ORBITAL DEBRIS AND THE TRAGEDY OF THE COMMONS: AN ECONOMIC FRAMEWORK TO ADDRESS THE FREE RIDER PROBLEM. Jeffrey A. Cleveland, Colorado School of Mines, 1500 Illinois St, Golden, CO 80401; jeffreycleveland@mines.edu

Introduction: Orbital debris and their associated collision risks to active satellites in both Low Earth Orbit (LEO) and Geosynchronous Orbit (GEO) are ongoing concerns to both launch operators and satellite owners/operators (SOOs). Since both of these location-based resources have finite carrying capacity, unrestrained overuse results in the economic problem known as the Tragedy of the Commons. Remediation through active debris removal can address this problem. Efforts initiated by governments through their national space agencies result in SOOs becoming beneficiaries of reduced collision risk at no cost and therefore free riders. The void created by the absence of any coherent economic policy opens the door for developing and implementing new economic models by motivating SOOs and their adjunct parties to internalize the costs of these externalities.

Defining the Orbital Debris Problem: Authoritative sources place the number of orbital debris in the range of 25,000 to 35,000 objects in both LEO and GEO. [1] The National Aeronautics and Space Administration (NASA) and the Department of Defense (DoD) track discrete objects as small as 2 inches (5 centimeters) in diameter in LEO and about 1 yard (1 meter) in GEO. These agencies track approximately 27,000 officially cataloged objects in orbit 10 cm and larger. [2] That number continues to grow; according to General B. Chance Saltzman, Chief of Space Operations for the United States Space Force (USSF) in written testimony to the Senate Armed Service Subcommittee on Strategic Forces on 10 March 2023:

> *The orbital debris problem continued to worsen in 2022. Seven spacecraft broke apart in orbit creating over 600 new pieces of debris…The International Space Station had 1,486 reportable conjunctions with space debris or spacecraft in 2022, a 233% increase from 2021. The increase was largely due to the Russian anti-satellite test in November 2021 which created 1,500 pieces of trackable debris…*[3]

The Tragedy of the Commons: The concept of the Tragedy of the Commons can be traced back to British economist William Forster Lloyd, who promulgated the idea in an 1833 essay analyzing the hypothetical problem of a rancher allowing his flock to graze indiscriminately on common (e.g., not owned via property rights) land, referred to as "the commons" under Anglo-Saxon law in Great Britain and Ireland at the time. If the rancher was focused solely on self-interest (in this case, the feeding of his flock), the common land, as a resource, would eventually be depleted, depriving other ranchers of land suitable for grazing.

American ecologist Garrett Hardin's essay "The Tragedy of the Commons" postulated that a resource can only remain viable and sustainable if users remain below that resource's carrying capacity. [4] Both Lloyd's and Hardin's ideas can be traced back to Aristotle, who wrote, "That which is common to the greatest number gets the least amount of care. Men pay most attention to what is their own: they care less for what is common." [5]

It can certainly be said outer space, which we will define as any area above the Kármán line of 100 km, can currently be classified as a "common," particularly in light of the Outer Space Treaty's Article II, which states, "Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means." [6]

The ongoing proliferation of orbital debris, along with prognostications of its continued growth, undoubtedly meets the criteria of the tragedy of the commons:

- Outer space, including the orbital regions of LEO and GEO, is devoid of property rights and available to all who wish to pursue activities in these areas.
- LEO and GEO are limited resources and have finite carrying capacities.
- These orbital carrying capacities are further limited by the presence of orbital debris.
- Any one participant (e.g., an individual nation-state actor) will be motivated primarily by self-interest to access and exploit the resource without being required to minimize orbital debris.

Understanding the Free Rider Problem: From an economic perspective, a free rider is a passive participant who receives a benefit from the actions (and investment) of a third party(s). The classic example of a free rider is a resident living downstream of an industrial plant that releases hazardous material into a river, rendering it uninhabitable for wildlife. When clean-up and prevention remediations are put into the place, the quality of the river water is improved, and the downstream resident is a direct beneficiary of that improvement, while not having directly contributed to those remediation efforts. Note that if tax dollars are used the resident becomes an indirect participant in those remediation efforts.

Regarding the orbital debris problem, any remediation approach whose costs are borne by individual constituents creates a free rider scenario for all other SOOs in LEO and GEO. Every piece of orbital debris remediated results in a marginal decrease in the likelihood of a damaging or catastrophic collision event. In turn, this reduces wasteful propellant consumption due to emergency orbital avoidance maneuvers. Finally, this decreased risk of collision lowers insurance premiums for both the SOO and the underwriting insurance provider (who benefits from lower premiums to their re-insurer).

Lack of Coherent Economic Policy: The National Science and Technology Council's (NSTC) Orbital Debris Research and Development (ODRAD) Interagency Working Group (IWG) published their National Orbital Debris Research and Development Plan aptly sums up the current economic policy challenges of orbital debris remediation, stating, "The market for debris removal and supporting R&D is small, largely due to the lack of defined responsibility for orbital debris removal or economic incentives to do so…they are an externality the market has little incentive to address." [7]

Currently there are two predominant models that describe the economic approach to orbital debris remediation: government funding (via national space agencies or consortiums) of research and development (R&D) programs, and commercial entities. [8] Recent government-funded initiatives include:

Sponsor	Awardee	Effort
NASA	TransAstra	Mini Bee Capture Bag (MBCB) to capture/enclose small spacecraft and debris
U.S. DoD	TransAstra	Optimized Matched Filter Tracking (OMFT) to better identify/track orbital debris
U.S. Space Force	KMI	"Gecko adhesion" to capture large debris objects (e.g., inert satellites, rocket bodies)
JAXA	Astroscale	Active Debris Removal for Phase I of JAXA's Commercial Removal of Debris Demonstration Project (CRD2)
ESA	ClearSpace	Active Debris Removal/In-Orbit Servicing project (ADRIOS)
UK Space Agency	ClearSpace; AstroScale	Clearing the LEO Environment with Active Removal (CLEAR); Cleaning Outer Space Mission through Innovative Capture (COSMIC)

Table 1: Recent Orbital Debris Remediation Contracts

On the commercial front, one example is CisLunar Industries (Denver, CO), which is developing technologies and delivery platforms for in-space capture of large debris to be processed into fuel rods for use as a propellant in vacuum arc thruster propulsion systems.

It is important to note that by funding their own initiatives, government entities such as the DoD and USSF are not free riders, but rather direct economic participants in the design, development, and implementation of active debris removal, which in turn reduces debris collision to their own various satellites. By the same token, however, SOOs such as DirecTV (11 satellites), Sirius XM (seven), and SpaceX (2,219) all benefit from these DoD and USSF programs.

Proposed Economic Framework: Classic economic theory addresses the free rider problem in one of three general ways. The first, privatizing the commons by granting property rights, is unworkable for space for obvious reasons. The second, regulation, could be accomplished through a variety of means, such as imposing taxes on users (both launch providers and SOOs) to pay for active debris removal, or limiting the number of users via quotas so as to not oversaturate the carrying capacity of the resource (e.g., LEO and GEO). This may be a workable solution for the future, but is not likely to gain acceptance beyond a national or limited international consortium.

The third way provides the greatest flexibility and opportunity for solution creativity, which economists call "internalizing the externality." In the realm of existing orbital debris, this would involve LEO and GEO participants developing and implementing mechanisms that provide a clear economic benefit to reducing collision risk from orbital debris. Such mechanisms could be brought forth by non-governmental SOOs, transforming them from free riders to direct participants. A similar model could be established by insurers, by offering reduced policy premiums and/or longer coverage periods in exchange for investment or direct participation in active debris removal. Finally, re-insurers (entities that reduce insurers' risk) could ultimately be the driving force behind such a scheme by motivating insurers to cascade those financial benefits down to the launch operator/SOO level.

References: [1] *National Orbital Debris Research and Development Plan* (2023). [2] Garcia, Mark. (2015) "Space Debris and Human Spacecraft," http://www.nasa.gov/mission_pages/station/news/orbital_debris.html. [3] United States Space Force Written Statement Before the Senate Armed Services Subcommittee on Strategic Forces (2023) United State Senate. [4] Hardin, Garrett. (1968) "The Tragedy of the Commons." *Science* 162, no. 3859, 1243–48. [5] Aristotle (n.d.) *Politics, Book II*, Chapter 3. [6] *Treaties and Principles on Outer Space* (2002) United Nations. [7] United States Space Force. [8] Emanuelli, M., G. Federico, J. Loughman, D. Prasad, T. Chow, and M. Rathnasabapathy. (2014) "Conceptualizing an Economically, Legally, and Politically Viable Active Debris Removal Option." *Acta Astronautica* 104, no. 1: 197–205.