Analysis
Paper

82/2026 24/11/2026

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Use of Space, Technological Barriers and Economic Value for Developed Societies



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Abstract:

Sending equipment into space, whether into orbit around the Earth or further afield, offers significant advantages and enables the development of solutions for the needs of society. These are, in many cases, entirely different from and superior to those possible on ground or through the use of aircraft. Significant technological barriers prevented their use in the past, but we now live in an age in which these barriers are being overcome with increasing efficiency. As a result, not only are more space-based solutions becoming both practical and economical, but more and more countries are also developing their own ways of accessing and utilising space. Major investments in innovation made by the United States and the Soviet Union to send their astronauts into Earth's orbit paved the way for its use in various forms. It was not long before other powers developed their own technology, and new countries continue to follow suit. Since the beginning, the advantages that space could offer the armed forces were clear, and pioneering treaties were also signed to slow down the deployment of weapons into orbit. However, technological development has gradually opened up multiple ways in which access can be advantageous, particularly in the fields of communications and intelligence.

Keywords:

Space exploration, secure communications, observation, intelligence, global positioning systems

How to quote:

DUQUE, Pedro. *Use of Space, Technological Barriers and Economic Value for Developed Societies*. Analysis Paper IEEE 82/2026.

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Introduction

The desire to explore has always been a fundamental characteristic of human nature. The prehistoric man's capacity for innovation set him apart from other species and enabled him to explore new regions with different characteristics from those of his ancestral lands. The ability to make fire enabled survival in colder temperatures; the creation of warm clothing helped in the same way; weapons prevented them from falling prey to animals with significant adaptive advantages to the natural environment they explored. Cooking allowed man to consume foods that, naturally, would not form part of their diet; the construction of shelters protected early humans from the outdoors; and boats enabled them to cross bodies of water. All this without having to wait the thousands of generations that other species would need in order to adapt naturally to a new environment (Tattersall, 2012).

And so the coldest and warmest regions, the driest and wettest, the highlands and the valleys all became populated. Within a relatively short time, exploration led to the expansion of the species. And this drive has continued: people have explored the oceans and their depths, caves, high mountain peaks, rainforests and, finally, we have turned our attention to space.

There is no doubt that space holds a fascination for everyone, and that the initial drive to develop technologies to conquer it was a consequence of that fascination. The technological powers saw in the conquest of space an opportunity to demonstrate to the world, in a way that was immediately understood, their capacity for innovation and their scientific and technical pre-eminence (Davenport, 2018). Conquering space was, and to a large extent still is, a way of demonstrating the success of a technological society.

Relatively Invulnerable

Satellites sent into orbit are completely immune to the events occurring on the Earth's surface or in the atmosphere. Natural disasters can disrupt land-based communications, but not those provided by satellites. For this reason, adequate preparation involving backup satellite systems can be highly effective in providing a rapid and coordinated response to the effects of any major disruption, be it due to natural causes or the consequence of an attack (Friedman, 2010). Just like communications, ground

observation will continue as long as the necessary space resources are available to do it.

It is natural to think that the armed forces around the world have major incentives to destroy their adversaries' satellites. China and the United States as well as Russia and India have all already tested weapons systems capable of destroying a satellite in low orbit, and there are growing suspicions that the same offensive capabilities may exist against geostationary satellites. Less aggressive techniques, such as signal interference, including from other satellites, have been in use for a long time and satellite manufacturers are doing their part to counter these threats.

Telecommunications: The Ideal Repeater

Communications have always been the foundation of strong states and empires. Coordination between the various levels of society's leadership made it possible to make the right decisions based on reliable data. The Roman Empire relied on its roads for the transport of troops and goods, but they were also made very smooth so that messengers could travel at high speeds. Furthermore, the maritime transport network was, and continues to be, essential for communication.

Other means of communication were developed to enable the transmission of information without the need for a physical medium. The Great Wall of China was equipped with watchtowers that were within sight of the adjacent towers, so that messages could be sent quickly from one to another using smoke or fire. The height of the towers meant that a relatively small number were required. A conceptually similar system was the optical telegraph, such as the lines installed for military communications between Madrid and various points along the coast. In these cases, the height of the towers was also essential.

The taller a tower is, provided the signal balance is correct, the larger the area it can cover. Mobile phone networks rely on a huge number of towers to function, as there are restrictions on their height, both due to urban planning and the wind. Using the air or space instead of a tower removes these limitations.

Arthur C. Clarke, who later became a world-famous science fiction writer, was the first to propose, in 1945, the use of geostationary satellites as radio repeaters to provide global

coverage. This is one of the great advantages of space: the possibility of direct contact with vast areas of the Earth. In fact, all it takes is three well-positioned satellites to connect with any point on Earth (Clarke, 1945). As early as the 1920s, both Herman Oberth (1923) and Herman Noordung (1929) carried out calculations which would make it possible, if rockets were developed as Oberth himself and Konstantin Tsiolkovsky had predicted (Tsiolkovsky, 1903, 1929), to use space in various ways, such as positioning stationary platforms above a point on the Earth's surface for observation or communications.

For decades, telecommunications satellites have provided global coverage, and for a long time they have been the last resource to fail: anywhere in the world, people can coordinate their activities using satellites or call for help if necessary. The COSPAS-SARSAT international system receives standardised emergency beacon alerts and is in operation continuously throughout the world; there are no areas that are beyond its reach[1]. Similarly, thousands of isolated regions around the world receive mobile phone signals via satellite, enabling their populations to enjoy connectivity.

The altitude at which a satellite must be placed in order to remain stationary above a point on the Earth's surface is extraordinarily high, at some 36,000 kilometres. Therefore, a high degree of sophistication and highly precise antennas are required for communication and, even so, the signal will always be subject to a certain delay determined by the speed of light. These technologies have been fully developed for many decades now, and modern satellites provide huge data capacities capable of serving thousands of users; however, the delay is a limitation for certain types of uses that require rapid user responses.

Satellites placed in lower orbits can provide a service without delay, but they have other limitations. One is the need for ground-based antennas that track the satellite as it passes at a high speed. The other is the need to place multiple (hundreds or thousands) of them into orbit so that they can 'jump' from one to another and ensure uninterrupted service. It has been less than a decade since these technical limitations were overcome, thereby enabling not only online computer games, but also highly significant uses in the fields of security and defence.

[1] Website: https://www.cospas-sarsat.int/en

Constellations of multiple satellites, such as the current Starlink and OneWeb, have enabled the creation of extremely significant and strategic applications and, therefore, all technology powers are seeking to gain access to a system of this kind. The European Commission has created a flagship programme in this area, known as IRIS^2 (Infrastructure for Resilience, Interconnectivity and Security by Satellite), which is discussed in detail later in this paper.

Surveillance and Intelligence: Permanent Observation

Observing the terrain has always been a key objective in the organisation of all human activities, particularly the use of large areas for agriculture or the strategic and tactical planning of military operations. Generals in the past needed a vantage point from which to make decisions and direct the movement of troops, and that necessity remains today. The first use of aviation in warfare was for observation from a truly advantageous vantage point, albeit with significant time constraints.

Another of the major advantages of space is the possibility of flying observation satellites for virtually indefinite periods of time, by taking advantage of the physics of orbits. Once an observation satellite has been placed in orbit, it can remain there for years with its engines switched off, using only a very small amount of fuel compared to that which an aeroplane performing the same function would need. Of course, using geostationary orbit has its advantages, as it simplifies everything, but the great distance from the Earth's surface makes it very difficult to design suitable cameras. Therefore, observation from space is achieved by using satellites stationed in lower orbits. These inevitably move at a high speed relative to ground level, so continuous observation requires having access to multiple platforms, which must be used in succession as they fly over the area to be studied or monitored.

Positioning: Geographical References

Major empires required precise measurements of the terrain. Both the Roman and Chinese empires carried out precise measurements and placed boundary markers to mark places or specific distances. With increasing precision, we realise that no point on

the Earth's surface is static. The Moon's gravitational pull not only causes tides in the oceans but also distorts the Earth's crust from 10 to 50 centimetres (Love, 1911).

The physics of orbits does, however, allow us to place geographical reference points in space whose position is known with great precision over time. This advantage, combined with the altitude, which provides a line of sight to large areas of land, has enabled us to create positioning systems, comprising just a few dozen satellites, which are now essential for a wide range of everyday uses.

Source of Resources and Energy

Another huge advantage of conquering space, although this has not yet been carried out on a useful scale, is the possibility of obtaining raw materials from other celestial bodies to supplement those in scarce supply on Earth. So far, only small amounts of material from the Moon have been recovered and, recently, a few grams from a couple of asteroids. However, the potential is huge and a much more economical access to space could create an entire industry centred on the extraction of raw materials (Lewis, 1996). Currently, many critical materials, which are in scarce supply on the Earth's surface, are the subject of disputes that are not only commercial, but also geopolitical. Discovering a new exploitable source would have a major impact on international relations and the balance of strategic autonomy.

On the other hand, large quantities of solar energy can be harnessed in space, as there are virtually no limits in orbit to the size that photovoltaic or concentrated solar power installations could reach. If the operational challenge of transporting that energy to the Earth's surface efficiently and safely were to be resolved, for which there are theoretical solutions, this could also have a major impact on the distribution of energy on Earth by using assets in space.

Research: Better than the Highest Mountain

Since ancient times, observing the sky required good weather conditions and clean air. The mountains have always been the best place, rising above a large part of the cloud cover; that is where the ancient astrologers used to go, and where we now install our

telescopes. Just as with observation of the ground, observation of the sky is greatly enhanced when done from space, as this eliminates the distortion caused by the atmosphere, and even allows for observation at wavelengths that do not penetrate the atmosphere at all.

Telescopes in space can be in different orbits, often chosen for operational convenience (for example, INTEGRAL[2]) or because of the maximum altitude that the chosen rocket could reach (for example, the Hubble, placed where the Space Shuttle could reach it for maintenance[3]). The best orbit for many observations is that which allows the universe to be observed without interference from the Sun; in particular, the so-called L2 orbit of the Sun-Earth system (after the great 18th-century mathematician and physicist Lagrange) is mainly used: a position on the Sun-Earth line that is permanently within our planet's shadow.

Space is also used to carry out tests under conditions of prolonged weightlessness, which is of great use in various scientific fields. The current International Space Station is home to hundreds of pieces of equipment where these experiments are carried out. Although it has not yet been possible to carry out on an economically useful scale, the possibility of improving (or even enabling) certain industrial processes using weightlessness should not be ruled out.

Technological Barriers

Working in space is not difficult because the technology is lacking, but rather because it is the most demanding environment humanity has ever faced. It is not just about advanced engineering, but about engineering pushed to its absolute limits in order to overcome an extremely hostile environment. And yet, here we are.

A hostile environment is not an obstacle; it is a filter. It removes improvisation; only the best-designed technology survives; excellence prevails. Each mission requires strategic thinking, optimisation and cooperation. It forces us to be more resourceful and speeds up the intelligence of our machines. The technological barriers of space are not walls; they are steps that force us to be better.

[2] Available at: https://www.esa.int/Science_Exploration/Space_Science/Integral_overview
[3] Available at: https://www.esa.int/Science_Exploration/Space_Science/Hubble_overview

Sending an object into space requires a huge amount of energy to be released in a very short space of time, which means that technically sophisticated methods are needed to achieve this. A current Falcon 9 rocket generates a take-off power of around 25 gigawatts (GW). If we wanted to transmit this power via a cable, the cable would be much thicker than the rocket itself. The ability to develop all that power within a lightweight structure and control it with precision requires a range of technologies that only became available from the second half of the 20th century. Notwithstanding the possible emergence of disruptive advancements in the future, currently the main barrier to using the undeniable and numerous advantages of space remains the launch cost, as discussed in the following chapter. The main driver behind the recent falling cost of this technology has been the development of rockets, parts of which return and land in order to be reused. As a result, the cost per kilogram for a large satellite weighing several tonnes has now been reduced from around 25,000 euros to 2,500 euros. The hope is that future launchers could reduce this price by a further factor of 10, primarily through an increase in the rocket's total capacity and a reduction in the operational costs associated with refurbishing the reusable sections.

What's more, in order to utilise space, it was necessary to overcome other barriers by developing specific technologies, given that no other field of engineering has to operate under the extreme conditions of remoteness, radiation and vacuum that are found in the space environment.

Its remoteness makes any physical maintenance almost impossible, which means that reliability must be much greater than in systems operated on land. It is therefore necessary to design satellites with duplicate systems and with the means to monitor every physical variable (including internal ones) in the various components, in order to detect or even predict failures. A sophisticated car may have a couple of hundred sensors, meanwhile a geostationary communications satellite may have twenty thousand. Not only is it necessary to have duplicate systems, but each one must be far more reliable than the equivalent equipment on land, which could be repaired or replaced much more easily.

The radiation environment, perhaps only comparable to equipment used in nuclear power stations, requires highly specialised technologies, notably in the field of electronics. Each of the integrated circuits in a satellite generally comes from a separate manufacturing line

to the circuits for terrestrial use and requires very different techniques to ensure that the radiation in space does not destroy them or alter the contents of their memory.

The vacuum means that all materials that could contain trapped air, solvents or adhesives must be eliminated, as these would be lost in the space environment or, worse still, exert pressure. For example, the welding techniques must be highly specialised, as a bubble could cause them to burst from the inside. On the other hand, the majority of, if not all, electronic components and computers use fans to cool hot parts. Needless to say, that cooling technique is impossible in a vacuum. Although Russia has manufactured satellites in which the electronics were housed within a pressurised compartment, in general, the cooling of electronics in space requires a sophisticated system of heat transfer through metals and the concentration of heat in radiators. These methods are entirely different from the technologies used on Earth and which, therefore, make design and manufacturing more difficult and expensive.

The Value of Space in Our Economy

Space is one of the emerging driving forces of the global economy. Its economic value is not limited to traditional satellite launch or manufacturing activities, but rather it encompasses an entire ecosystem that drives sectors as diverse as telecommunications, navigation, logistics, Earth observation, environmental management, defence, retail and mobility.

Space technologies now form part of the planet's critical economic infrastructure and bring value to telecommunications and connectivity, as satellite networks enable resilient global communications. Satellite constellations such as Starlink, OneWeb and Amazon LEO are transforming internet access. In navigation and transport, global positioning systems such as GPS, Galileo and GLONASS underpin global logistics, aviation, and maritime and land transport.

In addition, we must consider the advances that are enabling Earth observation in agriculture, environmental management, maritime security and disaster response, all of which rely on satellite data. Banking, e-commerce, power grids and telecommunications rely on the precise synchronization provided by satellites. And, of course, in defence and

security, where space is already a strategic domain in which a large part of modern military superiority is decided, as discussed later in this paper.

The aerospace industry has recently undergone a disruptive transformation through vertical integration, supported by vast amounts of U.S. public funding, which has made access to space more affordable. This has enabled the refinement of a long-standing idea: reusable, high-capacity launch rockets. As a result, the testing cycles for new uses of space are becoming increasingly shorter and more efficient.

Meanwhile, the deployment of satellite constellations has finally made it possible to apply the economies of scale that are so prevalent in other industries to the manufacturing of space vehicles. This has enabled a significant reduction in the cost per unit, not only because of the volume manufactured, but also because the reliability of the entire system is highly resilient to individual failures in certain units, which greatly reduces the cost of quality control at all levels.

This has not only led to the emergence of new companies, but also to a greater number of countries with space assets, which recognise the possibility of joining the scientific endeavour and are also seeking to acquire strategic autonomy.

It should also be noted that investment in space has a significant knock-on effect on innovation, skilled employment, technological development and advanced industry. Entire sectors such as mobility, autonomous transport, space tourism and cybersecurity are becoming more and more dependent on space. In fact, activities such as reliable weather forecasting for agriculture, insurance and transport, e-commerce and digital banking all require satellite synchronisation, as do global navigation for maritime transport and aviation, as well as climate monitoring and support for environmental policies. Without this infrastructure, the global economy would be slower, more expensive and less secure and resilient.

New standard communication protocols are emerging that will enable direct communication with mobile phones and cars. In addition, we must consider the changes materialising due to the that the widespread use of artificial intelligence (AI) and process automation. As well as that brought about by quantum computing, which represents a paradigm shift in the security for computers, communications and key transmission and generation.

All of the above indicates that space assets have enormous economic value, due to their replacement cost, but above all due to their multiplier effect on economic activity in advanced societies. Therefore, it is not only necessary to consider the protection of assets exclusively used by the armed forces or security systems, but also all other space-based systems, given that, in the event of conflict, they could become targets for an adversary, causing major disruptions to the economy of Spain.

Conclusions

The use of space, involving the placement of a wide variety of devices into orbit, offers significant advantages and holds great interest in terms of the improvement, and in some cases the facilitation of, many aspects of society. This has inspired major technological endeavours to overcome the barriers that it presents. During the second half of the 20th century, several technological powers, led by the Soviet Union and the United States, made significant investments in order to conquer space through the sustained and operational deployment of their satellites, and by sending astronauts there. Europe, Japan, India and (currently making a great effort) China have, to some extent, managed to develop their own equivalent technology.

The armed forces, as is usually the case, also recognised at an early stage the need to develop space-related capabilities. Secure and instant communication between any two points; the continuous observation and surveillance of large areas of land; the precise positioning of vehicles etc. are not only activities that must be protected due to their great importance and economic value to society, but they also constitute operational requirements of the highest priority for the armed forces themselves. As early as 1996, the United States Air Force introduced the concept of space superiority as one of its core competencies, and this trend has only grown since then. In contemporary conflicts, whoever has greater and better access to space-based data and communications has a decisive advantage; and, of course, in the event of a conflict between powers with space capabilities, the tendency will be to attempt to eliminate the adversary's space capabilities.

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