Public-Private Partnerships and the Allocation of Responsibility in Space Resource Governance

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Abstract. As the rapid commercialization of the space sector has led to the rise of public-private partnership (PPP) models for effective management and exploitation of extraterrestrial resources (outer space resources). This paper aims to analyze the structure, effectiveness, and challenges of PPPs in the context of space resource governance, with a particular focus on the allocation and sharing of responsibilities between government agencies and private enterprises. Through a comparative legal analysis of PPP legal frameworks in leading space technology countries, the study examines the dominant governance models in the space sector in the United States and China, as well as assesses the level of compliance with international space law, including the OST and related agreements or ragulations. The results show that although PPPs promote technological innovation and mobilize resources in the public and private sectors, there are still significant gaps in the allocation of legal responsibilities, regulatory oversight, and sustainability assurance. From there, the study provides policy recommendations to strengthen the governance framework to balance the innovation drive and the common interests of humanity in the exploration and use of outer space.

Keywords: public-private partnership (PPP), outer space, legal framework, The US, China.

1 Introduction

The aerospace field always holds appeal not only in specialized areas but also attracts other agencies, organizations, and individuals. It goes beyond simply expanding understanding of space science to include space exploration and resource sharing, reflecting a nation's military and economic strength. But today, space is evolving into a varied ecosystem with significant private sector involvement, no longer being solely a government-controlled area (particularly in the military sector) [1], Public-Private Partnership (PPP) models are increasingly playing a central role in the governance and exploitation of off-Earth resources. By 2030, the global space industry is expected to exceed $1 trillion [2], and by 2024, the private sector will make up about 80% of the industry's total revenue. The industry's total worth is expected to reach $570 billion, which is double what it was ten years ago, and it is expected to reach $2 trillion by 2040 [3]. Privatization of space resource exploitation activities on the one hand creates positive

© The Author(s) 2026
R. Hurriyati et al. (eds.), *Proceedings of the 10th Global Conference on Business, Management, and Entrepreneurship (GCBME 2025)*, Advances in Economics, Business and Management Research 407,
https://doi.org/10.2991/978-94-6239-819-1_100

effects in developing the economic and military potential of the country, but also has risks (environment, secrecy, responsibility, monitoring capabilities, etc.). [4]. Countries must improve their legal frameworks, coordinate the rights and responsibilities of the state and private sector, and address issues pertaining to national sovereignty, international legal obligations, and the interests of the global community in light of the growing scale and scope of commercial space activities [1].

PPPs in space, as opposed to traditional industries, are subject to certain limitations, including the "common property of mankind" - res communis [5], [6] nature of space, substantial technological risks, complex regulatory frameworks and data sharing requirements, and long-term environmental responsibility. The focus of discussions on governance and cooperation model design has shifted to the division of duties between parties, maintaining security, safeguarding national interests, and conforming to international norms like the "Outer Space Treaty" (OST). Although Article VI of the Outer Space Treaty makes States internationally responsible for national space activities, it does not provide a detailed supervisory framework for activities carried out by non-governmental actors. This limitation becomes more visible as public-private partnerships increasingly shape space exploration. In such arrangements, private entities may perform core operational functions, while States remain legally accountable under international law. The result is a regulatory grey area in which the boundaries of oversight, control, and responsibility are not always clearly drawn.

A closer examination of responsibility-sharing between public and private actors in extraterrestrial resource exploitation reveals a number of unresolved legal and policy concerns. Addressing these concerns is essential for building more coherent, effective, and accountable forms of public-private cooperation in the governance of space resources.

2 Methods

This study adopts a qualitative, doctrinal legal research design combined with comparative policy analysis to examine the allocation of responsibility in public-private partnerships (PPPs) governing space resource exploitation. Rather than testing a statistical hypothesis, the research maps how legal responsibility is distributed between public and private actors across different institutional models, and assesses the extent to which these arrangements comply with binding international space law.

2.1 Research Design and Case Selection

Four spacefaring jurisdictions — the United States, the European Union, China, and Russia — were purposively selected as comparative cases. These jurisdictions represent structurally distinct PPP governance archetypes identified in the space-policy literature: a competitive, milestone-based contracting model (United States); a multilateral, consensus-driven model (European Union); and centrally coordinated, state-owned-enterprise-led models (China and Russia). This variation allows the analysis to capture a representative range of responsibility-allocation practices rather than restricting the comparison to a single governance paradigm.

2.2 Data Sources

The analysis draws on secondary data gathered through documentary and legal-text analysis, comprising three categories of sources: (1) primary international legal instruments, principally the 1967 Outer Space Treaty (OST), the 1972 Convention on International Liability for Damage Caused by Space Objects, and related instruments such as the Moon Agreement; (2) national legislation and programmatic materials, including the U.S. Commercial Space Launch Competitiveness Act of 2015 and comparable regulatory documentation from the European Space Agency, the China Aerospace Science and Technology Corporation, and Roscosmos; and (3) secondary literature and industry data, comprising peer-reviewed journal articles, institutional reports (e.g., OECD, NASA, ESPI, Space Foundation, BryceTech), and case documentation on flagship programs (NASA's Commercial Crew Program, Galileo, Copernicus, Beidou, and GLONASS).

2.3 Analytical Framework

Data were analyzed using a comparative-matrix technique, in which each jurisdiction's PPP arrangement was coded against six analytical dimensions: (i) the lead government agency, (ii) the principal private-sector partner(s), (iii) the government's institutional role, (iv) the private sector's institutional role, (v) the risk-sharing or contracting mechanism, and (vi) an overall evaluation of governance outcomes. This framework, summarized in Table 1, structures the cross-national comparison presented in the Results and Discussion section.

Compliance with international space law was assessed qualitatively by mapping each jurisdiction's practical responsibility-allocation mechanism against the obligations set out in Articles VI, VII, and IX of the OST — namely, state responsibility for national activities, international liability for damage, and the protection of common interests in outer space. Gaps and overlaps were identified where domestic practice diverged from, or was not addressed by, the existing treaty framework.

2.4 Limitations

As a doctrinal and comparative-policy study, this research relies on publicly available legal texts, institutional reports, and secondary literature rather than empirical fieldwork, interviews, or quantitative datasets. The analysis is therefore interpretive in nature, and its conclusions should be read as an assessment of the formal-legal and policy landscape rather than as a measurement of implementation outcomes on the ground.

3 Results and Discussion

3.1 Comparative Analysis of PPP Models in Space Resource Governance

3.1.1 Overview of PPPs in Space Activities

Public-private partnerships (PPPs) can be understood as cooperative arrangements in which public authorities and private entities work together to produce outcomes that serve a public purpose. These outcomes may include infrastructure, technological capabilities, products, or services designed to benefit the wider community [7]. This form of cooperation has yielded considerable fiscal savings and has fundamentally

transformed the landscape of the space sector [8]. Specifically, it has shifted the domain from a state-dominated monopoly to a more innovative, dynamic ecosystem strongly influenced by private actors [9]. Not only has such collaboration enhanced technological capabilities, but it has also contributed to making space activities more sustainable, economically viable, and beneficial to both scientific advancement and social welfare [10]. In recent years, the liberalization of space markets – alongside the strategic ambitions of both governments and private enterprises – has accelerated the development of PPPs as a dominant model [11]. In 2023, the global space economy was estimated by The Space Foundation to be worth approximately USD 570 billion [3]. Of this, commercial activities accounted for USD 445 billion, representing 78% of the total space market [12]. These figures underscore the dramatic shift away from exclusive state control toward a prominent role for the private sector [13] [14].

PPPs allow governments to harness the innovation incentives and risk-sharing mechanisms of the private sector, thereby shifting their role from direct operator to that of coordinator, investor, and policy regulator [4] [15]. In this model, private firms assume much of the operational and commercial burden of space projects, including design, construction, operation, and financing. State agencies, however, continue to shape the sector by exercising oversight, setting strategic priorities, and facilitating market development [16]. These institutional developments have gradually created the legal and organizational conditions for space resource activities, large-scale satellite systems, and the expansion of human operations beyond Earth.

PPP models are primarily grounded in robust legal contracts – including milestone-based agreements [16] [17], operational service contracts, or comprehensive risk-sharing joint ventures [18] [19]. A consistent objective across these models is to reduce the burden on public budgets, accelerate implementation timelines, facilitate technology diffusion, and enhance global competitiveness [20] [16]. The structures and modalities of PPPs differ markedly across countries: the United States emphasizes competition and open bidding processes, whereas strategic-industrial models such as those in China and Russia prioritize state-owned enterprises as primary partners and maintain strict regulatory control [1] [21].

3.1.2 Comparison of Prominent PPP Models

In the United States, the PPP model in the space sector has evolved with notable diversity, marked by the adoption of competitive and flexible milestone-based contracts and the coordinating role of NASA. Acting as both a partner and a market creator, NASA plays a pivotal role in attracting private investment into space resource exploration [11]. his is most clearly demonstrated in the Commercial Crew Program (CCP), in which NASA collaborates with SpaceX and Boeing under milestone-based payment schemes. In 2024 alone, private investments in the sector surpassed USD 4 billion [22]. During 2015-2024, U.S. space startups secured approximately USD 55 billion in venture capital, accounting for nearly 60% of global private investment in the space sector. [22]. NASA's Commercial Crew Program demonstrates how public-private cooperation can reduce the cost of human spaceflight. Instead of relying exclusively on traditional government-managed transportation systems, NASA now contracts with private providers

such as SpaceX, whose Crew Dragon seats are estimated to cost approximately USD 60-67 million each. This figure is considerably lower than several earlier crew transportation arrangements, where estimated per-seat costs ranged from about USD 90 million to USD 291 million (Space Shuttle, Soyuz, Orion), depending on the system and calculation method [23]. Since 2020, SpaceX has conducted at least ten crewed missions to the ISS for NASA, from Crew-1 to Crew-10 (as of March 2025), alongside other commercial and private astronaut missions [24]. Furthermore, the ISS National Laboratory (ISSNL) exemplifies an open-access model of shared laboratory infrastructure, data, and collaborative scientific and commercial research involving private and academic partners [25]. For example, in cooperation with MassChallenge and Orbital Edge Accelerator, ISSNL funds innovation acceleration programs that enable startups to receive up to USD 500,000 in investment per project and conduct direct product development and testing on the ISS [26]. The strength of the U.S. PPP model lies in its combination of open market competition, transparent risk allocation through milestone contracts, and the state's strategic oversight role. This structure not only optimizes cost efficiency but also incentivizes broader development of space activities [14].

In Europe, the PPP model is a multilateral framework built on consensus, cross-border infrastructure and data-sharing collaboration. This model is characterized by the allocation of resources and the implementation of transnational PPP projects. The PPP model is guided by transparency and the prioritization of public interest. However, implementation can be slow due to the legal coordination complexities among EU member states [20]. European space programmes such as Galileo and Copernicus show how responsibility is often distributed across multiple public institutions rather than assigned to a single state agency. While Galileo was developed as Europe's satellite navigation system, Copernicus supports Earth observation and environmental monitoring. These programmes are implemented through cooperation between the European Commission and the European Space Agency, with Galileo alone reportedly involving costs of up to approximately USD 11 billion [28]. The program involves dozens of major multinational public and private contractors such as Airbus, OHB, Thales Alenia Space, Surrey Satellite Technology Ltd., ArianeGroup, along with numerous specialized subcontractors from various countries [27] [29]. Overall, the European PPP model is multilateral in nature, based on public oversight mechanisms, and emphasizes data governance and intellectual property rights. This model prioritizes collaborative research and development, yet this very feature renders it relatively inflexible, slow to adapt, and presents challenges in dispute resolution—particularly in determining the competent jurisdiction and applicable law.

In China, the PPP model functions within a framework that is centrally controlled by the state, where state-owned enterprises (SOEs) hold a significant position. A notable instance of this is the China Aerospace Science and Technology Corporation (CASC), which stands as the largest SOE in the nation and directly manages key satellite initiatives like Beidou and ChinaSat [30] [21]. By 2022, China's private space industry had experienced substantial growth, with more than 430 commercial space companies operational. It is anticipated that by 2024, the market value for this sector will reach USD 320 billion, reflecting an average annual growth rate of 22.3% since reforms began in this area. This rapid development reflects the increasingly significant role of private

actors within the space ecosystem, as well as the strong trend of commercialization in China's space industry [30]. In this context, China's PPP model reflects a clear hierarchy of decision-making, centralized resource allocation, and absolute state control over risk management. Strategic projects – such as telecommunications and Earth observation – are implemented by state-owned enterprises, while purely private firms are generally confined to supporting roles or subcontracted stages of the project. The Chinese PPP framework is designed to maintain the supremacy of state authority and to ensure national security and confidentiality. However, such a state-centred framework may restrict the commercial development of space resource activities and weaken the country's appeal to foreign investors.

In Russia, the public-private partnership (PPP) framework within the space industry is marked by a strong centralization and an almost monopolistic state influence. The State Space Corporation Roscosmos plays a pivotal role in this model, as it directly manages, controls ownership of, guides development efforts for, and operates the majority of key initiatives. Notable instances include the GLONASS global navigation system and Vostochny Cosmodrome [31]. A distinctive feature of the Russian model is its vertically integrated control – extending from policy direction and technological planning to asset ownership and system operation. Nearly the entire space value chain – from satellite design and manufacturing to launch and operation – is subject to Roscosmos's centralized approval and supervision. Compared to China's PPP framework, both models reflect a high degree of state centralization and control. However, in recent years, China has gradually opened "side door" for private enterprises to participate in auxiliary phases. By contrast, the Russian market remains largely closed to independent private actors, with limited competitive space or open mechanisms for technological innovation outside the traditional state-owned supply chain[32].

Overall, these models illustrate the inherent trade-off between the pace of technological innovation and the strategic objectives of individual nations. The United States stands out for its market integration and innovation capacity; the European Union emphasizes multilateral coordination and transparency; whereas China and Russia prioritize sovereignty and national security over market liberalization [4], [20], as detailed below:

Table 1. Comparative summary of national/regional PPP models in space resource governance.

Nation/Region	Example	Key Characteristics of PPPs	Governmen-tal Lead Agency	Private-sector partner	The government's role	Private sector's role	Risk sharing	Evaluation
USA	CCP	Open, competitive, milestone-based agreement	NASA	Space X	Regulator, primary customer	Innovation, operations	Milestone-based, shared respon-si-bility	Market-oriented focus, legally complex
EU	Galileo	Multilateral, consensus-driven, public interest-oriented	ESA, EC	Airbus, OHB, others	Leader of multi-national alliances	Consortium member	Co-ordinated, multi-national sharing	- Capable of coordinating multiple international contractors

								- Difficult to harmonize common standards and resolve disputes
China	Beidou	State-centric	CASIC, CASC	Huawei and other subordinate companies	Developer, financier	Supportive, secondary role	State-centralized control	State-centric; very limited private operation, difficult to attract foreign investment
Russia	GLONASS	Full state control,	Roscosmos	ISS-Reshetnev (state-owned enterprise)	Coordinator, financier	Subcontractor,	Full state authority	The state holds full authority; the

		defense-oriented				technical support		private sector acts as subcontractor, limiting the potential to attract foreign investment

3.2 Allocation of Responsibilities in PPPs for Space Resource Exploitation

3.2.1 Principles and Practices of Responsibility Allocation

International Legal Principles

Responsibility assignment in PPP projects related to the exploitation of space resources is based on fundamental principles of international law, particularly Articles VI and IX of the Outer Space Treaty (OST). According to these articles, a State holds international legal accountability for all activities conducted in outer space by entities within its jurisdiction, including both governmental bodies and private companies. This obligation includes ensuring that all exploitation activities fully comply with internationally accepted legal norms, technical standards, and safety protocols. Specifically, the key principles include:

Responsibility Attribution: The State of registry retains full responsibility for all PPP activities under its jurisdiction, including those implemented by private actors. In the event of an incident (e.g., collision, damage, space debris), the State must provide justification and compensation at the international level before pursuing liability claims against domestic private partners.

Authorization and Supervision: States are required to authorize, supervise, and continuously monitor all private space activities prior to launch or the implementation of PPP projects. This includes ensuring ongoing compliance with both international law and national regulations

Protection of Common Interests: Any PPP initiative must avoid harming the space environment or impeding other actors' access to space or extraterrestrial resources, in line with the principle that outer space constitutes the "province of all humankind."

Practical Allocation of Responsibility in Space PPP Models

In practice, responsibility within space-related PPPs is not allocated in a single way. It is shaped through a combination of contracts, licensing conditions, regulatory supervision, and risk-allocation mechanisms:

Milestone-Based Contracting Mechanisms (United States): Under NASA's Commercial Crew Program, specific technical, safety, and reporting responsibilities are clearly assigned to private contractors (e.g., SpaceX, Boeing). NASA retains oversight authority, conducting evaluations and approvals at each project stage. Financial and technical risks are shared through milestone-based payments, with provisions for compensation, remediation, and termination rights if a partner violates contractual obligations or jeopardizes national security. In the event of an incident (e.g., launch failure, satellite loss), the private company is responsible for initial response and mitigation. However, international accountability and compensation obligations ultimately rest with the U.S. government.

Transparent Responsibility Sharing in Europe (EU/ESA): Programs like Galileo and Copernicus adopt a responsibility-sharing model among member states, with strict rules on cost distribution, compensation obligations, data exploitation rights, and safe operational duties for all public–private partners in the joint venture. EU rule requires private partners to coordinate closely with regulatory bodies and comply with unified standards, especially in responding to incidents involving environmental harm or cross-border assets.
Centralized control and limited private liability in China and Russia: In these countries, state-owned enterprises take the lead and bear primary responsibility to the state. Private partners typically have limited roles, often restricted to subcontracting. The state exercises direct oversight and intervenes in major risks, while legal claims and liabilities are managed domestically under national laws before any international negotiation or engagement.

2.2.2. Gaps and overlaps in responsibility allocation

Although the international legal framework, such as the OST (OST 1967), has established the principle that states bear ultimate responsibility for all space activities conducted by private entities under their jurisdiction, the practical implementation of PPPs in space resource exploitation increasingly reveals numerous gaps and overlaps in legal, technical, and governance responsibilities.
First, there is a lack of clear regulation regarding resource ownership: The OST does not explicitly provide for private sector ownership of extraterrestrial resources, while simultaneously prohibiting any state from claiming sovereignty over any outer space territory or celestial body. However, some countries such as the United States and Luxembourg (e.g., the U.S. Commercial Space Launch Competitiveness Act of 2015) have enacted domestic laws recognizing such ownership rights for private entities (i.e., ownership of resources obtained from space mining activities), even though international law still regards outer space as the common heritage of humankind. This situation may give rise to multilateral legal conflicts when PPPs engage in transnational celestial resource exploitation projects, particularly in the absence of agreed principles on priority of access, benefit-sharing, or property dispute resolution.
Second, the management of incidents and obligations for multinational compensation remains unclear: In the event of collisions, asset loss, or environmental impact, Article VII of the OST provides that the state of registry of the satellite bears international responsibility. However, there is still no detailed cooperative standard on how to allocate responsibility, compensation, or reconstruction among private/PPP partners from multiple countries—particularly in cases involving public–private consortia, multi-layered ownership structures, or shared technology in large-scale projects. The absence of guidance for resolving multinational disputes leaves parties vulnerable to prolonged conflicts or overlapping rulings on liability and compensation..
Third, there is a lack of mechanisms for addressing environmental incidents in outer space: The rapid pace of commercial launches and the growing number of satellites and debris under PPP projects significantly increase the risks of space debris and off-Earth environmental impacts. To date, no binding international regulation exists regarding

responsibilities for remediation, debris removal, or the sharing of environmental management costs between public and private partners. The 1972 Liability Convention imposes state responsibility for damage related to space activities, but its scope mainly covers damage on Earth or to third-party entities, rather than addressing risks to the space environment itself. This creates a potential for "moral hazard," where both states and corporations may deny environmental obligations—especially in experimental or multi-phase investment projects.

Fourth, conflicts over jurisdiction and the clash between international and national laws: Some PPPs operate under two or more legal systems (e.g., EU member states with distinct domestic laws, or the United States when attracting foreign investors), creating difficulties in determining the competent adjudicative body and applicable law. Current dispute resolution mechanisms mainly rely on negotiation or arbitration (which requires prior agreement between parties); however, the enforceability of rulings often depends on the willingness to comply and the legal framework of each respective country.

4 Conclusion

The rapid development of public–private partnerships (PPPs) has been reshaping the governance structure of the space sector, expanding the potential for resource exploitation and commercialization beyond Earth, while generating new drivers for technological innovation, risk-sharing, and greater efficiency in public investment [4], [20]. PPP models in the United States, Europe, China, and Russia vividly illustrate the diversity in how power, responsibility, and benefits are allocated between states and private enterprises, deeply reflecting each country's institutional characteristics, strategic orientations, and level of development. However, the advancement of PPPs also reveals significant legal and governance gaps, especially concerning resource ownership, transnational environmental responsibilities, data transparency, and dispute resolution mechanisms, in a context where exploitation activities increasingly involve multiple actors and jurisdictions. Meanwhile, existing regulations under the OST and domestic legal systems have yet to keep pace with the rate of technological and commercial innovation, resulting in a lack of global standards on responsibility allocation, compensation, and the sharing of benefits and risks.

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