Orbital Use Fees Stifle Developing Space Programs

A Sociotechnical Research Paper
presented to the faculty of the
School of Engineering and Applied Science
University of Virginia

by

Ian Davis

April 6, 2021

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Ian Davis

Sociotechnical advisor: Peter Norton, Department of Engineering and Society

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Introduction

Space debris is an issue all spacefaring nations encounter. It presents a persistent threat to all orbiting satellites, where a chance encounter could result in complete destruction. As satellites become more and more ingrained into global operations, the amount of space debris, and the risk of encountering it, has increased dramatically (European Space Agency, 2020). The typical response to this problem is to implement a policy or technological fix. For example, all major space programs (American, Chinese, European, Indian, Japanese, and Russian) have agreed to several sets of guidelines towards the prevention of space debris. Several have proposed designs of technological fixes as well (IADC, 2019; Stokes et al., 2019; United Nations, 2010). However, the problem of space debris is an issue of incentives, not of policy or technology (Rao et al., 2020).

The most effective incentive, as suggested by Rao et al., is to charge an Orbital Use Fee (OUF). OUFs are an annual fee paid by commercial satellite operators for each satellite in orbit. An OUF would cause operators to maintain liability for their satellites until they are removed from orbit or placed into a graveyard orbit. These fees could be orbit and satellite specific, depending on the risk of space debris production (E&T editorial staff, 2020). Economically, OUFs present a possible solution to space debris. Though they present a viable solution to the problem of space debris, the effect of Orbital Use Fees on specific groups must also be considered. OUFs could stifle aerospace industries in countries with developing space programs as well as negatively impact government and civilian programs.

Review of Research

This paper extends upon the work of Rao et al. (2020), who first proposed the implementation of OUFs. Rao et al. propose that a fee structure similar to a carbon tax, of roughly $235,000 per satellite-year that would quadruple the value of the space industry by 2040 by dramatically reducing collision risk. They also claim that alternatives to OUFs such as technological solutions like debris-removing robots would worsen economic damages by increasing launch incentives. Figure 1 depicts historical and predicted data of low-Earth orbit (LEO) use. Solid black lines show historical data, red dashes show predicted data based off a continuation of the status quo open access model, and blue dashes show the effect of implementing OUFs. These graphs clearly show the implementation of OUFs leading to a reduction in orbital debris and collision probability at the cost of fewer satellites and launches to orbit.

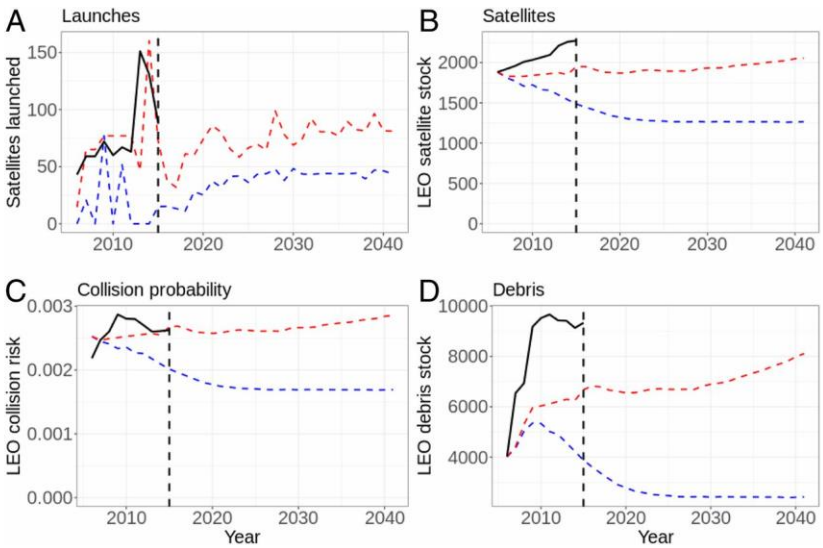

Figure 1. Historical and future model simulations of low-Earth orbit use (Rao et al., 2020).

An idea of importance is that of the negative production externality (NPE). An NPE is a cost imposed on society by a production decision that is not taken into account by the producer. For example, a factory might produce pollution as a byproduct, which decreases quality of life for people in the surrounding area. According to Helbling (2020), externalities represent a market inefficiency because the good or service is being overproduced. In this case, space debris represent an NPE, as the costs they incur are not carried by the producer. An OUF is a Pigouvian tax that force producers to internalize the externality, taking into account the additional costs on others when making their production decision (i.e., forcing producers to retain liability for the debris they produce) (Rao et al., 2020). However, the administration of George W. Bush (2004) states that the proposition that externalities require regulation or taxation to prevent market inefficiencies is debated.

An OUF creates a barrier to entry to the space market. Klapper et al. (2006, p. 597) discovered that high barriers to entry lead to decreased incorporation of new firms. The aerospace industry already has few entrants due to its capital-intensive nature. In addition, the presence of pre-established large-scale entities makes it even more difficult for a new entrant to establish themselves (Adamkasi, 2017). Barriers to entry typically lead to larger corporations with greater market power by allowing them to exploit economies of scale through lower average cost of production (Klapper et al., 2006, p. 597). Barriers to entry in a market are the defining characteristic of monopolies and oligopolies. According to OpenStax Economics (2016), monopolies are defined by a complete lack of competition in the production of a good or service, whereas oligopolies are depicted with only a small number of producers. In the case of space programs, where countries and private companies compete for the same orbital resources, OUFs would force out smaller companies and countries and prevent the entry of new programs.

The Outer Space Treaty of 1967 is the defining document describing space legislation. Closely following is a supporting document, “Convention on International Liability for Damage Caused by Space Objects”. In short, the Outer Space Treaty of 1976 protects the right for all states to have free access to space and asserts that states maintain ownership for all objects, or component parts, launched into space. The Liability Convention asserts that states are financially responsible for damages caused by objects they have launched into outer space.

How Orbital Use Fees Can Increase Prices

OUFs are a barrier to entry in the space market. Barriers to entry are "factors that can prevent or impede newcomers into a market or industry sector, and so limit competition. These can include high start-up costs, regulatory hurdles, or other obstacles that prevent new competitors from easily entering a business sector" (Hayes, 2021). The main proponents of OUFs, Rao et al., propose that these OUFs will be built upon a "pre-existing international governance institution" and revenues will be collected by national governments. In this case, OUFs represent regulatory hurdles in the form of taxes. Taxes will "increase the operating cost of a firm and can play an important role in the final entry decision of a possible newcomer." In addition, these regulatory barriers are "the most important and difficult to overcome barriers to the entry of new competitors" (Kotsios, 2010).

Barriers to entry are the defining characteristic to forming a monopoly or oligopoly. Krylovskiy claims that "oligopolies and monopolies may maintain their position of dominance in a market because it is simply too costly or difficult for potential rivals to enter the market." The space industry has relatively few sellers, with only a handful of countries and companies operating space programs (IADC, 2019). This is due to the capital-intensive nature of entering the aerospace market (Adamkasi, 2017). High barriers to entry as well as few produces indicates that an oligopoly has formed.

Oligopolies inhibit competition. Due to the lack of a dominant force (competition) in the industry, "companies may be tempted to collude with one another rather than compete, which keeps non-established players from entering the market" (Hall, 2019). When companies "agree to restrict competition, the result is often higher prices" (Federal Trade Commission, 2017). On the other hand, in a competitive market, with many companies, competition between companies leads to lower prices (Federal Trade Commission, 2021). Enforcing OUFs can be interpreted as an oligopoly trying to restrict entry into their market.

In addition to OUFs adding another barrier to entry to the space market, incumbent programs will be forced to increase their prices. In the case of a commercial entity, this will affect both the consumer and the producer, and will be represented as a combination of cutting into the producer's profits and increasing the price for consumers (Khan Academy, 2017) Because many space programs are nationally funded public services, there are no profits -- increasing the price of a satellite will be directly channeled to the taxpayer (Cowen, n.d.)

Increasing prices does not necessarily mean that demand will decrease a significant amount. Some goods, such as gasoline, will show very little change in quantity demanded, even if the price goes up massively. Consumers will always buy similar amounts of gasoline irrespective of price. These goods are known as inelastic. Elastic goods, on the other hand, show large changes in quantity demanded even if the price changes by only a small amount (Gallo, 2017). In other words, if the price of an inelastic good increases, the quantity purchased will not change a large amount. However, if the price of an elastic good increases, the quantity purchased will decrease, with this decrease depending on just how elastic the good is.

Many space programs first wet their feet by launching smaller satellites into low earth orbit (NASA, 2014). In fact, the majority of satellites are launched to low earth orbit (Roberts, 2020). In the case of a low earth orbit launch vehicle, the price elasticity of demand is greater than 1.0 (Hertzfeld, 2005). This means that for a 1% increase in price, quantity demanded decreases by more than 1%. Therefore, price increases will greatly decrease the quantity of satellites put into orbit, reducing prospective space competition even further.

Impact on the Consumer

Higher prices along with elastic demand requires that fewer satellites are put into space. Combining this with increased barriers to entry, excessive burdens are placed on new space programs. Because space programs are often associated with countries, these burdens can be perceived as targeting specific countries as a whole. In addition, as satellites placed into orbit are typically limited in scope to support only that country's interests (Belward & Skøien, 2015), it is unreasonable to expect satellite resources to be shared between nations. A notable exception is that of the United States' GPS, where the service provided by these satellites is given freely to other nations (National Coordination Office for Space-Based Positioning, Navigation, and Timing, 2021). However, the US has restricted use of GPS in the past, limiting accuracy for non-US military purposes and even restricting access to enemy nations (National Coordination Office for Space-Based Positioning, Navigation, and Timing, 2018).

Reduced access to satellite resources can negatively affect a nation's economy. Satellites have an extraordinary impact on a nation's technological capabilities, enabling massive increases in the efficiency of certain services and permitting services that were previously impossible. For example, communications in particular has been revolutionized by the advent of satellite technology, permitting access to cellular networks and the internet in places where it is unfeasible to lay cables or cell towers (Stone, 2004). In just the European TV broadcast sector, replacing satellite technology with an equal quality land-based method (in this case, fiber optics) is estimated to cost between 200 billion and 280 billion euros (Acker et al., 2020). Even data gathered by satellite imagery is extremely valuable. In northeastern Iowa alone, satellite data used to allow for more efficient management of agricultural production was valued at "as much as $858 million ± $197 million per year" (US Geologic Survey, 2013). Therefore, countries without access to satellite technologies are at a severe economic disadvantage. Widespread implementation of OUFs would hamstring the space programs of developing countries, further weakening their economies.

Case Study: Optical Fibers vs Satellite

The only equivalent technology to satellite communications systems, when compared in terms of speed, is fiber optic cables (Acker et al., 2020). As such, both technologies are used in modern communications systems. In a comparison done by Dealna, it was found that optical fibers have many advantages over satellite communications.

- Bandwidth and data rates: Optic Fiber supports higher bandwidth and data rates as compared to satellite.
- Mobility: Optic Fiber cannot be used in mobile applications and is suitable for fixed locations. Satellite communication is suitable for mobile applications.
- Reliability: Fiber Optic communication is more reliable than satellite.
- Terrain: Fiber optic is more suitable for urban areas and plains where digging / laying is easier. Satellite communication is suitable for remote areas and rough terrains like mountainous areas.
- Delay: Optic fiber has minimum or no delays making is suitable for real time applications. Satellite communication has an inherent propagation delay.
- Interference: Optic fiber has less or no Electromagnetic Interference EMI whereas Satellite communication has high EMI.
- Coverage: Satellites are suitable for providing point to multi-point services with large coverage like TV and radio.
- Cost:
    - Initial Cost: Depends on the size of network and whether the user wants to deploy complete network or part of it and lease the rest.

- Recurring Cost: Satellite has higher recurring cost than optic fiber communication.

From this, it may appear that optical fibers are the superior technology. However, satellite technologies carry the largest portion of communication traffic (Frempong, 2008). This is because the advantages which satellites do have are significant. People who do not have access to a physical connectivity become able to “join roundtable discussions from thousands of miles away” (Frempong, 2008). Even though optical fibers grant massive increases in speed, they are not mobile. The inherently wired nature of optical fibers requires that users be in a single location, permanently. Satellites, on the other hand, are wireless. Even though they suffer from communication delays, electromagnetic interference, and lower bandwidth, the fact that users can be mobile is indispensable (Optic fiber vs. satellite communication, n.d.). This mobility advantage has led the global satellite communications industry to be valued at approximately 41 billion, whereas the global optical fiber industry is only valued at 20 billion (Fortune Business Insights, 2020; Mordor Intelligence, 2020).

Even if a country replaces satellite communications with an equivalent amount of optic fiber, they will still experience major disadvantages. Mountainous regions are nearly impossible to connect via fiber optic cables and in regions with low population density it can simply be uneconomical to lay such cables. Satellites, however, can cover mountainous and rural areas with ease (Optic fiber vs. satellite communication, n.d.). Rural areas become able to access services that were previously unavailable, or at least exorbitantly expensive, for the first time. This includes internet connectivity and television.

Case Study: Weather

Modern weather forecasting is impossible without weather satellites. Satellites permit entire weather systems to be seen at once, something impossible with just localized ground stations. In an account of the first weather satellite by C. Choi, humanity was finally given the ability to see significant portions of the globe at once.

> The world's first weather satellite launched 50 years ago, on April 1, 1960. By capturing this high ground, weather satellites changed a key way that humans view the future, making it possible to foresee potential disasters before they arrive and prepare for them. Now scientists are helping to prepare the next generation of weather satellites.
> The first picture from this first satellite, called the Television Infrared Observation Satellite, known as TIROS-1, was a fuzzy image of thick bands and clusters of clouds over the United States. A picture captured a few days later revealed a typhoon approximately 1,000 miles east of Australia.

These hazy pictures changed weather forecasting forever. Meteorologists are now able to more accurately issue forecasts and warnings about severe weather events (Choi, 2010). These capabilities would not be possible without the quantity of data that can be measured even by a single satellite. The United States currently relies on just two satellites, GOES East and GOES West, for a large portion of all weather data supplied (National Oceanic and Atmospheric Administration, n.d.). Before the development of weather satellites, countries had to rely on ground stations and volunteers in order to collect weather data. A quote from the book “Isaac’s storm: A man, a time, and the deadliest hurricane in history” can sum up the inefficacies of ground stations.

> Even weather itself seemed at last under the control of man. The recently established U.S. Weather Bureau oversaw a weather monitoring network that included 158 regular observatories, 132 river outposts, 48 rainfall monitors, 2,562 volunteer observers, 12 West Indies stations, 9 coastal stations, and 96 railway posts throughout the country. One newspaper editorialist in 1900 called weather prediction "a complete science."

> It wasn't. The hard lesson that nature cannot be predicted, especially at the extremes of its behavior, was delivered to Isaac Cline, to the city of Galveston, and to the entire nation on September 8, 1900. On the evening of that day, the worst natural disaster in U.S. history roared out of the Gulf of Mexico and confronted Galveston with its own powerlessness in the face of nature's fury (…)
>
> Within a few hours of making landfall, the storm had scoured vast sections of the city clean of any man-made structure, deposited towering walls of debris in other areas, and killed upward of 10,000 people.

Without satellites, Galveston was wholly unprepared for the severity of the storm. Even though they had developed a state-of-the-art weather monitoring system, it was insufficient. Now, hurricanes can be detected days in advance, with their size and direction known well before they even make landfall. This can severely reduce the damages caused by weather.

Conclusion

The implementation of Orbital Use Fees as a Pigouvian tax to solve overproduction of satellites would increase the value of the space industry, but an increase in value does not reflect the concentration of that value across space programs worldwide. Charging an OUF on a per satellite per year basis increases the height of the barriers to entry in the space market. By increasing barriers to entry, one encourages the formation of monopolies and oligopolies, which inhibit competition. A decrease in competition leads to an increase in prices. The OUF compounds on that increase in price. In the case of low Earth orbit launch vehicles, a stepping stone for new space programs, the price elasticity of demand is greater than one, which means that increasing prices will see a more than unitary decrease in quantity demanded. Overall, increased barriers to entry combined with the increase in price of satellites will limit the entry capabilities of new competitors and limit the supply of those that do manage to enter the market.

Due to the massive value satellite technology brings to a nation's economy, nations without access to space are at a significant economic disadvantage, meaning that OUFs have the potential to severely inhibit the civilian, military, and commercial operations of nations with developing space programs.

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