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TAX MEASURES IN SERVICE OF HUMANKIND – TANGIBLE METHODS FOR PREVENTING EXCESSIVE CONGESTION OF LOW EARTH ORBIT AND THE OCCURENCE OF KESSLER SYNDROME

Acronyms/Abbreviations

Low Earth Orbit (LEO)
Outer Space Treaty (OST)
Research and Development (R&D)
Post Mission Disposal (PMD)
Base Erosion and Profit Shifting Tax 2.0 (BEPS 2.0)
Effective Tax Rate (ETR)
European Union Emissions Trading System (EU ETS)
Market Stability Reserve (MSR)
United Nations (UN)
UN Office for Outer Space Affairs (UNOOSA)
Organization for Economic Cooperation and Development (OECD)

Introduction

The following paper is created in belief of serving as a practical guideline for policymakers and legislators in future endeavors of development and implementation of tax measures on payload launches into LEO as well as becoming a baseline for specific scope of subsequent research in the area of space taxation and tax measures on payload launches into LEO.

Arising threat of the Kessler Syndrome

Named after Donald J. Kessler, the Kessler Syndrome (Kessler Effect) describes a scenario in which the density of objects in LEO is high enough that

collisions between objects could trigger a cascade effect, where each one collision generates space debris. Each collision increases the likelihood of further collisions exponentially, possibly in a self-sustaining reaction[1]. The occurrence of Kessler Syndrome would cause significant disruptions to global economy and might make future launches into LEO extremely challenging or even unfeasible for an extended period. The risk of its occurrence escalates with every piece of non--retrievable payload or debris left from completed missions in LEO[2].

In 2025 over 36,400 cataloged objects and more than 130 million accumulated space debris orbit Earth in LEO[3]. Number of objects launched into LEO is steadily increasing, with over 2000 objects launched in 2023 alone, and projections indicating over million objects planned for future launches. These are set to operate within more than 300 mega-constellations[4]. A realistic perspective grounded in recent advancements in SpaceX heavy lift vehicles launch capabilities.

On a cost per kilogram basis, a single-use Super Heavy Starship would reduce the current minimum cost of launches to LEO from $1,500 per kilogram with the Falcon Heavy, to approximately $150 per kilogram[5]. A Reusable Super Heavy Starship would further decrease the cost of launches to LEO to between $10 and $20 per kilogram of payload[6].

Provided that the use of these capabilities remains unregulated, undermined could be progress made by initiatives aimed at mitigating space debris production and promoting the sustainable utilization of Outer Space, LEO in particular[7].

Consequently, it is crucial to address the root cause of the problem – the rapid increase in the volume of payloads with low PMD rates being launched into LEO by heavy-lift vehicles, especially commercial missions in establishing numerous mega-constellations.

Provided that appropriate measures are developed and implemented within a reasonable timeframe, the number annual launches into LEO could be lowered, pace of LEO congestion decreased, and the risk of Kessler Syndrome occurrence stabilized, rather than continue to escalate at an exponential rate[8].

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[1] D.J. Kessler, B.G. Cour-Palais, *Collision Frequency of Artificial Satellites: The Creation of a Debris Belt*, „J. Geophys. Res." 1978, no. 83(A6), pp. 2637–2646.

[2] A. Mariappan, J.L. Crassidis, *Kessler's syndrome: a challenge to humanity*, „Front. Space Technol. Sec. Space Debris" 2023, vol. 4.

[3] ESA Space Debris Office, *ESA's Annual Space Environment Report*, Darmstadt 2024.

[4] A. Falle *et al.*, *One million (paper) satellites*, „Science" 2023, no. 382, pp. 150–152.

[5] T.G. Roberts*, Space Launch to Low Earth Orbit: How Much Does It Cost?*, 1.09.2022, https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost/ (20.09.2024).

[6] B. Wang, *How Will SpaceX Bring the Cost to Space Down to $10 per Kilogram from Over $1000 per Kilogram?*, 19.01.2024, https://www.nextbigfuture.com/2024/01/how-will-spacex-bring-the-cost-to-space-down-to-10-per-kilogram-from-over-1000-per-kilogram.html (20.09.2024).

[7] W.J. Harry, *The Future Impact of Much Lower Launch Cost, ICES-2018-58*, International Conference on Environmental Systems (ICES), Albuquerque, United States, 2018, 8–12 July.

[8] G.A. Henning, M.E. Sorge, G.E. Peterson, A.B. Jenkin, D. Mains, J.P. McVey, *Parameterizing large constellation post-mission disposal success to predict the impact to future space environment*, „Journal of Space Safety Engineering" 2020, vol. 7, issue 3, pp. 171–177.

Introduction of tax measures on the payload launches into LEO

With perspective of unprecedented growth in amount of payload launched into LEO, the adequate measures have to be taken by the international community to prevent the catastrophic outcome. One viable approach is the implementation of tax measures on such launches.

Tax measures could be integrated into the current framework of space governance and tax systems, especially in regard to OST. Article VI stipulates that nations are responsible for overseeing their respective space industries, laying the groundwork for the national administration of tax measures. Article II precludes national appropriation of outer space by claim of sovereignty but does not preclude the establishment of nationally or internationally governed measures, directed towards launches or operations under one's jurisdiction, opening the possibility to introduce the measures.

The inherent flexibility of tax measures enables legislators and policymakers to shape their form and rate, matching the objectives leading to their introduction. In this scenario, a key goal of tax measures would be to achieve at least a modest deceleration in the rate at which payloads are launched into LEO or directly reduce number of objects therein. In turn, the tax measures would be expected to generate revenue, that could be further directed into incentivizing selected areas. Despite commendable intentions, the introduction of tax measures might encounter obstacles. Jurisdictional disputes, for example, are expected to present a challenge for the application of tax measures. In addition to addressing the primary concern of space congestion, the specific design of the tax measures could yield several advantages. These might include increasing the significance of national and international public space agencies, fostering innovation, increasing PMD rates, reducing the number of overall objects in LEO and promoting a more diverse distribution of market share among space industry participants.

Focusing on primarily commercial operations

As an illustrative example, in 2024, SpaceX's Starlink constellation comprises over 7,000 satellites, which is a substantial portion of the approximately 10,200 operational objects in LEO. Despite their commercial intent to provide paid internet services, the Starlink satellites play a considerable role in the potential development of the Kessler Syndrome. They contribute to the dense population of independent objects in LEO, elevating the risk of collisions with smaller debris, which persists even with advanced collision-avoidance systems in place . From December 1, 2023, to May 31, 2024, Starlink satellites executed over 50,000 collision-avoidance maneuvers[9],

[9] T. Pultarova, *SpaceX Starlink satellites made 50,000 collision-avoidance maneuvers in the past 6 months. What does that mean for space safety?*, 23.07.2024, https://www.space.com/spacex-starlink-50000-collision-avoidance-maneuvers-space-safety (20.09.2024).

a figure that has doubled since the last semi-annual report and is expected to rise as more objects enter LEO and the number of satellites in the constellation grows, up to planned 42,000 units.

Given the necessity for innovation that space objects should provide, tax measures should be primarily levied on operators conducting similar activities. These operators, by the sheer volume of objects they deploy into LEO, congest the orbit and significantly increase the likelihood of debris generation. They also contribute to the escalating complexity of collision-avoidance systems, essential, even for objects with scientific or R&D purposes.

Consequently, the principal responsibility for tax measures should fall on the most substantial contributors to the rapid proliferation of objects in LEO, namely the operators of mega-constellations.

Stimulating innovation by tax incentives

To foster innovation, the introduction of tax measures should be accompanied by tax incentives for operations that have clearly defined scientific objectives. When properly implemented, exemptions from the new tax measures could lead to much higher rate of missions with R&D purposes operating in LEO. This would lead to stimulation of innovation, granting a competitive advantage to companies dedicated not only to achieving commercial goals, but also to conducting scientific research.

Additionally, by granting appropriate tax incentives sourced from tax measures to national and international public space agencies engaged in scientific missions, we can expect an enhanced prominence of these entities and a direct increase in likelihood of realizing the projects requested by the academia.

Article I OST declare that "the exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development". The following prevents the establishment of internationally mandated tax measures that could hinder the ability of developing nations to become launching states, Therefore, whenever the following were to be introduced, a consideration on provision of tax incentives for nations that would suffer heavy losses to such introduction would need to be warranted[10].

As an alternative, if the intended outcome of the tax measures would be to artificially stimulate international collaboration, worth considering might be the provision of tax exemptions for space objects that provide full telemetry and mission results data sharing, which could incentivize transparency and cooperation in space endeavors.

[10] C. Steer, *Who Has the Power? A Critical Perspective on Space Governance and New Entrants to the Space Sector*, „Ga. J. Int'l & Compar. L." 2020, no. 751.

Increasing orbit retrieval rates

Long-term hazard to the safe operational space environment's utility posed by new mega-constellations is not fully understood. Potentially achievable, yet undemonstrated PMD success rates are 95–97%, which would enable humanity to sustain larger levels of activity in LEO[11].

In order to sustain operations in LEO without major disruptions, PMD success rates need to be in 90% range in the short to mid-term, with additional measures to solve problem of undisposed mass, and in 95-99% in long term of ~200 years[12]. Current PMD rates stand as low as 20–30%, despite a rush for a change[13].

As follows, an adequate tax measures could become the necessary remedy in increasing the PMD rates.

Model tax measures

Considering the variety of tax measures implemented globally, the primary objective of reducing payload launches into LEO, along with any additional goals set by legislators, could be achieved through multiple distinct forms of tax measures.

It is important to differentiate between taxes and fees. Taxes are compulsory charges that do not necessarily correlate with the benefits received by an individual taxpayer, whereas fees are charged in exchange for the provision of specific, quantifiable services or goods[14].

To establish a broad foundation from which other, more tailored tax measures can be developed, ones that are most appropriate for the current state of the space sector and LEO activities, the examples provided here, encompassing both taxes and fees, are intentionally varied. It is important to recognize that these examples may not represent the optimal solution to the issue at hand, but rather serve as illustrative models aimed at mitigating the risk of the Kessler Syndrome and fostering the sustainable development of LEO.

Fee on the duration of an object's presence in LEO

Proposed fee would be levied annually on every object in LEO, charging for the use of LEO space. The fee would be calculated based on the time an object remains in orbit, regardless of its size.

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[11] G.A. Henning, M.E. Sorge, G.E. Peterson, A.B. Jenkin, D. Mains, J.P. McVey, *Parameterizing large constellation*…

[12] *Ibidem*; M.K. Zhu, *A break-even analysis of orbital debris and space preservation through monetization*, „Journal of Space Safety Engineering" 2022, vol. 9, issue 4, pp. 600–611.

[13] *Ibidem*.

[14] H.D. Spitzer, *Taxes vs. Fees: A Curious Confusion*, „Gonz. L. Rev." 2002, no. 335.

A fee structured around the duration of an object's presence in LEO incentivizes the timely removal of objects from orbit, as failing to align with this priority could become prohibitively costly. The financial impact of this fee aims not only to reduce the number of objects launched into LEO but, more critically, to decrease the actual number of objects occupying LEO at any given time.

The tax measure model based on a fee for the time an object spends in LEO is further examined in publication of A. Rao, *et al.*, Orbital-use fees could more than quadruple the value of the space industry[15]. The study suggests that this measure could significantly increase the long-term value of the satellite industry by 2040, from an estimated $600 billion to approximately $3 trillion. This is attributed to the discouragement of unnecessary launches and the encouragement of safer operational practices. The model proposes an optimal fee starting at about $14,900 as of 2020, increasing annually by 14%, which would equate to roughly $235,000 per satellite-year by 2040.

However, more preferable system facilitated by the model would be creation of a system akin to tradable permits for operating objects in LEO, similar to a cap-and-trade system employed in carbon markets (for instance the most prominent EU ETS system)[16]. Governments or an international authority would be allowed to issue a finite number of permits for operations in LEO, which would be tradable, allowing companies to buy and sell launch rights with value based on market demand. By design, the system would lead to reduction in number of objects present in LEO but might lead to significant reduction of employment in regulated sectors[17]. To minimize the negative turnout, a pilot phase and gradual implementation of the system in set phases could be implemented. However, with the adequate measures in place that could still lead to reduction in employment in area of 5–10% in the final phases of system implementation[18].

Flexibility of the measure would allow for fee adjustments based on real-time evaluations of orbital congestion. Launches that occur during periods of high congestion, particularly to more crowded orbits, would be subject to higher fees. Conversely, launches during less active periods or to less congested orbits would incur lower fees.

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[15] A. Rao *et al.*, *Orbital-use fees could more than quadruple the value of the space industry*, PNAS 2020.

[16] R. Schmalensee, R.N. Stavins, *Lessons Learned from Three Decades of Experience with Cap and Trade Richard*, „Review of Environmental Economics and Policy" 2017, no. 11(1), pp. 59–79.

[17] F. Biancalani, G. Gnecco, R. Metulini *et al.*, *The impact of the European Union emissions trading system on carbon dioxide emissions: a matrix completion analysis*, „Sci Rep" 2024, no. 14, 19676; A. Dechezleprêtre, D. Nachtigall, F. Venmans, *The joint impact of the European Union emissions trading system on carbon emissions and economic performance*, „Journal of Environmental Economics and Management" 2023, vol. 118, 102758.

[18] U. Wagner *et al.*, *The Causal Effect of the European Union Emissions Trading Scheme: Evidence from French Manufacturing Plants*, 2014.

In cap-and-trade system, the market would be self-regulatory and less predictable. Introduction of system comparable to EU ETS MSR would be advised to stabilize the market and mitigate possible allowances overhang in the short term. However, as MSR does not increase resilience to shocks and lowers price predictability in the mid to long term, a suitable alternative, designed for the specific type of measure could be developed[19].

Fee on size of the payload launched into LEO

This proposed measure would impose a fee on every payload launched into LEO, that is calculated based on the object location in universal size classification.

Volume rather than mass of an object is more representative indicator of the satellite real size in LEO, as to some extent it determines the base probability of object colliding with another object on a given orbit, reflecting the object's effective surface of exposure.

Therefore, to reflect volume of the object, while still taking into account its mass, a universal size classification of an object would be developed, as reflected in A.S.R.C. Botelho, L.X. Ademir Jr., A Unified Satellite Taxonomy Proposal Based on Mass and Size[20]. In presented classification, satellites would be grouped into 10 classes and various subclasses, following specific rules depending on mass and volume, encompassing objects with mass ranging from 1,000,000 representing interplanetary spacecrafts on the other, leaving room for possible technological advances. For practical purposes, volume and mass required for launch of payload might be taken into consideration.

The financial burden imposed by this fee would raise the expense of launching into LEO, which is expected to lead to a decrease in launch frequency. By placing the responsibility for the fee on the launch service providers and clarifying that these costs are to be transferred to the customers or organizations carrying out the launch, the fee system could be significantly streamlined in comparison to the income tax approach outlined in 4.3, where such direct cost pass-through may not be feasible.

However, unlike the income tax model, this fee-based approach would necessitate tax exemption for missions with established scientific objectives or those conducting R&D work. Without such incentive, the fee could impede essential research activities, the unobstructed continuation of which should be of paramount interest to all stakeholders.

An alternative to a straightforward fee, would be a refund-based fee, refunded provided that the object is deorbited. This could provide a strong incentive to

[19] S. Borghesi, M. Pahle, G. Perino, S. Quemin, M. Willner, *The Market Stability Reserve in the EU Emissions Trading System: A Critical Review*, „Annu. Rev. Resour. Econ." 2023, no. 15, pp. 131–152.

[20] A.S.R.C. Botelho, L.X. Ademir Jr, *A Unified Satellite Taxonomy Proposal Based on Mass and Size*, „Advances in Aerospace Science and Technology" 2019, no. 4, pp. 57–73.

increase the use of reusable launch vehicles, self-deorbiting satellites, and actuate a rise of companies offering retrieval services from LEO.

Provided that a universal size classification would be introduced, final classification of burden should be relatively straightforward. Classification of satellites to 10 classes would allow for more personalized approach, compared to general fee per volume or mass of an object.

Tax on revenue from payloads launched into LEO

This taxation approach, primarily designed to reduce the number of payload launches into LEO would subject any revenue generated from payloads launched into LEO by the payload provider to an income tax, applied in addition to pre-existing income taxes. Notably, missions with established scientific objectives or those conducting R&D work would likely be exempt from taxation, given that they typically do not generate income.

A significant limitation of this tax measure is its singular focus on reducing launches without addressing the retrieval of objects from LEO after their missions. Additionally, imposing an extra tax solely on revenue from objects in LEO could lead to a downturn in the space sector, where due to the imposed taxes, investments into space sector would produce lower returns compared to other comparable industries. The tax however would be considered adjusted covered tax under BEPS 2.0 Pillar II, which mandates a minimum ETR of 15% on income. Following tax measure would be adjustable within that framework, not requiring to cover tax over 15%, unless otherwise specified by national legislation.

Determining who bears the tax burden would also pose a challenge, whether should it fall on the corporation operating the LEO-launched object, or should the capital's source be traced, shifting the burden to the ultimate parent entity of the capital group.

Additionally, accurately determining the exact income derived from payloads in LEO would be complex, especially when considering the potential use of downside or upside methods for income calculation. While feasible, choosing an appropriate method would be challenging[21].

Allocation of revenue from tax measures

The formula of tax measures require allocation of revenues to body capable of utilizing them. That is either national governments or internationally governed funds, preferably affiliated with the UN or the OECD.

[21] *OECD Handbook on Measuring the Space Economy*, Paris 2022.

National governments

Allocation of revenue from tax measures to national governments or tax regulatory bodies might possibly enhance national regulatory oversight, foster innovation in the individual launching states and incentivize effective governance of the existing space industry, by further centralizing the industry over current major launching states.

Nations could utilize the revenue to support their space program, incentivize private companies to perform R&D works and adopt sustainable practices which may include developing debris removal technologies, designing sustainable satellites, improving space traffic management systems and end-of-life deorbiting technologies.

Determining the rightful recipients of the revenue could pose challenges. Depending on the chosen framework, the beneficiary could be the state from which object is launched, the state where the operating corporation is based, or the state of the ultimate parent entity of the capital group, if the source of capital is traced.

Internationally governed funds

Allocation of revenues to internationally governed funds, serving global interests would certainly increase international cooperation in LEO and encourage participation in space activities of new launching states, ensuring equitable access to sustainable development opportunities. To utilize already established facilities, fund should be managed by an internationally governed entity such as the UNOOSA, OECD.

Alternatively, a new institution could be established. An internationally administered fund dedicated to incentivizing R&D works by the developing space actors would ensure that the tax revenue supports global interests. The fund could provide funding for developing countries to increase their involvement in the space economy, while adhering to sustainable practices. Implementing a grant program for space sustainability and scientific missions, which might be exempt from standard tax measures, could also contribute to the long term health of LEO and boost international collaboration.

Hybrid Approach

A hybrid model would allocate a portion of the tax revenue to national governments and contribute to development of internationally administered funds. This dual approach would address both national interests and global sustainability

objectives, fostering a more equitable and collaborative framework for space governance. However, delimitation of responsibilities and excess amount of governance might become an issue.

Strategies for implementing tax measures

The method of tax measures implementation will vary based on the decision regarding beneficiaries of the generated revenue.

Implementation could occur at the national level, with individual states enacting the tax measures, or at the international level.

For national-level implementation, a universal global tax rate would need to be established to prevent the emergence of jurisdictions with preferential rates, or so called tax havens. The BEPS 2.0 Pillar II initiative has demonstrated that a universal global tax rate for a specific tax (such as corporate income tax) can be set with adequate international governance and the collective efforts of OECD and G20 countries.

Under this first approach, tax measures would be collected and regulated by national tax authorities, but the system would be internationally harmonized through agreements among spacefaring nations, potentially under the auspices of the UNOOSA or the OECD.

An alternative approach to implementation on national level would involve establishing a new international organization, which would directly administer the tax. All entities launching payloads into LEO would be mandated to register with organization. The tax would be imposed and collected based on criteria that have been globally agreed upon, in line with the internationally selected tax measure.

Impact of tax measures on the sustainable development of LEO

The urgency to secure the sustainable development of LEO is clear, as the proliferation of space debris increase the risk of the Kessler Syndrome occurrence. With the long-term implications in mind, the time for decisive action is now, not in the future. Nonetheless, the introduction of tax measures may encounter resistance from the private space sector, necessitating a careful balance between economic interests and environmental sustainability.

Tax measures targeting payload launches into LEO could represent a significant stride toward its sustainable development. By incentivizing efficiency and R&D works, reducing objects launched to LEO annually, increasing retrieval rates, and fostering international cooperation, tax measures might have a crucial role in development of LEO. The revenue generated from these tax measures should be

allocated to grant programs and R&D initiatives encouraging the management of orbital congestion and the advancement of active debris removal and satellite retrieval technologies. By adequately governed internationally administered funds, limited access to space sector by developing nations could also be addressed.

Undoubtedly, the greatest challenges lie in selecting appropriate tax measure, determining the beneficiaries of the revenue, and integrating the chosen approach into the international tax law framework.

Provided that uniform stance on the development of measure would be agreed upon, its implementation become not only an adequate action, but a necessary last resort to prevent excessive orbit congestion, the Kessler Syndrome and ensure a long-term sustainable development of LEO.

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Summary

In 2025 over 36,400 cataloged objects and more than 130 million accumulated space debris orbit Earth in LEO. Number of objects launched to LEO is steadily increasing, with over million scheduled to launch in the future that are to operate in more than 300 mega constellations. Unregulated usage of these capabilities could diminish established achievements of movements towards sustainable use of Outer Space, LEO in particular. The paper will analyze implementation of additional tax measures on launches to LEO, by outlining what types of tax measures could provide the most feasible method to reduce number of satellites in LEO. Accordingly, a possibility of provision of tax incentives on operations with established scientific goals and possibility to incentivize orbit retrieval rates will be considered. Finally, paper will analyze how introduced tax measures would contribute to sustainable usage and development of LEO.

Keywords: taxation, international space law, orbit congestion, space debris, long-term sustainability of outer space activities

ŚRODKI PODATKOWE W SŁUŻBIE LUDZKOŚCI – KONKRETNE METODY ZAPOBIEGANIA NADMIERNEMU ZATOROWI NISKIEJ ORBITY ZIEMSKIEJ I WYSTĘPOWANIU ZESPOŁU KESSLERA

Streszczenie

W 2025 r. ponad 36 400 skatalogowanych obiektów i ponad 130 mln zgromadzonych śmieci kosmicznych orbituje Ziemię na LEO. Liczba obiektów wystrzelonych na LEO stale rośnie, z ponad milionem obiektów zaplanowanych do wystrzelenia w przyszłości, które mają działać w ponad 300 megakonstelacjach. Nieuregulowane wykorzystanie tych możliwości może zniwelować zrównoważone wykorzystanie przestrzeni kosmicznej, w szczególności LEO. W artykule przeanalizowano wdrożenie dodatkowych środków podatkowych dotyczących startów na LEO poprzez określenie, jakie rodzaje środków podatkowych mogłyby zapewnić najbardziej realną metodę zmniejszenia liczby satelitów na LEO. W związku z tym rozważono możliwość zapewnienia zachęt podatkowych dla operacji o określonych celach naukowych oraz możliwość wprowadzenia dotacji na rzecz zwiększania szybkości deorbitacji obiektów. Finalnie artykuł przeanalizował, w jaki sposób wprowadzone środki podatkowe przyczyniłyby się do zrównoważonego wykorzystania i rozwoju LEO.

Słowa kluczowe: opodatkowanie, międzynarodowe prawo kosmiczne, zatłoczenie orbity, śmieci kosmiczne, długoterminowy zrównoważony rozwój działalności w przestrzeni kosmicznej