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Putting a Price on Space: The Economic Value of Space-Based Communications and the Cost of Terrestrial Redundancy

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Abstract: The trajectory of space-based communications has evolved rapidly, from a state-monopolized strategic asset to a dynamic commercial marketplace, fundamentally altering the economics of global information exchange. We focus on the value of space-based communications infrastructure. We estimate the approximate cost of replacing space-based data flow infrastructure with land-based infrastructure. This includes an increased mix of land-based radio transmission systems and land and sub-ocean cables. There are other dimensions outside this assessment, including communications for navigation and linkages for remote areas. Nonetheless, the exercise provides a lower bound estimate of the capital costs needed to replace space-based communications capacity and so provides a rough benchmark for the replacement cost of space-based communications services. We estimate $450-$500 billion in initial global investment, followed by tens of billions in annual maintenance costs. Even then, such a network would still fail to cover deep-ocean and polar regions effectively.

Keywords: space-based communications, space economics, communications economics, new space

JEL codes: L63, L96, O33

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1. Introduction

In 1945 Arthur C. Clarke proposed a system of geosynchronous satellites for communications, while Isaac Asimov suggested space based solar power in 1941. While technology has changed tremendously since then (Clarke imagined manned communications space stations rather than Musk-type satellite constellations), satellites are indeed a key element in global communications, as well as land use management, navigation, and national security surveillance. The scope is expected to expand further with energy transmission from orbit, as well as possible resource extraction from extra-planetary sources. All of this means expansion of private sector activities in space, with an associated ecosystem supporting launch, equipment design and construction, and operation.

The trajectory of space-based communications has evolved rapidly from a state-monopolized strategic asset to a dynamic commercial marketplace, fundamentally altering the economics of global information flows. This transformation, spanning from the mid-20th century to the present, reflects a shift in the locus of innovation from public agencies to private entities, driven by the dual imperatives of technological capability and economic efficiency. This evolution is not merely technological but also deeply rooted in the changing political economy of orbital access and spectrum allocation. [1]

In this paper we evaluate the contribution of space to global economic activity, focusing narrowly on the communications dimension. We focus on the value of space-based communications infrastructure. We estimate the approximate cost of replacing space-based data flow infrastructure with land-based infrastructure. This includes an increased mix of land-based radio transmission systems and land and sub-ocean cables. There are other dimensions outside this assessment, including communications for navigation and linkages for remote areas. Nonetheless, the exercise provides a lower bound estimate of the capital costs needed to replace space-based communications capacity and so provides a rough benchmark for the replacement cost of space-based communications services.

2. Historical Context

2.1 Space-Based Communications

The commercial utilization of space for communications began as a derivative of Cold War geopolitical rivalry. At the start of the modern space era, capabilities for space-based activities were exclusively the domain of state actors. However, from this starting point the private sector's involvement was catalysed early on (Elbert 2008). On the American side, funded by AT&T and Bell Telephone Laboratories, the launch of Telstar 1 in 1962 marked the seminal moment of privately sponsored space activity. It demonstrated the potential for relaying television and telephone signals across the Atlantic. This proof of concept further catalysed the creation of the Communications Satellite Corporation (COMSAT) via the Communications Satellite Act of 1962. This was a clear legislative signal from the United States Congress that they recognized the immense commercial potential inherent in orbital infrastructure.

The deployment of Intelsat I (Early Bird) in 1965 established the commercial viability of geosynchronous orbit (GEO) for continuous transoceanic connectivity. This GEO placement of communications satellites fundamentally altered the cost structure for international

[1] LEO satellites like Starlink from SpaceX also allow the bypassing of government control. While a government may set rules on how it is supposed to work, almost anyone can pack all they need to access Starlink into a small package and carry it where they want. In Iran, for example, recent unrest led to the government cutting off the Internet. However, they had no way to 'turn off' Starlink, so that it has still worked. Earlier examples include Eastern European access from behind the Iron Curtain to Western entertainment.

telecommunications. It radically reduced the cost per telephone circuit for intercontinental communications from approximately $100,000 in the mid-1960s to a few thousand dollars within two decades. (See Elbert 2008; Kodheli et al 2020). This early commercial era was characterized by consortium models (primarily INTELSAT) where risk and capital were pooled by state-backed entities to build global networks. However, the public-private model of state-sanctioned monopoly entities began to fracture by the 1980s. The U.S. deregulated the launch industry in 1984 with the Commercial Space Launch Act. This ended the NASA monopoly on payload deployment, allowing private launch service providers to emerge. This in turn fostered the beginning of a competitive private market for orbital insertion.[4.] This development continues today.

The turn of the millennium also saw the emergence of the "New Space" (NS) paradigm. NS is characterized by venture-backed firms targeting access to Low Earth Orbit (LEO). In contrast with the higher cost of earlier GEO satellites from the legacy era, this new phase has emphasized large scale constellations of lower cost satellite to both reduce latency and to increase capacity. The best-known example is SpaceX's Starlink. Starlink deployment began in 2019. The aim is a constellation of over 40,000 satellites providing low-latency broadband globally. Other constellations are planned as well to compete in the same space. Amazon's Project Kuiper is targeting is a large-scale constellation for broadband market, while state-backed initiatives include the European Union's IRIS system and China's Geespace. (See Kodheli et al 2020; Homssi et al 2022). Overall, the shift has been remarkable. By 2024 the commercial sector accounted for 78% of the $613 billion global space economy. This is a major change from government-dominated spending profiles of the early space age (Odom 2024). Privatisation has also shifted risk burdens from taxpayers to private equity. This has driven efficiencies unattainable under cost-plus government contracting models. It has also raised a new class of worries about anticompetitive behaviour and potential for cartelization of the commercial launch and space-based communications industries.

The expansion of commercial space-based communications has been accompanied by a growing economic ecosystem supporting the expansion, both vertically and horizontally. This in turn has led to complex value chains that extend far beyond the satellite operators themselves. Notably, the transition from expendable launch vehicles (ELVs) to reusable systems has fundamentally altered the marginal costs for orbital access. The cost to launch a kilogram of payload to LEO historically ranged from $10,000 to $20,000 using the Space Shuttle or legacy ELVs. This has plummeted in the NS era. Available commercial data indicate that reusable architectures like the Falcon 9 have reduced launch costs by a factor of nearly 27. Theoretical floors are approaching $100-$200 per kilogram are projected for the next generation of heavy-lift vehicles (Adinoyi et al 2022). This reduction in entry barriers has in turn driven catalysed a surge in upstream manufacturing. As a result, mass production techniques are now being applied to satellite buses, reducing unit costs from tens of millions to under $500,000 for LEO units. (See Punalla et al 2025; Odom 2024.) The cost developments underpin the economic feasibility of satellite constellations.

While sometimes overlooked in favour of orbital assets, the ground segment also constitutes an important and expanding element of the NS ecosystem. The proliferation of satellite constellations has required a parallel expansion of ground stations to support telemetry, tracking, and command (TT&C), as well as associated user terminals (Fortune 2026). Indeed, the largest segment of the satellite industry remains ground equipment. This is driven by the need for advanced electronically scanned aperture (ESA) antennas that track fast-moving LEO satellites (Daehnick et al 2020). This market segment is critical to the integration of space-based data flows with terrestrial networks. This technology provides a physical gateway between the orbital and fiber-optic domains.

While the private sector has become increasingly important, state actors remain pivotal in this ecosystem. They are not merely regulators but also anchor tenants. For example, the U.S. Department of Defense (DoD) leverages commercial capacity to augment military SATCOM, creating a hybrid ecosystem where commercial viability is often underwritten by national security contracts (CRS 2023). This symbiosis is evident in the Space Development Agency's proliferated warfighter space architecture, that relies heavily on commercial bus designs and launch services to achieve resilience. While representing only 9% of satellite volume, the defence sector captures 48% of the total market value. This highlights the premium placed on secure, resilient communications (Hitchens 2025).

Innovation has been a primary deflationary force in the sector, serving to lower cost. This has enabled a shift from scarcity of bandwidth to abundance. The transition from analogue, "bent-pipe" transponders to digital, regenerative payloads allows optimization of available spectrum. This "software-defined" capability means operators can dynamically beam capacity to high-demand areas (Newmann and Napier 2026; Al-Hraishawi et al 2022). In particular, the technology allows for flexible resource allocation and on-orbit reprogramming. Furthermore, the miniaturization of electronics has enabled the CubeSat and SmallSat revolution. Capabilities previously reserved for multi-ton buses can now be packaged into platforms weighing less than 500 kilograms (Al-Hraishawi et al 2022).

Inter-satellite links (ISLs), utilizing optical laser communications, represent a critical leap in network topology. By routing traffic between satellites in orbit rather than bouncing signals back to ground stations, ISLs reduce latency and dependency on geographically distributed ground infrastructure. This technical capability is crucial for bypassing geopolitical bottlenecks and data localization regimes, creating a true orbital mesh network. Additionally, the utilization of higher frequency bands—from C and Ku bands to Ka, Q, and V bands—has expanded available bandwidth, facilitating the high-throughput satellite (HTS) systems that now rival terrestrial DSL speeds in capacity (Newmann and Napier 2026; Al-Hraishawi et al 2022).

2.2 Terrestrial Communications

There has been a fundamental shift from copper-based telephony to fiber-optic digital highways. While satellites offer ubiquity, fiber offers far greater capacity. Since 1960, the fundamental physics of guided light transmission replaced electrical signals for long-haul transport, driven by the insatiable demand for bandwidth. As a result, concurrent with the space race, terrestrial communications have also undergone a revolution. The deployment of the first transatlantic fiber-optic cable, TAT-8, in 1988 marked the inflection point where terrestrial (sub-ocean) capacity began to decisively outpace satellite capacity for point-to-point trunking (Ferguson 2025). TAT-8 had the capacity to carry 40,000 telephone connections simultaneously, four times that of previous copper cables. This set the precedent for the exponential growth in terrestrial throughput (CRS 2022).

The privatization of telecommunications monopolies in the 1980s (e.g., British Telecom, AT&T divestitures) unleashed a wave of private investment in fiber infrastructure. This has led to a shift from strictly public investment to private and public-private initiatives in subsea infrastructure. Today, the global subsea network comprises over 550 active cables stretching 1.4 million kilometres. This network caries approximately 99% of intercontinental data traffic (Ferguson 2025). Its infrastructure underpins the global economy, facilitating over $10 trillion in financial transactions daily. (See Economy Insights 2025; Bueger & Liebetrau 2021).

Unlike early consortium models, where national carriers jointly funded cables to share risk, the modern era is dominated by content providers (hyperscalers). This includes Google, Meta, Amazon, and Microsoft, who have shifted from purchasing bandwidth to financing entire proprietary cable systems to ensure low-latency links between their data centers. By 2022, these content providers accounted for over two-thirds of all internet traffic and financed 100% of planned new cables on the Atlantic route. (See Kavanagh et al 2025; Burdette 2025). This vertical integration reflects the critical nature of terrestrial data pipes to the business models of the digital giants.

The deployment of fiber-to-the-home (FTTH) and 5G wireless networks on land has been driven by the need to support bandwidth-intensive applications at the edge. By 2025, the capital expenditure (CapEx) for 5G alone is projected to exceed $1.1 trillion globally. This reflects the immense scale of terrestrial network densification required to support modern digital economies (Tran 2026). Private sector activity has also expanded to include tower companies (TowerCos) and independent fiber providers, segregating the passive infrastructure from the active service layers to optimize capital efficiency (Green et al 2025).

The terrestrial ecosystem has evolved through advancements in optical networking, specifically Dense Wavelength Division Multiplexing (DWDM) and Space Division Multiplexing (SDM). DWDM allows multiple data streams to travel simultaneously over a single fiber using different light wavelengths, while SDM increases the number of fiber pairs within a cable. These technologies have enabled cables to scale from gigabit to petabit capacities without laying new glass, merely by upgrading the terminal equipment. For instance, modern cables like Google's Dunant can support 250 terabits per second (Tbps), a staggering increase from the mere gigabits of the 1990s (Green et al 2025.

While progress is impressive, the economics of terrestrial networks are constrained by both geography and by population density. The cost of deploying fiber is highly sensitive to terrain and urbanization. In the United States, costs can range from $20,000 per mile for aerial deployment to over $120,000 per mile for underground construction in complex environments. In heavily rural areas, the cost to pass a single home with fiber can exceed $53,000 (CRS 2025). This divergence in marginal cost creates the "digital divide" that space-based solutions aim to bridge. It presents a market opportunity. While fiber offers unmatched capacity and low operational expenditure (OpEx) once deployed (typically 3-5% of CapEx annually), its high upfront CapEx makes it economically unviable for the "last mile" in sparse regions. As a result, the "digital divide" presents a market opportunity (Giovannetti et al 2025).

3. Governance, Security, and Risk

The legal foundations for communications are split between a state-centric liability model for space and a more fragmented, industry-led model for the oceans. These differences are summarized in Table 1 below and discussed in detail in text that follows.

3.1 Governance of Space-Based Communications

Private space-based communications activities take place in an environment with weak regulation and little established space law for private actors. For example, existing United Nations treaties, such as the Outer Space Treaty (OST) of 1967, reflect Cold War politics. The drafters did not anticipate the need to define private property rights in space. This has led to ambiguity about the operation and liability of orbital satellite constellations. While Article II of the OST bans "national appropriation," legal scholars continue to debate whether this extends to private entities. Efforts to amend the structure of existing treaties have not been ratified by major spacefaring countries. As a backstop, more voluntary measures grounded in soft law have been pushed, like the Artemis Accords (promoted by NASA and the U.S. Department of State). Yet these are themselves seen as reflecting clear national interests. (Odom, 2024; Weinzierl, 2018).

This legal ambiguity means that private activity in space, including extraction and use of space-based resources, is neither prohibited nor permitted under existing international law. It also means that legal ambiguity, including property rights, is a cloud over private investment in the sector (Odom, 2024; Rhimbassen & Rapp, 2021; Aggarwal & Sircar, 2023). Further complicating things are the responsibilities of the "launching state" and associated commercial entities.[2] In response, there has been a move by individual nation states to fill the vacuum of binding international commercial space law with national laws. These define property rights in space for national entities, impose technical requirements related to safety and management of space debris, and aim to establish a more stable legal environment for firms operating in space. However, such national laws still operate within the ambiguity of international law. (See Smith, Baumann & Wintermuth, 2023 for an extensive overview of the evolving legal landscape). They have also, already, led to emergent tax competition in the space sector (See Simon, 2021 on Luxemburg tax strategies in this respect). In addition, because a binding international framework is missing, companies will be able to "shop" for the most favourable regulatory regimes with respect to space regulations (including space junk management).

Table 1. Legal foundations for governance of communications

Feature	Space-Based (Outer Space Treaty & ITU)	Terrestrial/Subsea (UNCLOS)
Primary Treaty	1967 Outer Space Treaty (OST)	1982 UN Convention on the Law of the Sea
State Liability	Absolute. States are responsible for all national activities, including private ones.	Weak. Focuses on negligence (fishing/anchors); limited state liability for private damage.
Regulatory Body	ITU. Coordinates orbital slots and radio frequencies globally.	Fragmented. No global equivalent to the ITU; governed by landing-point nations.
Economic Barrier	"Paper satellites" (squatting on spectrum/slots).	Permitting and security standards vary by national jurisdiction.

Source: See discussion in text.

The technical allocation of orbital slots and radio frequency spectrum is governed by the International Telecommunication Union (ITU), a specialized agency of the UN. The ITU Radio Regulations constitute a binding treaty that coordinates the use of frequencies to prevent harmful interference, a prerequisite for the economic viability of satellite services. However, the regulatory landscape is strained by the "New Space" volume. The ITU's "first-come, first-served" filing procedures have led to a "paper satellite" problem, where entities file for massive constellations, they may never build to squat on valuable orbital real estate and spectrum rights.

[2] The OST establishes the foundational principles of non-appropriation and peaceful use. Crucially for commercial actors, Article VI of the OST stipulates that States Parties bear international responsibility for national activities in outer space, whether carried out by governmental or non-governmental entities. This provision effectively makes states the insurers of last resort for private commercial actors, necessitating rigorous national licensing regimes to mitigate liability risks under the 1972 Liability Convention. The Liability Convention establishes absolute liability for damage caused by space objects on the surface of the Earth or to aircraft in flight, further incentivizing states to strictly regulate the financial and technical competence of their private space operators.

This practice creates artificial scarcity and barriers to entry for new competitors (Weissberger 2026).

In contrast to the rigorous state-responsibility model of space, terrestrial cross-border communications are governed largely by the UN Convention on the Law of the Sea (UNCLOS) regarding subsea cables. UNCLOS affords freedoms to lay and maintain cables on the continental shelf and high seas but provides weak protection against intentional damage. Its provisions primarily focus on negligent damage by fishing or anchoring, rather than deliberate sabotage or grey-zone warfare (CSA 2018). Unlike the liability regime for space objects, the protection of subsea cables relies heavily on industry norms and private maintenance agreements, such as the Atlantic Cable Maintenance Agreement, rather than enforceable international statutes. There is no global regulator for subsea cables equivalent to the ITU's role for spectrum; governance is fragmented across national jurisdictions where cables land, creating a patchwork of security and permitting standards (CRS 2022; Bueger & Liebetrau 2021).

3.2 Space-Based Data Flows and Data Localization

The proliferation of data localization laws—mandating that data generated within a country be stored and processed domestically—poses a fundamental challenge to the architecture of modern satellite networks. As of 2023, 100 such measures were in place in over 40 countries (Giovan e al 2023), and 67 countries by 2025 (Digital Policy Alert 2026). Such measures are driven by motivations ranging from privacy protection to national security and digital protectionism (Ganz et al 2024). We provide a summary in Table 2.

These regimes clash with the technical capabilities of LEO constellations, particularly those using Inter-Satellite Links (ISLs). ISLs allow data to be routed dynamically through the orbital mesh, potentially bypassing national gateways and inspecting firewalls. This creates significant legal friction. For instance, the EU’s General Data Protection Regulation (GDPR) restricts data transfers to jurisdictions lacking adequate protection. If a satellite captures imagery or routes traffic from a European user via a ground station in a non-compliant jurisdiction, or even processes data "in orbit" (which is legally ambiguous territory), it may violate these regulations (Trico et al 2025; Ferrazzan et al 2024). The concept of "data sovereignty" implies that data is subject to the laws of the country of origin, but the transnational nature of satellite footprints makes compliance complex and costly. Operators may be forced to geofence services or disable terminals in strict jurisdictions, fragmenting the global network and undermining the economic efficiency of the constellation. The U.S. has also entered this arena, with the Department of Justice issuing rules in 2024 to restrict the transfer of sensitive personal data to "countries of concern," further complicating the compliance landscape for global satellite operators (Khan et al 2025).

Table 2. Data Localization Summary

The Conflict: Over 60 countries now require data to be stored and processed domestically. However, LEO satellites use Inter-Satellite Links (ISLs) to route data through an orbital mesh, often bypassing the very national firewalls and "gateways" designed to monitor or localize that data.
Legal Ambiguity: Processing data "in-orbit" is a jurisdictional grey area. If an AI satellite processes European data while over the Pacific, it may inadvertently violate the GDPR or recent U.S. Department of Justice rules restricting data transfers to "countries of concern."
Consequence: Operators are increasingly forced to geofence services, disabling capabilities in certain regions to avoid massive compliance fines, which effectively fragments the "global" internet.

Source: See discussion in text.

3.3 Physical and Systemic Threats

The security environment for space assets has deteriorated, introducing systemic risks that threaten the economic viability of the sector.

The deployment and testing of anti-satellite (ASAT) weapons pose a catastrophic risk to the orbital commons. The Russian direct-ascent ASAT test in November 2021, which destroyed the Cosmos 1408 satellite, generated over 1,500 pieces of trackable debris and hundreds of thousands of smaller fragments. This event forced the International Space Station (ISS) to manoeuvre to avoid collision, highlighting the indiscriminate nature of orbital debris. (The Guardian 2020). Such kinetic events exacerbate the risk of "Kessler Syndrome," a cascading chain reaction of collisions that could render LEO unusable for generations. Furthermore, despite the OST’s prohibition on placing nuclear weapons in orbit (Article IV), recent geopolitical tensions have seen Russia veto UN Security Council resolutions reaffirming this ban. This has raised credible fears of orbital nuclear capabilities designed to disable commercial and military constellations via electromagnetic pulse (EMP) or persistent radiation belts, which would destroy the electronics of unhardened commercial satellites. A single high-altitude nuclear burst would create an Electromagnetic Pulse (EMP) capable of frying the unhardened electronics of thousands of commercial satellites simultaneously (Bongers & Torres 2024; Zwanenburg & Peperkamp 2026).

Cybersecurity presents another pervasive vector of risk. Unlike terrestrial fiber, which typically requires physical access to tap or cut, satellite uplinks and downlinks can be jammed or spoofed from a distance. The intrinsic dual-use nature of communications satellites—serving both civilian internet and military command and control—makes them legitimate military targets under the Law of Armed Conflict. This blurs the lines of distinction between combatant and non-combatant infrastructure, increasing insurance premiums and capital costs for private operators who must now price in the risk of being targeted in great power conflicts. Suspected state actors (notably in Eastern Europe) frequently jam GPS and SatCom signals to degrade navigation and timing. Additionally, satellite uplinks can be compromised to seize control of a spacecraft or intercept data. Because hardware in orbit cannot be "unplugged" or easily patched, a single vulnerability can remain active for the satellite's entire lifespan (Carlo & Obergfaell 2024).

4. The Economics of the Status Quo

4.1 Demand and Supply Side Drivers

We provide a summary of major demand and supply side drivers in Table 3. The global space economy is projected to grow from $613 billion in 2024 to $1.8 trillion by 2035. Within this, the satellite internet market alone is forecast to grow at a compound annual growth rate (CAGR) of 20.4%, potentially reaching $18.59 billion by 2030. Conversely, the subsea cable market continues to grow but at a more mature pace, with investment focused on route diversity rather than raw capacity expansion alone (CRS 2022; Odom 2024).

The current patterns and emerging trends in global communications are drive by underlying demand and supply-side drivers. These are summarized in Tables. The current global communications architecture is characterized by a stark division of labour, driven by the distinct economic and physical properties of the mediums. Subsea cables carry approximately 99% of intercontinental data traffic, facilitating trillions of dollars in daily financial transactions with capacities measured in hundreds of terabits per second (Tbps) (Ferguson 2025). In contrast, satellite systems handle a fraction of the total volume (estimated at <1%) but provide critical coverage to the 40-50% of the global landmass and maritime environments that remain unreachable by fiber (Croshier 2022). However, in cloud computing and AI processing, Orbital Edge Computing is likely to further disrupt current patterns.

Table 3 Major demand and supply side drivers

Demand Side
Ubiquity and Mobility: The demand for "always-on" connectivity for aviation, maritime, and autonomous logistics is the primary driver for the satellite market. While fiber connects fixed points efficiently, satellites connect moving targets. The large number of connected IoT devices requires ubiquitous coverage that only space can provide economically. Latency Sensitivity: Financial markets and real-time applications increasingly value the lower latency of LEO satellites over fiber for specific long-distance routes (e.g., London to New York). Light travels roughly 30% faster in the vacuum of space than in the glass of a fiber optic cable, giving LEO constellations a theoretical speed advantage that high-frequency traders are willing to pay a premium for. Resilience: The increasing frequency of cable cuts—whether accidental (anchors, fishing) or due to sabotage—drives demand for physically distinct redundant paths. The severance of Red Sea cables in 2024, which impacted 25% of Asia-Europe traffic, underscored the fragility of terrestrial bottlenecks and the value of an orbital backup.

Supply Side
Launch Costs: The collapse in launch costs from ~$10,000-$20,000/kg to under $200/kg (for heavy lift) enables the "megaconstellation" model. This allows satellites to be treated as consumable ammunition rather than bespoke artifacts, permitting rapid technology refresh cycles. Mass Production: Satellite manufacturing has moved from artisanal to industrial scales. The cost of manufacturing a satellite has dropped from $50M-$100M for legacy GEO satellites to approximately $500,000 for mass-produced LEO units.

Source: See discussion in text.

4.2 Relative Speed of Space-Based Data Flows and Processing

The transition to laser-based ISLs allows satellites to function as autonomous routers in space. Instead of bouncing a signal immediately back to a local ground station (GSL), the data travels across multiple satellites at the speed of light in a vacuum—which is roughly 30% faster than light traveling through the silica glass of a fiber-optic cable.

Before ISLs, providing internet over the Atlantic or at the poles was nearly impossible for LEO constellations because you couldn't build ground stations in the middle of the ocean. Laser links now allow a satellite over the mid-Atlantic to hop data to a neighbour that is over a coastal gateway.

Modern constellations like Starlink (V2/V3) or Blue Origin's TeraWave can theoretically operate with a fraction of the ground stations once required. One gateway can serve as the "exit point" for data generated thousands of miles away. This means that ISLs allow operators to route data around "unfriendly" jurisdictions or areas with strict data localization laws, as the data stays in the "international waters" of space until it reaches a trusted landing point.

This shift to ISLs has drastically lowered the "ground station density" required for global coverage. In addition, the math of latency has flipped. For long-distance (intercontinental) communication, a space-based mesh is often superior to terrestrial fiber. Light in fiber moves at $0.67C$ (where C is the speed of light in a vacuum). Light in space moves at C. In addition, fiber cables must follow geography (coastlines, mountains, city layouts). Laser links move in straight lines between satellites, resulting in a more direct "great circle" path (Newmann and Napier 2026; Al-Hraishawi et al 2022).

5. The Value of Space

We turn next to estimates of the economic value of space vs. terrestrial communications, focusing on substitutability, replacement and maintenance costs, and the economics of redundancy. In this section we attempt to quantify the economic value of space-based communications by estimating the cost to build a terrestrial system capable to the extent possible of providing equivalent functionality, meaning global ubiquity and precise timing.

Evaluating the "Value of Space" through the lens of replacement cost reveals a staggering disparity. While space-based infrastructure is often viewed as a high-cost frontier, it serves as a massive economic "shortcut" for global services. Replicating its core functions—ubiquity, redundancy, and timing—using only terrestrial assets would require a global mobilization of capital exceeding $450 billion.

5.1 Substitutability

The relationship between space and terrestrial infrastructure is largely complementary, but direct competition is emerging in specific segments. In rural and remote residential broadband, LEO satellites are a direct and often superior substitute for terrestrial fiber or fixed wireless. The cost to pass a rural home with fiber can exceed $53,000, rendering it economically unviable without massive subsidy. In contrast, a satellite terminal costs the consumer approximately $600 with no per-mile infrastructure cost to the provider (Tarnowski 2025). Here, space wins on marginal cost.

For backhaul and enterprise connectivity, satellites serve as a partial substitute or backup. They cannot match the sheer throughput of fiber (a single modern cable can carry 200+ Tbps, while an entire LEO constellation might offer ~50-100 Tbps aggregate capacity). Thus, satellites cannot replace the core internet backbone but are vital for continuity during terrestrial outages.

There are also critical areas where there is limited or no scope for substitution. This includes defense in contested environments. In scenarios where terrestrial nodes are destroyed or denied by adversaries, space-based communications are irreplaceable for Beyond Line of Sight (BLOS) command and control. HF radio offers a backup but lacks the bandwidth for modern data-centric warfare. This also includes deep blue ocean operations. Maritime operations far from shore have no terrestrial alternative. While HF radio exists, it provides kilobits of data, whereas modern maritime operations require megabits or gigabits for crew welfare and operational telemetry (Khalil et al 2023).

5.2 Infrastructure and maintenance

Table 4 provides a broad comparison of deployment costs, lifespans, and relative fixed vs. operational costs. For space-based communications, the estimated cost to deploy a first-generation mega-constellation ranges from $5 billion to $10 billion initially. This CapEx covers the manufacturing and launch of thousands of satellites (Bronson & Gladstone 2023). For such systems, maintenance is synonymous with "replacement." Because of the combination of atmospheric drag and technical obsolescence, the LEO satellites that make up a mega-constellation have a lifespan of only 5-7 years. This pace of loss and obsolescence means that an operator like Starlink needs to launch roughly 2,000 satellites annually just to maintain a steady-state fleet size. This leads to a high and recurring CapEx burden (Baccelli et al 2024; Bronson & Gladstone 2023).

Table 4. Deployment costs, lifespans, and relative

Feature	Subsea Fiber Cables	LEO Satellites (e.g., Starlink)	Terrestrial Wireless (5G/6G)
Capacity	Petabits (Pbps) per cable	Terabits (Tbps) per constellation	Gigabits (Gbps) per cell
Latency	Low (~60ms Atlantic)	Lower (~30-40ms Atlantic)	Very Low (<10ms local)
Cost Profile	High fixed / Low marginal	High fixed / Medium marginal	Medium fixed / Low marginal
Lifespan	~25 Years	5–7 Years	10–20 Years
Deployment	$30k–$50k per km	$500k per unit + Launch	$50k–$200k per tower

Source: discussion in text.

For terrestrial systems, cable construction costs for subsea cables range between $30,000 and $50,000 per kilometre. The construction of a single trans-Pacific cable system can cost upwards of $400 million (CRS 2022). To replicate the connectivity of space, one would need to lay cables to every inhabited island and remote coast. Such costs that scales linearly with distance. At the same time, in contrast with space-based systems, the annual maintenance costs for subsea cables is relatively low. Estimates range between 3% and 5% of the initial capital cost or roughly $1million $3million per repair operation (CRS 2022; Kavanagh et al 2025). However, these figures are for ocean cables and intercontinental connections. They do not take into account the high cost of terrestrial fiber and wireless deployment to reach final end-users. In the U.S. alone, the estimated cost for fiber-optic installation in the U.S. ranges from $33,000 to $66,000 per kilometre, while the cost for a combination of wireless and fiber deployment to provide broadband access to rural communities globally max be over $415 billion (Abilla 2025; Oughton et al 2023).

5.3 Cascade Events and Infrastructure Loss

The centralization of global data flows through a limited number of subsea cable choke points (e.g., the Red Sea, the Strait of Malacca, the Luzon Strait) creates systemic fragility in the terrestrial network. A coordinated attack or a catastrophic natural disaster severing these cables would effectively isolate entire continents from the global digital economy. In such a scenario, space-based infrastructure provides the only physically distinct, geographically dispersed redundant path.

However, the space domain itself is not immune to catastrophic failure. It faces the risk of a "cascade event," or Kessler Syndrome, where the density of objects in LEO reaches a critical threshold such that collisions generate debris which triggers further collisions. This would render orbital shells unusable for decades or centuries. The 2021 Russian ASAT test, which generated a long-duration debris cloud, demonstrated the immediacy of this threat (Liang et al 2024). A total loss of space-based communications—whether through kinetic war, nuclear EMP, or debris cascade—would necessitate a full reversion to terrestrial systems. This would expose the massive coverage gaps where terrestrial infrastructure is economically or physically impossible to deploy.

5.4 Capital Expenditures for Terrestrial Redundancy

Terrestrial systems struggle with the "law of diminishing returns" in remote areas. Replacing the functional utility of space-based systems with terrestrial alternatives is not merely a matter of laying more fiber optic cable to match bandwidth. It also involves replicating the ubiquity (coverage) and timing synchronization capabilities of satellites using ground-based assets. This is a massive engineering and economic undertaking.

Table 5. Summary of investment costs

Infrastructure Component	Satellite Solution	Terrestrial Replacement Cost	Key Driver
Rural Broadband	~$10B (e.g., Starlink)	$418 Billion	"Last mile" fiber in remote terrain.
Global PNT (Timing)	GPS (Built-in)	$12 Billion	Building global eLoran/Atomic clock networks.
Strategic Subsea	N/A (Redundant)	$20 Billion	Diversifying routes (Arctic/South-South).

Source: See discussion in text.

At a macro level, replacing the capacity of satellites is trivial. Terrestrial fiber already dominates in volume. However, the connectivity (reach) of satellites is another matter. We break down the investment required to build a terrestrial network that approximates the global reach of satellite constellations. We provide a summary of investment costs in Table 5, with detailed discussion below.

In terms of strategic subsea expansion, replicating the path diversity and resilience provided by satellites with a subsea network requires expanding into non-commercial routes. These include Arctic cables and direct South-South links that bypass established hubs. Such construction costs have been estimated at $40,000 per kilometre (CRS 2022). This means it would cost approximately $20 billion in initial Capital Expenditure (CAPEX) to deploy an additional 500,000 kilometres of strategic redundancy cables.[68] These estimates are for the "wet plant" alone.

Even greater than the subsea costs are the costs of the "last mile" in rural and remote areas. Such areas are currently served or targeted by satellites. The IMF study has estimated that connecting the 3 billion currently unconnected people (mostly in rural areas where fiber is not viable) via terrestrial means (fiber/4G) would cost $418 billion globally. (Again, see Abilla 2025; Oughton et al 2023). This figure represents the terrestrial "replacement cost" for the connectivity that LEO satellites can provide for a fraction of the infrastructure investment (e.g., a $10 billion constellation).

Finally, we come to PNT (Positioning, Navigation, Timing). GPS systems are not just navigation tools. GPS provides the clock for global financial markets, telecom networks, and power grids. While we often think of GPS for directions, its most critical financial role is as a stratum-zero-time source, providing the nanosecond-precision timestamps required by law and logic to sequence millions of trades per second. Global financial regulations (such as MiFID II in Europe and CAT in the U.S.) mandate that transaction timestamps be accurate to within 100 microseconds of Coordinated Universal Time (UTC).

A 24-hour GPS outage would trigger a systemic "time crisis" in global financial markets. Without this "global heartbeat," the primary mechanism of modern finance—High-Frequency Trading (HFT)—would likely collapse within minutes. Local server clocks are notoriously inaccurate and begin to "drift" the moment they lose their GPS sync. Within the first hour after loss of GPS, the discrepancy between exchange servers (e.g., New York vs. London) would exceed legal limits. Compliance officers would be forced to halt trading to avoid "time-leakage" fraud and regulatory penalties. Arbitrage algorithms would fail, potentially causing "ghost" trades or accidental "flash crashes." Recent economic assessments (including 2024–2025 studies by the Brattle Group and NIST) estimate that a total GPS failure would cost the U.S. economy alone approximately $1.6 billion per day. (See O'Connor et al 2019). To provide redundancy against such a loss of GPS requires finding a terrestrial backup for timing synchronization. Currently, what is known as an Enhanced Loran (eLoran) system is the leading terrestrial alternative. For the U.S. alone, building a nationwide eLoran system has been estimated to cost approximately $400-$500 million in initial CAPEX.[70] The UK has already committed £155 million for a similar resiliency program. Scaling this to a global terrestrial timing network would likely require $10-$15 billion in coordinated infrastructure investment. (Again, see O'Connor et al 2019).

Based on the costs in Table 5, our "total initial investment" estimate is $450 billion. This covers the initial investment to build terrestrial redundancy for space-based connectivity and timing ($418B for rural broadband + $20B for strategic subsea + $12B for global PNT backup).

5.5 Annual Operational Expenses for Terrestrial Redundancy

Building the redundant infrastructure is only the first step in the estimation exercise here. Maintaining a network that spans the entire globe, ostensibly including hostile terrain and remote oceans, also means substantial annual costs.

Turning first to terrestrial fiber and wireless maintenance, the operational expenses (OPEX) for terrestrial networks are non-trivial. As noted earlier, maintenance costs are relatively low for fiber (3-5% of CAPEX). In contrast, in remote areas the wireless towers required to replace satellite coverage require high OPEX for security, access, and power (often diesel generators in off-grid areas). Annual OPEX would likely range between $10-$20 billion annually for coverage of the landmass currently only served effectively by satellites.

In contrast to terrestrial fiber and wireless, the annual operating cost of an eLoran system would be relatively modest. For the U.S., it is estimated at $50 million per year. Scaling this globally (based on the CAPEX estimates underlying Table 5) implies $1.25 billion to $1.5 billion annually This is lower than the $1.84 billion annual sustainment cost of the GPS constellation. This means that terrestrial timing redundancy may be economically more cost efficient and sustainable, even if navigation redundancy (which eLoran provides but with less precision than GPS for some applications) is less rendered less capable (O'Connor et al 2019).

5.6 Special Wireless Challenges

Finally, certain sectors, particularly maritime and aviation, simply cannot be wired. To replace satellite communications for maritime activities would require a massive expansion of high-frequency (HF) radio infrastructure and potentially also high-altitude platform systems (HAPS). In this regard, modern wideband HF can provide email and basic data. As such it can serve as a partial fallback for satellite comms. Establishing such a global HF backbone for maritime redundancy requires re-fitting the global merchant fleet. This includes an estimated $2 billion investment in wideband HF radio and shore stations. At an estimated cost of $5,000 per ship (per industry sources), it also includes equipping 50,000+ merchant ships at a cost $250 million. Such shore station infrastructure would need to involve significant state engagement.

To approximate the broadband speeds of satellites for maritime and aviation users, fleets of stratospheric drones or balloons (High Altitude Platform Systems, HAPS) could be deployed. The costs involve both fixed and variable costs, with overall costs being lower for HAPS systems than LEO satellites. HAPS units cost between $5 million and $34 million to deploy and operate (FRONTEX 2023; Karlik 2020). A global HAPS network to replace maritime satellite coverage would require thousands of platforms to cover shipping lanes, implying a cost of roughly $15-$20 billion in initial investment, with high recurring costs for platform recovery and relaunch.

6. Conclusions

The economic value of space-based communications lies not in its raw capacity, which is dwarfed by terrestrial fiber, but in its unique topology. It is ubiquitous, resilient, and physically distinct from the terrestrial grid. The analysis we present here indicates that the "replacement cost" of space is bifurcated.

At first glance, replacing the overall data volume of satellites is negligible. The global subsea fiber network already carries 99% inter-continental data traffic and has ample dark fiber capacity. However, this is not the end of the story. Replacing the functional coverage and timing synchronization provided by space assets would be a massive economic undertaking. It would require building a terrestrial network to connect the 3 billion unconnected people, backing up global timing synchronization with eLoran, and providing basic connectivity to maritime and aviation sectors. We estimate $450-$500 billion in initial global investment, followed by tens of billions in annual maintenance costs. Even then, such a network would still fail to cover deep-ocean and polar regions effectively.

For the defence sector and for critical infrastructure (finance, power grids), space is not just a cost-saver. It is a single point of failure. A loss of space assets would impose immediate economic costs, estimated at $1.6 billion per day for GPS for the U.S. alone due to timing desynchronization and logistics failures. Consequently, while the cost of building terrestrial redundancy is high, the cost of not having space-based systems—measured in lost economic activity and strategic vulnerability—is orders of magnitude higher. Space remains the ultimate high-ground utility, one whose economic value is defined by the prohibitive cost and physical impossibility of its total terrestrial replacement.

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