Astro-Environmentalism: Towards a Polycentric Governance of Space Debris

Jean-Frédéric Morin and Benjamin Richard
Université Laval

Abstract

The Earth's orbital space is increasingly threatened by debris. It is frequently described as a common-pool resource vulnerable to a 'tragedy of the commons' scenario. Scholars have suggested ambitious policy proposals to tackle the tragedy of space debris and assure the sustainability of the Earth's orbits. Their proposals can be classified into three categories: hierarchical regulations, economic incentives and property rights. All three categories require some form of central coordination. However, there might be an alternative approach to the problem and other potential solutions. Elinor Ostrom suggested that decentralized, polycentric systems are appropriate for governing common-pool resources. Anecdotal evidence suggests that a polycentric form of governance can encourage a more sustainable use of the Earth's orbits.

1. Sustainability in outer space

Space is a polluted environment. Recent estimates suggest that there are around 34,000 pieces of debris larger than 10 cm orbiting around the Earth (European Space Agency, 2020). Human activity in space is largely responsible for orbital debris, which can consist of defunct satellites, fragments from the break-up of satellites, separated stages of launch vehicles, discarded propellant tanks, tools dropped by astronauts or even tiny flecks of paint. Depending on its altitude, space debris has different degrees of persistence: from a few days, in the case of debris that is less than 200 km above the Earth's surface, to almost indefinitely, if the debris is approaching Geosynchronous Earth Orbit (GEO) altitudes (36,000 km above the Earth's Equator). Peak debris density in Low Earth Orbit (LEO) occurs at 885 km, where orbital debris persistence is assessed in centuries (Anz-Meador et al., 2018).

The pollution of the Earth's orbital space by debris is a problem of major importance. Debris often delays spacecraft launches, causes radio frequency interference, spoils telescope observations, damages space structures and requires avoidance manoeuvres. Even a tiny fleck of paint can be highly destructive when travelling at a velocity of 25,000 km/hour. The Space Shuttle was struck with a microparticle of debris in 1983, which cracked its windscreen. In 1996, part of an old rocket hit and damaged a French satellite in operation. In 2009, a United States Iridium commercial satellite was destroyed in collision with a defunct Russian satellite. Damage of this sort can have severe consequences, as societies increasingly rely on satellites for weather forecasting, traffic control, geolocation and navigation, broadcasting, communication, Internet, etc.

What makes the problem a major concern is the fact that space debris pollution has a self-generating character: when a piece of space debris collides with another space object, they explode, creating additional debris, thus increasing the likelihood of future collisions. The 'Kessler Syndrome' refers to a possible chain reaction of collisions that create an exponential amount of new debris (Kessler and Cour-Palais, 1978). A self-propagating cascade of collisions of this type would restrict outer space activities and could ultimately block humankind's access to space. Although the probability of such an event is still unknown, it will only increase with the unsustainable use of space.

A sustainable use of the Earth's orbital space requires three types of action: (1) mitigation efforts to reduce the creation of new debris; (2) monitoring activities to track even the smallest debris; and (3) remediation initiatives to remove existing debris (Baiocchi and Welser, 2010). Engineers are inventing various new devices to address the technical aspects of these actions. However, the greatest challenge remains the problem of collective action: how can actors be encouraged to invest money and effort when the benefits and risks are shared by all.

This paper reviews the various policy proposals to address this problem of collective action. The next section presents the canonical description of the pollution of the Earth's orbital space as a tragedy of the commons. The following section discusses three types of policy solutions, which are commonly suggested. They rely on centralized coordination, which is based on regulation, incentive and property rights, respectively. The last section introduces a less intuitive, but more feasible (and perhaps even more effective) approach, based on polycentric governance.

2. The tragedy of space debris

The Earth's orbital space is commonly referred to as a *common-pool resource* (Salter, 2015; Taylor, 2011; Tepper, 2019). Goods vary along two dimensions: (1) excludability, that is, the capacity of preventing others from benefiting from the resource; and (2) rivalry, namely, the degree to which one person's consumption of a resource prevents another person from consuming the same resource. A common-pool resource is a resource that is both nonexcludable and rivalrous (Ostrom, 1990, 2010).

The Earth's orbits are nonexcludable: preventing others from enjoying the benefits of the Earth's orbits is difficult under the present treaty regime for outer space, most notably the 1967 Outer Space Treaty, which provides that 'Outer space [. . .] shall be free for exploration and use by all States [. . .]' (Article I). The Earth's orbits are also rivalrous: once a spacecraft or even a piece of debris is in a given orbital slot, another spacecraft cannot simultaneously occupy the same location. This especially holds true in the case of the most congested orbits, such as the Low Earth Orbit and polar orbits. Resources that are nonexcludable and rivalrous, such as the Earth's orbits, are common-pool resources.

According to the traditional view, being a common-pool resource makes the Earth's orbital space particularly vulnerable to the 'tragedy of the commons' (Hardin, 1968). This classic problem of collective action in environmental governance inexorably leads to the overexploitation and degradation of open access resources. When resources are nonexcludable and rivalrous, each individual actor has an incentive to consume as much of the resources as they can before their competitors do. Similarly, there is little incentive for each actor to invest in conservation, since the benefits would be diluted among the entire community of actors. Thus, space actors have an incentive to continue using the Earth's orbits unsustainably, without taking the necessary action to remediate the problem or reduce the activities that create more space debris. According to this traditional account, individual rational behaviour produces an irrational collective outcome: orbits are congested with debris.

John Vogler (2012, p. 61) observes that 'the designation of areas and resources as global commons is evidently related both to technological change and scarcity'. Recent developments suggest both variables are also playing out in the context of the 'tragedy of the space commons' (Shackelford, 2014, p. 435). Lower launch costs and the development of smaller satellites have led to the proliferation and diversification of space actors (Adolph, 2006). An increasing number of countries, including developing countries, now have their own satellites. In addition, the space industry is growing rapidly, with numerous privately-owned satellites and private launch services. Projects for space-based Internet connections – involving Google, Facebook and Amazon – will place thousands of satellites in orbit. SpaceX already launched more than 800 satellites since May 2019 and is planning to deploy up to 42,000 satellites in the coming decades. These developments will make space even more congested and increase the risk of collision.

3. Centrally-coordinated solutions

The Outer Space Treaty provides that the exploration and use of space 'shall be the province of all mankind' (Article I). By suggesting that humanity shares a custodial responsibility over this domain, the treaty invites the international community to establish mechanisms to guarantee its sustainable use. However, few measures to improve sustainability have been implemented and the tragedy of space debris is getting worse.

Several scholars have suggested ambitious policy proposals to overcome the unfolding tragedy of the space commons. They can be classified into three broad categories: (1) hierarchical regulations; (2) economic incentives; and (3) property rights.

3.1. Hierarchical regulations

Top-down regulations, combined with monitoring and sanction mechanisms, can alleviate the tragedy of the commons. Clear and nondiscriminatory rules facilitate convergence towards cooperative behaviour, while enforcement mechanisms dissuade freeriding. This is the model underlying several agreements governing high-sea fishing and transboundary air pollution.

Existing treaties on outer space, such as the Outer Space Treaty and the Liability Convention, provide an insufficient regulatory framework for dealing with the orbital debris problem (Roberts, 1992). Their references to space debris are indirect and ambiguous. For example, it is not clear if legal concepts, such as 'harmful interference', 'harmful contamination' and 'space objects' apply to the full range of space debris. Other multilateral instruments formally dealing with space debris, such as the United Nations Space Debris Mitigation Guidelines, are nonbinding.

Several authors recommend a more precise and obligatory regulatory regime to fill the important gaps in the existing treaties. Their proposals include calls to amend existing treaties (Gupta, 2016) or to adopt a new treaty on space debris (Hollingsworth, 2013; Imburgia, 2011; Mejía-Kaiser, 2020). Scholars assert that a clear and stable legal framework would give new impetus to help make progress on the space debris problem, for example, developing cost-effective debris-removal techniques. More importantly, a solution to the space debris problem in the form of a binding international agreement could legally require countries to implement actions for the sustainable use of the Earth's orbital space. States would then be expected to enforce treaty provisions on their citizens and private corporations. Furthermore, monitoring and penalty procedures would constrain spacefaring nations into achieving set targets.

However, reforming an existing regulatory framework can be more challenging than establishing one from scratch. The stakes are clearer and greater than they were in the 1960s, when space activities were limited. Moreover, the existing treaties created expectations, established reference points, structured institutions, shaped policies and channelled investments. Space actors are embedded in the regulatory system they created, which means they are hostile to disruptive regulatory changes (Phillips and Pohl, 2020). As a result, reaching a multilateral agreement is increasingly difficult. The last legally-binding multilateral treaty was the 1979

Moon agreement. It was ratified by only 18 states, which did not include any of the space superpowers.

The high vulnerability of space operators to damage arising from the proliferation of new space actors, especially in low Earth orbit, accentuate the need for managed interdependence. In 1963, the International Telecommunication Union was given the mandate of managing the allocation of orbits and radio spectrum in geostationary orbit given increasing radio interference between satellites. A similar legal regime aiming to manage physical collisions between satellites is possible in principle. Yet, the proliferation of space actors increases the transaction cost of a negotiated solution, making this outcome gradually less likely.

Given the potential difficulties of addressing the problem of space debris through negotiated mechanisms, advocates of a hierarchical regulatory regime have called for an International Court of Justice (ICJ) ruling on debris. A ruling would avoid the risk of diplomatic inertia and provide the authoritative framework to apply the principles of general international law to space debris. For example, it has been suggested that the International Court of Justice adjudicate space debris as an environmental nuisance in violation of the principle of responsibility for transboundary harm (Kellman, 2014). As such, polluters would be held legally responsible for tackling the problem of space debris and would be required to ensure that the use of the Earth's orbital space is more sustainable.

However, a judicial ruling would lack the scope to make specific obligations more comprehensive. A ruling can provide general principles, but not the details required to implement them. A global effort to resolve an issue as intricate as the sustainable use of orbital space requires the genuine mobilization and leadership of the main spacefaring states (Kellman, 2014; Salter, 2015). Consequently, judicial resolution would eventually have to give way to diplomatic processes, which brings us back to the obstacle of transaction costs.

3.2. Economic incentives

Since the writings of Arthur Cecil Pigou (1932), the standard economic approach to solving the tragedy of the commons is to force actors to internalize the social costs of their activity, that is, the negative externalities. Orbital debris is a negative externality associated with the launch of spacecraft and satellites into space. Some scholars have suggested a tax on launches as a potential economic solution to the orbital debris problem (Adilov et al., 2015; Adolph, 2006). This type of tax could be linked to the size of the externality in order to deter unnecessary launches and incentivize the use of debris mitigation technology. By raising the private cost of generating more pollution in the Earth's orbits, the creation of debris would be reduced. Moreover, the revenue collected from this tax could be invested in active debris removal (Adilov et al., 2015).

Environmental taxation is frequently used by governments at the domestic level, but seldom internationally. The main obstacle to introducing taxation to govern global commons is the absence of a global government. Indeed, not a single international entity has the legitimacy and the necessary authority to levy a tax or impose a limit on the quantity of pollution emitted. One rare exception is the International Seabed Authority, which collects fees for deep-sea mining activities. This mechanism was negotiated in the 1970s, before there were any mining activities on the international seabed. Nonetheless, it was highly controversial and the United States is still not a member of the Authority. While the seabed provisions of the United Nations Law of the Sea Convention are based upon the principle of 'common heritage of humankind', which provides the normative basis for legitimate collective public management at the international level, space treaties largely avoid using this concept. One exception is the 1979 Moon Treaty, whose common heritage idea of equitable distribution of the economic benefits derived from space activities among all states is an important reason for its alleged failure (Keefe, 1995).

Meyer (2010) suggests considering space as a 'district' under the authority of an international entity that would collect taxes on private space activities on behalf on the international community. This suggestion is unlikely to receive universal support, as private space activities are already flourishing in several countries. In the absence of a universal taxation scheme, it is likely that private space actors would relocate their launch activities to countries that do not levy tax. This would create an incentive for states aspiring to attract space investment to reject any form of taxation on space activities.

An additional challenge is that environmental externalities are difficult to quantify in monetary terms. What monetary value should be attributed to the exploitation of an orbital slot? If environmental externalities are overestimated, businesses and taxpayers are likely to oppose a new tax, which they consider unjustified. Inversely, if they are underestimated, environmental degradation continues as environmental taxes essentially serve as licences to pollute, which rich corporations can afford to pay for the common goods they use.

Another type of economic incentive is to subsidize those who adopt virtuous behaviour. Drago (2019) recommends a 'reward-for-recovery' scheme, similar to the maritime law of salvage. Under the maritime law of salvage, a person or entity who retrieves a ship that is lost or in peril at sea is entitled to a reward for performance. When applied to the context of space law, rewards would also be provided in cases where the salvor performs 'a service that saves the environment' (Drago, 2019, p. 419). Otherwise, space companies have no incentive to spend money to remove existing orbital debris. Applying the maritime law of salvage to outer space would financially support the development of remediation technologies by rewarding innovators.

On a political level, subsidies are attractive because they spark less concentrated opposition than taxation. However, they require public funding. One option is to create an international debris removal fund. Undoubtedly, some countries, especially those who are not major polluters, will be reluctant to contribute financially. Moreover, determining the correct size of the economic incentive is problematic. A modest subsidy would not provide sufficient incentives for innovation, while a generous subsidy would require more resources than economically optimal (Salter, 2015).

3.3. Property rights

A third category of potential solutions to the tragedy of the space commons involves the attribution of property rights. For the Nobel laureate Ronald Coase, the problems raised by externalities can be solved with clearly specified property rights (1960). Owners of these rights have an incentive to protect their property and ensure their sustainable use in order to maintain their market values. They can also use contracts and litigation to ensure that they receive fair compensation in the event of damage to their property. Thus, under this system, the market rather than a public or an intergovernmental authority defines the price of environmental externalities, which is a way round the pricing problem associated with taxation (Salter and Leeson, 2014). The role of governmental authorities is to allocate property rights and institutionalize a market where these rights can be sold, rented or auctioned.

Following this logic, scholars have suggested 'dividing space resources into parcels and award[ing] them to nations via a lottery' (Cooper, 2003, p. 117). In 1988, following a campaign led by developing countries against the allocation of geostationary orbit slots based upon the principle of 'first come, first served', the International Telecommunication Union devised a plan that effectively divided among all nations a certain portion of radio spectrum and orbit. Some advocates of the 'territorialization of space' consider that the management of space debris requires a 'higher level of regulation', which individual states can provide more effectively than the international community (Elhefnawy, 2003, p. 56). Alternatively, once a state obtains jurisdiction over a section of the Earth's orbit, it could divide it and auction small portions to private entities. This would be akin to the extension of sovereignty rights under the law of the sea, which allows states to grant fishing licences to private entities.

There are obvious difficulties with implementing this kind of mechanism in outer space. The Outer Space Treaty forbids states from extending their territorial sovereignty to outer space (Article II). This rules out the possibility of attributing clear private property rights in outer space (White, 2002). In 1976, a group of equatorial countries issued the Bogotá Declaration as an attempt to assert sovereignty over the geostationary orbit located above their respective territories. Given the legal regime for space, their claim was largely rejected by other states. Even if we put aside these legal difficulties, the practical challenges of defining property rights in outer space are significant. For example, while satellites in Geosynchronous Earth Orbit may remain above a given country indefinitely, satellites in Low Earth Orbit do so for only a short period of time, completing their orbit around the Earth in approximately 90 minutes. In other words, 'the physical characteristics of space make the establishment of traditional, spatially demarcated property rights impractical, especially for LEO' (Taylor, 2011, p. 258).

Accordingly, scholars suggest that property rights could be associated with the externalities rather than with a geographical territory. This is the logic underlying carbon credit schemes, which allow businesses to emit a certain quantity of pollutants per year. Similarly, property rights could take the form of tradable debris licences (Taylor, 2011). These would essentially be property rights for a virtual quantity of space, which companies would choose to utilize or sell. When growth in space activity generates an increase in demand for licences, their price is likely to rise. Businesses would then be encouraged to develop new technology to reduce the creation of debris, to avoid having to buy another licence. They could even make a profit by selling the licence initially allocated to them or bought at auction. Similarly, the development of space debris removal technology would be encouraged if space companies could offset future debris pollution by removing debris from orbit (Taylor, 2011).

The 1971 Convention on International Liability for Damage Caused by Space Objects already provides a framework for compensation. Moreover, the 1974 Convention on Registration of Objects Launched into Outer Space helps to identify space objects and their owner. However, these conventions were not designed to address the problem of space debris and remain ambiguous (Roberts, 1992). In their current form, they do not provide an adequate framework to make satellite operators liable for the debris they create, that is, they do not induce operators to internalize their environmental externalities (for example, by purchasing an insurance against the emission of debris) (Wang, 2016).

In line with other centrally-coordinated solutions, property-based solutions would require the adoption or revision of international treaties. There is a broad consensus in the literature that the space debris problem requires a multilateral response centred around a comprehensive regulatory regime (Kurt, 2015). However, as the next section discusses, there might be another way to conceive of the problem and its solutions.

4. Envisioning a polycentric governance system

Many critics of the tragedy of the commons metaphor argue that it provides an inaccurate description of the problem at hand and, therefore, fails to propose a specific solution. Elinor Ostrom, the first woman to receive the Nobel Prize in Economic Sciences in 2009, refutes the presumption that if common-pool resources are not governed by a central authority, which imposes rules on resource users, they will inevitably be overexploited until exhaustion (Ostrom, 1990, 2010). She argues that, under certain conditions, collective action can be achieved when users self-manage common-pool resources. She finds that polycentric governance systems are often more effective for achieving sustainable outcomes than centralized solutions.

Governing access and use of the commons through a polycentric system of governance can have 'considerable advantages' (Ostrom, 2010, p. 552). Polycentric systems favour the experimentation of different approaches, which generate learning and innovation. As such, they provide the flexibility necessary to self-correct and evolve incrementally (Tepper, 2014). These are significant benefits for governing complex problems, characterized by high uncertainty, a wide diversity of actors and changing technologies. Compared with centralized systems, polycentric systems might come at the cost of redundancies and ambiguities. This may be a price worth paying for a governance system capable of adapting to a changing environment.

However, not every polycentric system governs common-pool resources sustainably. Ostrom (1990) developed an eight-principle framework that outlines the conditions necessary for a successful polycentric system. Building on these principles, some space governance scholars consider that orbital debris governance could be improved incrementally (Kurt, 2015; Shackelford, 2014; Tepper, 2014; Weeden, 2012; Weeden and Chow, 2012).

The space governance system is already polycentric. It is made of multiple international regimes, including a liability in space regime, the satellite allocation regime, the moon regime and the international space station regime (Stuart, 2013). It fits the definition of a 'regime complex', for example, an 'array of partially overlapping and non-hierarchical institutions' (Raustiala and Victor, 2004). Regime complexes are a middle ground between a fully integrated regime centred around one key institution and a highly fragmented collection of unrelated institutions (Keohane and Victor, 2011).

The actors involved in orbital debris governance are closely connected through different forums. They include space agencies, NGOs, universities, satellite operators, launch systems and military organizations from all over the world. They meet and discuss orbital debris at various forums, including the United Nations Working Group on the Long-term Sustainability of Outer Space Activities, the Inter-Agency Space Debris Coordination Committee, the European Space Research and Technology Centre, the International Telecommunication Union, the United Nations Group of Governmental Experts on Transparency and Confidence-building Measures in Outer Space Activities, the International Organization of Standardization's Subcommittee on Space Systems and the International Astronautical Congress (Baiocchi and Welser, 2010).

Over time, these highly connected actors have adopted hundreds of institutional arrangements related to space sustainability, at bilateral, regional and multilateral levels (Gallagher, 2010; Jakhu, 2011). Some are legally binding and others are not. These arrangements include guidelines, information-sharing platforms, memorandums of understanding, political declarations, codes of conduct and standards. One example is the Space Safety Coalition, an '*ad hoc* coalition of companies, organizations, and other government and industry stakeholders'. It recently adopted the 'Best Practices for the Sustainability of Space Operations', a set of standards to promote the implementation of the 21 Long-Term Sustainability guidelines approved by the United Nations Committee for the Peaceful Use of Outer Space (UN COPUOS) in June 2019 (Space Safety Coalition, 2020). Some actors have adopted practices that go beyond their legal requirements and are investing massively to address the problem (Kurt, 2015; Mejía-Kaiser, 2009). Several spacefaring nations adopted measures and procedures consistent with space debris mitigation before the United Nations General Assembly endorsed the COPUOS Space Debris Mitigation Guidelines (Kurt, 2015). Commercial initiatives that could address the threat of space debris are also emerging alongside government and international frameworks, with the launch of the first privately-funded active debris removal mission planned in March 2021 (Astroscale, 2020).

Anecdotal evidence points to ways in which this polycentric form of governance can encourage a sustainable use of the Earth's orbits. For example, a network of optimal observatories, controlled by universities in Italy, Switzerland and the United States are conducting observation campaigns to monitor space debris. According to Hossein and his coauthors (2020, p. 30), 'heterogeneous capabilities of the different observatories represent an advantage for acquiring a wider set of debris monitoring data with different techniques'. The fact that various autonomous actors voluntarily share information to solve a common problem is consistent with Ostrom's view that a polycentric system offers adaptive solutions to the governance of common-pool resources (Johnson-Freese and Weeden, 2012).

Similarly, most of the largest commercial satellite operators have joined the Space Data Association (SDA), an industry-led initiative to improve space situational awareness through the sharing of members' operational data (Space Data Association, 2020). By providing a standardized and secure way of exchanging private information about the movement of its members' satellites, the SDA complements governmental and nongovernmental initiatives capable of monitoring dead satellites and nonfunctional debris. In 2014, the SDA reached a data sharing agreement with the United States Department of Defence tracking operation to collaborate on space situational awareness. The potential for mutual monitoring, learning and cooperation is further evidence of the benefits of a polycentric system for the sustainable governance of the Earth's orbits (Ostrom, 2010).

5. Conclusions

Ostrom's perspective on common-pool resources suggests that revolutionizing space governance, by adopting a new treaty, levying a global tax or allocating property rights might not be necessary to tackle the problem of space debris. An alternative to these centralized solutions could be to build on the existing polycentric nature of space governance. Yet, several adjustments might be required to build trust among actors, clarify rights and expectations, encourage broad participation and solve unavoidable disputes (Weeden and Chow, 2012). Although this approach is more ambiguous, complex and messy than centralized solutions, it might be more realistic. Creating an institutional mess on Earth might be our best shot at clearing our debris out of space.

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Author Information

Jean-Frédéric Morin is Canada Research Chair in International Political Economy and Full Professor at the Political Science Department of Université Laval (Quebec City, Canada). His research looks at international institutions and the governance of common-pool resources.

Benjamin Richard holds a B.A. in Public Affairs and International Relations and a M.A. in International Studies, from the Université Laval, Quebec City, Canada. He works as a research assistant for the Canada Research Chair in International Political Economy.