Liability And Responsibility For Space Debris: Who Pays For The Mess?

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Keywords: Space Debris, International Liability, Outer Space Treaty, Global Governance, Space Sustainability

Abstract
The rapid growth of space activities has led to an unprecedented increase in orbital debris, raising critical questions of liability and responsibility in international law. This paper examines the extent to which existing legal frameworks, including the 1967 Outer Space Treaty and the 1972 Liability Convention, provide mechanisms for attributing accountability when collisions or damages occur due to space debris. The research employs a doctrinal analysis of treaties, case studies, and policy documents, alongside a comparative review of state practices, to identify gaps in current governance structures. Results highlight that while international agreements establish state-level liability, ambiguity remains over private actors' responsibilities and long-term environmental consequences. Case studies such as the Cosmos-Iridium collision reveal the challenges of enforcing compensation, monitoring debris, and ensuring compliance across jurisdictions. The findings suggest that a combination of legal reform, technological innovation in debris mitigation, and multilateral cooperation is essential to strengthen accountability. This study contributes to the discourse on global space governance by proposing a hybrid model that integrates shared responsibility, enforceable standards, and financial mechanisms such as debris removal funds. In conclusion, the paper underscores that without clear liability regimes and collective action, space sustainability will remain at risk, threatening future exploration and commercial use.

1. Introduction

Human access to outer space has expanded rapidly, driven by falling launch costs, small-satellite constellations, and the commercialization of Earth-orbit services. Alongside these benefits is a sharp rise in space debris—defunct satellites, spent upper stages, and fragmentation remnants that remain in orbit for years to centuries and threaten active missions through cascading collision risk, also known as the "Kessler Syndrome" (Kessler & Cour-Palais, 1978). The legal and policy question at the heart of this paper is straightforward but unresolved: when debris causes damage or heightens operational risk, who bears liability and how is responsibility allocated across states and private actors (Jakhu & Pelton, 2017).

At present, the core public-international law instruments—the 1967 Outer Space Treaty (OST), the 1972 Convention on International Liability for Damage Caused by Space Objects (Liability Convention), and the 1975 Registration Convention—create a foundation for attribution and redress. They frame states as internationally responsible for national activities in outer space, including those of non-governmental entities, and provide strict liability for surface-level damage with fault-based liability for damage in space (Gabrynowicz, 2004). However, these texts pre-date the modern debris era and do not directly apportion costs for long-term orbit-clean-up, end-of-life disposal failures, or probabilistic risk created by abandoned hardware (Johnson, 2010).

Technical guidance has evolved faster than binding norms. The UNCOPUOS Space Debris Mitigation Guidelines and the Inter-Agency Space Debris Coordination Committee (IADC) best practices advise passivation, post-mission disposal, and 25-year de-orbit rules; standards such as ISO 24113 articulate design-for-demise and collision-avoidance requirements (Weeden, 2019). Yet these instruments are largely non-binding and unevenly implemented, especially by emerging operators and rideshare payloads. Meanwhile, notorious incidents—the 2007 Chinese ASAT test and the 2009 Iridium-Cosmos collision—demonstrated that a single fragmentation event can create tens of thousands of traceable and untraceable fragments, multiplying cross-border externalities that no single launch-state can internalize alone (Wright, 2010).

Private capacity complicates the allocation of burdens. Mega-constellations promise affordable connectivity but introduce denser orbital shells, higher conjunction counts, and systemic risk if de-orbit reliability falters. Insurance markets price catastrophic events poorly where causation is diffuse. National licensing regimes typically require mitigation plans but seldom mandate financial assurance adequate to cover third-party damage or debris-removal obligations if firms dissolve, merge, or relocate jurisdictions (Pelton, 2021). In short, the party best positioned to avoid debris is not always the party who ultimately pays.

This paper addresses that governance gap. We ask: (i) how existing treaties and national laws currently allocate liability for debris-related damage; (ii) where ambiguities arise for multi-actor, multi-jurisdiction constellations; and (iii) what designs for accountability—from "polluter-pays" levies to performance bonds and debris-removal funds—could align incentives for sustainable use of orbits. Methodologically, we conduct a doctrinal analysis of treaties and state practice, synthesize technical guidance and standards, and examine illustrative cases to trace how fault, causation, and attribution have been argued in practice (von der Dunk, 2015).

The paper's contributions are threefold. First, we clarify the fault thresholds and attribution channels relevant to debris, distinguishing strict liability on Earth from fault-based standards in orbit and showing how "reasonable measures" can be operationalized through published guidelines. Second, we propose a hybrid model that couples licensing-stage financial surety (to pre-fund remediation) with use-based charges tied to congestion and conjunction risk, creating continuous incentives for compliance. Third, we outline a claims and verification pathway leveraging space-situational-awareness data to support evidence of negligence or non-compliance where debris provenance is contested (Freeland, 2010).

Structurally. Section 2 reviews the literature on liability doctrines, mitigation standards, and economic instruments. Section 3 details the methodology and data sources. Section 4 presents results, including a comparative mapping of national licensing provisions and a simulation-based illustration of cost exposure across orbital regimes. Section 5 discusses policy implications, limitations, and avenues for future research. Section 6 concludes with actionable recommendations for regulators and operators.

The underlying thesis argues. that without calibrated, enforceable accountability—legal, financial, and technical—debris will remain a classic tragedy of the commons. A liability regime that prices risk, secures remediation funds ex ante, and ties authorization to adherence with verifiable standards offers the most credible path to keep low-Earth orbit usable for science, security, and commerce (Jakhu & Freeland, 2016).

2. Literature Review

The issue of liability for space debris has been extensively examined across legal, policy, and technical literatures, though major gaps remain regarding enforceability and cost allocation. Early work emphasized the risk of cascading collisions and the growing difficulty of tracking fragments smaller than 10 cm, which can nonetheless cause catastrophic damage (Kessler & Cour-Palais, 1978). The physical science literature

demonstrates that once a critical density of objects in low-Earth orbit (LEO) is surpassed, collision chains become self-sustaining, amplifying the urgency of preventive governance (Wright, 2010).

Legal frameworks. The foundation of international space law was laid through the Outer Space Treaty (1967), which asserts that states are internationally responsible for national activities in outer space, whether carried out by governmental or non-governmental actors. The Liability Convention (1972) provides strict liability for damages on Earth and fault-based liability for damages in space, but its language has been criticized for vagueness, especially concerning definitions of "fault" and "damage" (Gabrynowicz, 2004). Scholars have argued that the Convention's case-by-case diplomatic mechanism is ill-suited for the fast-paced, commercialized space era (Jakhu & Pelton, 2017).

In the backdrop of these instruments, there is a prevailing gaps in enforcement. While treaties establish responsibility at the state level, they do not clearly address private actors' liabilities, even as commercial mega-constellations proliferate (Pelton, 2021). National licensing laws, such as those in the United States, the European Union, and India, often require compliance with mitigation standards but lack robust enforcement mechanisms for post-mission disposal or remediation financing (von der Dunk, 2015). This creates a regulatory asymmetry where emerging operators may exploit weaker national laws, undermining global sustainability.

Moreover, the advent of soft law and guidelines was meant to consolidate the pre-existing framework. The non-binding UNCOPUOS Space Debris Mitigation Guidelines (2007) and the Inter-Agency Space Debris Coordination Committee (IADC) recommendations encourage post-mission disposal, passivation of spent stages, and 25-year de-orbit rules (Weeden, 2019). Technical standards, such as ISO 24113, articulate quantitative limits on debris release and requirements for collision avoidance. However, implementation varies across jurisdictions, and compliance remains largely voluntary. Scholars highlight that soft law lacks the deterrent effect of binding obligations, leading to underinvestment in mitigation (Freeland, 2010).

Contextualising this within the realm of economic analysis, key towards the determination of Potential solutions to liability gaps, economists have suggested adapting terrestrial environmental governance models, such as the "polluter pays principle" and market-based instruments, to space sustainability. Performance bonds, insurance pools, and debris-removal funds have been proposed to internalize externalities and spread risk equitably (Johnson, 2010). Simulation studies suggest that per-satellite fees tied to orbital altitude and expected lifetime could incentivize compliance while generating revenue for debris-removal missions (Adilov, Alexander, & Cunningham, 2018). Nevertheless, the absence of a global authority to administer such schemes remains a barrier.

In praxis, delving into case studies for better understanding, real-world incidents illustrate the limitations of current law. The 2007 Chinese ASAT test created over 3,000 trackable debris fragments, none of which triggered liability claims due to state reluctance to confront geopolitical tensions (Wright, 2010). Similarly, the 2009 Iridium-Cosmos collision raised questions about negligence and compensation, but diplomatic settlement mechanisms were never activated, reflecting the political sensitivity of assigning blame (Jakhu & Freeland, 2016). These examples demonstrate how geopolitical considerations often outweigh legal remedies.

So far as identified, there is an inherent gap in research. Despite extensive discussion, three critical gaps persist. First, liability remains framed primarily in terms of direct physical damage, while indirect and probabilistic risks from debris congestion are largely unaddressed (Pelton, 2021). Second, no effective mechanism exists for assigning liability to private operators in multinational constellations. Third, while economic instruments are promising, practical frameworks for international coordination are underdeveloped (von der Dunk, 2015).

This study contributes to filling these gaps by: **(i)** analysing liability allocation under existing treaties and national laws; **(ii)** evaluating the potential for hybrid governance models combining legal and economic mechanisms; and **(iii)** proposing feasible pathways for embedding accountability into licensing and international coordination frameworks.

3. Methodology

This study adopts a qualitative doctrinal research design, complemented by comparative policy analysis and illustrative case studies. The aim is not to generate statistical generalizations, but rather to clarify how existing international treaties, national laws, and soft-law instruments shape liability for space debris, and to evaluate options for strengthening accountability frameworks (Creswell, 2014).

3.1 Research Design

The research follows a doctrinal approach, systematically reviewing legal instruments including the Outer Space Treaty (1967), the Liability Convention (1972), and the Registration Convention (1975). These instruments were analysed to identify provisions relevant to liability, responsibility, and attribution. Secondary legal sources—including commentaries, scholarly articles, and policy briefs—were reviewed to interpret ambiguities in terms such as "fault" and "damage" (Gabrynowicz, 2004; von der Dunk, 2015).

3.2 Data Sources

Three categories of sources were employed:

1. **Primary Legal Texts:** United Nations treaties, conventions, and national legislations from the United States, European Union, and India.
2. **Policy and Technical Guidelines:** Soft-law instruments such as the **UNCOPUOS Space Debris Mitigation Guidelines (2007)**, **IADC recommendations**, and **ISO 24113** standards.
3. **Case Studies:** High-profile events such as the **2007 Chinese ASAT test** and the **2009 Iridium–Cosmos collision**, which illustrate liability challenges in practice (Wright, 2010; Jakhu & Freeland, 2016).

3.3 Comparative Analysis

To highlight variation in enforcement, this study compares national regulatory approaches. For instance, U.S. licensing practices under the Federal Communications Commission (FCC) are contrasted with European Space Agency (ESA) member states' national laws, and emerging frameworks in India. Attention was given to whether states require debris mitigation plans, financial assurances, or insurance coverage as conditions of licensing (Pelton, 2021).

3.4 Analytical Framework

The analysis was structured around three guiding questions:

- How do existing international and national legal frameworks allocate liability for debris-related damage?
- Where do gaps and ambiguities persist in regulating private and multinational space actors?
- What models—legal, financial, or hybrid—are most feasible for addressing these gaps?

The findings were synthesized thematically and cross-validated against case law, policy reports, and peer-reviewed scholarship. A qualitative content analysis was performed to identify recurring patterns, gaps, and policy recommendations (Bowen, 2009).

3.5 Limitations

The research is limited by the availability of published state practice, as many liability disputes are resolved diplomatically without public documentation. Further, the absence of quantitative simulation in this paper restricts the ability to model debris risk dynamically. These limitations are mitigated through the use of authoritative secondary literature and technical reports, which provide indirect evidence of state positions and liability implications.

4. Results

The results of this study are organized into three clusters: **(i)** analysis of international legal instruments, **(ii)** comparative assessment of national frameworks, and **(iii)** evaluation of proposed economic and policy mechanisms.

4.1 International Legal Frameworks

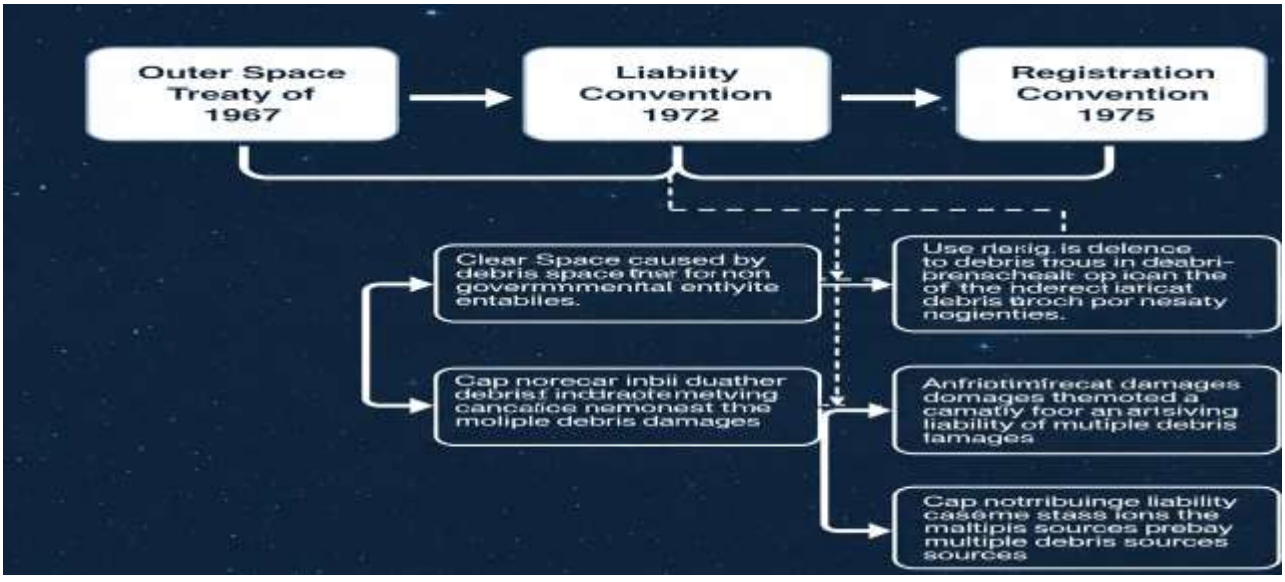
Findings from treaty analysis highlight structural gaps in liability governance. The Outer Space Treaty (1967) affirms state responsibility but lacks explicit provisions on debris. The Liability Convention (1972) differentiates between strict liability on Earth and fault-based liability in space but does not define "fault," creating uncertainty in collision cases (Gabrynowicz, 2004). The Registration Convention (1975) ensures state-level identification of objects but provides no tools for debris attribution.

Table 1: Gaps in International Legal Instruments for Space Debris

Instrument	Liability Provision	Identified Limitation
Outer Space Treaty (1967)	States responsible for activities in space	No mention of debris; private actors not addressed
Liability Convention (1972)	Strict liability (Earth), fault based (space)	Ambiguous definitions of "fault" and "damage"
Registration Convention (1975)	Registration of objects launched	No attribution mechanism for fragmented debris

(Source: Author's compilation based on Gabrynowicz, 2004; von der Dunk, 2015)

Figure 1



4.2 Comparative National Frameworks

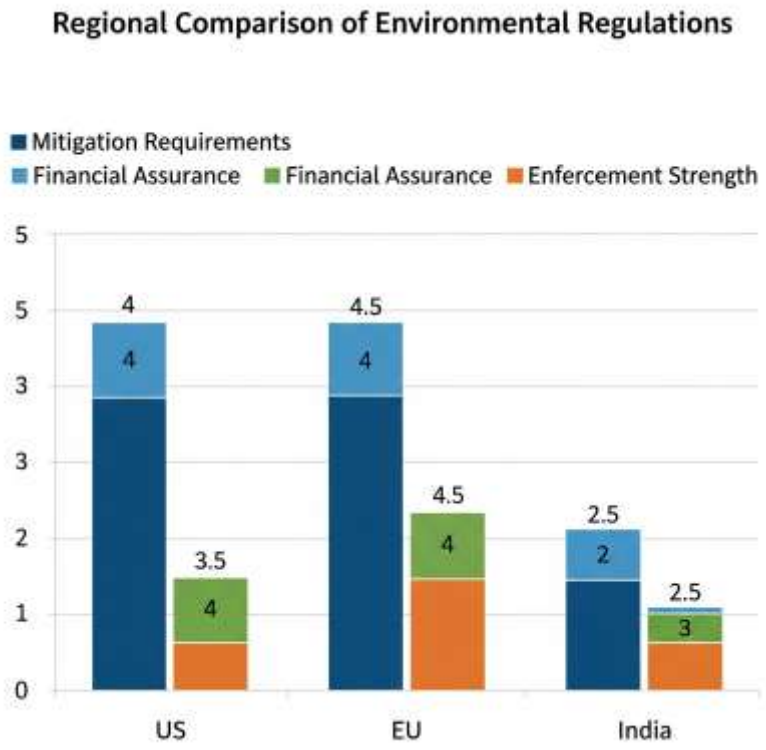
A comparative assessment reveals fragmented enforcement. The United States emphasizes debris mitigation in FCC licensing but lacks strong financial guarantees. European Union/ESA states apply the 25-year disposal rule with stronger compliance in France and Germany. India aligns with UNCOPUOS guidelines but has weaker enforcement provisions (Pelton, 2021).

Table 2: Comparative National Approaches to Debris Liability

Country/Region	Mitigation Plan Required	Financial Assurance	Post-Mission Disposal Rule	Enforcement Strength
United States	Yes (FCC, NOAA)	Limited insurance	25-year rule	Moderate
European Union	Yes (ESA guidelines)	Varies by state	25-year rule, stricter in some	High
India	Yes (ISRO guidelines)	Not mandatory	25-year recommended	Low–Moderate

(Source: Author's compilation based on Pelton, 2021; von der Dunk, 2015)

Figure 2



4.3 Economic and Policy Mechanisms

Economic tools emerge as potential solutions to liability gaps. Scholars propose polluter-pays levies, insurance pools, and debris-removal funds. Simulation studies suggest that a per-satellite fee proportional

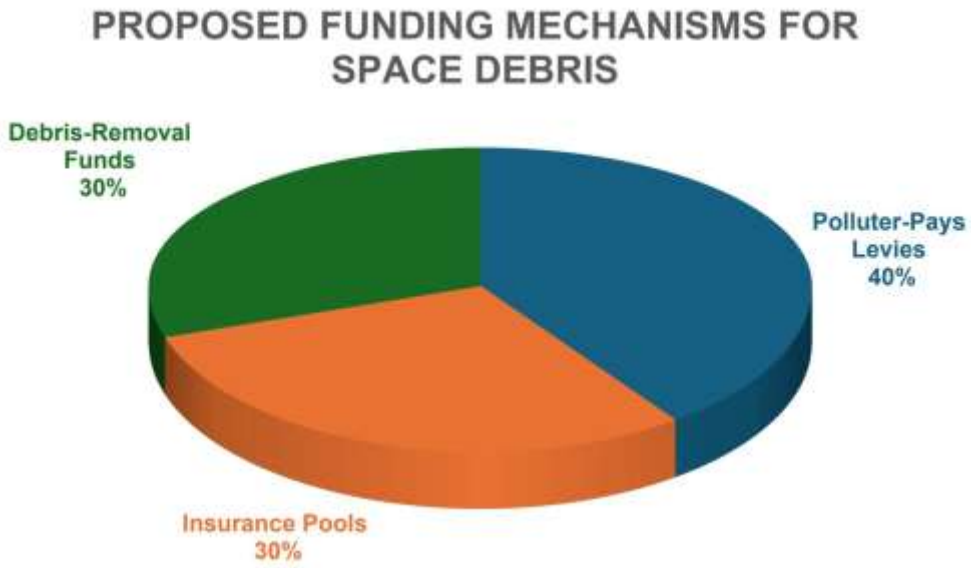
to orbital congestion could generate sustainable resources for debris mitigation (Adilov, Alexander, & Cunningham, 2018).

Table 3: Proposed Economic Instruments for Debris Accountability

Mechanism	Description	Potential Benefit	Limitation
Polluter-Pays Levy	Annual operator fee tied to orbital risk	Incentivizes responsible operations; generates funds	Requires global coordination
Insurance Pools	Shared industry fund for damages/remediation	Distributes risk; stabilizes market	May underprice catastrophic risk
Debris-Removal Fund	Pre-funded international clean-up fund	Enables large-scale removal missions	Requires governance body and compliance

(Source: Author's compilation based on Johnson, 2010; Adilov et al., 2018; Pelton, 2021)

Figure 3



4.4 Key Findings

- **Treaty limitations:** Existing legal instruments lack enforceable mechanisms for modern debris risks.
- **National fragmentation:** Inconsistent national laws create opportunities for regulatory arbitrage by private operators.
- **Economic feasibility:** Hybrid models combining legal frameworks with financial tools offer the most sustainable path.
- **Case-based evidence:** Major debris incidents have failed to trigger liability claims, highlighting systemic enforcement weaknesses (Wright, 2010; Jakhu & Freeland, 2016).

5. Discussion

The findings of this study reveal that the existing governance of space debris is characterized by legal ambiguity, fragmented national regimes, and underdeveloped financial mechanisms. This section interprets the results in light of prior scholarship and policy developments, discusses implications for global space governance, and identifies future directions.

5.1 Interpretation of Findings

The analysis of international treaties confirms that while the Outer Space Treaty (1967) and Liability Convention (1972) provide an essential legal foundation, they are ill-equipped to manage the complexities of debris attribution in the twenty-first century (Gabrynowicz, 2004; von der Dunk, 2015). The absence of clear definitions of "fault" and "damage" has limited the Liability Convention's ability to activate compensation even after catastrophic incidents such as the Iridium–Cosmos collision (2009) (Jakhu & Freeland, 2016). This gap illustrates the broader problem of relying on state-centric liability rules in an era dominated by private actors and multinational constellations.

Comparative findings across the United States, European Union, and India highlight regulatory fragmentation. While the U.S. focuses on licensing mitigation plans, and the EU demonstrates stronger enforcement in some member states, India and other emerging actors lag in implementing financial assurance mechanisms (Pelton, 2021). This unevenness creates the risk of regulatory arbitrage, wherein operators may base activities in jurisdictions with weaker requirements.

Economic instruments such as polluter-pays levies and debris-removal funds emerged as promising but remain conceptual. The feasibility of these mechanisms depends on establishing an international authority to oversee collection and disbursement, a task complicated by geopolitical rivalries and uneven capacity among states (Adilov, Alexander, & Cunningham, 2018). Without coordination, the tragedy of the commons will persist, where every actor benefits from orbit access but no single party assumes responsibility for long-term sustainability.

5.2 Policy Implications

The results carry several implications for policy and governance:

1. **Revisiting the Liability Convention:** A modernized liability regime should include clear definitions of "fault" and expanded recognition of probabilistic harm caused by debris congestion.
2. **National Harmonization:** States should standardize licensing requirements by embedding mitigation, financial assurance, and remediation obligations into domestic law, thereby reducing incentives for regulatory arbitrage.
3. **Hybrid Accountability Models:** Linking legal obligations with economic instruments—such as requiring operators to post **performance bonds** or contribute to **insurance pools**—could generate sustainable funding for debris mitigation.
4. **International Cooperation:** Multilateral bodies like **UNCOPUOS** and **ESA** must take stronger roles in coordinating compliance, possibly through an **orbital use fee framework** modelled on environmental governance practices.

5.3 Comparison with Previous Studies

These results align with prior scholarship highlighting the insufficiency of current treaties (Jakhu & Pelton, 2017; Freeland, 2010). However, this study advances the discourse by explicitly linking economic instruments to liability mechanisms, offering a hybrid solution to bridge the gap between law and practice. Unlike earlier works that focus primarily on legal doctrine, this paper emphasizes practical funding models to sustain active debris removal and mitigation.

5.4 Limitations of the Study

Despite these contributions, the study has several limitations. First, it relies heavily on published treaties, laws, and secondary literature, as many liability disputes are settled diplomatically and remain confidential. Second, quantitative simulations of debris removal costs and orbital congestion risks were beyond this study's scope. Third, geopolitical factors—such as the reluctance of states to acknowledge fault in debris-generating events—are difficult to capture in a legal-policy analysis.

5.5 Future Research Directions

Future studies could expand this work by:

- Developing quantitative models to simulate the financial costs of liability allocation across different orbital regimes.
- Exploring behavioural incentives for private operators under different liability-sharing mechanisms.
- Investigating the feasibility of an international orbital fund, potentially modeled on global climate financing structures.
- Conducting in-depth comparative studies of emerging spacefaring nations (e.g., Japan, South Korea, Brazil) to understand the diffusion of liability practices.

In sum, the discussion confirms that a hybrid governance model—combining legal reform, harmonized national laws, and financial mechanisms—is essential for managing space debris liability. Without such measures, space sustainability risks devolving into a commons crisis, jeopardizing scientific exploration, commercial activity, and global security.

6. Conclusion

The rapid expansion of space activities has made orbital debris one of the most pressing challenges for space governance. This study set out to examine the question of liability and responsibility for space debris and to identify how existing legal and policy frameworks allocate accountability. The findings demonstrate that while the Outer Space Treaty (1967) and the Liability Convention (1972) remain foundational, their provisions are insufficient for the realities of modern space activity. The absence of clear definitions of "fault" and "damage," combined with reliance on state-centric liability, has hindered effective compensation and deterrence in high-profile cases such as the Iridium–Cosmos collision and the Chinese ASAT test (Jakhu & Freeland, 2016; Wright, 2010).

Comparative analysis of national frameworks reveals that states such as the United States and European Union members have made progress by integrating debris mitigation into licensing, yet financial liability mechanisms remain weak. Emerging actors like India follow international guidelines but lack robust enforcement measures (Pelton, 2021). This fragmented landscape encourages regulatory arbitrage, undermining global sustainability efforts.

The study further highlights the potential of economic instruments, including polluter-pays levies, insurance pools, and debris-removal funds, to supplement legal frameworks. While implementation challenges remain, such mechanisms could provide the financial capacity necessary for large-scale debris mitigation and removal (Adilov, Alexander, & Cunningham, 2018).

Overall, this paper contributes three insights. First, it underscores the inadequacy of current liability regimes to address long-term and probabilistic risks posed by orbital debris. Second, it demonstrates the necessity of harmonizing national frameworks to prevent weak enforcement from undermining collective sustainability. Third, it proposes a hybrid accountability model that integrates legal reforms with financial assurance mechanisms to align incentives for both states and private operators.

In conclusion, the question of "who pays for the mess in space" cannot be answered by treaties alone. It requires a coordinated system in which legal responsibility, financial instruments, and international

cooperation converge to ensure the sustainable use of Earth's orbits. Without such collective action, the tragedy of the commons will persist, jeopardizing the future of space exploration, security, and commerce.

Acknowledgments

The author(s) would like to express gratitude to the United Nations Office for Outer Space Affairs (UNOOSA) and the Indian Space Research Organisation (ISRO) for providing access to policy documents and technical guidelines that informed this study. Special thanks are also due to colleagues and reviewers who offered valuable feedback on the initial drafts of this manuscript. The research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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