sustainability of space missions by establishing voluntary guidelines to reduce future risks. Even though it provides a more comprehensive picture of what is happening in space, each member state has only adopted the guidelines that apply to its own settings. For example, the long-term sustainability targets of the United States have predominantly focused on enhancing the safety and efficiency of space operations, strengthening international cooperation, stimulating public's awareness of space exploration and minimizing future space debris [25]. Alternatively, Japan's efforts have centered around enhancing space situational awareness, pursuing opportunities for cooperation for the use of space for maritime domain awareness and creating new markets for Japan's space industries [26,27]. Although these types of contemporary, politically and economically centered sustainability issues constitute daunting tasks, the scope of this section is to highlight and systematically examine a broader range of sustainability discourses, particularly those that are relevant to the private commercialization of space. As such, the next section will expand on a wide spectrum of discourses that pertain to sustainability in the context of space exploration.

2.1. A review of discourses regarding sustainability in the context of space exploration

The idea of sustainable space exploration as promoted by advocates of space development rests on the assumption that our species will inevitable push the boundaries of our current civilization towards outer space. This development would in theory be brought forth by concepts such as space tourism [28], lunar and asteroid mining [29], and the colonization and industrialization of extraterrestrial astronomical bodies [30]. Following this line of thought the National Commission on

Space, a panel of experts appointed by the 40th president of the United States, Ronald Reagan in 1986, advocated that humankind is destined to expand to other worlds with the purpose of establishing colonies on extraterrestrial astronomical bodies [31]. Moreover, the National Space Society (NSS), an international nonprofit educational and scientific organization created in 1987, set out that their vision for space exploration is to expand human civilization into space and use the vast resources of space for the betterment of humanity [32]. Furthermore, among the society's beliefs are "individual rights, unrestricted access to space, personal property rights, free market economics, government funding for high risk R&D, international cooperation, democratic values, enhancement of Earth's ecology and protection of new environments" [32]. A number of space advocacy groups, such as the Space Frontier Foundation, the Space Studies Institute and the Mars Society, share the beliefs of the NSS focusing particularly on space colonization and exploitation [30].

Thoughts regarding the potential colonization of space emerged primarily as a measure to avoid an improbable yet high-impact event referred to as a "black swan" event which is capable of dramatically eradicating all life on Earth [33,34]. The extinction of humanity as unlikely as it sounds, could be brought about by a number of causes [35], such as changes in the composition and the radiative output of the sun [36,37], threats from nuclear warfare, pandemics, anthropogenic climate change, disruptive technologies [38], impacts from large comets or asteroids [39,40] or from social collapse following a large catastrophe [41]. Proposed solutions to such existential threats (which could ensure the sustainable development of human civilization over time) include space colonization (i.e. the creation of colonies on extraterrestrial bodies such as Mars or the Moon), the deployment of isolated refuges away from the Earth's surface [42] or the construction of a "doomsday shelter" [43]. However, although potentially capable of alleviating the risk of such events, these solutions are often described as being financially infeasible as they require copious amounts of investments that could otherwise be allocated towards alleviating contemporary social sustainability issues such as poverty and pollution [44].

An additional consideration of space exploration is that, as specified by NASA, it can stimulate the creation of both tangible and intangible sustainable benefits for humanity [45]. Tangible impacts include all the innovation-related benefits that typically result from investment in these programs, such as new devices and services that spin off into the marketplace. Additionally, space exploration leads to advances in science and technology and furthers workforce development and industrial capabilities, which significantly contribute to the economic progress of space-faring nations. On the other hand, intangible benefits include the enrichment of culture, the inspiration of citizens and the building of mutual understanding as a result of international cooperation among space-faring nations.

Another reference to sustainability in space policy states that the concept of sustainable space activities pertains to the preservation and protection of the Earth's environment, and is not necessarily directly related to social development or economic growth [46]. These concerns are related to the control of orbital debris, the regulation of the usage of the electromagnetic spectrum and the enforcement of planetary protection policies that ensure that space missions do not contaminate extraterrestrial environments during exploration missions [46]. Ryder W. Miller, an advocate of astroenvironmentalism, a concept that applies the values of environmentalism and sustainability to advancements in space exploration, commercialization and militarization, also supports the protection and conservation of celestial bodies. This concept promotes ideas such as the need for maintenance of the space surrounding Earth in order to clear pollution, debris and garbage, and minimize the human waste and machinery left behind by space explorers [47]. A number of science fiction writers and journalists, such as William F. Nolan, Karl Grossman and Gar Smith are also concerned about the environmental implications of space exploration [48]. Particularly, Grossman et al. [49] were worried about the potential dangers of the utilization of plutonium in outer space missions, whereas Smith et al. [50] focused on space pollution and the complexity that underlines the creation and corporate compliance with international space laws. Other parties within the space policy community are also concerned about space security, such as ensuring that space is utilized for peaceful purposes. This is dictated by the 1967 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 (a.k.a. Outer Space Treaty) [51].

However, regardless of comments made by advocates of sustainable space exploration, the space science community trying to be practical in formulating plans regarding space development seems to be devoting little to no attention to the idea of preserving and protecting pristine extraterrestrial environments. Conversely, they are increasingly interested in discussions concerning activities that have a large impact on the environment of such bodies. One of these activities is "terraforming" (a.k.a. "planetary engineering"), that is, purposely modifying the atmosphere, temperature, surface topography or ecology of a planet or other bodies to transform their inhospitable environment to that of Earth which could be characterized as habitable for the species native to our planet [52,53]. On that note, it is also important to note that despite such interest in terraforming Mars and other astronomical bodies, today's engineering capabilities limit such endeavors and as such these concepts are viewed as nothing more than sophisticated illustrations of interesting but speculative ideas [54].

Further, the growing perception regarding the progressive depletion of natural resources on Earth has also shifted the focus of scientists and private investors to an activity that goes by the name of "asteroid mining" which is the exploitation of raw materials from asteroids and other minor planets, including near-earth objects. Asteroid mining was once perceived as an activity that was in the realm of science fiction though it could become a reality through the use of advanced technologies and directed investments [55–58]. Many believe that the technology necessary to achieve such expeditions already exists and that it just needs to be adapted to extraterrestrial environments [59]. Asteroids are known to contain valuable resources as they can be rich in elements such as neodymium, scandium, yttrium, iridium, platinum, palladium, gold, and silver among others [60]. All of these elements are rare on Earth and have the potential to justify and even outperform the high cost associated with space mining expeditions. The resources of just one asteroid in our solar system could be worth up to $95 trillion [61], significantly higher than the world's total GDP in 2016 [62]. When scientists think of sustainability in terms of harvesting resources, they typically conduct research on technological improvements that can alter the environmental impacts of Earth-based mining. Most do not consider the consequences of removing part of the mining industry from Earth altogether, which could benefit the environment by reducing terrestrial mining activities, thus preserving the planet's limited resources [63]. It is worth mentioning at this point that the concept of extraterrestrial mining has ignited a heated controversy in literature with respect to where humanity draws the moral line when it comes to the commercialization of astronomical bodies. Some oppose space mining on the grounds that astronomical bodies may be occupied by microscopic organisms which have intrinsic value, based on their own "rudimentary interests" [64]. Others maintain that even abiotic astronomical bodies have intrinsic value and as such should remain undisturbed [65]. Another group argues that the aforementioned ethical approaches are largely overblown [66] as asteroids are uninhabitable, have no atmosphere and their exploitation causes no damage to ecospheres since they are considered to be lifeless rocks, nothing more than left-overs from the formation of the solar system [63].

Though the extent to which the privatization of space could positive or negatively affect the socio-environmental sustainability of humanity's living space remains to be seen, it is imperative to outline at this point what types of benefits can private space organizations provide in

order to demonstrate the value they could create. As such, the next section is dedicated to a brief historical overview of the emergence of the concept of the privatization of space and the role played by private space organizations in today's space exploration missions.

3. The privatization of space

For the greatest part of the space age the role of private companies was limited to that of government contractors particularly because in the late 1960's spacefaring activities were predominantly centered around the development of military missions that aimed at enhancing national security [67], manned missions to space or the launch of commercial satellites. Ever since then, several factors such as scientific advancements, the growing interest of spacefaring nations in benefitting financially and socially from space activities and the possibility of asset recovery have increased the private sectors' share of responsibility in space flight [68,69]. In turn, this increased participation of the private sector in manned and unmanned space missions have led us to a point in time where many space activities are comprised of a mixture of private and public elements. For instance, the launch of publicly owned and funded robotic spacecraft is expediated significantly through the contribution of the private sector in the development of advanced propulsion technologies [70]. Moreover, the distinction between the private and public sectors' attempt to commercialize space has been further blurred by the introduction of commercial cargo and crew initiatives. In an attempt to clear the confusion between the “private” and “public” commercialization of space, throughout the remaining of this paper the “private” commercialization of space shall refer to the collection of space activities that are performed and funded entirely by the private sector and ultimately aim at increasing the profits of its shareholders. Simply “commercialization of space” on the other hand shall refer to the activities that are conducted through the collaboration of private and public sectors.

During the past couple of years, private companies have been increasingly responsible for managing or supporting operations related to outer space and are now capable of launching their own satellites into low earth orbit (LEO) [71]. NASA's Commercial Crew Development program is a notable example of how the private space launch market has been experiencing a steady growth during the 21st century. The Dragon capsule, a spacecraft developed by Space X, an American aerospace manufacturer and space transport services company, became the first commercial spacecraft to successfully rendezvous with and attach itself to the international space station (ISS) in May 2012 [72–74]. This incremental phenomenon of space commercialization has gained tremendous momentum in the 21st century and past events clearly indicate that it has reached a point of no return. According to a 2015 report by the Space Foundation, the overall space-related investments (which consist of rocket and satellite launches, ground services, satellite manufacturing, etc.) reached a total of $330 Billion worldwide in 2014, 76% ($250.8 Billion) of which were derived from commercial space activities [75]. This provides clear evidence of how intertwined private and public organizations have become in this sector, and this interdependency and interconnectedness could incrementally grow stronger through the diversification of the activity portfolios of private organizations.

This commercial use of outer space can arbitrarily be divided into two categories: “traditional” and “novel” approaches (Fig. 1); both of which have the capacity to deliver remarkable direct (e.g. scientific knowledge) and indirect (e.g. reduced chance of a global catastrophic risk) environmental, social and economic benefits to society. Under the umbrella term of traditional approaches there is a vast collection of corporate strategies which aim at generating revenue through the provision of services or manufacturing of goods. The private entities that are actively utilizing traditional approaches to make profit through outer space activities typically include the manufacturers of satellites, launch vehicles, spacecrafts, rovers and probes as well as the providers

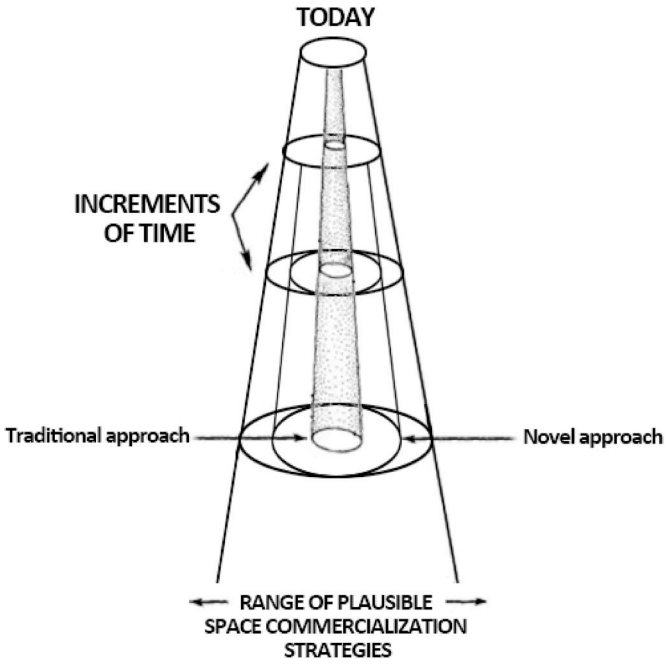

Fig. 1. The two-part typology of commercial use of outer space as illustrated through a “cone of plausibility” diagram.

of third-party services. Although these private entities function in various fields within the space industry, they all operate under a highly sophisticated risk assessment regime which employs proven, well-tested and generally reliable techniques and strategies. In turn, the products of such approaches are transformed in time into direct societal benefits that take the form of technologies that span a wide range of fields such as power generation and storage, water filtration or advanced robotics. On the other hand, novel approaches are those that are comprised of strategies that aim towards exploiting the currently untapped potential of outer space by providing goods and services that were either previously not thought of, or were considered as technically and/or economically infeasible (e.g. asteroid mining, space tourism and the creation of space colonies). As highlighted in chapter 2.1 earlier, these novel approaches could provide a number of indirect, long-term benefits to society. Amongst others, these could take the form of the enhancement of the natural resources of planet Earth and/or the alleviation of environmental degradation and climate change through the deceleration of mining on Earth. It is worth noting that although the novel approaches to the private commercialization of space are not deemed cost-effective as of yet, they hold great potential for enhancing the socio-environmental sustainability of our species.

The importance of the benefits that stem from the privatization of space exploration and its relevance to terrestrial and extra-terrestrial sustainability has been highlighted in the past by numerous representatives from all over the world. For example, a convention in Lucca, Italy, on November 10, 2011 concluded that the conspicuous benefits of space exploration include:

> “Fueling future discoveries, addressing global challenges in space and on Earth through the use of innovative technology, creating global partnerships by sharing challenging and peaceful goals, inspiring society and especially the younger generations through collective and individual efforts and enabling economic expansion and new business opportunities” [76].

Nevertheless, some authors argue that the benefits brought forth by the private commercialization of space are often exaggerated and constitute nothing but segments of an “overly optimistic picture” [77]. According to an article published in The Wall Street Journal, the

partnership between public and private space companies has been sporadically unfruitful and financially unsustainable, showcasing as an example the failed joint project between NASA and Lockheed Martin which resulted in a cost of over one billion dollars [78]. Additionally, in contrast to governmental space agencies (which are funded by taxpayers and focus on the general development of space exploration), private companies are driven by profitability and the interests of the entity's shareholders, and thus are less likely to join an endeavor purely for the generation of knowledge. According to some, this suggests that the influence of the private commercialization of space on sustainable exploration will initially be limited and contingent on the ability of the given private company to generate sustainable income [79]. Furthermore, despite recognizing the potential technological progress that can be made and the appeal of obtaining valuable resources, some maintain that the privatization of space exploration is a highly unpredictable venture, which has brought a number of financial, political and technological considerations to the forefront. As noted by Julie Payette, space exploration is "*as much a foreign policy and human achievement as it is a technical one*" [80]. Although many authors recognize the gravity of such issues, the analysis of the financial and technological obstacles for the private commercialization of space exploration is beyond the scope of this paper and as such will not be examined further.

Nevertheless, the authors maintain the assumption that the increasing shift of ownership from the public to the private sector will bestow upon humanity considerable sustainable value through the enablement of highly efficient, cost-effective operations [81] that can exploit the untapped potential of suborbital and orbital space [82]. As such, this paper shall continue by scrutinizing one of the major stumbling blocks underlying the development of space exploration, namely the ambiguous nature of space laws with respect to property rights [83]. This ambiguity stems from the 1967 Outer Space Treaty, which disincentives private investments in the field of space exploration and technology and is the major reason underlying the reluctance of companies to move outside the boundaries of LEO. Under these circumstances, it is important to explore the current legal space framework in order to highlight an ideal regime which could provide the assurance that the private industry requires in order to undertake high risk space exploration.

4. International space law

Francis Lyall and Paul B. Larsen [84] assert that the concept of space law has been a subject of debate since as early as 1926. According to these authors the very scope of space law was initially ill-defined, was limited to dealing with the practical problems of venturing towards outer space, and could technically be applied to everything from commercial contracts to more general issues such as a state's behavior in space [84].

An important precedent for the development of international space law was the 1959 Antarctic Treaty which sets aside Antarctica as a scientific preserve, establishes freedom of scientific investigation and bans all military activities on the continent [85]. These objectives were exactly what the world leaders were concerned about during the era of the space race and were interested in accomplishing through an international agreement governing space activities. This became evident when the launch of the Soviet Union's Sputnik 1 on October 4, 1957 and Sputnik 2 on November 5th acted as a catalyst for the establishment of NASA by the U.S congress [86]. President Eisenhower proposed to use the principles of the Antarctic Treaty as a stepping stone in order to design an independent agency that regulates all space activities within the United States [87]. The United Nations then established the UN Office of Outer Space Affairs (UNOOSA) to promote international cooperation in space [88], and founded COPUOS in 1959 to oversee future treaties and agreements and generally ensure the peaceful use of outer space. At present, five international treaties and a number of other agreements have laid the framework of space law under the jurisdiction of COPUOS [89]. These five major treaties have been designed to produce some semblance of order by taking into account the different legal systems, values, interests and debates of the parties involved in space activities [90]:

1. The 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty or "OST")
2. The 1968 Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (Rescue Agreement)
3. The 1972 Convention on International Liability for Damage Caused by Space Objects (Liability Convention)
4. The 1976 Convention on Registration of Objects Launched into Outer Space (Registration Convention)
5. The 1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (Moon Treaty).

The Outer Space Treaty (OST), which forms the basis of international space law entered force on October 1967 and was signed by 104 nations across the globe. Article I of the OST provides that "exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interest of all mankind alike" [91]. However, at the time of the Treaty's adoption two states held a monopoly on space activities, namely the United States and the former Soviet Union [92]. Thus, the true source of interest for the rest of the nations to sign such a treaty stemmed from the fear that the two space powers would exploit outer space to gain a decisive advantage over other nations [93]. Additionally, some parties to the treaty, particularly the old Soviet Union, wanted space activities to be the sole preserve of governments. However, after several negotiations with the United States a compromise was achieved in article VI of the treaty that "Paved the way for the private sector to conduct space activities side by side with the government and the intergovernmental organizations" [1].

The treaties following the OST extended it to reflect the pace of technological evolution and applied its generalities to particular situations. Particularly, the Rescue Agreement (1968) requires that any state party of the convention that becomes aware that the personnel of a spacecraft are in distress must notify the launching authority and the Secretary General of the United Nations [94]. The Liability Convention (1972) [95] defined terms such as "damage", "launching" and "space object" among others, and highlights who will be responsible for the damage caused by the launching of objects into outer space (a treaty that was widely accepted by states that were not capable of space flight). The Registration Convention (1976) stated that all objects launched into earth orbit or beyond must be recorded by an appropriate space authority [96].

Another important piece of legislation was the Moon treaty, which does not only apply to the Earth's satellite but to all celestial bodies in the solar system and which entered into force in 1984 [97]. The principle behind this treaty is centered around the idea that the resources or territories that are outside the boundaries of Earth are the common heritage of mankind and as such their exploitation would have to be governed by the international community. Due to its severe stance against the ownership of property in space it has been referred to as the "arch-enemy of space exploration" [98] and is considered a failure, as of 2019 it has not been ratified by any state that engages in self-launched manned space exploration missions or has future plans to do so (i.e. the United States, European Space Agency, Russia, People's Republic of China, Japan and India) [99]. Nevertheless, this document remains important as it is the only treaty that contemplates at all the issue of ownership of property in space.

Despite the existence of the aforementioned international legislation, as with all international laws the actual efficacy of these treaties is debatable as nations often ignore their precepts or disagree on the

meaning of their substance [84]. In the specific context of international space law, the legal debate over the regulations regarding private property in space is indeed intricate. Although the OST sets out a number of general principles to be expanded upon, it did not mention specifically any guidance with respect to the ownership of extra-terrestrial property. Even when the OST strictly mentions that no member of the treaty shall own celestial bodies, it does not mention anything about private entities per se. According to Stephen Gorove's comment in 1969, "The Outer Space Treaty in its present form appears to contain no prohibition regarding individual appropriation or acquisition by a private association or an international organization" [100].

Further, the very existence of the Moon Treaty indicates that its predecessor, the Outer Space Treaty, did not outlaw private ownership of extra-terrestrial bodies, for if it did there would be no need to ratify the Moon treaty in the first place. Thus, it can be noted that currently the Outer Space Treaty does not explicitly prohibit private property in space. Despite such evidence, the international community is still puzzled by the concept of private ownership in space as many governmental and non-governmental agencies maintain that the Outer Space Treaty specifically states that appropriation of space property is not permitted [101], on the grounds that the private sector is an extension of the state that they represent and as such private ownership in the realm of outer space is prohibited [102]. Others assess that this ambiguity constitutes a "loophole" that allows the private sector to utilize the resources of outer space freely and for personal benefit [100].

Furthermore, the increasing number of claims and attempts to sell, buy or even keep extraterrestrial properties illustrate the problem of ambiguity regarding ownership of property in space [103]. The legal premise of the Eros Project is a fine example of this, portraying the complexity of the matter [104]. Gregory Nemitz claimed ownership of a near Earth asteroid called 433 Eros on the Archimedes Institute's Private Property Rights Registry in 2000. Eleven months after the incident, NASA permanently parked the NEAR shoe-maker probe on the asteroid on February 12, 2001 [105]. Mr Nemitz, being aware that the probe had no way of removing itself from the asteroid by utilizing its own propulsion system, charged NASA twenty dollars as a fee for parking the probe on his property. NASA, as was expected, refused to pay the fees by claiming that such a request has no foundation in law. Another similar example portraying the complexity of the issue involves the Apollo astronauts. When the mission's crew brought moon rocks back to Earth NASA declared them to be property of the U.S government. Ever since their landing, the international community has acquiesced to the United States claim of ownership over rocks harvested from the Moon [63].

In light of such ambiguity and the fact that regulatory certainty is a vital component for the success of non-traditional space ventures, the United States' Senate Commerce, Science, and Transportation space subcommittee held a number of hearings in an attempt to identify which legislative alterations could foster growth in the commercial space industry [106,107]. The results indicated that although there was consensus regarding the general preservation of the 50-year old OST, there was indeed a need for "light hand" adjustments [106]. The hearings culminated in the establishment of Spurring Private Aerospace Competitiveness and Entrepreneurship (SPACE) Act of 2015, which among other legislative changes, allowed US citizens to:

> "engage in commercial exploration for and commercial recovery of space resources (including water and minerals, but excluding biological life)" [108].

Although this act reiterates that the United States has no sovereignty over objects in space, it has ignited a heated controversy amongst scholars with respect to whether the law truly conforms to international space law, specifically the OST. The U.S House Committee on Science, Space and Technology denies such allegations on the ground that the right to extract natural resources from extraterrestrial bodies is:

> "Affirmed by the State practice and by the U.S State Department in Congressional testimony and written correspondence" [109].

Further, Frans von der Dunk, a law professor at the University of Nebraska, claims that although the Act does not explicitly violate any laws, it as of yet unclear whether private efforts towards space mining are legal [110]. On the other side of the spectrum, Fabio Tronchetti, a professor at the Harbin Institute of Technology, argues that the SPACE Act constitutes an unlawful act of sovereignty, as it violates the provisions in OST which prohibit the ownership of extraterrestrial property [111].

It thus seem that a "light" revision of the current international space law with respect to private property rights in space is necessary to stimulate growth in the private space industry and encourage private entities to take on the risks involved with the development of space technologies [112]. Essentially, the endorsement of a given law is often contingent on its ability to set coherent goals and requisite targets. As stated by Lyall and Larsen, who use the Law of the Sea as an informative analogy, "*the practice* [of a law] *need not be wholly uniform, but must be undertaken in the belief that it is binding and required by law as opposed to being merely convenient or mutually beneficial*" [84]. Particularly, the international community could utilize one of the existing laws (i.e. OST or Moon Treaty) as a steppingstone towards explicitly recognizing the extra-terrestrial property claims of corporations that meet certain specified conditions, thus paving the way for a sustainable privatization of outer space. However, questions would nevertheless arise as to which country should these corporations be paying tax to, given that their extraterrestrial activities take place in an environment of ambiguous geopolitical boundaries. To that end the authors would like to venture the possibility of establishing a platform which enables such commercial entities to forward wholly or partially their corporate tax to the United Nations directly. This would ensure that the profits of such ventures could clearly be channeled to the sustainable development of mankind on planet Earth, and provide a viable long-term source of funding to the U.N.

5. Concluding remarks

Although the concept of the "Earth's environment" is one with which most people feel some affinity, many would find it rather difficult to identify with an unfamiliar topic such as "space environment", let alone its sustainable development. Additionally, given the confusion within the scientific community surrounding the term "space sustainability", to say that sustainable space exploration is not well understood would be an understatement. Sustainability in the context of space exploration is at the bare minimum understood as an activity of contentious importance that depending on the author, limits the risk of human extinction, minimizes space pollution or environmental degradation in space (such as space debris) and/or increases the welfare of humanity on Earth (by technological advancements in fields such as medicine or environmental management). However, regardless of its perceived importance, the budget of individual space actors (both public and private) is severely constrained and as such tend to focus only on what is strictly necessary to remain operational (such as abiding by technical specifications, government policy and other strictly defined requirements). Therefore, if sustainability is not quickly identified as a requirement it is more likely than not that it will not be provided for. Thus, a coordinated effort to develop a strategy to ensure the sustainability of space exploration activities is required, and the first step towards achieving that goal would be to make space relevant to problems on Earth in a way that it can be understood by the general public.

Moreover, a phenomenon that can significantly affect the financial sustainability of space exploration (which can, as explained earlier, affect the long-term sustainability of the human race on Earth) is the issue of privatization of space which is itself dependent on current

international space laws. As of today, space treaties and agreements strive to address a variety of matters, such as the preservation of space and Earth's environment, liability for damages caused by space objects, the settlement of disputes, the use of space-related technologies and international cooperation. However, despite the attempt of the United Nations and the international community to reach a mutual agreement on the controversial domain of property ownership, the treaties remain a potential disincentive to the economic utilization of space and find the major spacefaring countries in disagreement.

The envisioned legal regime to encourage private firms to undertake the high risk and high cost involved in activities of space exploration would have to explicitly recognize extra-terrestrial property claims of individuals and corporations that meet specified conditions. As such, based on the conclusions made through this paper, it is considered that with the right negotiation terms, the current treaties can be revised so as to become steppingstones for the advancement of space exploration that could potentially bring forth significant changes to the environment surrounding planet Earth. Finally, one way that such privatization efforts could be seen to benefit of mankind as a whole is that any taxation resulting from it should be paid directly to the United Nations, or that at least some fraction of the profits should fund this organization.

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