


Navigating the space frontier: Insights into the current state and future potential of the space economy

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1. Introduction

Space, once a symbol of human aspiration and the final frontier, has evolved into an indispensable part of our global infrastructure, marking a significant transition from a mere destination for exploration to an economic backbone [1]. This paper sets the stage for a comprehensive exploration of the modern space economy, a field characterised by its rapid evolution, immense economic potential, and a shift from defence-driven government initiatives to commercial pursuits. Since Neil Armstrong's historic lunar landing in 1969, our reliance on space has intensified, now influencing every aspect of modern life, from satellite-assisted navigation to global communication networks. The economic significance of space is evident in numerous sectors, with satellite infrastructure playing a crucial role in telecommunications, finance, weather forecasting, and defence. For instance, positioning navigation and timing (PNT) services, originally developed for military applications, now underpin global financial transactions, transportation logistics, and emergency response systems. Without these space-based systems, disruptions in supply chains, telecommunications, and critical infrastructures would be inevitable. As highlighted by Van Camp and Peeters [2], a large-scale failure of satellite networks could severely impact global economies, demonstrating the indispensable nature of space-based capabilities. The burgeoning space economy, which is driven by the increasing commercial and strategic value of space, is on the brink of a new era—one that promises unprecedented opportunities but also highlights the imperative for the sustainable and responsible utilisation of space [3,4].

The space economy has become a rapidly expanding and strategically important domain, influencing industries and economies worldwide. The space economy can be defined as 'the economic space that encompasses all economic activities related to the development, production, operation, and commercialisation of space-based infrastructure, technologies, and services'. It includes contributions from both the public and

private sectors, spanning the manufacturing of satellites, launch vehicles, ground stations, and space platforms as well as the downstream industries that utilise space-enabled capabilities, such as satellite communications, Earth observation (EO), navigation, and scientific research [4,5]. The evolution of the space economy has been significantly shaped by the emergence of New Space, a paradigm shift from a government-dominated model to a market-driven ecosystem. This transformation has been fuelled by private investment, venture capital, and cost-efficient technological innovations, accelerating the commercialisation and democratisation of space activities [1,6]. The New Space economy is characterised by increased competition, modular production techniques, and service-oriented business models, making space-based technologies more accessible, scalable, and integrated across global industries.

The motivation for conducting this literature review stems from the pressing need to understand the economic dimensions of space activities, which have significant implications for both research and practical applications. From a research perspective, the space economy represents a dynamic and rapidly growing field that demands comprehensive analysis to grasp its complexities and potential [3,7]. As space activities transition from government-led initiatives to commercial ventures, it is crucial to examine the factors driving this shift and their impact on economic growth, technological innovation, and international collaboration. In terms of practical applications, the findings of this review provide valuable insights for policymakers, industry leaders, and stakeholders involved in the space economy. Understanding the economic drivers and challenges associated with space activities will enable better decision making and foster innovation, investment, and sustainable growth. Additionally, this review highlights the need for international cooperation to address the regulatory, legal, and ethical issues associated with space activities. By providing a new point of view for the classification of economic activities within the New Space economy, this review will support the development of policies and strategies that

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maximise the benefits of space activities and mitigate potential risks.

Our research addresses the following key questions.

- What are the key factors affecting the future development potential of the overall space economy?
- How have the key development factors changed since the early days of the space economy?

These questions are crucial to investigate because a deeper understanding of these factors can significantly enhance academic research, as well as having important practical impacts on the space economy. For example, identifying economic drivers and barriers helps pinpoint what stimulates growth and what obstacles must be addressed, thus facilitating more effective policy and strategic decisions. Recognising the role of new entrants can shed light on how innovation and competition transform the industry, and establishing robust measurement standards and economic models ensures accurate analysis and sound investment decisions. This improved understanding can drive technological advancements, foster international collaboration, and ultimately contribute to solving global challenges, such as climate change, through enhanced space capabilities.

2. Methodological review and approach

We aimed to address critical aspects of the space economy through our research questions, examining the foundational factors and historical context that led to its emergence, the technological innovations and market dynamics driving its growth, and the status of commercial and governmental activities in space. Additionally, we identified barriers to the development of the space economy—such as regulatory challenges, high costs, and technical risks—and explored the technological, financial, and policy-related requirements for sustainable growth. We also assessed future development potential, focusing on emerging opportunities and the key drivers of the space economy’s trajectory.

In taking this approach, we concentrated on various factors influencing the origins and evolution of the New Space economy, with a focus on key drivers such as innovative business models and their impact on global competition [8]. We used an amended version of the framework presented in the *Organisation for Economic Co-operation and Development (OECD) Handbook on Measuring the Space Economy, 2nd edition* [4] to classify our findings in an economic context. We focused our literature search on the period 2018–2023, as this period marked a notable surge in relevant research, particularly in the sphere of commercial space applications [3,4]. Our systematic literature review encompassed an extensive search across multiple databases, including SAGE, Scopus, IEEE Xplore, ABI/INFORM, EBSCO (Academic Search Elite, Business Source Premier, eBook Collection, and Regional Business News), and Taylor & Francis. The last database queries were conducted on 9 April 2024, covering literature published up to 31 December 2023.

We employed ‘space economy’, ‘satellite account’, ‘new space economy’, ‘space economic’, and ‘space economics’ as keywords to identify and retrieve pertinent articles. However, our methodological approach extended beyond keyword-based analysis to a systematic qualitative review of full texts. Articles were assessed in their entirety to ensure that the identified themes were contextually accurate rather than based solely on the presence of specific terms.

To enhance the rigour of our findings, we applied a structured contextual analysis framework to determine whether key terms were used in reference to historical, contemporary, or future developments [9,10]. This ensured that interpretations of economic drivers and trends were temporally accurate. Additionally, thematic coding was employed to differentiate between incidental mentions of terms and substantive discussions relevant to our research questions [9,10]. Our analytical process involved a two-step approach: (i) quantitative occurrence analysis—mapping the frequency of relevant terms across the dataset to establish broad thematic trends, and (ii) qualitative impact

assessment—evaluating how key terms were used within each article, ensuring that terms were not overemphasised based purely on frequency [9,11].

This approach mitigated the risk of disproportionately weighing frequently mentioned but contextually marginal topics while ensuring that critical but less frequently mentioned themes received appropriate attention. In our analysis, term frequency was not assumed to be directly proportional to impact; the significance of a given theme was determined through qualitative evaluation, considering factors such as policy relevance, economic implications, and cross-sectoral linkages [9,11]. This methodological structure allowed us to distinguish systematically between casual mentions of key terms and in-depth discussions pertinent to our research questions. In general, it should be noted that while the tables and graphs displayed throughout this article primarily reference quantitative occurrence, these findings are in line with our qualitative findings. The decision to present the data from a quantitative occurrence point of view was made to provide readers with tangible, easy-to-understand numeric values.

Furthermore, to strengthen the validity of our conclusions, we analysed how each article addressed the identified themes, ensuring that our findings accurately reflected content rather than merely the presence of specific terminology. While this literature review provides a broad view of prevailing discussions in the literature, we acknowledge that it differs from empirical studies using surveys or direct interviews in which researchers’ perspectives are explicitly gathered. Future research could complement this literature review with empirical methodologies to further validate and refine our findings [10,11].

We initially identified 4,619 papers through our database search. A multi-phase screening process was then applied (Table 1). After title and abstract screening, we narrowed the scope to 226 papers. We excluded non-English publications, yielding 221 papers, and then conducted thorough full-text reviews. Ultimately, 98 articles were selected for detailed analysis, as they best epitomise the core themes of business model innovation, technological advancement, and the impact of public policy on the space economy [9–11].

To ensure accurate temporal classification, we categorised the findings into three primary historical periods.

1. **Early state-driven phase (1950s–1990s):** Characterised by Cold War era government-led investments, where military applications and national prestige were dominant factors.
2. **Transition phase (1990s–2010s):** Marked by the gradual commercialisation of space activities, including the expansion of satellite services and increasing private-sector involvement, largely through government contracts.
3. **New Space phase (2010s–present):** Defined by venture-capital-driven commercialisation, disruptive innovation, and increased autonomy of private space enterprises from traditional government-funding structures.

This classification allowed us to track how economic drivers evolved

Table 1
Selection criteria for accepted articles.

Phase	Description	Count of Articles
Phase 1	Database query: SAGE, SCOPUS, IEEE, ABI, EBSCO (Academic Search Elite, Business Source Premier, eBook Collection, and Regional Business News), and Taylor & Francis	4,619 articles meeting the set criteria.
Phase 2	The title and abstract were verified, and selections were made based on that information.	226 articles meeting the set criteria.
Phase 3	Publications in languages other than English were excluded.	221 articles meeting the set criteria.
Phase 4	Articles were read and analysed thoroughly. Those that did not fully meet the selection criteria were excluded.	98 articles meeting the set criteria.

over time and to ensure that historical, present, and projected future developments were appropriately contextualised.

The identified articles were published across 49 journals, and the distribution of publications by year (2018–11; 2019–9; 2020–15; 2021–11; 2022–26; 2023–26) shows a notable increase in publication quantity since 2022. In terms of the number of articles published, the top publishing journals for the examined articles were *Space Policy* (17), *Acta Astronautica* (12), *Astropolitics* (9), and *New Space* (5), which accounted for about 44 % of the examined articles. Most other journals identified in this research published only one of the examined articles.

We aimed to identify key factors related to the origins, present status, and future potential of the space economy, focusing on both state and private actor roles. Our review covered a range of journals, emphasising diverse contributions within space politics, policy, and international business. The findings indicate a substantial focus on US companies within the articles (Fig. 1), with particular emphasis being placed on the pivotal role of SpaceX (Fig. 2) in the emerging space economy, especially its entrepreneurial strategies and public–private partnerships.

As we conduct our research at the forefront of economics-focused New Space research, we recognise the potential for imperfections in our selection methodology. Therefore, our analysis should be perceived primarily as a broad exploration and synopsis of the factors shaping the growth of a sustainable (new) space economy and its future rather than a complete listing of all related works. The 98 international academic papers chosen for our literature review nevertheless epitomise the most pivotal contributions in this academic domain. We wish to acknowledge that our aim is to provide the academic community with a foundation for the examination and classification of these activities. Due to the factors mentioned above, it is challenging to construct a comprehensive categorisation system for ‘New Space’ activities, which is why we have taken the first steps in that regard in this paper.

3. Quantifying the multidimensional space economy: challenges, governance, and evolving segments

When defining the space economy, particularly within developed economies, we encounter the significant challenge of distinguishing space-related activities from other economic activities. In this systematic literature review, we explored various theoretical frameworks and

models intended to clarify the economic dynamics of space activities [1, 4,12]. This encompassed economic theories related to technological innovation, market expansion, and regulatory impacts. By examining the broader context of the space economy, including geopolitical influences, technological advancements, and market trends, we identified and categorised the specific characteristics of various segments of the space economy [4]. This approach enabled us to understand the unique attributes and economic contributions of each segment. Our methodology involved sourcing data from multiple databases and academic journals, screening articles using relevant keywords, and synthesising the findings of the selected studies.

According to the OECD [8], the rapid evolution of commercial space activities necessitates a dynamic and nuanced understanding of the space economy. This evolving landscape is further complicated by the lack of a uniform definition of the space economy, leading to inconsistencies in the literature. To address these inconsistencies, our research employs the framework provided by the *OECD Handbook on Measuring the Space Economy* [4] as a baseline. The OECD framework classifies the space economy into the following key segments: (1) satellite communications, (2) PNT, (3) EO, (4) space transportation, (5) space exploration, (6) science, (7) space technologies, (8) generic technologies or components that may enable space capabilities, and (9) defence.

In addition to these established segments, our literature review identified three emerging structural factors that frequently appear in contemporary research: cooperation, regulation, and satellite constellations. These elements did not originate from the OECD classification but were derived directly from our systematic literature review, representing an original contribution of this study. Their inclusion reflects a clear empirical emergence from the analysed corpus of articles rather than an arbitrary addition. The selection of these three specific categories was based on a systematic content analysis, wherein they repeatedly appeared across multiple sources as key determinants shaping space-related economic activities.

The criteria for inclusion were.

- Recurrence in scholarly discourse: These themes were consistently referenced as pivotal influences on the space economy across numerous studies.

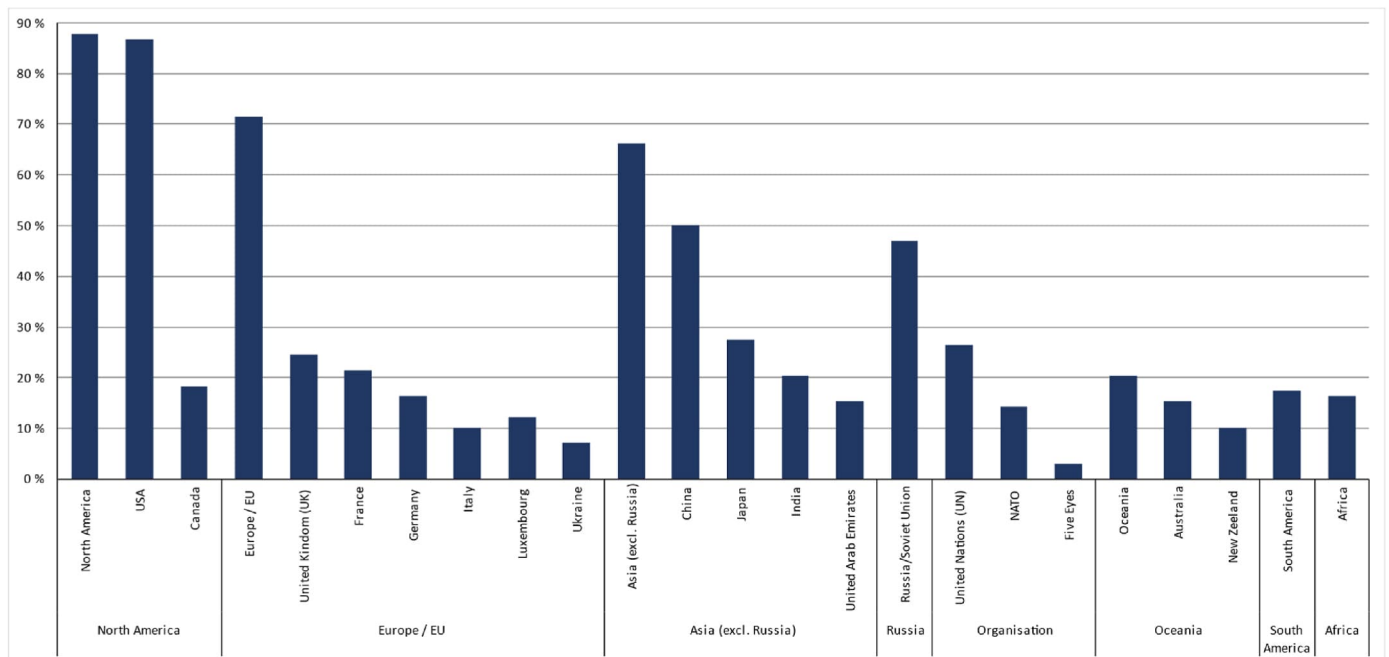


Fig. 1. Share of articles featuring selected geographic areas or governmental organisations.

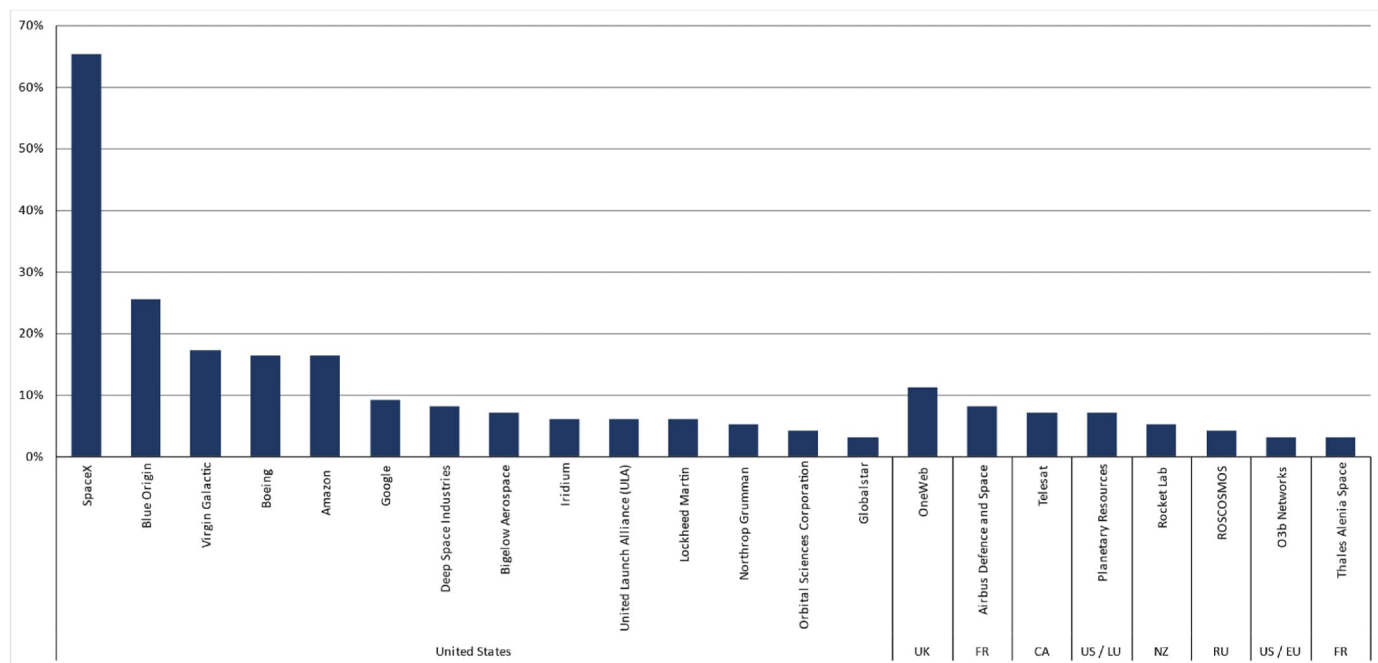


Fig. 2. Share of articles mentioning a certain company (where N > 1).

- Distinct economic and strategic impact: Unlike many general themes, these categories demonstrated a direct and traceable influence on space-sector investment, policy formation, and market structuring.
- Interconnection with OECD-defined segments: While the OECD classification categorises economic activities, these three elements function as cross-cutting structural determinants of growth, shaping the development and expansion of those activities.

It is important to clarify that these categories do not compete with or attempt to replace the OECD segmentation. Instead, they complement and enhance it by addressing key external drivers that influence the development of OECD-defined space activities. The OECD classification delineates space-related industries (such as PNT services, space transportation, and satellite communications) by their economic function. In contrast, cooperation, regulation, and satellite constellations are systemic factors that influence the evolution of these industries rather than constituting distinct economic activities themselves [4].

To illustrate this distinction.

- Cooperation (e.g. international partnerships, joint ventures, public-private collaborations) is a governance and economic enabler, shaping how OECD-classified activities are conducted.
- Regulation (e.g. legal frameworks, compliance standards, national space policies) defines the operational environment in which space activities take place.
- Satellite constellations and miniaturisation (e.g. Starlink, OneWeb) represent a disruptive technological shift impacting multiple OECD-classified segments, such as telecommunications, EO, and PNT [4].

By integrating these elements, our research extends the analytical depth of the OECD framework, providing a holistic perspective that captures both the activities themselves and the structural factors shaping their development. This distinction eliminates potential confusion between economic segments and their underlying drivers.

The governance and legislation of space activities are crucial for the space economy’s development, ensuring stability in space operations. However, ambiguity remains regarding the specific laws and norms applicable to many space economy activities [3,13]. The 1967 Outer Space Treaty, despite being the principal framework for international

cooperation, occupies an ambiguous position regarding space resource use [13,14]. The growing reliance on space systems across civilian markets and military uses has amplified the importance of space politics and economics in global relations [15,16]. As space activities evolve, so does the demand for comprehensive and adaptable space law, emphasising the need for consistent national and international regulatory frameworks to navigate the complexities of space activities.

By adopting the OECD framework and expanding it to include the new categories identified in our literature review, we provide a more comprehensive analysis of the space economy. This approach not only facilitates a clearer understanding of current trends and challenges but also supports the development of targeted policies and strategies that can foster growth in this dynamic sector. Our research highlights the need for continuous refinement of measurement frameworks to keep pace with rapid developments in space activities. As the space economy continues to evolve, incorporating emerging categories and trends into established frameworks will be crucial for maintaining an accurate and actionable understanding of this multifaceted domain.

4. The dawn of the space economy: How it all came to be

The evolution of the space economy has traditionally been segmented into three phases. Initially, space exploration was a state-driven affair, with agencies such as NASA championing endeavours propelled by the quest for national prestige and seminal space missions [12,17–23]. This period was characterised by monumental events such as the launch of Sputnik I, igniting the Cold War’s ‘Space Race’ and shaping the foundation of international space law [20,21,24]. As superpower competition in space began to wane, the landscape shifted, with private enterprises progressively becoming pivotal in this new market, driving technological innovation and heralding a new era in the sustainable development of the space economy [25].

The transition from a government-led space sector to a market-driven, innovation-centric space economy was fundamentally driven by digitalisation. The integration of big data analytics, cloud computing, and AI-driven automation transformed space-based infrastructure into a scalable commercial sector. By reducing operational costs, improving accessibility, and enabling real-time decision making, digital technologies significantly accelerated the commercialisation of satellite services.

Following the Apollo programme, the space industry faced the challenge of sustaining its workforce and industrial capabilities, prompting governments to support early commercial applications such as satellite telecommunications, weather monitoring, and EO. The integration of digital technologies into space-based infrastructure played a crucial role in this shift, enabling real-time data analytics, software-defined satellites, and AI-driven automation to optimise operations and expand commercial opportunities. During this period, companies such as Hughes, Intelsat, and Boeing were key in developing the commercial satellite market, initially relying on government contracts before gradually shifting towards independent revenue models. The development of geostationary satellite communications in the 1970s and 1980s exemplifies this transitional phase, as space infrastructure became increasingly integrated with private-sector interests. The widespread adoption of digital platforms further facilitated the commercialisation of space-based services, providing a foundation for data-driven applications in various industries.

The New Space economy, as it is understood today, emerged much later, shaped by venture capital investments, technological innovation, and a more risk-tolerant entrepreneurial approach. Unlike the earlier phase of commercialisation, New Space companies such as SpaceX, Blue Origin, and Planet Labs leveraged private financing, cost-efficient production methods, and rapid iteration cycles to challenge established aerospace incumbents. SpaceX's first successful orbital launch in 2008 symbolised this shift, underscoring the growing role of private entities and marking the beginning of a new era in space entrepreneurship. The increasing reliance on digitalisation, including cloud-based satellite data processing, automated EO analytics, and AI-driven mission planning, further enabled this transformation by making space services more scalable and accessible.

Simultaneously, the United Nations Office for Outer Space Affairs (UNOOSA) was instrumental in cultivating an inclusive and developmental space economy, emphasising essential pillars such as economy, society, accessibility, and diplomacy [21,26]. Additionally, the strategic importance of space extended beyond exploration, as space assets became integral to the global power structure and defence, marking the beginning of a 'Second Space Age' characterised by the intermingling of private initiative and public enterprise in space ventures [21]. The focus during this era was on economic and strategic gains, including the development of cis-lunar economies and resources for cost-effective operations [19]. These developments reflected a shift in the geopolitical dynamics of space, with the major powers again contesting for space leadership [27].

In the third, industry-driven phase, commercial space applications further reshaped the industry. New commercial entities, supported by public funding and government initiatives, began to play a significant role, indicating a move towards more diversified and commercially oriented business models [20,28–30]. This entrepreneur-driven phase represents the current state of the space economy, characterised by equity-funded ventures that introduce disruptive innovations and alter market dynamics. It demonstrates a significant paradigm shift in business models [3] and a more pronounced role for private funding and entrepreneurship, diverging from prior government-led initiatives and reflecting a dynamic, evolving space economy.

4.1. The search for hegemony and national prestige as the starting point

The emergence of the space economy was closely tied to the Cold War era's geopolitical dynamics. The race to the moon, motivated by national prestige and hegemony, was a crucial catalyst in space technology development. The United States and the Soviet Union, as the leading superpowers, channelled substantial investments into their space programmes, as the blocs perceived space dominance as a symbol of national power and technological superiority [16,18,19,31–36]. This rivalry not only advanced space technology but also laid the foundation for the space economy.

The quest for space exploration, which was primarily driven by the pursuit of national prestige, significantly influenced international relations and global power dynamics [16,37]. The militarisation of space during this period extended beyond national security, reflecting a broader strategy for asserting dominance in space [18]. Governments recognised the strategic importance of space for defence and intelligence, leading to a direct public role in the management of space technology and resources. These Cold War dynamics shaped public policies and business models in the space sector, with governmental control being prevalent in terms of technology, infrastructure, and finance. The role of space assets in military operations and strategic planning further highlighted their importance for national security [29,31,38,39].

Therefore, the emergence of the space economy can be attributed to the Cold War quest for national prestige and technological superiority. The US–Soviet rivalry accelerated space technology advancements, symbolising national power and paving the way for the evolving space economy. The ongoing influence of this era's legacy is evident in the space programmes of both established and emerging spacefaring nations, in which the pursuit of space achievements continues to shape business models, international relations, and public policies.

4.2. Determinants of space economy growth

The development of the space economy has been driven by a set of fundamental economic, technological, and policy determinants, rather than by industrial sectors alone. While traditional classifications categorise space activities into industries such as defence, PNT, satellite communications, and EO, these sectors emerged in response to key enabling factors rather than acting as independent drivers of growth.

Through our analysis, we identified eight primary **determinants of space economy growth**.

- **Technological innovation** – Advances in satellite miniaturisation, reusable launch vehicles, and automation have expanded market accessibility.
- **Economic investment** – Government funding, venture capital, and commercial financing models have supported industry expansion.
- **International collaboration** – Multilateral agreements, public–private partnerships, and global cooperative missions have facilitated growth.
- **Regulatory frameworks** – Legal structures governing spectrum allocation, commercial licensing, and sustainability policies shape industry dynamics.
- **Scientific research** – Innovations in aerospace engineering, materials science, and computational modelling enable new applications.
- **Market demand** – Increased reliance on satellite-based services, including broadband and navigation, has driven commercial activity.
- **Infrastructure development** – The expansion of launch sites, satellite constellations, and data processing centres enables large-scale operations.
- **Geopolitical strategies** – National security concerns, competition for orbital resources, and space policy influence market structures.

These determinants interact to shape the evolution of space-based industries. For instance, the rise of satellite communications was enabled by regulatory liberalisation, telecommunications investment, and technological improvements in geostationary relay systems. Similarly, EO services expanded due to scientific advances in remote sensing, increased governmental funding, and open data policies that encouraged commercial applications.

Understanding these determinants is essential for analysing how and why different space sectors have emerged. The following sections explore key space economy industries, illustrating how their development has been influenced by these fundamental growth drivers.

4.3. The emergence and growth of the new space economy through growth determinants rather than segment growth

The development of the space economy is driven by fundamental economic and technological determinants of growth, rather than by specific industrial sectors [39–41]. While defence, PNT, space exploration, space transportation, satellite communications, EO, and science represent core application areas of the space economy, they are not, in themselves, the forces that generate economic expansion. Instead, our analysis identified a set of underlying growth drivers that enable and shape the evolution of these industrial segments [32,42,43].

These determinants of growth include technological innovation, which continuously lowers costs and expands space-based applications, and financial investment, where public funding from agencies such as NASA and ESA, along with private capital from venture funds, acts as a key catalyst [3,44,45]. International collaboration enhances research capabilities and market access, while regulatory frameworks provide the legal and institutional foundation for sustainable and competitive space activities [17,29,46]. Infrastructure development, including launch capabilities, satellite constellations, and ground-based assets, further enables large-scale commercialisation [47]. Market demand for services such as broadband, EO, and navigation fuels continuous economic activity, while scientific research contributes to long-term innovation and technological spin-offs [32,40]. Finally, security and geopolitical interests influence investment flows and policy decisions, reinforcing the strategic importance of space activities [39,48].

It is essential to distinguish these growth determinants from the economic segments they influence. The OECD classification provides a structured segmentation of space-related industrial activities, categorising them into areas such as satellite communications, space transportation, and PNT services. However, this classification does not explicitly address the forces that drive economic growth within these segments. Our framework complements the OECD approach by introducing a distinction between the industrial domains of the space economy and the fundamental drivers that enable their expansion [40,41] (Fig. 3).

Defence has been a vital component in the formation of the space economy, with investments in military purposes catalysing significant technological advancements [18,39,49]. The military applications of space technologies, ranging from satellite reconnaissance to secure communication systems, are crucial for modern defence strategies and national security. Early developments, such as the NAVSTAR programme, laid the foundation for what would later become the Global Positioning System (GPS), demonstrating the strategic importance of satellite-based navigation. Similarly, MILSTAR, a secure satellite communications system, exemplifies the role of defence-driven innovation in advancing global communication infrastructure. This focus has not only enhanced military capabilities but also spurred innovations in various space technologies, which extend beyond defence to impact other sectors of the space economy [48,50,51]. This crossover has created new market opportunities and business models, showing the interconnectedness between defence and commercial space activities. As a result, the defence sector’s role in the space economy has extended beyond national security, stimulating broader technological innovation and contributing to the sector’s growth.

Positioning, navigation, and timing (PNT) services have emerged as a cornerstone in the growth of the space economy, being essential for a broad range of applications, including navigation, logistics, telecommunications, and disaster management. The development and diversification of systems such as GPS, Beidou, Galileo, and the Global Navigation Satellite System (GLONASS) exemplify the segment’s significant advancements and investments, with applications extending from tracking for precision weaponry to timestamping for financial transactions and guidance for agricultural practices [40,48,49]. Governmental support has been pivotal in advancing PNT technologies, with governments recognising their strategic value in areas such as national security and environmental management [39]. This has led to the integration of PNT with satellite communication technologies, revolutionising numerous sectors and significantly contributing to the global space economy [33,50]. While initially focused on defence applications, PNT services have expanded their reach, especially through mobile applications, as seen in major civilian infrastructure initiatives

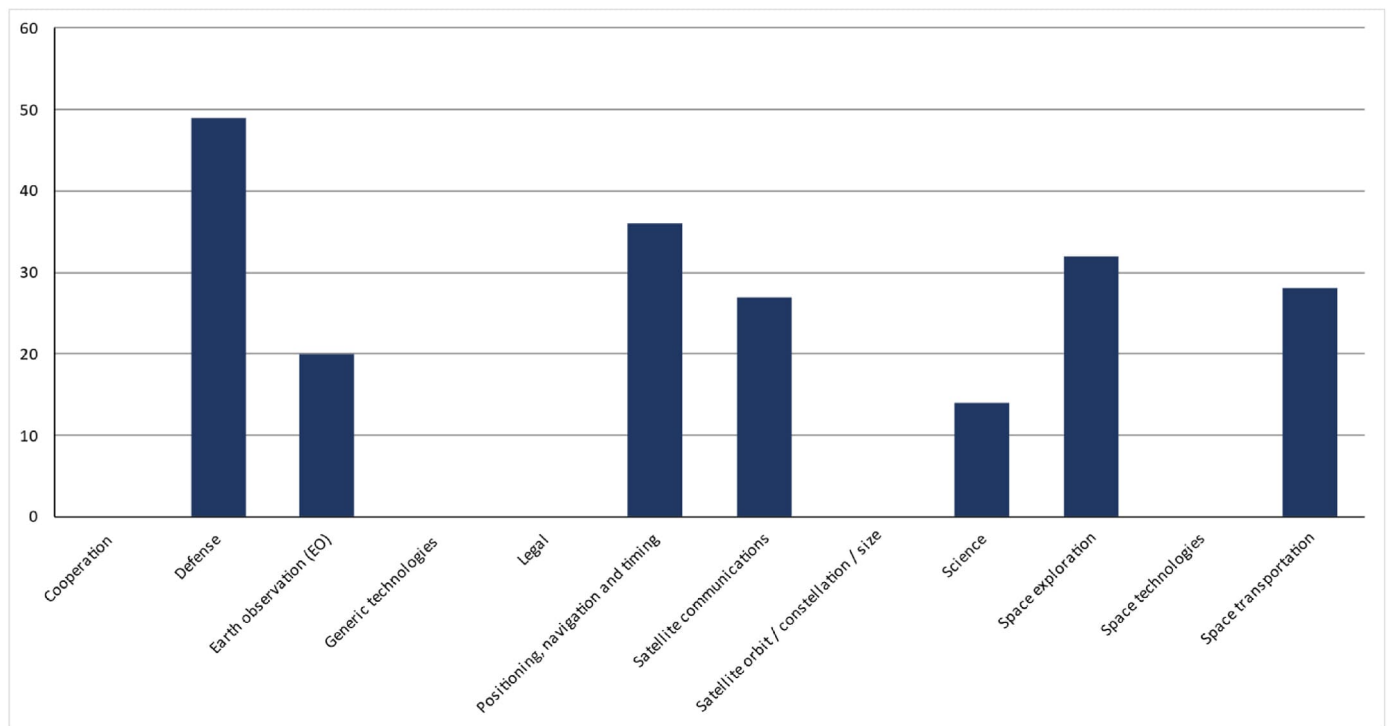


Fig. 3. Attribution of growth determinants explaining past growth by space economy segment – number of articles mentioning the identified growth determinants in relation to specific segment.

such as the European Galileo system, demonstrating the broadening scope of and high demand for applications. Now indispensable in industries from transportation to finance, PNT services have achieved foundational status in the space economy, having evolved from their defence-oriented beginnings into versatile, cross-sectoral applications [16,42].

Space exploration and space transportation have also had a crucial influence on the formation of the space economy. These technologies, which involve launching satellites into orbit and enabling human space travel, have revolutionised various sectors, including defence, finance, agriculture, and maritime traffic management, becoming an integral part of our global, wireless, and mobile information infrastructure [18, 52]. Simultaneously, these advancements in space transportation systems have played a vital role in broadening access to space, thereby fostering the expansion of the space economy.

The growth of the space economy has been significantly propelled by advancements in satellite communication technologies, which are essential for applications from military operations to global information transfer. Government support has played a critical role, particularly in defence and national security, regarding which satellite communications provide strategic advantages in intelligence and situational awareness [18,39,48]. Additionally, the development of these technologies contributes to national prestige and international influence while simultaneously fostering innovation in various scientific fields [1,16,42, 53].

Earth observation (EO) technologies have become closely linked to the growth of the space economy, revolutionising data gathering about Earth's systems through satellites. These advancements have led to new applications in scientific research and commercial ventures and have been supported by significant governmental backing because of their strategic value in terms of defence and environmental monitoring [39, 48–50]. The strategic importance of EO technologies in defence has also driven substantial military investments, enhancing global situational awareness [40,42]. Furthermore, the development of EO technologies contributes to national prestige and scientific progress, underscoring their key role in advancing the space economy [1,16,53].

The expansion of the space economy has also largely been driven by advancements in scientific research, particularly that devoted to the earth sciences and understanding the universe overall. Governmental support has been vital and has focused on the strategic importance of space science in areas such as defence and environmental management [34,39]. This focus, coupled with military investments in space-based research on intelligence and situational awareness, has propelled economic growth in the sector [16,40]. Moreover, the prestige and technological advancements associated with space exploration have furthered governmental influence and innovation in various scientific fields [1,16,53]. The continued evolution of the space economy is thus shaped by these scientific advancements, which are supported by both governmental and private-sector initiatives.

The expansion of the space economy is the result of a complex interplay between technological innovation, government support, and strategic defence priorities. Governmental involvement has been pivotal, providing financial, infrastructural, and moral backing, which has fuelled development and ensured the long-term viability of the space economy. Initially driven by the defence sector's need for advanced situational awareness, global communication, and intelligence, the space economy evolved as advancements in one area spurred growth in others. Significant technological advancements, such as reusable rockets and miniaturised satellites, have drastically reduced the cost of space activities, driving substantial investments. The increasing demand for satellite-based services, combined with government initiatives and funding for defence and scientific research, drove the creation of the initial infrastructure for commercial space activities. Thus, the growth of the space economy has been driven by a synergy between technological advancements, reduced operational costs, and robust government support, highlighting the critical role of both the governmental and private

sectors in its evolution.

5. The overarching role of digitalisation in the space economy

Digitalisation has emerged as a transformative force reshaping the global economy, with profound implications for the space sector. As a key enabler of the transition from phase 2 (government-driven commercialisation) to phase 3 (market-driven expansion) of the space economy, digitalisation has facilitated new business models, enhanced service scalability, and lowered entry barriers for private actors [12,42]. The increasing integration of digital platforms, data processing, artificial intelligence (AI), cloud computing, and big data analytics into space-related activities has accelerated the commercialisation of space applications and expanded their economic impact across various industries [52].

The widespread adoption of digital connectivity and cloud-based infrastructures has enhanced the efficiency, accessibility, and automation of space services [8,52]. Satellite infrastructure now functions as a critical component of the digital economy, generating vast amounts of data that can be rapidly processed and monetised through cloud computing and AI-driven analytics [25]. This development has enabled the rise of data-as-a-service (DaaS) and platform-based business models, allowing space-derived information to be seamlessly integrated into diverse sectors such as agriculture, logistics, finance, and urban planning [49].

The digital revolution has also played a pivotal role in reducing operational costs and improving market accessibility for emerging space companies. The proliferation of software-defined satellites, AI-powered mission planning, and real-time geospatial analytics has allowed private players to optimise satellite utilisation, enhance service precision, and introduce scalable solutions tailored to commercial demands [54,55]. Furthermore, edge computing capabilities on satellites are minimising the need for extensive ground processing, enabling faster decision making and more autonomous satellite operations [56].

Beyond data-driven applications, digitalisation has also facilitated collaborative innovation and global market integration. The convergence of machine learning algorithms, blockchain technology, and Internet of Things (IoT) networks with space-based infrastructure has unlocked new commercial frontiers, including real-time asset tracking, automated EO analytics, and space-based financial instruments [17,57].

By accelerating the transition towards a fully digital, interconnected space economy, these advancements have significantly lowered the barriers to entry for non-traditional space actors, fostering the growth of the New Space industry [3,57]. The next phase of space economy expansion will likely be shaped by the increasing reliance on AI-driven decision making, enhanced cybersecurity frameworks, and the integration of terrestrial and space-based digital ecosystems [49,58].

This evolution underscores the necessity of incorporating digitalisation as a core determinant of space economy growth rather than as a secondary technological advancement. As the industry continues to expand, future policies and investments must ensure that regulatory frameworks, cybersecurity standards, and digital infrastructure support the sustainable integration of digital technologies within the space economy [4,42].

6. Present status of the space economy

The space economy is undergoing significant growth, diversification, and commercialisation. It encompasses a wide range of activities, from space manufacturing and satellite communications to asteroid mining and prospective future colonisation efforts [1,59]. Governmental roles remain crucial in shaping this economy through regulatory guidance and the stimulation of expansion in various domains, including consumer applications and entertainment [29,59,60]. In today's interconnected world, the space sector—hosting over 12,000 satellites from more than 80 countries—is integral to numerous industries, providing a

broad array of global services [61]. The resurgence of human space travel for tourism, scientific experimentation, and satellite deployment is further propelling the industry's growth.

While private enterprise has gained substantial traction in the space sector, global state powers still dominate, with only a few key actors truly shaping the industry's future [1,31]. As the questions emerging in the sector are complex and multidisciplinary, scholars from fields including economics, industrial organisation, and public finance play central roles in understanding and shaping the development of the space economy [27,31,42,62]. As power balances in the space domain evolve, the implementation of New Space concepts can alter existing hierarchies—particularly in market economies with competitive private offerings. However, nation-states will almost certainly strive to preserve their positions at the top of the space power hierarchy, leveraging public space agencies and regulation to maintain their advantages. Novel funding schemes and collaborations with the private sector are crucial for harnessing the economic potential of space [16,31].

Valued at over \$350 billion annually, satellite communications are a cornerstone of the expanding space economy and are experiencing transformative technological advancements [27]. These services, vital for global connectivity, play diverse roles—from commercial telecommunications to defence operations—highlighting their versatility [39]. The adoption of novel technologies, including 5G and 6G in satellite systems, signifies a major leap forward, ushering in an era of lower communication latency and improved global internet coverage [54, 63–65]. Furthermore, the rise of extensive low Earth orbit (LEO) satellite networks, exemplified by SpaceX's Starlink, is revolutionising the field by enhancing deployment scales and accessibility. The societal and economic impact of satellite communications is profound; however, challenges such as managing space debris and ensuring secure connectivity are critical considerations for sustainable advancement in this domain [54,64].

Positioning, navigation, and timing services are now indispensable across various sectors, including aviation, maritime transport, finance, and military operations [2,40]. Modern activities increasingly rely on PNT services, and defence-related investments in this segment remain significant [16]. However, the expansion of PNT services to new applications presents challenges such as orbital congestion and the need for enhanced space traffic management and cybersecurity measures [40, 50].

Earth orbit technologies—particularly EO satellites—have expanded from military reconnaissance to vital tools for environmental monitoring [40,50]. Innovations in satellites and sensor technology, aided by cost reductions, are addressing today's environmental challenges. The European Commission's Copernicus programme, in partnership with the European Space Agency (ESA), demonstrates EO's global impact by fostering businesses and new services [1,3]. Trends in EO, especially the deployment of constellations in LEO, now offer continuous imaging and video analytics, expanding EO's relevance to sectors such as finance. The evolving role of EO promises new opportunities in both the public and private sectors [3,16].

Space transportation, which is crucial for expanding the space economy, is shaped by factors such as cost, launch frequency, and technological risks [3,16,31,66]. Innovations by new players—most prominently SpaceX's development of reusable rockets—have revolutionised the launch sector, enabling it to transition from exclusive military dominance to widespread commercial and civil use, including the routine deployment of small satellites [3,21,31,67]. This shift is also evident in major spacefaring nations such as the US and China, where government and private ventures are increasingly intertwined [3,68]. The rise in commercial launch services and the nascent space tourism industry exemplify the sector's growth [69–71].

Space exploration, a significant technological catalyst since 1957, has transitioned from being state driven to involving commercial and private competitors [72–74]. The Cold War era's US–Soviet rivalry accelerated human spaceflight and captivated global attention, setting

the stage for today's primarily peaceful space utilisation and efforts at conflict prevention [75]. Space exploration continues to drive technological and industrial advancements; for instance, proposed lunar bases serve as testbeds for innovations in energy and robotics [52,60]. The prospect of extraterrestrial resource extraction (e.g. mining asteroids or the Moon) is gaining momentum, attracting both private companies and government interest [52,75].

Science—particularly human-spaceflight-related science—plays an integral role in the space economy by fostering innovation and creating markets for technologies with broad commercial applications. Environmental challenges and climate change have hastened the development of sophisticated satellites and sensors that are critical for meteorological and climate data collection [3]. The proliferation of CubeSats (compact 10 cm-class satellites), pursued by academic and industrial actors, has improved global connectivity and lowered the cost of space exploration, benefitting fields such as astronomy and planetary science [76]. Notably, advances in CubeSat antenna technology have enhanced communication capabilities, which are vital for both research and commercial uses [77]. Government support remains essential for space science initiatives, contributing to advanced space technology and national defence [78].

The growing interest in space technologies has significantly deepened our understanding of the cosmos and has delivered numerous benefits to humanity. The International Space Station (ISS) exemplifies these advancements: it serves as a hub for cutting-edge research and technology demonstration while also benefitting areas such as human health and global education, thereby contributing to the space economy [20]. Space research has improved climate models and recycling processes on Earth. However, the rapid expansion of space activities presents serious challenges, particularly in terms of space sustainability. A major issue is orbital debris: an estimated 300,000 fragments pose collision risks to satellites [20]. Addressing this issue requires global cooperation and innovative approaches, including regulatory measures and incentives for debris mitigation [79].

The integration of generic and commercial off-the-shelf (COTS) technologies into satellite production has revolutionised the space sector by enhancing capabilities, reducing costs, and driving innovation [1,3]. The rise of CubeSats, supported by COTS components, along with specialised suppliers enabling bulk production, exemplifies the shift towards cost efficiency [1,52]. Vertical integration—merging service operations with manufacturing—has streamlined supply chains by eliminating complex contracting [1]. Additionally, advanced methods such as additive manufacturing (3D printing) are pushing space capabilities forward [1,52]. However, reliance on generic technologies raises cybersecurity and quality concerns, necessitating robust protection measures [52].

The space economy is rapidly maturing while continuing to experience significant growth and diversification. Key sectors—such as satellite communications, PNT services, EO technologies, space transportation, and space science—are at the forefront, increasingly adopting generic technologies to drive down costs and enhance service availability. The current state of the space economy is characterised by a dynamic environment, rapid development, and growth driven largely by commercial activities and motives. The integration of advanced technologies and the entry of private companies have revolutionised these segments, making space more accessible and economically viable. Innovations in satellite technology, the development of reusable launch vehicles, and competitive markets encouraging cost reduction and efficiency have facilitated the shift from government-led initiatives to commercial enterprises. The democratisation of space—with contributions from pioneers such as SpaceX—is creating new opportunities. However, reliance on a limited number of innovative players concentrated in specific regions carries a risk of systemic bottlenecks or failures if these actors' capabilities are not realised or diversified. Collaboration between governments, the private sector, and academia is essential to navigate these challenges and harness the full potential of the space

economy.

6.1. Factors slowing down the development of the space economy

While the space economy has experienced rapid and continuous growth in recent decades, we identified several major challenges that hinder its expansion. Three primary factors and two secondary ones emerged as potential impediments based on our review.

- **Complexity and cost of space technologies** – The advanced technologies driving the space economy also present significant barriers. Their complexity, the necessity for global cooperation, and the inherent risks of space activities can slow development. High costs and large risks associated with activities such as human spaceflight and deep-space exploration can impede progress if not managed [16].
- **Inadequate and ambiguous legal frameworks** – Gaps and uncertainties in space law and regulation create an environment of uncertainty that can affect business investments and slow industry development. The UNOOSA has outlined four pillars for future space activities—economy, society, accessibility, and diplomacy—as guiding principles, but effectively navigating the complex legal landscape remains vital for continued growth [3].
- **Integration of generic technologies and cybersecurity** – The increasing use of generic and COTS technologies introduces variability in availability and risk. Lower launch costs, increased capital, and improved capabilities of small satellites broaden access to space but come with challenges, such as cybersecurity threats, that complicate the adoption of innovations from outside the traditional space sector [3].
- **Insufficient scientific advancement** – Slower-than-anticipated progress in certain areas of space science and technology can subtly hinder growth. Complex scientific challenges and the need for international cooperation in projects, such as large space telescopes or deep-space probes, create difficulties [80]. A lack of breakthroughs or sustained investment in fundamental space science might limit long-term innovation.
- **Constraints in space transportation development** – Despite recent improvements, high launch costs and significant risks remain barriers. The interplay between factors such as cost-effective satellite delivery and launch frequency highlights the importance of affordable, reliable space transportation. New competitors are innovating with SmallSat launchers and other solutions [3,16,81], but overcoming the remaining cost and risk hurdles is essential for further growth.

Space technologies thus serve a dual role in the space economy—driving growth but also presenting potential barriers. Their complexity and the need for global cooperation shape the pace of development. The quest for innovative technologies to overcome these challenges is critical, yet high costs and large risks can impede progress [3,16]. International cooperation, while vital for space exploration and large projects, also introduces complexities that can slow advancement [3].

The legal and regulatory framework plays a crucial role in shaping the space economy. Inadequacies and ambiguities in current space law create uncertainty, affecting business investment and slowing industry development [3]. The United Nations and other bodies stress the importance of globally consistent regulations and norms. Navigating this legal landscape effectively is vital for the continuous growth and expansion of the space economy.

Progress in the space economy is closely linked to innovation in generic technologies and components that enhance space capabilities. While access to space is broadening due to lower launch costs, increased capital, and improved small-satellite capabilities, the varying availability of and risks associated with these generic technologies pose substantial challenges to sustainable growth [3]. Additionally, threats

such as cyberattacks underscore the need for secure technologies, complicating the incorporation of innovations from outside the traditional space sector.

A lack of scientific advancement and slower development in space transportation also subtly hinder the space economy's growth. Complexities in space science and the need for international collaboration can create difficulties in pushing the boundaries of knowledge [80]. Similarly, high costs and significant risks in space transportation mirror barriers in other sectors and continue to constrain growth [82]. A focus on cost efficiency and risk reduction has led new competitors to innovate in launch systems and satellite development [3,16,81], indicating that solutions to these interconnected challenges are actively being pursued.

In conclusion, the growth of the space economy is intricately linked to various factors, each presenting unique challenges and opportunities. Despite tremendous advancements, the space economy still faces barriers such as high capital requirements, regulatory hurdles, and technical risks. The complexity of space technology, long development cycles, and substantial upfront investments pose challenges for both new entrants and established companies. Regulatory issues—including the need for international coordination and compliance with diverse laws—further complicate the landscape. While space technologies and innovations offer significant growth opportunities, their complexity and cost, along with legal challenges, can impede progress if not properly managed [3,74]. Scientific advancements and improvements in space transportation capabilities are crucial for industry growth, yet they face hurdles such as the need for international collaboration and high exploration costs [80,82]. Overcoming these challenges will require coordinated efforts by policymakers, businesses, scientists, and other stakeholders to harmonise their actions, surmount barriers, and fully realise the potential of space exploration and utilisation [3,16].

6.2. Requirements for the space economy to develop

A myriad of determinants essential for the space economy's future also shape its growth trajectory. Fig. 4 presents a structured framework differentiating between space-related economic activities and the underlying factors that influence their growth. While activities such as satellite communications, EO, and space transportation define key industrial segments of the space economy, their expansion is contingent upon determinants of growth such as public and private investment, regulatory frameworks, and technological advancements. Conversely, barriers such as high costs, regulatory constraints, and limited infrastructure development can inhibit market growth [3,74]. This distinction allows for a more precise understanding of how structural factors shape the evolution of space-based industries.

The evolution of the space economy is driven by technological innovation, government policies, and private-sector investment. As the field matures, diverse investors—including venture capitalists and research institutions—are increasingly funding space-related projects. This influx of capital is advancing technologies such as reusable rockets, miniaturised satellites, and advanced propulsion, reducing the costs of access to space and creating new commercial and scientific opportunities [3,74]. The space economy also offers an interdisciplinary platform for scholars: engineers and scientists develop new materials and propulsion technologies, economists and policy analysts assess economic impacts and regulatory needs, and social scientists explore societal implications such as space tourism [3,16]. Integrating these diverse insights can shape the space economy to maximise benefits and address challenges.

The space economy's growth is propelled by the adoption of generic technologies to enhance space exploration and commerce. This growth hinges on utilising high-quality components supported by innovative resource optimisation strategies [74]. Efficiency gains are achieved through disruptive innovations and streamlined supply chains focused on mass production and system integration [3]. Trends towards standardisation and miniaturisation are critical, enabling cost-effective

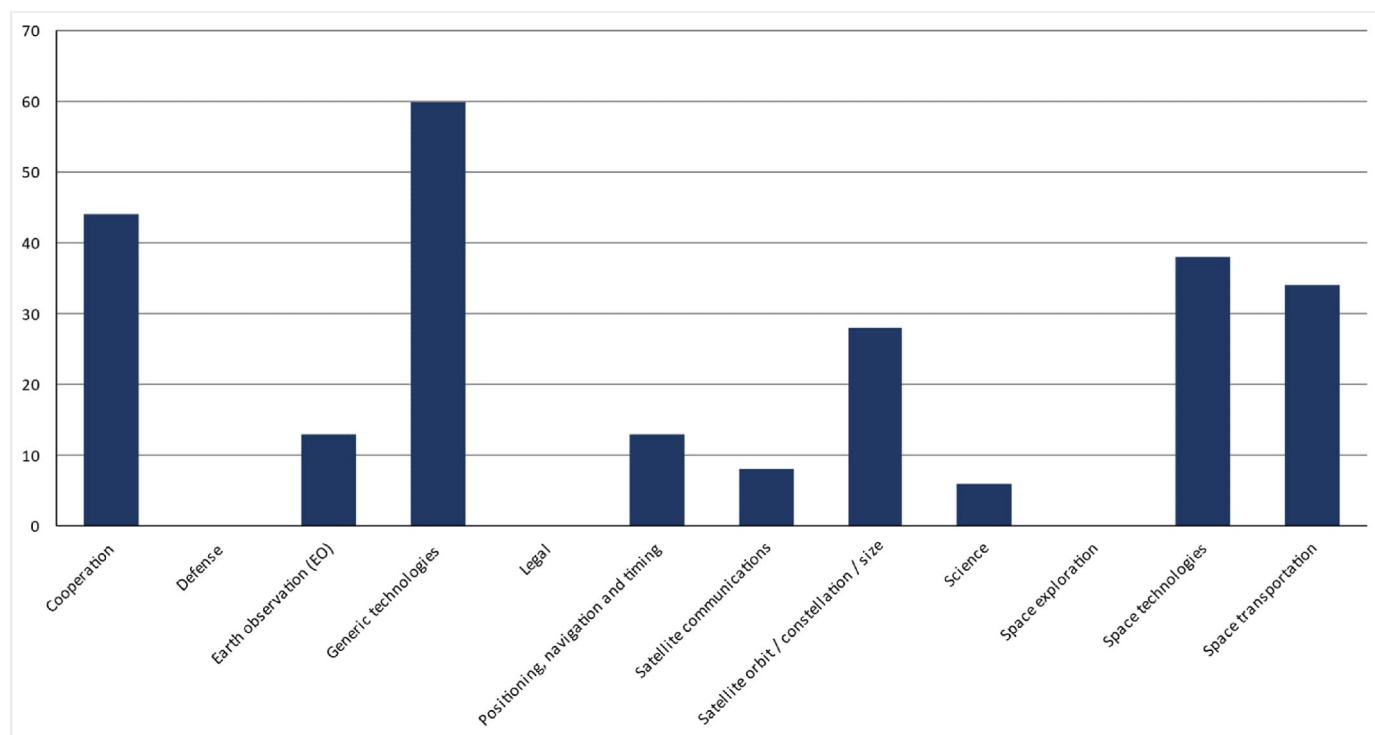


Fig. 4. Development requirements per space economy segment – number of articles mentioning development requirements for a specific segment as the basis for a broader expansion of the New Space economy.

satellite manufacturing. The industry's commitment to excellence is reflected in its shift to design-centric production and advanced data analytics. Innovations such as augmented reality, 3D printing, AI, and the IoT are pivotal in the evolution of space operations, especially in integration and automation [3,16,83].

Disruptive innovations across products, processes, and services are initiating a new phase of space exploration and commercialisation. The trend towards standardisation, coupled with miniaturisation, is revolutionising satellite production, making it both cost effective and efficient [3,16]. Collaboration is key, as demonstrated by organisations such as UNOOSA that emphasise the global benefits of space technologies, especially for developing nations [3]. Moreover, the commercialisation of space transportation—driven by leading industry players and government support—is democratising space access and marking a pivotal shift in the industry [3,16]. These developments collectively provide an optimistic view of the space economy's future trajectory, underscoring its potential and the vast opportunities it offers.

International cooperation involving both the public and private sectors is becoming increasingly vital for space commerce. The United Nations Office for Outer Space Affairs emphasises the need to make space technologies accessible to all, especially developing countries, highlighting space's role in the economy, society, and diplomacy [3]. Such global collaboration is essential for advancing technology and improving economic efficiency. Partnerships between governments, industry, and academia are crucial for sharing resources, knowledge, and expertise, leading to effective public-private ventures. These collaborations range from private companies utilising government infrastructure to joint ventures blending state and private investments. Despite the benefits, challenges such as the lack of a comprehensive legal framework and political or economic risks pose barriers to the full potential of cooperative space initiatives [3,16].

Space technologies play a crucial role in shaping modern society—for example, by advancing satellite communications and integrating satellites with terrestrial networks [54]. These improvements enrich various domains, including civil aviation, climate monitoring,

and space exploration. They address immediate societal needs (such as remote education and telemedicine) while also contributing to long-term objectives such as sustainable space operations [52]. The development of space transportation is fundamental to the growing space economy [84]. Initially limited to highly trained astronauts, spaceflight is becoming more accessible thanks to companies such as SpaceX, Virgin Galactic, and Blue Origin [84]. This democratisation of space access is supported by agencies such as NASA, which endorses commercial crew and cargo flights to the ISS [57,85]. The commercialisation of space transportation, including space tourism and lunar missions, relies on technological advances and new business models that reduce costs for both satellites and launch vehicles [22,49,67,84]. The deployment of large satellite constellations and the potential for rocket-based point-to-point travel on Earth are transforming space operations [85]. However, as the sector grows, addressing issues such as space debris will be vital to maintaining space as a sustainable resource [55,84,86].

The space economy is increasingly influenced by the strategic utilisation of LEO, the deployment of new satellite constellations, and the growing demand for small satellites. LEO's low latency is ideal for real-time communications and EO, enhancing global connectivity and offering cost-effective solutions [16,39]. Satellite constellations in LEO are set to transform global communication networks and continuous EO, providing near-real-time coverage [36,76,87]. The trend towards miniaturisation has popularised smaller satellites such as CubeSats, which are more affordable and efficient—appealing particularly to start-ups and New Space ventures due to their ability to be mass produced and deployed in large numbers [3,88]. The future of the space economy is closely linked to the effective application of these technologies, which are crucial for sustainable growth and indicative of the sector's direction.

In addition to the primary growth factors, traditional space economy segments such as satellite communications, EO, PNT, and science continue to play significant roles in the space economy's development. Although these fields did not emerge in our literature review as drivers

of growth per se, they benefit from and support the overall growth factors through co-innovation and synergies. For the space economy to continue developing, several requirements must be met. These include continuous technological advancement, increased private and public investment, and the development of standardised measurement frameworks. International cooperation and collaboration are also essential in addressing regulatory and legal challenges, ensuring that space activities are conducted responsibly and sustainably [3,16]. Developing robust economic models to assess the return on investments in space exploration and related activities is crucial for informed decision making and fostering future growth [3,74].

7. The shift towards commercialisation and private-sector involvement in the space economy

Fig. 5 The shift towards commercialisation and greater private-sector involvement in the New Space economy is clear. The space economy is projected to reach a total valuation of \$2.7 trillion by 2045, indicating not only economic but also political significance for numerous nations, as the commercial space sector is expected to grow exponentially [59, 75,89]. The rapid expansion of the space industry is propelled by the emergence of global internet constellations, currently its fastest-growing segment. This development exemplifies the technological advancements that are ushering the space economy into unprecedented realms of possibility [2]. Overall, the space economy will not become any simpler in the future—each of its segments will influence its growth and trajectory. Separating these sectors from each other is challenging, but focusing on the underlying growth determinants provides clarity. It is crucial to differentiate between economic activities (e.g. satellite communications, EO, space transportation) and the structural determinants that shape their growth.

While topics such as ‘legal’ and ‘cooperation’ may be categorised separately in some analyses, they should not be interpreted as stand-alone economic activities. Instead, these factors serve as cross-cutting determinants of growth that influence multiple sectors of the space

economy. For instance, space regulations impact defence, PNT services, satellite communications, and scientific research alike, and cooperation shapes the development of commercial space markets, international missions, and space governance.

To improve conceptual clarity, our analysis focuses on the true determinants of space economy growth, aligning with the eight key factors identified in conclusion: technological innovation, international collaboration, economic investment, regulatory frameworks, scientific research, market demand, infrastructure development, and geopolitical strategies.

Advancements in space technology have significantly reduced costs and expanded the scope of viable space activities [6]. The development of reusable launch vehicles, for example, has dramatically cut launch expenses and increased launch frequency, allowing far greater access to space [34]. Small satellites and software-defined spacecraft have introduced greater flexibility, enabling commercial actors to scale operations efficiently [4]. Emerging capabilities such as in-space manufacturing, robotic assembly, and AI-assisted mission operations are expected to further expand economic opportunities [12]. These innovations not only enhance existing applications—such as EO and satellite communications—but also enable entirely new sectors, including space resource extraction and interplanetary logistics [90].

Digitalisation plays a transformative role in the space economy by integrating AI, cloud computing, and big data analytics into space-based services [15]. The proliferation of digital platforms has enabled real-time geospatial intelligence, automated satellite operations, and predictive maintenance for spacecraft [1]. The expansion of cloud-based satellite data analytics has lowered barriers to entry, allowing new players to provide data-driven solutions across various industries, including agriculture, finance, and logistics [4].

Additionally, the convergence of edge computing with satellite networks has enhanced data processing capabilities, reducing latency and improving service efficiency [71]. As digital infrastructure extends further into space, developments such as blockchains and decentralised ledgers are emerging to ensure secure data transactions, particularly in

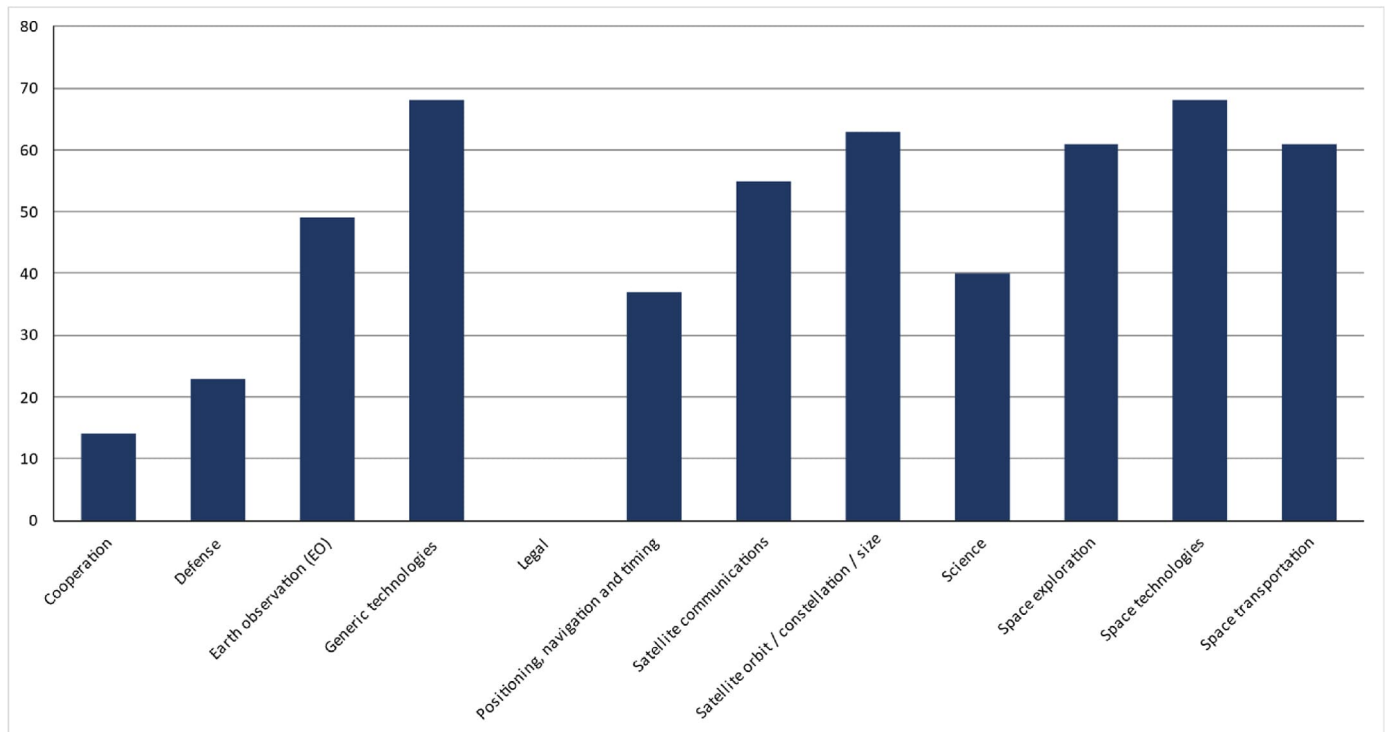


Fig. 5. Attribution of growth determinants' future potential per space economy segment – number of articles mentioning potential for the identified growth determinants in relation to a specific segment.

satellite asset management and space commerce [12].

The growth of the space economy is strongly linked to investment trends, with both public- and private-sector funding playing crucial roles [4]. Historically, space activities were largely government funded, but there has been an increasing influx of private capital from venture capital firms, institutional investors, and sovereign wealth funds [90].

Public–private partnerships have become essential in supporting large-scale projects, such as global satellite constellations, lunar exploration missions, and in-orbit servicing industries [1]. Market demand for space-based services (including broadband connectivity and precision navigation) continues to drive investment in downstream applications [15]. Future developments such as space-based solar power and deep-space resource extraction will depend on sustained financial backing and evolving business models [59].

Regulatory frameworks play a crucial role in shaping the commercial space sector [4]. Governments and international bodies are responsible for establishing laws and policies governing spectrum allocation, space traffic management, and commercial space activities [1].

As private actors take on a larger role, regulators must strike a balance between encouraging innovation and ensuring safety, sustainability, and fair competition [15]. The regulatory landscape must also address emerging challenges such as space debris mitigation, satellite cybersecurity, and intellectual property rights for space-based manufacturing [71]. Standardisation efforts led by organisations such as the UNOOSA and the International Telecommunication Union (ITU) are vital in fostering global cooperation and stability in space activities [12].

The expansion of space-related infrastructure is critical for the sustainable growth of the space economy [4]. The increasing number of launch facilities, ground stations, and inter-satellite communication networks has enhanced global connectivity and accessibility [90]. Mega-constellations developed by companies such as Starlink and OneWeb have transformed satellite-based internet services, although they also introduce new challenges such as orbital congestion and sustainability [1]. Meanwhile, modular spacecraft design, additive manufacturing, and COTS components are reducing costs and increasing production scalability [71]. The ability to manufacture key space components in orbit will further reduce reliance on Earth-based logistics and open new frontiers for industrialisation in space [12].

National governments view space as a strategic economic and security asset, leading to increased investment in defence-related space programmes and competition for leadership in space-based markets [4]. Government-backed initiatives such as the US Artemis Accords, China's Belt and Road Space Information Corridor, and Europe's Secure Connectivity Programme are shaping the landscape of international space policy [1]. As the commercial space sector continues to expand, global competition for market dominance will intensify [15]. However, geopolitical tensions must be managed through strategic alliances, cooperative agreements, and resource governance frameworks to ensure that the benefits of space exploration and commercialisation are equitably distributed [71].

International partnerships have played a significant role in shaping the space economy, from cooperative research projects to multinational exploration programmes [4]. The ISS is a prime example of successful collaboration between space agencies of multiple nations [1]. Future projects—such as lunar bases and deep-space missions—will require continued cooperation between governments, commercial enterprises, and international organisations [15]. Establishing global norms for space governance and fostering sustainable economic practices will be essential to ensuring long-term growth in the space economy [12].

8. Conclusion

Our research highlights that the expansion of the space economy is not solely the result of sectoral growth but is fundamentally shaped by underlying economic, technological, and policy determinants. While

traditional classifications (such as those used by the OECD) segment the space economy into industries such as satellite communications, EO, space transportation, and defence, our analysis demonstrates that these sectors have emerged because of structural, linked determinants of growth rather than acting as independent drivers of economic development.

Through a systematic literature review, we identified eight key determinants that influence the development of space-related industries: technological innovation, international collaboration, economic investment, regulatory frameworks, scientific research, market demand, infrastructure development, and geopolitical strategies. These factors collectively shape the pace and direction of the space economy by influencing capital allocation, regulatory conditions, technological feasibility, and strategic priorities. Among these, digitalisation has emerged as a fundamental enabler that accelerates commercialisation, enhances data-driven decision making, and expands market accessibility.

The integration of AI, cloud computing, and big data analytics into satellite infrastructures has transformed how space-based services are delivered and utilised across multiple industries. Cloud-based satellite data analytics, automated Earth observation processing, and AI-driven mission planning have significantly reduced operational costs and increased service scalability. As a result, digitalisation has lowered barriers to entry, enabling a more competitive and diverse space economy. Furthermore, the growing convergence between terrestrial and space-based digital infrastructures is unlocking new commercial opportunities, reinforcing the role of space as a key enabler of the broader digital economy.

Rather than treating economic growth in the space sector as a linear expansion of predefined industrial categories, this study emphasises the dynamic interaction between enabling factors and industrial outcomes. For example, while satellite communication has grown into a dominant sector, its expansion has been contingent on advancements in telecommunications infrastructure, launch services, deregulation, digital networking capabilities, and sustained public–private investments. Similarly, the growth of space transportation has been driven by cost reductions in launch systems, reusable rocket technology, and policy support for commercial spaceflight, rather than being an inherent enabler of the space economy itself.

Furthermore, the increasing role of New Space actors and private-sector investments has fundamentally altered the structure of the space economy, shifting it from a government-driven model to a market-oriented ecosystem. The rise of venture-backed firms, digital platform-based services, and scalable business models has enhanced competition and innovation across space-based industries. However, this shift has also introduced new challenges, including regulatory adaptation, digital security risks, sustainability concerns, and geopolitical competition, which will shape the trajectory of the space economy in the coming decades.

To provide a more accurate conceptual framework, future studies should focus on the determinants driving economic activity in space rather than relying solely on industrial classifications. Additionally, policymakers should prioritise investment mechanisms, regulatory stability, digital infrastructure, and technological advancements to ensure sustainable growth. As the space economy progresses, digitalisation will remain a key driver of innovation, market expansion, and industry transformation. By shifting the analytical approach from sectoral segmentation to economic enablers, this study offers a clearer understanding of how space-based industries evolve and what factors will define their future development.

CRedit authorship contribution statement

Mikko Punnala: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Santeri Punnala:** Writing – review & editing,

Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. Arto Ojala: Supervision, Methodology. Heidi Kuusniemi: Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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