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DEVELOPING A FRAMEWORK AND POTENTIAL POLICIES FOR SPACE SUSTAINABILITY BASED ON SUSTAINABLE MANAGEMENT OF COMMON-POOL RESOURCES

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ABSTRACT

Over the past few years, achieving the long-term sustainability of space activities has become a central goal of many policy initiatives. Space sustainability is emerging as a core element of national policy and international initiatives. However, while more policymakers and stakeholders are recognizing the importance of space sustainability, none have developed an effective strategy, and accompanying policies, for accomplishing it.

This paper examines scholarly research from the fields of economics and governance theory and evaluates its potential to serve as a roadmap for a space sustainability strategy. In particular, it examines Nobel Prize Winner Elinor Ostrom's principles for sustainable governance of common-pool resources (CPR). These principles were distilled from decades of studies on dozens of CPR situations. They capture the best practices of CPRs that have been used sustainably for decades or even centuries, thus avoiding the famous "Tragedy of the Commons," without being either completely privatized or controlled by a Leviathan entity.

Ostrom's principles highlight the need for clear definitions of boundaries for the space domain, what entities are considered resource appropriators, rules tailored to fit the domain, who has a say in formulation of collective-choice agreements and operational rules, monitoring of behavior and accountability, graduated penalties, conflict-resolution mechanisms, and nested arrangements. When viewed in the context of the space domain, these principles highlight some long-standing issues, such as the definition of where space begins and gaps in the existing liability regime; and emerging issues, such as the concept of shared or collaborative space situational awareness as a monitoring and verification mechanism and how best to include emerging and developing space actors in negotiations and decision making.

The paper concludes that Ostrom's principles highlight specific areas on which to focus initial space sustainability efforts and national and international policy on this subject. It also recommends further analysis into how best to translate her principles to the space domain, where they may not be wholly applicable due to the unique nature of space, and how to evolve space governance institutions and mechanisms over time to best suit the unique environment of outer space.

I. THE EMERGENCE OF SPACE SUSTAINABILITY AS A POLICY OBJECTIVE

Over the last few years, a new theme has emerged within the field of space policy. Although many States have long recognized the importance of outer space for national and international security and global business, there is a growing realization that the ability to use space for its benefits on Earth is not guaranteed forever. Driven in large part by events such as the intentional destruction of a weather satellite by China in 2007 [1] and the accidental collision between an active American and an expired Russian satellite in 2009 [2], an increasing number of policy initiatives have identified the long-term sustainability of the space environment and humanity's activities in space as an important policy goal.

The most prominent example is the National Space Policy of the United States of America, issued by the White House on June 28, 2010, which states [3]:

> *"The United States considers the sustainability, stability, and free access to, and use of, space vital to its national interests"*

At the international level, the concept of space sustainability is also gaining traction. In June 2007, Gerard Brachet, then Chairman of the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS), suggested that the long-term sustainability of space activities should be a future focus of UN COPUOS [4]. Through an informal working group, the concept was further expanded upon and in June 2009, UN COPUOS agreed to create an official agenda item for the "long-term sustainability of outer space activities" within its Scientific and Technical Subcommittee (STSC) [5]. In June of 2011, the STSC agreed on terms of reference and methods of work for the Working Group on this agenda item. The goal of the Working Group is to create a set of voluntary guidelines for reducing risks to the long-term sustainability of outer space activities for all participants in those activities and to ensure that all countries are able to have equitable and long-term access to outer space and the resources and benefits afforded by it.

This paper examines the core concepts of a commons, or common-pool resources (CPR), and global commons. It discusses the popular theory known as the "tragedy of the commons" and the work of Elinor Ostrom, who has spent decades studying various CPRs. Through her work, she has identified eight principles that were present in every case of a successfully managed CPR. This paper concludes with a brief examination of how those principles might apply to the CPR of outer space. The authors argue that these principles can serve as a framework for developing national and international policies for the long-term sustainability of outer space activities by identifying weaknesses in the existing space governance framework and suggesting alternative mechanisms, be they economic, political, technical, or legal.

II. GOVERNANCE OF A COMMONS

A. What is a "commons"?

A "commons," or more precisely, common-pool resource, is a resource environment or domain that is characterized by an open access problem; meaning it is difficult to effectively bar others from accessing and benefitting from that resource. A "CPR is sufficiently large that it is difficult, but not impossible, to define recognized users and exclude other users altogether." [6] A "global commons" is a specific type of CPR with four broad characteristics [7]:

> *1. They are not owned by any single entity;*
>
> *2. Their utility as a whole is greater than if broken down into smaller parts;*
>
> *3. States and non-State actors with the requisite technological capabilities are able to access and use them for economic, political, scientific, and cultural purposes; and*
>
> *4. Those same actors are able to use them as a medium for military movement and as a theater for military conflict.*

The oceans, airspace, Antarctica, and outer space are traditionally categorized as global commons because they exhibit these aforementioned characteristics. In recent years, some have deemed cyberspace a global commons as well, though many disagree with this characterization.

B. Avoiding the "Tragedy of the Commons"

Governance challenges in CPRs center on preventing overexploitation of a resource system. They can broadly be divided into two categories: solving appropriation problems and solving provision problems. Appropriation problems deal with the allocation of a fixed, time-independent quantity of resource units [6]. Typical examples are oil fields and gold mines. Conversely, provision approaches focus on the time-dependent, productive nature of investment in the resource itself [6]. In addition, Ostrom points out that it is important to distinguish between the resource system, such as a parking garage or a fishery, and the flow of resource units, parking spaces or fish.

Perhaps the most famous portrayal of these CPR governance issues stems from Garrett Hardin's influential 1968 paper "The Tragedy of the Commons" [8]. As human civilization develops, it grows more reliant on extracting and exploiting natural resources. However, this increasing demand leads to a pattern of over-exploitation and environmental degradation resulting in "tragedy," especially in commons scenarios. Their open access nature incentivizes users to consume as much as possible before others do, leading to a vicious cycle of mismanagement and over-consumption that ultimately causes environmental degeneration beyond repair. Hardin argued that the only way to avoid this tragedy was either to install a Leviathan authority, which would manage and oversee the resource management, or to privatize the commons.

Many have criticized Hardin for oversimplifying the nature of commons governance. Ostrom has been foremost amongst his critics. She argues - and supports with substantial empirical evidence - that many CPRs have been successfully governed without resorting either to a centralized government or a system of private property [6]. In fact, there are numerous cases where resource users have effectively self-organized and sustainably managed a common-pool resource in spite of centralized authorities and without instituting any form of private property. Moreover, she has pointed out that both the "Leviathan" or private property management schemes are just as likely to fail as other efforts.

Ostrom developed an eight-principle framework from her extensive research on successful and unsuccessful attempts to govern common-pool resources. These eight principles outline the conditions necessary to successfully and sustainably manage commons resources without a centralized government or private property regime. In every otherwise dissimilar case where common-pool resources were successfully managed, these eight elements were present [6]:

1. Clearly-defined boundaries of the CPR (effective exclusion of external unentitled parties)

2. Congruence between governance structure or rules and the resource context

3. Collective-choice arrangements that allow most resource appropriators to participate in the decision-making process

4. Effective monitoring by monitors who are part of or accountable to the appropriators

5. Graduated sanctions for resource appropriators who violate community rules

6. Low-cost and easy-to-access conflict resolution mechanisms

7. Self-determination of the community is recognized by higher-level authorities

8. In the case of larger common-pool resources: organization in the form of multiple layers of nested enterprises

C. Adaptive Governance

One caveat to this conceptual framework is that it is primarily derived from the experiences of small-scale, local or regional commons. Thus, it is not a foregone conclusion that Ostrom's principles can be extrapolated to a "global commons" such as outer space. However, in recent years, Ostrom and other scholars have published additional work showing that these principles are, in fact, applicable to larger commons resources. Their work has focused on the concept of "adaptive governance," which refers to a quality of institutional evolution inherent in a given

CPR governance structure. In these larger, more complex, environments [9]:

> *"…a set of rules crafted to fit one set of socioecological conditions can erode as social, economic, and technological developments increase the potential for human damage to ecosystems and even to the biosphere itself. Furthermore, humans devise ways of evading governance rules. Thus, successful commons governance requires that rules evolve."*

Adaptive governance refers to the way in which the structure of rules, norms, and enforcement mechanisms adapt and evolve over time as information about or characteristics of the commons environment expand or change. The term connotes a positive transformation, implying that an institutional arrangement is able to "evolve to [better] satisfy the needs and desires of [a] community in a changing environment." [9]

The concept of adaptive governance is especially applicable and fitting for the space domain. Human activity in space is a relatively novel phenomenon. Human utilization and exploitation of space as a resource environment is even more so. In the handful of decades since the dawn of the Space Age, humans have approached and used space for an ever-changing and growing list of purposes. The number of actors and entities present in space has also grown rapidly in recent years. All of these factors combined indicate an environment that will be undergoing significant social, economic, and environmental flux into the foreseeable future, making an adaptive governance structure critical to successful management.

It is also worth noting that adaptive governance is not always a conscious or deliberate process. In many cases, this institutional evolution takes place organically or informally. As Hatfield-Dodds et al explain, "this implies that achieving improvements in the efficacy of institutional arrangements will generally require the development of collective action strategies that are both 'efficiency enhancing' and 'adoptable,'" which will in turn facilitate adaptability [9]. Adaptive governance occurs best when policy prescriptions and governance strategies that are beneficial and worthwhile are proposed, meaning they enhance efficiency or provide net welfare gains for those involved, and when they are "adoptable," meaning they are politically palatable and practically feasible. It remains to be seen whether or not the space governance regime has already demonstrated signs of adaptability, or if it is not yet codified or entrenched enough to undergo adaptation. Either way, the international community and space actors should keep in mind the concept of and necessity for adaptive governance as they shape the space regime.

III. OSTROM'S PRINCIPLES IN THE CONTEXT OF THE NEAR-EARTH ORBIT CPR

Although outer space as a whole is a global commons, it is not useful to discuss a single governance model for the entirety of outer space. Such a governance model would have to deal with the infinite size of the entire universe. Thus, in the same way that the global commons of the Earth's oceans contains multiple CPRs, each representing individual resource extraction areas such as fisheries or oil fields, separate CPRs need to be defined within the global commons of space.

For the purposes of this paper, the authors will focus specifically on governance of "near-Earth orbit," defined as the region of outer space containing satellites in orbit around the Earth that provide services and benefits to users on Earth. Other regions of outer space, such as orbits around the Moon, Mars, or the asteroid belt, are CPRs in their own right, and would almost certainly require a different or tailored governance framework.

For the near-Earth orbit CPR, the resource system has more in common with parking garages than fisheries. Most of the current benefits gained from use of Earth orbit are derived from satellites in the CPR, and although near-Earth orbit encompasses a substantial volume, there are only a limited number of regions – parking spaces -- where a satellite can orbit to provide these benefits. This results in an increasing crowding of active satellites into these finite regions, along with the long-lived remnants of old satellites and space activities. Additionally, all objects in space must use portions of the electromagnetic spectrum to perform their functions and communicate with the Earth, with certain portions of the spectrum being more suitable for various applications. Thus, there is also a crowding of space appropriators into similar or overlapping frequencies. These physical and electromagnetic crowding issues are the primary allocation and provision problems in the near-Earth orbit CPR, and orbital slots and frequency bands comprise the primary resource units.

In the following sections, the authors examine each of Ostrom's principles in the context of the near-Earth orbit CPR and these provisioning problems, focusing on any gaps the principles highlight in the existing governance framework and potential areas to focus on for space policies.

A. Clearly Defined Boundaries

Defining the boundaries of the CPR is an essential first step before any governance mechanism can be devised or evaluated. Boundaries set the limits of what is being governed, who has the right to make use of it, and which governance regime applies. As Ostrom eloquently states [6], '…so long as the boundaries of the resource and/or the specification of individuals who can use the resource remain uncertain, no one knows what is being managed or for whom."

The debate over the boundary between air and space, or if one even exists, has been raging since the beginning of the Space Age. This is partly due to the desire of certain States to refrain from clearly defining the boundary between space and air domains lest it limit their freedom of action. Others have argued that there is no existential need to define the boundary of where space begins and that doing so could complicate existing activities and might not anticipate future technological developments [10]. Some space actors have operational definitions of space as beginning at 100 kilometers above sea level, but it is not a universal definition, nor is it enshrined in international law.

For effective governance, the boundaries of the near-Earth orbit CPR do not need to be precisely defined in a technical sense, but rather, agreed to in a regulatory and operational sense by space actors. Defining a set altitude at which airspace ends and outer space begins is less important than having a clear definition of where the air regulatory regime applies versus an outer space regulatory regime.

The terminology used to describe space objects does not help this debate. Traditionally, the term "sub-orbital" has been used to describe objects that move through space but do not remain in orbit. The source of the confusion is that "sub" suggests that an object's velocity is below what is required to stay in orbit and does not refer to altitude. Thus a sub-orbital object may reach altitudes of more than 1,000 kilometers above the Earth's surface yet an orbital object might be only 250 kilometers above the Earth's surface.

This presents a particular problem in the case of sub-orbital spaceflight, where a space vehicle carrying tourists goes up to the very edge of space at about 100 kilometers for a few minutes before returning to the atmosphere. Such a vehicle has much more in common with high-altitude aircraft than spacecraft and yet is technically in the same category as a sounding rocket that carries a scientific payload up to 1,300 kilometers, well above many LEO satellites.

A potential solution to this confusion was proposed by Professor Henry Hertzfeld of George Washington University in testimony before the U.S. Congress [11]. Hertzfeld suggested that the term "sub-orbital" be redefined to indicate spaceflight below a certain low altitude, perhaps 100 or 120 kilometers, which defines the upper limit of national airspace from a regulatory perspective. Hertzfeld then suggested that a new term called "non-orbital" be defined to include all objects that go into space above the sub-orbital altitude, but which do not have sufficient velocity to achieve orbit. This would effectively separate sub-orbital tourism from sounding rockets, allowing different regulatory regimes to be applied to each.

In regard to defining users of the near-Earth orbit CPR, the use of outer space by all for peaceful purposes is enshrined in Article I of the 1967 Outer Space Treaty [12]. However, in developing a governance framework, it is necessary to elaborate on this concept and more specifically classify users of the near-Earth CPR. The most readily useful means of classification is by capabilities. When considered from a capabilities perspective, three groups of resource appropriators for the space CPR emerge.

Those in the first tier are *spacefaring States*, defined as those having the full spectrum of space capabilities, including launch and satellite manufacturing and operation. A second tier of *space-capable States* consists of those who operate one or more satellites, but lack indigenous launch capacity. And finally, there are *space users*, those entities – public, private, and individual – who use space services and data.

Each of these different groups - spacefaring States, space-capable States, and space users - might have differing rights, responsibilities, and governance roles, despite all being authorized appropriators of the near-Earth orbit CPR.

B. Congruence

Ostrom found that successful management of a CPR occurred when the governance structures were specifically tailored to the CPR in question. A successful governance system and its rules were congruent with the specific physical and technical characteristics of the CPR and not forcibly copied from another CPR. While this seems intuitive, it can be tougher to implement in practice. Often times a simile between two domains will be made in an effort to facilitate understanding and rule-making. This can result in overlooking key fundamental aspects of one domain or the other that make the comparison a poor fit.

For example, the near-Earth orbit CPR is often compared to the maritime domain. Both are considered by many to be global commons and share some significant similarities. Thus it is tempting to apply governance solutions that worked in the maritime domain to outer space. However, these similarities only go so far and a one-size-fits-all application of the maritime regime to space will ultimately lead to incongruence.

Operationally, military space activities in many countries are lumped in with other branches of service, such as air or air defense forces, because they may not justify a separate command structure of their own. This too can lead to situations where national governance structures are ill-fitting for managing space activities.

Lastly, from a physical perspective, space has several unique aspects that must be taken into consideration in any discussion of governance structures. First, it is vast, especially compared to other domains on Earth. The volume of space to the GEO orbit encompasses trillions of kilometers, which is impossible to continuously monitor at all times. Second, and more importantly, the unique physics of orbital mechanics must be dealt with. An object in orbit stays in orbit because it is moving around the Earth at a velocity that offsets the Earth's gravity, which is continuously pulling it towards the Earth. The velocity needed to continuously fall towards the Earth is a function of altitude. Thus, velocity in orbit is not an independent variable that can be changed at will: any change in velocity will result in a change in the object's orbit.

An example of where the physics of space comes into play is in trying to apply rules associated with maritime safety to the space domain. The Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) states [13]:

> *"Any vessel must proceed at a safe speed at which she can take action to avoid collision and be able to stop within a distance suitable to the prevailing conditions"*

At first glance it would seem beneficial to adopt this same rule as a means of helping prevent collisions in outer space, but runs contrary to the unique physical characteristics of the space domain.

C. Collective Choice Arrangements

Ostrom's research shows that CPR institutions where resource appropriators participate in shaping and modifying operational rules are more likely to result in long-lasting and successful governance. Rules designed and set by entities that do not directly utilize a CPR can lead to unwieldy, ill-fitting, or even harmful results and could provoke backlash and non-compliance amongst the actual users. CPR users are more likely to understand the specific nuances of various situations and craft rules which better fit the CPR. Having a say in governance also increases the likelihood that appropriators will follow the rules.

The international mechanisms for negotiating formal space governance agreements are mainly housed in the United Nations system, specifically the General Assembly (UNGA). Within the six permanent committees of the UNGA, space is considered in two. The First Committee, generally dealing with Disarmament and Security, focuses on space within its Conference on Disarmament (CD), which examines military issues such as weapons and an arms race in space. The Fourth Committee, which considers political issues, focuses on the civil and commercial uses of space through UN COPUOS. Many of the foundational legal principles for outer space stem from treaties produced by UN COPUOS since its formation in 1959. Another UN entity, the International Telecommunication Union (ITU), also plays a significant role in space governance mechanisms through its coordination and regulation of the electromagnetic spectrum.

All of the formal bodies mentioned above have advantages and disadvantages as a governance-creating body for space. However, none of them fully satisfy the criteria in Ostrom's principle. For example, both UN COPUOS and the CD have been used to create binding agreements and operate by consensus, but exclude private entities from being formal members, limit the role of non-governmental entities, and have strict limits on their mandate (non-military for UN COPUOS, disarmament for the CD). The ITU broadly includes States and private companies, but does not operate by consensus and does not possess any power of enforcement or ability to impose sanctions against violators of its rules and regulations [14].

Outside of these formal bodies and mechanisms, there are other ways in which States and non-States can influence space governance. In addition to the *de jure* law established by international treaties and binding agreements, there is also a significant body of *de facto* law and regulation created as the result of State practice. Such custom and practice can evolve into customary international law and thus become legally binding, even in the absence of a formal treaty. However, there is no set or widely accepted standard of when common practice qualifies as customary international law and many differing opinions exist on whether or not a specific practice is in effect customary international law.

While the existing regulatory framework for space, developed in the 1960's and 1970's, is considered by many as outdated and insufficient for addressing the multitude of challenges and increased number of space actors that have developed since that time, the impetus to change or extend it by creating new or additional binding treaties and agreements is limited. Thus, there has been a trend among space actors to use non-binding approaches to bolster space governance through the creation of norms and standards. These soft law efforts include the recent proposal by the European Union for a voluntary International Code of Conduct for Outer Space Activities [15]. This document covers the security, safety, and sustainability of space activities, attempts to distinguish between behavior in space that is 'responsible' and 'irresponsible' and establish norms of behavior that some argue could eventually lead to a legally-binding agreement.

Together these shortcomings lead the authors to the conclusion that, in order to fully satisfy Ostrom's principle, space needs a forum open to participation by all three tiers of appropriators of the space CPR (spacefaring States, space-capable States, and space users), but not operating on a consensus basis, thus having less chance of being gridlocked by the actions of one or a few actors. This will not be easy as it deals with one of the biggest issues in space governance: freedom of action. Just as the victors of World War II and the nuclear powers refused to submit their national sovereignty to the United Nations without retaining veto power, it will be difficult to establish a forum for space where the existing first tier space powers cede any of their freedom of action. However, it is difficult to see a path towards the long-term sustainable use of the near-Earth orbit CPR without such a sacrifice.

Another serious issue is membership limits in such a forum, given that practically everyone on Earth is a user of space and, thus, could be affected by governance decisions. In this, lessons can perhaps be drawn from the governance mechanisms for the Internet, which also struggle with the issues of freedom of action, sovereignty, and an all-inclusive user base.

D. Monitoring

In any CPR, the ability for resource appropriators to determine whether or not others are following the rules is an essential element. Monitoring is needed to ensure that all the resource appropriators are complying with norms and rules. Ostrom's research shows that optimal monitoring occurs when done by the resource appropriators themselves or when monitors are beholden to the appropriators. This eliminates the need to trust a third-party monitor, allows each resource appropriator to determine for itself that others are following the rules, and means appropriators know they are being watched by their peers as well. This can be done either by a shared scheme of monitoring or one where the resource appropriators take turns in a monitoring role. In either case, it is important that the costs of monitoring be kept low and/or the benefits from monitoring high [6].

In the near-Earth orbit CPR, information, data and services regarding the space environment, and particularly regarding hazards to infrastructure in orbit and on the ground, is known as space situational awareness (SSA) [16]. The bulk of SSA is derived from radars and optical telescopes located on the Earth's surface or in orbit. Because satellites are continually in motion around the Earth, a geographically distributed network of sensors is needed to establish a sufficient SSA capability. It is also necessary to include satellite operators, especially commercial entities: those who own or operate a satellite, and thus have access to its telemetry, almost always know its location in space more accurately than can be determined by an outside party using a sensor.

Currently, only the United States has anything close to such a global network, with Russia having the second best [17]. Several European states have individual SSA sensors, but the European Union has only recently considered creating a European SSA Network. Many other States have individual sensors which could provide some SSA data, but these alone are not sufficient to create full SSA capacity. The existence of many individual sensors and several partial global networks creates the opportunity for international collaboration and cooperation in sharing SSA data. Such sharing could obviate the need for any one State to shoulder the huge financial burden of building their own geographically distributed global sensor network, as well as the political burden of finding friendly and secure locations in suitable locations to host the sensors. Even without sharing, separate collection of data by multiple States fulfills Ostrom's principle of monitoring of the CPR by the resource appropriators themselves and would allow multiple States to monitor or verify at least some activities in space.

Although not required, an international organization created to combine participant-provided SSA information for distribution to resource appropriators could also satisfy Ostrom's principle, as long as such an organization is beholden to the resource appropriators, in this case States and satellite owner-operators. An example of this is the recently-created Space Data Association (SDA), an international non-profit created by leading commercial satellite operators. The purpose of the SDA is to confidentially combine data provided by participating operators with other data sources, most likely from governments, and to provide safety services to participating operators [18]. The operators themselves form the Board of Directors of the SDA and as such, set the data sharing rules. However, for now, the SDA has limited potential as a governance body because participation is presently limited to commercial entities, although some level of data sharing with governments is possible and currently under discussion.

However, the effectiveness of SSA, or any monitoring scheme based on SSA, exists only for CPR rules that can be monitored by remote sensing of activities in space. For example, rules or norms stipulating proper disposal of a spacecraft at the end of its operational life by either maneuvering to a graveyard zone or by de-orbiting into the Earth's atmosphere can be monitored by SSA techniques [19]. Likewise, rules prohibiting the testing or use of hyperkinetic weapons that create large amounts of space debris could be monitored by SSA. However, rules that prevent the creation or possession of space weapons by States cannot be sufficiently monitored by SSA; such rules would require intrusive on-site inspections and, even then, a determined actor could likely circumvent them. Weapons-like effects can also be created using spacecraft that were designed for non-weapons purposes. Thus, SSA could be seen as a way to monitor and enforce norms or rules of behavior, without requiring traditional arms control measures or formal treaties.

A monitoring system for the near-Earth CPR based on SSA data sharing will need to address the challenges arising from such sharing, including proprietary corporate information, classified government information, legal restrictions, and data validation and authentication. However, none of these are new or unique challenges and all have been addressed in other domains. Furthermore, some have been successfully addressed specifically for SSA by the SDA. Perhaps the true hurdle for the near-Earth CPR is convincing resource appropriators that such challenges are mainly a function of trust (or lack thereof). It is also necessary to look at the monitoring costs of any proposed CPR rule, cost distribution among resource appropriators, and the relative benefits of any such system to the appropriators.

E. Graduated Penalties

In the event of noncompliance with an established rule or norm, a successfully managed CPR has a system of graduated sanctions or penalties in place to punish rule-breakers. Ostrom's research showed that effective governance occurred when minor and infrequent infractions were allowed for through a flexible system of sanctioning and punishment. One-time or minor violators were punished to a certain extent, but not so severely that they were forced or opted out of the regime. For example, a first-time cheater might be publicly admonished or stripped of resource extraction rights for a short amount of time, but not shunned or disenfranchised interminably. Ostrom also found that the most sustainable systems enabled these minor violators to rebuild their reputation within the CPR. One-time violators might be required to contribute more to shared maintenance responsibilities or put in more monitoring hours to make up for their noncompliance. This not only shows that rule-breakers are punished, but allows them to demonstrate in turn their renewed commitment to the regime.

A system of graduated penalties helps circumvent typical regime enforcement issues. Members may be unwilling to commit to strict enforcement measures for fear of limiting freedom of action in the future or having to follow through on politically unsavory sanctions at a later date. As a result, many governance solutions lack any teeth at all, thereby rendering them ineffectual. Flexible penalties enable enforcement and give the regime some teeth without committing members to unduly harsh action for instances of future noncompliance.

A comparison between the 2007 and 2010 Chinese anti-satellite tests may demonstrate how such a system of graduated penalties might work in a space sustainability framework. On January 11, 2007, China successfully destroyed one of its polar orbiting satellites using a ground-launched ballistic missile system. It conducted the test without any prior warning to the international community or space commercial sector. The destruction of the satellite during the test created the largest orbital debris cloud in history in a very crowded orbital region [20]. The international community, while upset by the irresponsible nature of the weapons test, did not respond with formal sanctions. Rather, a few spacefaring nations, including the United States, expressed their concerns through quiet diplomatic channels. Only Japan took public action and, even then, it merely issued a statement condemning the act. Formal sanctions would have led to a politically tense and potentially hostile situation amongst established space powers, including the United States and Russia who have previously tested their own anti-satellite weapons in orbit. Conversely, by opting for a more informal and flexible form of "diplomatic scolding," the international community was able to avoid a public, political altercation while potentially influencing Chinese action in the future.

This moderate "scolding" was supplemented by the U.S. operation "Burnt Frost" in February 2008, which potentially served as an example of how best to conduct such a test. Operation "Burnt Frost" used a sea-launched ballistic missile to destroy a re-entering American satellite, believed to pose a threat to Earth. The U.S. gave a number of briefings to the public, the United Nations, and privately through diplomatic channels. Further, the intercept was done in such a way as to substantially limit the amount of orbital debris it created.

On January 11, 2010, China conducted what is widely considered to be another ASAT test of the same system used in 2007, but it was executed in a much more responsible fashion, with prior warning given to other space players and without the creation of orbital debris [21]. One might argue that the diplomatic opprobrium triggered by the 2007 ASAT test, coupled with the lack of diplomatic criticism encountered by the U.S. after Operation Burnt Frost, effectively influenced Chinese behavior surrounding the second test. This would be an example of how first-time or one-time instances of noncompliance might be met with lighter, or less severe, punishment in the hope that cheaters will "learn their lesson" and "play nice" *within* the system in the future. Simultaneously, it helps users avoid having to follow through on unpalatable, tougher penalties for every minor case of noncompliance.

F. Conflict Resolution Mechanisms

Another key principle of sustainable governance scenarios involves conflict resolution mechanisms. In successfully managed CPRs, low-cost and quick resolution mechanisms were available to appropriators when a conflict over rules or resource extraction occurred.

The Convention on International Liability for Damage Caused by Space Objects of 1971, hereafter referred to as the Liability Convention, established the legal basis for damage liability resulting from space activities. Eighty-eight States are currently party to this formal treaty. In the context of Ostrom's principle, the Liability Convention has some major drawbacks as a low-cost and quick conflict resolution mechanism. It requires that all claims for damage compensation be presented by a State to a launching State through formal diplomatic channels or the United Nations Secretary-General [22]. This has the disadvantage of raising the issue at hand to a formal diplomatic issue, likely bringing into play the broader political relationship between the States, even for cases that might involve commercial actors.

The only case to invoke the Liability Convention was the 1978 crash of the Soviet Cosmos 954 satellite in northern Canada. The satellite's nuclear reactor failed to separate and re-entered the Earth's atmosphere along with the satellite at the end of its life. This resulted in a radioactive debris field over a large swath of northern Canada. The issue was eventually settled by a formal agreement between the USSR and Canada, with the USSR paying 3 million Canadian dollars in compensation [23]. However, this was accomplished without invoking the Claims Commission mechanism outlined in the Convention, which has never been formally used.

The ITU also has mechanisms for handling disputes involving electromagnetic interference and GEO orbital slots between Member States [14]. These mechanisms include provisions under Article 15 of the ITU Convention for notification to the ITU and coordination between the concerned States and non-binding recommendations from the ITU's Radiocommunications Bureau [14]. Member States also have the option to request arbitration through Article 41 of the ITU Convention, which is binding if the Member States involved are also party to the Optional Protocol on the Compulsory Settlement of Disputes [14]. However, to date neither Article 41 nor the Optional Protocol has been used to resolve disputes. Instead, bilateral negotiations between the concerned States or Article 15 of the ITU Convention have been used [14].

Recently, there has been another development that could potentially create a new dispute resolution mechanism for space that could bolster what already exists in the Liability Convention. The Permanent Court of Arbitration (PCA) in The Hague has recently created draft rules for arbitration of disputes relating to outer space activities, which are currently under review by Member States. The PCA was created by the first Hague Peace Conference in 1899 and is one of the oldest institutions for international dispute resolution [24]. A very unique characteristic of the PCA is that it is empowered to handle disputes between various combinations of States, private parties, and intergovernmental organizations. Thus the PCA can handle a dispute relating to outer space activities between two States, two commercial entities, or even a commercial entity and the State within which it resides.

There are other potential conflict and dispute resolution mechanisms that exist within the international system, but many of these lack defined thresholds or triggers in the space context. For example, there are no consensus definitions of what constitutes use of force or threat of use of force in space or against a space object. While overt kinetic destruction of a satellite by another State would seem to readily meet these thresholds, temporarily jamming or blinding a satellite would likely not, even though it could produce the same effect from a military standpoint.

G. Nested Enterprises

Finally, for larger commons, Ostrom's research showed that in successfully managed CPRs, the governance structure was embedded in a multi-level, nested arrangement to facilitate effective and successful implementation. In other words, rules at one level were reflected or supplemented by rules at other levels.

Nested enterprises are already in place to some extent in the space domain – while many of the existing governance rules stem from formal treaties, they require implementation at the national level through regulation and laws. This affords each state the flexibility to implement their international legal obligations in a manner consistent with their national policies and laws.

The Outer Space Treaty establishes the nation-state as the primary responsible authority when it comes to space activities. Therefore, enforcement and verification of compliance needs to take place at both the international and national levels in that States must ensure that space companies, civil actors, private citizens, and national militaries comply with international law.

The drawback to this approach is the inconsistency among States in adopting national regulations covering some critical areas, which is usually correlated to the space capabilities of the State. Spacefaring States, especially those with a long history of space activities, are more likely to have the national policies, regulations, and laws in place to thoroughly implement the strictures of international treaties and other agreements. This primarily takes the form of licensing of space activities, including launching and radiofrequency usage. The heterogeneity in national regulations can lead to satellite operators searching for "flags of convenience", where they try and find the Launching State which has the least amount of regulations or controls.

The development of Ultra Low Mass (ULM) satellites or cubesats has greatly lowered the economic barriers to entry for building a satellite and has enabled many more States and other entities to own or operate a satellite. In the past decade, almost seventy ULM satellites have been launched into space [25] and there are currently thirty-seven in orbit [26]. Furthermore, the rate at which they are developed and launched is accelerating. For many States, a ULM satellite is their first satellite, and they may not have the policies and regulations in place to fully comply with their international responsibilities, nor the expertise to develop them. Moreover, many ULM satellites are launched by another State as a "piggyback" to a larger primary payload. The Launching State in this situation may be incurring legal responsibilities that they are not fully considering.

One way to alleviate this problem could be an information awareness campaign to provide the tools, guidance, and expertise necessary to help States understand their responsibilities, as well as develop the appropriate policies and regulatory mechanisms consistent with their space activities.

V. CONCLUSIONS

This paper was a preliminary examination of Ostrom's principles in the context of sustainable governance of the near-Earth CPR and it demonstrates that her principles can be useful when discussing potential space governance problems and solutions. Increasing recognition of sustainability challenges in the near-Earth orbit CPR – regardless of terminology used – is a necessary, but by no means sufficient, step toward effective governance.

Application of Ostrom's principles identified some key considerations for examining the space governance problem. First, the potential future growth of sub-orbital transportation and space tourism industry indicates that policy makers should consider establishing a regulatory boundary between airspace and the near-Earth orbit CPR. Second, although comparisons with other domains can be useful, care must be taken to ensure that the unique physical characteristics of space are taken into account when applying solutions from those domains to outer space. Third, the existing decision making fora need to be reexamined in light of the plethora of new space actors to ensure that all have appropriate roles in establishing space governance rules and mechanisms. Fourth, conflict and dispute resolution mechanisms need to be examined with an eye towards efficiency and ease of access. Fifth, space actors should develop graduated penalties for those appropriators who act contrary to established norms and rules. Sixth, more work needs to be done on implementing existing international laws and requirements at the regional and national levels, while also informing new actors about their rights and responsibilities. Finally, monitoring of the space environment and the behavior of space actors using SSA is crucial to successful long-term sustainable governance, with an emphasis on ensuring that more States and other space actors have the ability to access shared information as well as their own capabilities.

This paper is only intended to be a start and further analysis of Ostrom's principles in the context of space is needed, as well as identifying and examining other conceptual frameworks that may be applicable. Further, and perhaps most challenging, these academic concepts need to be translated into concrete, feasible, pragmatic, and implementable steps for this exercise to be of real value to policymakers.

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