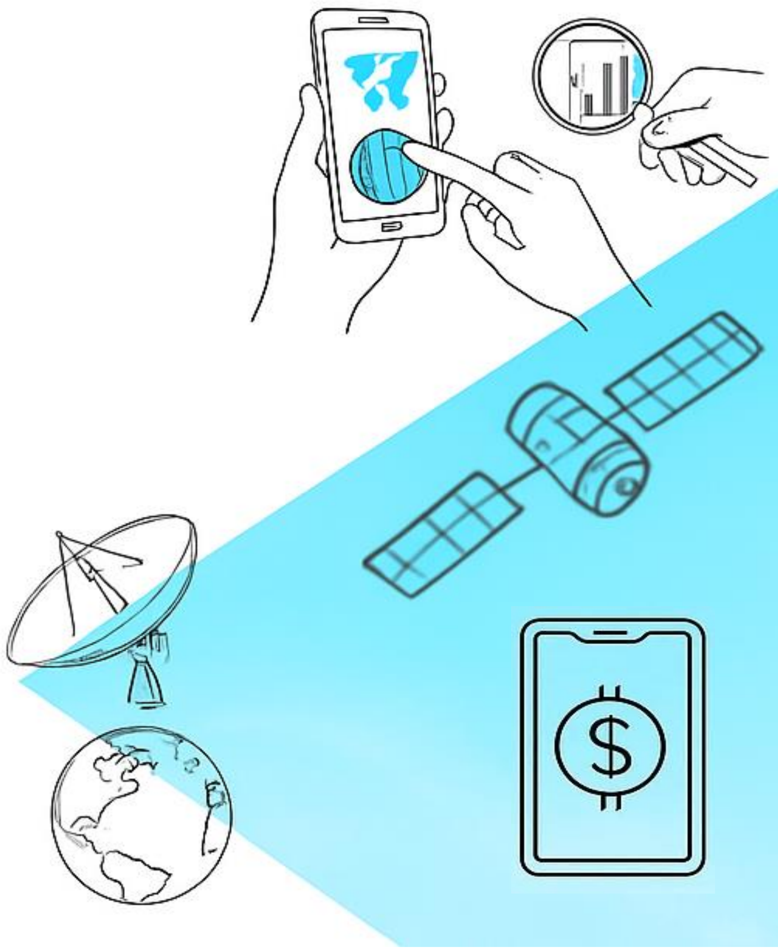
CENTRE for AEROSPACE & SECURITY STUDIES

Economic Spillovers from Advancements in the Global Satellite Sector

Zahra Niazi
Research Associate



Working Paper

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Abstract

The global satellite industry has rapidly evolved into a powerful economic force, influencing a wide range of industries far beyond the aerospace sector. Within the space sector, the advancements in the satellite industry, from low-Earth orbit (LEO) mega-constellations to flexible launch systems, have catalysed the development of a larger, more dynamic, and cost-efficient sector, albeit with new competitive and sustainability challenges (unintended spillovers on targeted unit). Between sectors, the advancements act as catalysts for productivity and inclusion by connecting the unconnected and optimising industries, such as agriculture and transport (intended spillovers on non-targeted units). In the diagonal dimension, they have demonstrated that innovation can come with undesired externalities for other sectors (unintended spillovers on non-targeted units). The challenge lies in maximising the positive spillovers while mitigating the negatives with a forward-looking approach. This entails that while some measures, such as stringent policy actions for space debris mitigation and traffic management, may impose new costs on the space industry, particularly space operators, they will prevent larger economic fallout in the long run and protect the enormous downstream value the satellite sector provides to other industries. Moreover, satellite firms and secondary industries/sectors should actively collaborate to ensure smooth spillovers, avoid conflict, and capitalise on each other's strengths.

Keywords: LEO mega-constellations, Satellite miniaturisation, Very High Throughput Satellites (VHTS), Satellite-enabled IoT, AI onboard satellites, Economic Spillovers. Satellite Communications (SatCom), NewSpace Industry, Space Economy, Satellite Market Growth, Earth Observation (EO) Satellites

Introduction

The global satellite industry has emerged as a vital component of the world economy today. From USD 362.3 billion in 2025, the industry's market size is forecasted to reach USD 729.5 billion in 2034 by recording a compound annual growth rate (CAGR) of 8.1%.[1] In essence, the industry comprises three technology stacks: the Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS), Geospatial Intelligence (GEOINT), and Satellite Communications (SatCom).[2] GNSS include satellites and the associated infrastructure that deliver positioning, navigation, and timing (PNT) services throughout any terrestrial region and under any weather conditions.[3] GEOINT encompasses geospatial data collection as well as analysis and dissemination for capturing Earth's physical features and their locational and relational aspects.[4] SatCom provides the communication links that connect diverse points on Earth, enabling the transmission of laser and radio wave signals between satellites and terrestrial destinations.[5]

Each stack has three layers or verticals: infrastructure, distribution, and application.[6] The infrastructure layer provides the services of building, launching, and operating space-based assets to generate data. For example, the American space technology company, Maxar Technologies, launches satellites that produce geospatial data for clients. Similarly, the defence and aerospace manufacturer Lockheed Martin deploys GPS satellites. The distribution layer includes the hardware and software that receive, analyse, store, and distribute data from space-based assets. For example, SkyWatch is a geospatial data platform within the distribution layer that offers fast, easy, and reliable access to geospatial data. Another company, Trimble, makes terminals that receive GPS signals transmitted by satellites. Finally, the application layer consists of the software and hardware that use this data to offer products and services to

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1 Precedence Research, "Satellite Market Size, Share, and Trends 2025 to 2034," April 2, 2025, https://www.precedenceresearch.com/satellite-market.

2 Chad Anderson, *The Space Economy: Capitalise on the Greatest Business Opportunity of Our Lifetime* (Hoboken, New Jersey: John Wiley & Sons, Inc., 2023).

3 Bernhard Hofmann-Wellenhof, Herbert Lichtenegger, and Elmar Wasle, *GNSS – Global Navigation Satellite Systems* (Vienna: Springer, 2008).

4 Nitya Thakur, Aditya Virk, and Vivek Nanda, "Geospatial Intelligence: A Comprehensive Review of Emerging Trends and Applications in 2024," *International Journal of Research Publication and Reviews* 5, no. 9 (2024): 376-381, https://doi.org/10.55248/gengpi.5.0924.2413.

5 Athanasios D Panagopoulos et al., "Special Issue on Satellite Communication Systems and Networking," *EURASIP Journal on Wireless Communications and Networking* (2012): 283, http://jis.eurasipjournals.com/content/2012/1/283.

6 Anderson, *The Space Economy*.

customers. Regrow Ag is one such company within the application layer that leverages satellite imagery to monitor crop conditions and assist agronomists in making data-driven decisions. Likewise, Niantic's gaming application, Pokémon GO, uses GPS data to enable location-based augmented reality experiences.

In recent years, the satellite industry has been characterised by rapid growth and advancement, with significant economic, social, and environmental impacts. Major leaps – from low-Earth orbit (LEO) mega-constellations to onboard artificial intelligence (AI) – have demonstrated the industry's potential to act as a powerful engine of growth and productivity across different economic sectors. These innovations have drastically lowered costs, opened new markets, and facilitated numerous other industries. Given this, the paper aims to provide an in-depth assessment of the economic spillovers from advancements in the global satellite industry. The aim is to provide a knowledge base for decision-makers to identify and harness the opportunities in the form of positive economic spillovers while managing the challenges i.e. adverse spillovers.

The paper is structured as follows: first, it outlines the study's methodology and framework for assessing the economic spillovers. This is followed by an identifying major advancements in the global satellite industry. It then assesses the economic spillovers emerging from those advancements, followed by a conclusion and policy recommendations.

Methodological Framework

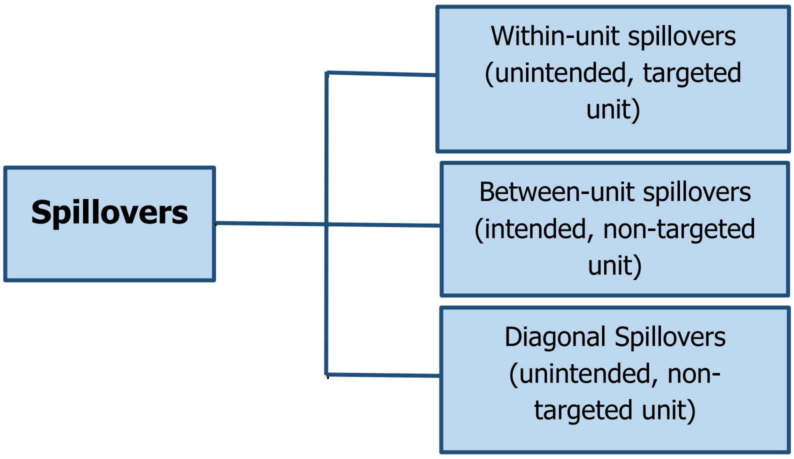
The study is based on secondary data sources. Relevant information was collected from books, academic journal articles, government publications, industry reports, and online platforms. These sources were selected for their credibility and relevance. The data was reviewed and synthesised to support the analysis of trends and developments within the industry and their economic spillovers.

The study adopted the INTENTS framework (Intended Non-intended Targeted Non-Targeted Spillovers) to link the advancements in the global satellite sector with economic spillovers. The framework covers three types of spillovers: within-unit, between-unit, and diagonal.[7] Within-unit spillovers refer to the unintended effects of

7 Igor Francetic et al., "Framework for Identification and Measurement of Spillover Effects in Policy Implementation: Intended Non-intended Targeted Non-targeted Spillovers (INTENTS),"

an intervention on the same unit within which the intervention has occurred. According to this definition, the within-unit effects can be considered spillovers if they are sufficiently distinct from the intended outcome of the intervention. Between-unit spillovers refer to the intended effect of an intervention on units besides the one where an intervention has occurred. Diagonal effects, on the other hand, refer to the impact an intervention on a targeted unit generates on a non-targeted unit.

Figure 1: INTENTS (Intended Non-intended Targeted Non-Targeted Spillovers) Framework



Source: Igor Francetic et al., "Framework for Identification and Measurement of Spillover Effects in Policy Implementation: Intended Non-Intended Targeted Non-Targeted Spillovers (INTENTS)," *Implementation Science Communications* 3, no. 30 (2022), https://doi.org/10.1186/s43058-022-00280-8.

The section below identifies the major advancements in the global satellite sector.

Key Advancements in the Global Satellite Sector

Low Earth Orbit (LEO) Mega-Constellations

First launched in 2019 by SpaceX, LEO mega-constellation is a large network of satellites positioned in LEO. Typically orbiting Earth at altitudes ranging from around 160 to 2,000 kilometres above the Earth's surface, a LEO mega-constellation offers the benefit of low latency. For reference, it reduces the time it takes for data to travel between two points, from approximately 477 milliseconds inherent in Geostationary Earth Orbit (GEO) service to less than 27 milliseconds.[8] Compared to traditional

Implementation Science Communications 3, no. 30 (2022), https://doi.org/10.1186/s43058-022-00280-8.

8 John Garrity and Arndt Husar, "Digital Connectivity and Low Earth Orbit Satellite Constellations: Opportunities for Asia and the Pacific," (working paper, Asian Development Bank, Philippines, 2021), https://www.adb.org/publications/digital-connectivity-low-earth-orbit-satellite-opportunities.

satellites predominantly positioned in geostationary orbits that cover a fixed geographic area, a LEO mega-constellation offers the advantage of widespread geographical coverage, including remote regions, and the multiple satellites working together in a coordinated pattern allow for frequent revisits of the same area on Earth.[9]

The most prominent example of a LEO mega constellation is SpaceX's Starlink, which aims to provide high-speed, low-latency global internet access through a large network of satellites in Low Earth Orbit (LEO); other notable LEO mega-constellations include Iridium Next, OneWeb, and Globalstar, all of which are primarily focused on satellite internet services.[10]

Satellite Miniaturisation

Small satellites (SmallSats) or miniature satellites, including those with a mass of below 1100 lb or 500 kilograms (kg), have revolutionised space access by providing cost-effective platforms for various missions.[11] Particularly notable are the CubeSats, measured in units of 10x10x10 cm (1U), with a typical mass of 1-10 kg.[12] Although first introduced in 2003,[13] CubeSats are now being launched into space at an ever-increasing speed, which positions them as an ongoing advancement in the satellite sector. As of April 2025, 2,730 CubeSats had been launched into space.[14] The highest number was launched in 2023, with 359 units deployed.[15] Several developing countries, such as Kenya, Ghana, Nigeria, Pakistan, Bangladesh, Bhutan, Rwanda, and the Philippines, have also launched CubeSats.

Since CubeSats are smaller and cost-effective, they can more easily be launched as constellations, allowing for frequent data collection and widespread coverage.

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9 Ibid.

10 Jingrui Zhang et al., "LEO Mega Constellations: Review of Development, Impact, Surveillance, and Governance," *Space: Science & Technology*, (2022), https://doi.org/10.34133/2022/9865174.

11 Joseph R. Kopacz, Roman Herschitz, and Jason Roney, "Small Satellites an Overview and Assessment," *Acta Astronautica* 170, (2020): 93-105, https://doi.org/10.1016/j.actaastro.2020.01.034.

12 Daood Ilyas, "Orbital Propagation and Formation Flying of CubeSats within QB50 Constellation," (Master's Thesis, University of Liège, Liège, 2011), https://ltu.diva-portal.org/smash/record.jsf?pid=diva2%3A1030977&dswid=9595.

13 Michael Swartwout, "The First One Hundred CubeSats: A Statistical Look," *Journal of Small Satellites* 2, no. 2 (2013); 213-233, https://jossonline.com/storage/2021/08/0202-Swartwout-The-First-One-Hundred-Cubesats.pdf.

14 Erik Kulu, "World's Largest Database of Nanosatellites, Over 4400 Nanosats and CubeSats," Nanosats Database, Accessed March 20, 2025, https://www.nanosats.eu/.

15 Ibid.

Additionally, due to their specialised and mission-specific design, equipping these systems with advanced sensors is a more practical and effective approach.[16]

Very High Throughput Satellites (VHTS)

Very High-Throughput Satellites (VHTS) are communication satellites that can provide significantly higher capacity and bandwidth than traditional high-throughput satellites (HTS). By utilising multiple concentrated spot beams, advanced digital signal processing, wideband payloads, and higher frequency bands, such as Ku- and Ka-frequency bands that provide frequency reuse efficiency, they can deliver significantly more data at higher speeds, sometimes reaching terabits per second (Tbps) throughputs, over vast geographical areas.[17]

A notable example is the ViaSat-3 constellation, comprising three geostationary ViaSat-3 class satellites designed to offer throughput of up to 1Tbps.[18] The first of these satellites was launched in 2023. Another prominent example is the SES mPOWER constellation, which comprises seven satellites, the first two launched in 2022. Several more VHTS are expected to go into orbit in the coming years and play a significant role as facilitators of upcoming 6G networks.[19]

Satellite-Enabled Internet of Things (IoT)

IoT-enabled devices such as trackers, sensors, and monitoring devices equipped with satellite communication can establish a direct connection with satellites in space.[20] These devices collect data from their surroundings and transmit the packaged data to the satellites. Once received by satellites, the data is relayed back down to ground stations located on Earth before being sent to the intended recipient. Satellite IoT offers crucial advantages, including extending the reach of IoT networks to remote and underserved areas, ensuring that devices can communicate regardless of their

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16 Shreya Mane, "Theoretical Overview on CubeSat Technology," *International Journal of All Research Education and Scientific Methods* 12, no. 1 (2024), 1107-1113, https://www.researchgate.net/publication/377663430_Theoretical_Overview_on_CubeSat_Technology.

17 Olfa Ben Yahia et al., "Evolution of High-Throughput Satellite Systems: A Vision of Programmable Regenerative Payload," *IEEE Communications Surveys and Tutorials*, (2024), https://doi.org/10.1109/COMST.2024.3450292.

18 Ramon Mata Calvo et al., "Optical technologies for very High Throughput Satellite Communications," *Proceedings* 10910, (2019): https://doi.org/10.1117/12.2513819.

19 Yahia et al., "High-Throughput Satellite Systems."

20 Anna Talgat et al., "Enhancing Physical-Layer Security in LEO Satellite-Enabled IoT Network Communications," *IEEE Internet of Things Journal* 11, no. 20 (2024), 33967-33979, https://doi.org/10.1109/JIOT.2024.3436621.

location. Moreover, the direct connection between IoT devices and satellites facilitates low-latency communication, enabling real-time monitoring, reducing delays in data transmission, and enhancing operational efficiency.

Some major entities in the satellite IoT market today include Iridium Communications, Inmarsat Global Limited, Globalstar, Orbcomm, Myriota, and Eutelsat, among others, which have been driving the innovation and adoption of this technology. Iridium Communications is the leading company, operating a constellation of 66 LEO satellites and offering global satellite IoT services.[21]

Laser Inter-Satellite Links (LISLs)

Laser Inter-Satellite Links (LISLs) are a communication technology that establishes optical data links between satellites in orbit. At its core, it involves using laser-based communication to establish high-speed data links between satellites, enabling faster, more secure, and direct data transmission between satellites without relying on ground stations. It focuses on enhancing data relay efficiency between satellites to optimise network coverage and reduce latency. A notable example is the implementation of Optical Inter-Satellite Links (ISLs) in SpaceX's Starlink constellation.[22]

Advanced Ground Systems

The next-generation ground systems, attributable to innovation in telemetry, command-and-control satellites, and tracking, have emerged among some of the significant satellite technology trends. Radiofrequency (RF) communication terminals, including electronically-steered and phased-array antennas, allow ground stations to track multiple satellites simultaneously and with the least possible human intervention, thus making satellite tracking faster and more efficient.[23] Moreover, optical and smart RF communication enables smarter (quicker and more reliable) upstream and downstream data transfer. Additionally, decentralised communication terminals can be installed on moving objects or remote locations, providing data links in remote places or in motion. Ground stations can also facilitate software-defined satellites to

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21 Xiaoming CHEN, Zhaobin XU, and Lin SHANG, "Satellite Internet of Things: Challenges, Solutions, and Development Trends," *Frontiers of Information Technology & Electronic Engineering* 24, no. 7 (2023), 935-944, https://doi.org/10.1631/FITEE.2200648.

22 Starlink, "Satellite Technology," Accessed March 26, 2025, https://www.starlink.com/technology.

23 Iryna Bursuk, "Explore the Top 10 Satellite Industry Trends in 2025," *SpaceTech* (blog), StartUs Insights, November 30, 2021, https://www.startus-insights.com/innovators-guide/satellite-trends-innovation/.

autonomously adapt their bandwidth distribution and functionality in response to evolving user demands.

For example, ThinKom Solutions collaborated with Kongsberg Satellite Services (KSAT) to develop ground station arrays capable of near-instantaneous tracking of multiple satellites, enhancing efficiency and reducing human intervention.[24] Likewise, ALCAN Systems developed liquid crystal-based phased-array antennas that electronically steer beams without mechanical parts, enabling efficient satellite tracking. This trend is expected to pick up further momentum in the coming years.

Artificial Intelligence (AI) Driven Approaches

Launched by the European Space Agency (ESA) in 2020, 'Φsat-1' or 'Phi-Sat-1' was the first AI-powered satellite, demonstrating the potential of AI for advanced Earth observation tasks.[25] Since then, many more satellites have made it into the orbit with AI onboard. These developments reflect a step change in capability, enabling high-precision object detection and more accurate data provision.[26] Moreover, AI capabilities allow for the analysis of satellite data onboard in real-time and without processing it on the ground, producing instantaneous insights and reducing the bandwidth required for data transmission.[27] They also contribute to reducing bandwidth usage by enabling the data to be transmitted to Earth in a compressed manner.[28] More importantly, AI capabilities help prevent space collisions by allowing autonomous orbit adjustments to avoid other satellites or space debris.[29]

On the ground, AI-driven approaches allow for more accurate and significantly faster interpretation of large datasets, enhancing the accuracy and efficiency of data interpretation.[30] Advanced AI techniques, such as generative adversarial networks (GANs) and reinforcement learning, also offer improved solutions for optimising

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24 ThinKom Solutions, Inc, "ThinKom and KSAT Explore Radically New Approach to Satellite Ground Stations," April 17, 2023, https://www.thinkom.com/news/thinkom-and-ksat-explore-new-gateway-array.

25 The European Space Agency, "Φsat," Accessed March 15, 2025, https://www.esa.int/Applications/Observing_the_Earth/Ph-sat.

26 Tamina Lund, "On-Board Processing with AI for More Autonomous and Capable Satellite Systems," (Master's Thesis, Luleå University of Technology, Luleå, 2022).

27 Ibid.

28 Ibid.

29 Ibid.

30 Hafez Ahmad and Shakila Islam Jhara, "AI-Driven Approaches for Real-Time Satellite Data Processing and Analysis," *NASA Science*, Accessed March 16, 2025, https://assets.science.nasa.gov/content/dam/science/cds/science-enabling-technology/events/2025/accelerating-informatics/PM_6_Ahmad.pdf.

observation timings, handling varied satellite data, and producing synthetic data to fill coverage gaps.[31] Companies such as Orbital Insight, Planet Labs, Airbus, Capella Space, IBM, BlackSky, Maxar Technologies, SpaceKnow, and Ursa Space Systems exemplify the growing integration of AI in the analysis of satellite data.[32]

Advanced Satellite Launch Systems

Satellite launches have significantly advanced with the development of advanced reusable vehicles, new technologies, and flexible launch services. Reusable launch vehicles, such as by Blue Origin or SpaceX, have allowed for more frequent launches while lowering the launch costs, offering up to a 65 per cent decrease in launch expenditure.[33] Alternative ways to launch satellites, including air-launch-to-orbit (ALTO) and launch through spacecraft and drones, have enabled launch site flexibility while reducing delays.[34] Particularly notable is the ALTO method, which involves launching smaller rockets at altitude from a heavier conventional horizontal-take-off aircraft to carry satellites to LEO.[35] While the concept is old, recent commercial and technological advancements have made the method more viable and attractive for space launches.

Companies like Virgin Orbit, Rocket Lab, and Innospace have also introduced launch vehicles designed specifically for smaller payloads, enabling affordable and more frequent access to space.[36] Additionally, another innovation in the ground-based launch services is the containerisation of small satellites, that involves packaging

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31 Ibid.

32 Tiana Warner, "8 Companies that Brilliantly Turn Satellite Imagery into Intelligence," *FME by Safe Software*, October 23, 2017, https://fme.safe.com/blog/2017/10/8-companies-brilliantly-turn-satellite-imagery-intelligence/.

33 Matthew Christie, "Crouching Rivals, Not-So-Hidden Dragon: SpaceX and the Future of Launch Competition – Part 1," *London Economics: Space in Focus*, no. 16 (2024), https://londoneconomics.co.uk/blog/publication/crouching-rivals-not-so-hidden-dragon-spacex-and-the-future-of-launch-competition-part-1.

34 Bursuk, "Satellite Industry Trends."

35 Rajesh Uppal, "Air-launch-to-orbit Brings Space Launch to any Airport and Covert Military Satellite Launches," International Defense, Security & Technology, May 9, 2023, https://idstch.com/military/air/air-launch-to-orbit-brings-space-launch-to-any-airport-and-covert-military-satellite-launches/.

36 "Recent Innovations in Launch Vehicle Technology: A Global Perspective," *RIDE* (blog), August 14, 2024, https://www.ridespace.io/articles-de-blog/recent-innovations-in-launch-vehicle-technology-a-global-perspective.

multiple small satellites within a standardised, protective container, allowing for cost-effective and efficient deployment into LEO constellations.[37]

The following section assesses the economic spillovers emerging from advancements in the global satellite sector.

Economic Spillovers

Within-Unit Spillovers

Explosive Growth of the Global Satellite Sector: Advances in the global satellite sector have boosted investment in the industry, expanding the economic base of the sector. Notably, the miniaturisation of satellites and flexible and cheaper launch systems have lowered traditional barriers to entry in the satellite industry, catalysing its explosive growth over recent years.[38] The years 2023 and 2024 marked a record number of 221 and 259 orbital launches, respectively,[39] and the count of active satellites has grown impressively over the past few years. The industry went from having 1,980 satellites operating in various Earth orbits at the end of April 2018[40] to over 10,000 by the end of March 2025, with SmallSats comprising the majority of the recent satellites launched. Notably, SmallSats represented 97 per cent of the total spacecraft launched in both 2022 and 2023.[41] The result will be a much more competitive, innovative market with a diversity of players (from Silicon Valley start-ups to universities building CubeSats). The global satellite market is expected to continue to undergo substantial growth over the next decade, with the number of Earth Observation (EO) satellites in orbit alone projected to almost triple over the period.[42]

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[37] Richard P. Welle et al., "The DiskSat: A Two-Dimensional Containerized Satellite," (paper, 35th Annual Small Satellite Conference, Salt Lake City, August 6-11, 2021).

[38] Organisation for Economic Co-operation and Development, "The Space Economy in Figures," December 15, 2023, https://www.oecd.org/en/publications/the-space-economy-in-figures_fa5494aa-en.html.

[39] Space Foundation, "The Space Report 2024 Q4 Shows Record Annual Launches, Strong H2 Market Performance, and Growing Demand for Tracking and Removal of Orbital Debris," January 21, 2025, https://www.spacefoundation.org/2025/01/21/the-space-report-2024-q4/.

[40] Andy, "How many Earth Observation Satellites are in Space in 2018?" Pixalytics Ltd,, September 5, 2018, https://www.pixalytics.com/eo-satellites-in-space-2018/.

[41] BRYCE TECH, "Smallsats by the Numbers 2024," March, 2018, https://brycetech.com/reports/report-documents/Bryce_Smallsats_2024.pdf.

[42] NOVASPACE, "Earth Observation satellites set to triple over the next decade," July 11, 2024, https://nova.space/press-release/earth-observation-satellites-set-to-triple-over-the-next-decade.

Job Growth: Advancements in the global satellite sector are enabling new job creation within the space industry. The rise in satellite launches due to rapid advancements in the sector, for example, has increased employment opportunities for launch operations, logistics, and support services. Likewise, the growth in space manufacturing is boosting job creation in production and technical roles. Additionally, lower barriers to entry in the industry are encouraging new start-ups to innovate and develop satellite-based solutions, resulting in more job opportunities. According to the Space Foundation, the space sector added more than 26,000 jobs between 2022 and 2023 alone in the space heavy hitters, such as Europe, the US, India, and Japan.[43] This growth was nearly a fourfold increase compared to the previous year, reflecting rapid growth in the satellite sector.[44]

Market Shifts: New advancements in the satellite industry have also undermined parts of the legacy satellite market. A prominent example is the satellite communications industry, as new LEO constellations reduced the competitiveness of legacy players. Companies like Viasat and Inmarsat (providers of geostationary satellite internet) have had to merge or pivot as Starlink's low-latency, low-cost service pulls away customers.[45] This represents a competitive shock that may not have been fully anticipated by those players even a few years ago.

New Costs on Satellite Operators: The rapid increase in satellites and launches has a byproduct: congested orbits and a higher risk of space debris collisions. Companies must invest in collision avoidance measures and debris removal technologies while complying with stricter regulations, imposing new costs on satellite operators. For instance, the US Federal Communications Commission (FCC) introduced a new rule in 2022 requiring LEO satellites to deorbit within five years of mission end (rather than 25) to curb debris growth,[46] increasing costs for satellite operators due to shorter mission life and advanced propulsion systems. Likewise, in 2020, the Organisation for Economic Cooperation and Development (OECD) reported that debris protection measures accounted for approximately 5-10 per cent of total mission

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43 Douglas Gorman, "New Data Shows a Rapidly Expanding Space Workforce," *Payload*, October 23, 2024, https://payloadspace.com/new-data-shows-a-rapidly-expanding-space-workforce/.

44 Ibid.

45 European Commission, "Mergers: Commission Clears Viasat's Acquisition of Inmarsat," May 25, 2023, https://ec.europa.eu/commission/presscorner/detail/en/ip_23_2915.

46 Will Wiquist, "Fcc Adopts New '5-Year Rule' for Deorbiting Satellites to Address Growing Risk of Orbital Debris," *Federal Communications Commission*, September 29, 2022, https://docs.fcc.gov/public/attachments/DOC-387720A1.pdf.

expenses for geostationary satellites, and for satellites in LEO, the costs are even higher.[47] These costs would have grown further due to increased satellite launch activity since 2020 and rising insurance premiums. If debris generation is not curbed, the future costs could be far greater.

Economic Activity in Debris Mitigation: On the flip side, the challenge of debris has also stimulated innovation and economic activity in debris mitigation. A new niche of 'space traffic management' and 'debris removal services' has emerged within the space sector as a direct response. Companies like ClearSpace SA are being funded by agencies like ESA for active debris removal missions,[48] while firms such as D-Orbit offer deorbit kits and propulsion solutions for end-of-life satellite disposal.[49] Meanwhile, LeoLabs provides real-time debris tracking and risk assessment services to satellite operators,[50] and Astroscale delivers on-orbit servicing and compliance solutions.[51]

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47 The European Space Agency, "The Cost of Space Debris," May 7, 2020, https://www.esa.int/Space_Safety/Space_Debris/The_cost_of_space_debris

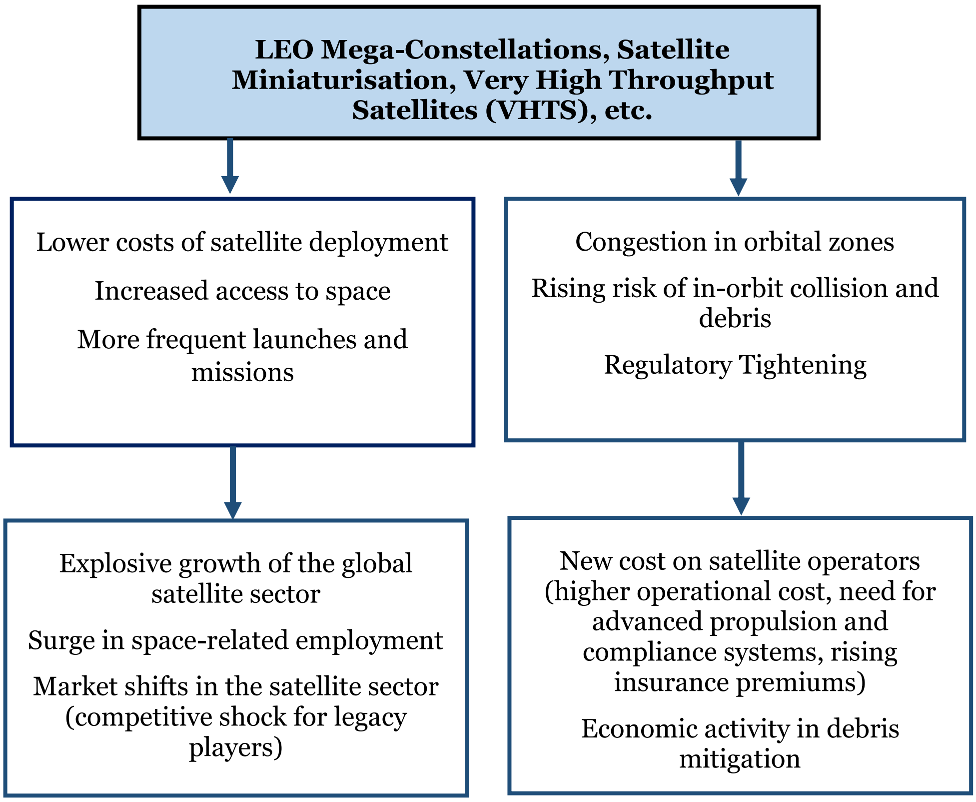
48 The European Space Agency, "ESA Purchases World-first Debris Removal Mission from Start-up," December 1, 2020, https://www.esa.int/Space_Safety/ESA_purchases_world-first_debris_removal_mission_from_start-up.

49 Madhubrata Chatterjee, "D-Orbit's Deorbiting Kit: A Unique Onboard Solution of Space Debris Mitigation by Actively Deorbiting Launch Adaptors from the LEO Orbits," (lecture, 2024 Clean Space Days, Highbay, Netherlands, October 9, 2024), https://indico.esa.int/event/516/contributions/10005/.

50 LeoLabs, "Low Earth Orbit Visualization," Accessed April 1, 2025, https://platform.leolabs.space/visualization.

51 Astroscale, "Astroscale is Dedicated to on-orbit Servicing across all Orbits," Accessed April 1, 2025, https://astroscale.com/.

Figure 2: Within-Unit Spillovers from Advancements in the Global Satellite Sector



Source: Author's Compilation

Between-Unit Spillovers

Productivity Gains: Recent advancements in satellite technology are enhancing productivity across multiple economic sectors by introducing faster data collection, improved accuracy, and enhanced monitoring capabilities. The most prominent case in point is the agricultural sector. The miniaturisation of satellites has led to affordable daily Earth imaging services. Today, companies like Planet Labs operate fleets of more than 200 mini-satellites that capture the entire Earth's land surface every day.[52] A case study in the US showed that a farmer cooperative (Organic Valley) used Planet's imagery-based pasture management tool and achieved a 20 per cent increase in pasture utilisation for dairy farms.[53] In other words, farmers could grow and use 20 per cent more fodder by identifying grazing patterns and field issues from frequent satellite data, directly boosting productivity and income.

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52 Casey Dunn, "How space tech scaleup Planet Labs is driving agricultural productivity," *evokeAG*, November 23, 2022, https://www.evokeag.com/how-space-tech-planet-labs-driving-agricultural-productivity.

53 Ibid.

Likewise, satellite-enabled IoT devices are transforming farming and ranching, especially in remote areas. For example, ranchers use satellite-connected collars and water tank monitors to manage cattle herds spread over vast rangelands. This connectivity allows for tracking animal health, optimising breeding cycles, and managing water resources. One Spanish company's IoT livestock trackers (using the Astrocast nanosatellite network) led to an observed 20 per cent increase in herd reproduction rates by enabling farmers to detect issues timely and more accurately.[54]

Another prominent example is the mining sector. Satellite technologies in mining are being adopted in various regions such as South America, Africa, and Central Asia. Advancements in the global satellite sector enhance mining productivity by enabling faster decision-making, improving equipment management, and optimising resource exploration. Improved EO data enhances mineral exploration by accurately identifying geological structures and resource deposits, minimising exploration time and costs.[55] Real-time data transmission via LEO satellites allows mining teams to detect equipment faults early, reducing downtime and improving operational efficiency.[56]

Cost-Reduction across Different Sectors: Advancements in satellite technology have demonstrated the potential to reduce costs across different economic sectors. In agriculture, for instance, farming solutions leveraging satellite-enabled IoT and low-cost sensors have shown potential to transform resource management. Farmers can assess soil moisture, crop health, and weather conditions in real-time, reducing excessive irrigation, fertilisers and pesticide use. This approach has demonstrated tangible benefits, such as reported water savings of over 50 per cent and a 41 percent reduction in fertiliser usage by farmers in Kenya employing Synnefa's satellite IoT technology.[57] Such efficiency gains directly enhance farm profitability and local food supply.

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54 Astrocast, "Smart Livestock Tracking Powered by Satellite IoT," April 5, 2023, https://www.astrocast.com/news/smart-livestock-tracking-powered-by-satellite-iot/.

55 K.V. Raevich et al., "Space Technologies of Earth Remote Sensing in Applied Problems and Theoretical Studies in Mining," *Eurasian Mining* 1, no. 1 (2023), 3-6, doi: 10.17580/em.2023.01.01.

56 Ibid.

57 Victor Xu, "How Satellite IoT Is Driving Innovation in the Energy & Agriculture Industries," Kratos Defense & Security Solutions, July 24, 2024, https://www.kratosdefense.com/constellations/articles/how-satellite-iot-is-driving-innovation-in-the-energy-and-agriculture-industries.

Another case in point is the supply chain and transportation sector. Large-scale satellite constellations offer real-time global tracking, even in remote regions where traditional systems fall short.[58] Satellite IoT devices provide real-time data on container conditions, location, and environmental changes, enabling informed decisions, optimised routes, and timely deliveries. Miniaturised satellites have made frequent, cost-effective launches possible, improving data refresh rates for tracking applications.

Bridging the Broadband Gap and Business Expansion: Advancements in satellite technology are transforming global connectivity, enabling businesses in remote areas to thrive. Half of the Viasat-3 constellation's (VHTS in geostationary orbit) capacity is allocated to unconnected or underserved regions.[59] Likewise, services like SpaceX's Starlink provide high-speed internet to underserved areas. The economic logic is clear: better connectivity fuels business growth, e-commerce, education, and productivity in those regions.

The hospitality sector, specifically the food and beverage services segment, serves as a case in point. Lakeside Café in the rural UK, for instance, faced major internet issues due to poor fibre coverage.[60] This affected card payments and led to lost sales, especially post-pandemic. Attempts with other providers and 4G routers failed to solve the problem. Switching to Starlink in August 2023 brought immediate, reliable internet access, described by the business owner as a boon for business.[61] Likewise, Coco's, a restaurant chain in rural Mexico, faced challenges due to unreliable internet connectivity, which hindered their operations and customer service. By adopting Starlink's satellite internet service, Coco achieved high-speed, reliable connectivity, enabling efficient operations, improved customer satisfaction, and business growth.[62] Governments in various countries are partnering with satellite operators to extend internet access.

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58 Alizée Acket-Goemaere et al., *Space: The $1.8 Trillion Opportunity for Global Economic Growth*, report (Geneva: World Economic Forum, 2024), https://www3.weforum.org/docs/WEF_Space_2024.pdf.

59 Viasat, "The highest capacity satellites ever built," Accessed April 5, 2025, https://www.viasat.com/about/what-we-do/satellite-fleet/viasat-3/capacity/.

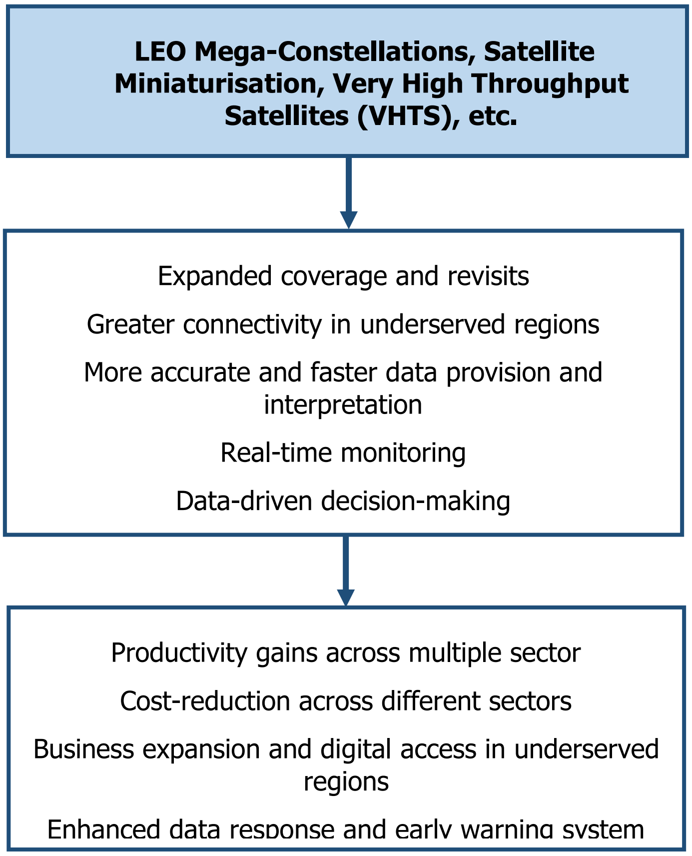
60 Ambition North Wales, "Case Study: Lakeside Café," Accessed April 3, 2025, https://ambitionnorth.wales/media/bsihlpcv/cs-rdc-lakesidecafe.pdf.

61 Ibid.

62 Starlink, "Case Studies," Accessed April 5, 2025, https://www.starlink.com/business/case-studies.

Improved Disaster Management and Environmental Monitoring: Many advances in the satellite realm strengthen the ability to monitor and react to natural disasters and environmental changes. A prime example is European Data Relay System (EDRS), nicknamed the 'SpaceDataHighway.' EDRS uses laser inter-satellite links on two geostationary satellites to instantly relay data from low-Earth Sentinel observation satellites to the ground.[63] This system was developed to reduce the time delay in receiving large volumes of imagery. Likewise, onboard algorithms have demonstrated the potential to detect events like forest fires in the imagery and immediately trigger an alert to the relevant agency on the ground. This has a clear economic spillover: space technology speeds up decision cycles in emergency management, potentially saving lives and reducing damage by enabling quicker evacuations and targeted resource deployment.

Figure 3: Between-Unit Spillovers from Advancements in the Global Satellite Sector



Source: Author's Compilation

63 Michael Witting, "EDRS – the 'SpaceDataHighway' for Earth Observation data," Innovation News Network, August 26, 2020, https://www.innovationnewsnetwork.com/edrs-the-spacedatahighway-for-earth-observation-data/6620/.

Diagonal Spillover Impacts

Market Disruptions: While many cross-sector impacts were intended, some competitive disruptions were an unintended byproduct of the satellite sector's advancements. The most prominent example is the emergence of competitive dynamics between satellite broadband and terrestrial broadband, which were initially seen as complementary. The vast scale of Starlink and VHTS capacity has started to disrupt rural broadband markets. Some telecom providers, such as in Africa, now find that satellites are drawing customers faster and cheaper.[64] This unintended competition may lead to losses for those fibre projects.[65] Conversely, it could encourage terrestrial providers to improve and reduce prices, an unintended benefit for consumers in those areas. For instance, ISPs in Zimbabwe have already been forced to slash prices to retain customers in response to Starlink's entry.[66] Likewise, it could also prompt some terrestrial providers to seek partnerships with satellite operators and improve their rural offerings.[67] For instance, Mobile Telecom Network (MTN) has already been partnering with several Low Earth Orbit (LEO) communication providers, including Starlink, in select markets to enhance connectivity in rural areas.[68]

Changing Investment Patterns: The space sector has seen a significant growth in investment activity, including due to the advancements in the satellite sector, with total annual investment increasing from USD 300 million to over USD 10 billion between 2012 and 2021.[69] In the third quarter of 2024, investments reached USD 2.6 billion, a 64 per cent year-over-year increase.[70] This enormous amount of investment

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64 Telecom Review Africa, "Satellites in the Spotlight: Terrestrial Operators Face New Competition in Africa's Rural Markets," October 4, 2024, https://www.telecomreviewafrica.com/articles/features/4488-satellites-in-the-spotlight-terrestrial-operators-face-new-competition-in-africa-s-rural-markets/.

65 Ibid.

66 Tech Point, "Competitors are Slashing Prices to Compete with Starlink in Zimbabwe," October 25, 2024, https://techpoint.africa/news/competitors-compete-starlink-zimbabwe/.

67 Ibid.

68 IOL, "MTN open to Low Earth Orbit deals as satellite debate heats up," Accessed June 11, 2025, https://iol.co.za/sundayindependent/news/2025-06-10-mtn-open-to-low-earth-orbit-deals-as-satellite-debate-heats-up/.

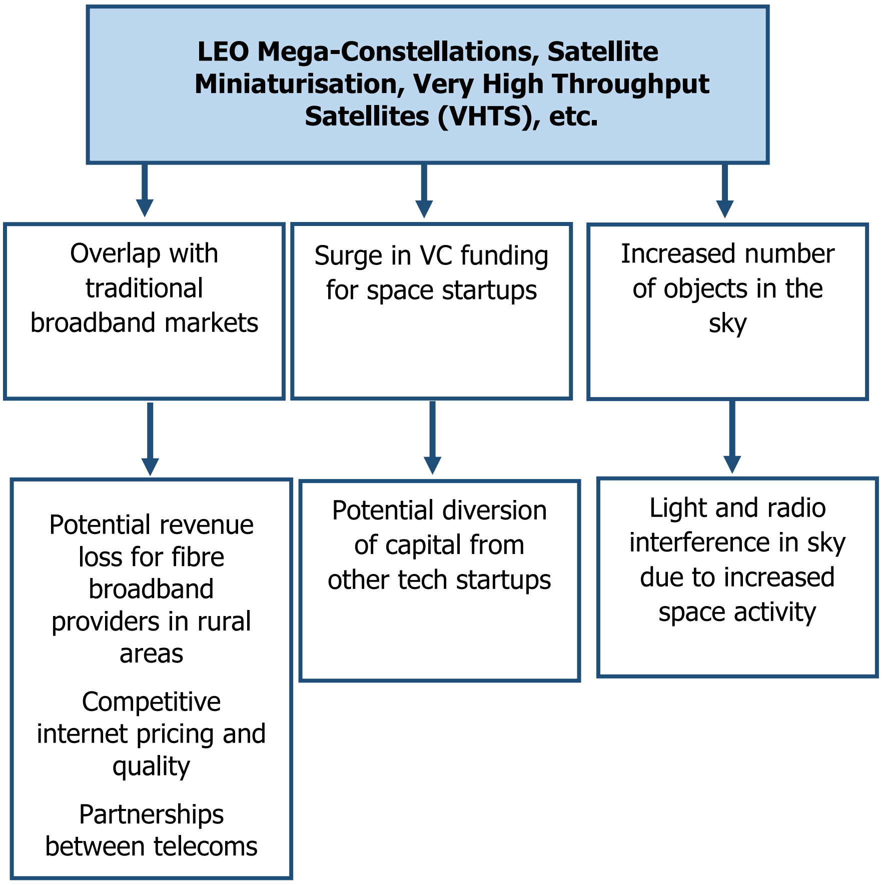
69 Rob Bland et al., "A Different Space Race: Raising capital and Accelerating Growth," *McKinsey*, November 16, 2022, https://www.mckinsey.org/industries/aerospace-and-defense/our-insights/a-different-space-race-raising-capital-and-accelerating-growth-in-space.

70 Alyssa Lafleur, "Space Tech Funding Surges 64% YoY in Q3 2024 Amid Rising Defense Investments," *Space Insider*, October 7, 2024, https://spaceinsider.tech/2024/10/07/space-tech-funding-surges-64-yoy-in-q3-2024-amid-rising-defense-investments.

flowing into space startups suggests a potential diversion of capital from other tech sectors.

Interference with Astronomy and Space Science: The deployment of thousands of new satellites can impact the astronomical community by influencing scientific observation and research. Notably, light pollution and radio frequency interference due to the sheer number of objects in the sky can interfere with astronomical observations,[71] potentially causing scientific miscalculations and financial losses.

Figure 4: Diagonal Spillovers from Advancements in the Global Satellite Sector



Source: Author's Compilation

[71] Sheer Abbas, "Challenges to Space Activities in the Context of Mega Satellite Constellations: A Focus on Environmental Impacts," *Journal of Astronomy and Space Sciences* 42, no. 1 (2025): 1-13, https://doi.org/10.5140/JASS.2025.42.1.1.

Conclusion and Policy Recommendations

The ongoing advancements in the satellite sector demonstrate the far-reaching economic spillovers that can arise from innovation. They exemplify that technological changes come with both opportunities and responsibilities. Within the space sector, they have catalysed the development of a larger, more dynamic, and cost-efficient industry, albeit with new competitive and sustainability concerns. Between sectors, the advancements continue to unlock new capabilities and benefit a broad spectrum of industries and public services. In the diagonal dimension, they have demonstrated that innovation can come with externalities, including negative externalities that must be managed. As these technologies mature, their integration into various sectors is expected to deepen. By understanding these within-unit, between-unit, and diagonal effects, decision-makers can better harness the opportunities while responsibly managing the challenges. Outlined below are the proposed policy recommendations.

Invest in Strengthened Space Debris Mitigation and Traffic Management: Both industry and policymakers must invest in strengthening space debris mitigation and traffic management now (such as through stricter de-orbit rules, funding debris removal tech, and improved tracking) so that the long-term economic risks of orbital congestion are minimised. While stringent measures to strengthen space debris mitigation and traffic management may impose new costs on the space industry, particularly space operators, they will safeguard its sustainable growth, prevent larger economic fallout in the long run, and protect the enormous downstream value satellites provide to other industries. NASA estimates that shortening post-mission orbital lifetimes from 25 years to 5 or 15 years offers significant benefits, potentially exceeding costs by a factor of tens.[72]

Foster Collaboration: Satellite firms and other industries should actively collaborate to ensure smooth spillovers. For instance, more joint ventures or data-sharing agreements between satellite data providers and the agricultural sector can help tailor solutions that maximise economic impact, making intended spillovers more effective. Likewise, telecom companies and satellite operators can share spectrum and infrastructure to avoid conflict and capitalise on each other's strengths.

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[72] NASA Office of Inspector General and Office of Audits, *NASA'S Efforts to Mitigate the Risks Posed by Orbital Debris*, report (Washington, D.C.: NASA, 2021), https://oig.nasa.gov/wp-content/uploads/2024/02/IG-21-011.pdf.

Leverage Public Policy for Positive Spillovers: The government should recognise the satellite sector as critical infrastructure and support its integration into the broader economy. Programs should include cost-effective satellite solutions to realise the intended cross-sector benefits fully. This can involve complementary funding programs to, for example, fund user terminals for satellite broadband in remote areas or provide grants to farmers to adopt satellite IoT tools.

Monitor and Adapt: The pace of change in the satellite realm means stakeholders must continuously monitor spillover effects and be ready to adapt strategies. Governments and international space governance bodies should set up multilateral forums to share data on impacts (e.g., market shifts, etc.) can help identify issues early and ensure that the overall economic outcome remains positive. Additionally, space agencies and economic ministries should jointly track metrics like internet uptake due to satellites, IoT-driven productivity boosts, or employment changes, to quantify benefits and justify further investment or course-corrections in policy.

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