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ORIGINAL PAPER

The Coming of Age of Space Satellite Industry: Transitioning from a Growth to a Maturity Life Cycle Phase

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ABSTRACT

From the perspective of the evolution of modern mass-production industrial sectors, the establishment of an industry can occur in a typical sequence of four conceptual phases: the *introduction* phase, in which a new technological concept is introduced; the *growth* phase, in which application of this concept in the form of a product or service is undertaken; the *maturity* phase, in which the direct use of the product and the advent of product-enabled services establish the new economic sector, and an eventual *decline* phase when one or more substitute products appear. Most of the current industrial products may be considered systems. The application of established concepts, such as interchangeable parts, permits firms to manufacture systems on a large scale, making sophisticated products available to society at manageable prices. The large availability of a product in a socioeconomic environment favors the use of this product in innovative ways, many of them unprecedented. In this way, introducing an innovative product in the market may nucleate a whole new industry over time, which may experience growth either through the continual evolvement of the product or expansion of the breadth of applications. Recent years have shown impressive development in the space industry. This article presents data that suggests that the global satellite space industry is transitioning from a *growth* to a *maturity* stage. It will be argued that barriers to entry are still at a level that permits Brazil, given its current position, to engage in the global space industry.

Keywords: Government/Industry relations; Mass production; Industrial sector; Space economy; Aerospace industry; Industry life cycle.

INTRODUCTION

Since the beginning of the space age, space technologies and their applications have experienced significant development. The pace of change has been high enough for the emergence of a new industry sector in a few decades, referred to as the space industry or, more specifically, the commercial space industry. The space industry involves the commerce, access, and exploration associated with outer space (NASA 2021). The emergence of the space industry is driven by technology (Krafft *et al.* 2014), with high-technology organizations in different parts of the world competing and arranging themselves in various production chains. The industry's value chain includes the manufacture and use of core space infrastructures, such as satellites and launchers, and space-enabled applications, such as television (TV) broadcasting, telecommunications, earth observation, and navigation.

The Organization for Economic Cooperation and Development (OECD) proposed the concept of Space Economy as the aggregate of activities and resources that benefit "… human beings in the course of exploring, researching, understanding, managing,

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and utilizing space …" (OECD 2022, p. 19). Satellites, launchers, launching services, and ground control stations with related equipment are considered essential elements of the space sector. The definition of *space economy*, thus, includes all industries linked to these essential elements, such as services and products in areas such as agriculture, environmental protection, natural resources management, telecommunications, satellite TV services, navigation, and transportation, to name a few (UNOOSA 2021). It also includes research and development activities and the advancement of scientific knowledge.

In 2021, the estimated revenues of the global space industry were worth US$ 386.4 billion compared to US$ 322.0 billion in 2014 (SIA 2015; 2022). As will be shown ahead, from 2001 to 2021, the satellite space industry revenues increased by a factor of 2.8, while in the same period, the United States Gross Domestic Product (US GDP) grew by 1.5 (SIA 2006; 2022; BEA 2022).

According to current data, there are around 3,500 active objects in orbit, with public and private owners belonging to more than 80 nations (Union of Concerned Scientists, UCS 2022). There are now about 400,000 direct jobs in the worldwide space industry (Benchmark International 2022). Only in the United States, for instance, there were 151,797 estimated jobs in the industry in 2021, showing an 18.4% increase in five years (Space Foundation 2022).

It is undisputed that the emergence of new industries is relevant to a country's economic and social development (Mosk 2010, p. 211; OECD 2019, p. 41). On the one hand, from a socioeconomic perspective, the emergence of new industries favors the creation of new jobs with average wages typically higher than those of other established sectors (NASA, Moon to Mars Program 2020, p. iv). This fact translates into new income opportunities in a country's economy, favoring economic policy since a fundamental challenge of modern economies is devising strategies to channel wealth to households through employment and entrepreneurship opportunities. On the other hand, from a structural perspective, new industries can represent an element of modernization for the whole industrial area of a country. They may revitalize economic growth and induce the development of superior technologies that benefit the entire economy (Forbes and Kirsch 2011). But barriers to entry must be tackled.

Over time, such barriers are decreasing in the space sector. The arrival of new private actors and the advent of public-private partnerships have significantly impacted the rhythm of activity in the space sector, increasing opportunities. With access to new funding provided by private and venture capital investors, companies incremented innovation and developed new technologies. The advent of smaller satellites and increased launch opportunities have also reduced costs substantially. These elements have significantly impacted the sector's growth (Citi GPS 2022; UNOOSA 2021, p. 4).

Indications that the space industry might be transitioning to a maturity stage come from two main tendencies: (i) a shift of activity from public to private organizations and (ii) a shift in the form of production of space systems from artisanal to mass production.

From a retrospective view of the development of space activities at large, one sees that space activities began in government organizations and primarily concentrated on demonstrating the possibility of access to outer space in the context of geopolitics disputes (NGS 2022). Soon after, significant scientific and economic applications began to be revealed, primarily from studying the Sun-Earth interaction and from experimental satellites on communications and Earth remote sensing. Over time, commercial services in communications, TV broadcasting, Earth remote sensing, and launch services, to name a few, became established, with the focus of activity shifting slightly toward private organizations (Britannica 2022). Quite recently, with the maturation of space technologies and the advent of additional applications, such as global navigation satellite systems (GNSS), space tourism, commercial space transport, and global internet access, space activity has shifted significantly towards private organizations (OECD 2014, p. 49).

The settlement of the global space industry closely follows the history of space activities. Initially, there was the production of core space systems by government organizations, with the support of a few private companies as suppliers (FAA 2014). As commercial applications came to light and demonstrated viability, private companies began to spring up in the space scenario, giving rise to a nascent space industry in a typical *introduction* phase of the space industry's life cycle. Over time, with the extensive dissemination and proliferation of applications, the number of firms, and countries, involved in the space industry grew, with the industry entering a *growth* phase. Currently, the number of firms and the volume of space systems production suggests that the space industry might be transitioning into a first *maturity phase* of the space industry's life cycle.

During this evolution, one may contend that the manufacturing of core space systems has evolved from artisanal production to mass production (Harebottle 2021). In the beginning, satellites were designed and manufactured with very low recurrence. Each design was unique, and its manufacturing could be considered artisanal. Over time, orbital platform subsystems gained standardized versions, and the concept of commercial-off-the-shelf mechanisms, equipment, subsystems, and even orbital platforms emerged. Nowadays, there are entire commercial constellations, such as Starlink and OneWeb, with thousands of identical satellites, characterizing what might be envisaged as the onset of mass production of space systems (Messier 2022; OneWeb 2022).

The emergence of new industries represents an opportunity for the economy of countries that display the necessary resources to overcome barriers to entry. How governments might stimulate the emergence of the space industry in their economies is an open question and depends on multiple factors. Among them, one may cite: the availability of resources, the international positioning of the country, availability of financing, existing restrictions and regulations, high costs of research and development, availability of suppliers, the national political institutional structure (Spencer *et al.* 2005).

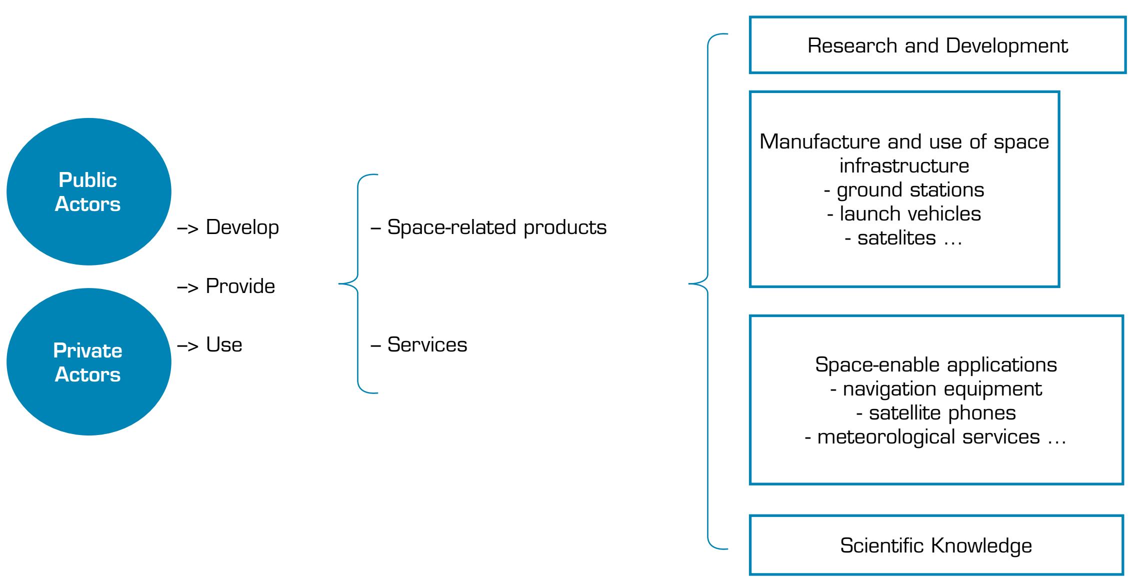
This article will present data that suggests that the global space industry is transitioning from a developing to a maturing stage. It will then be argued that barriers to entry are still at a level that permits Brazil, given its current position, to engage in the global space industry.

SPACE INDUSTRY AND SPACE ECONOMY

In broad terms, Porter (1980 p. 5) defines an industry as a group of firms producing products or services that are close substitutes for each other. In this definition, products or services are defined regarding a given market segment, i.e., an aggregate of customers with similar buying needs. According to the OECD (2012), the space industry comprehends the various businesses and organizations involved with the *space economy*, which is defined as:

> The Space Economy is the full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilising space. Hence, it includes all public and private actors involved in developing, providing and using space-related products and services, ranging from research and development, the manufacture and use of space infrastructure (ground stations, launch vehicles and satellites) to space-enabled applications (navigation equipment, satellite phones, meteorological services, etc.) and the scientific knowledge generated by such activities (p. 20).

Figure 1 shows a schematic view of the definition. It is should be noted that it is comprehensive, covering activities related to scientific knowledge and research and development, which goes beyond typical commercial activity.



Source: Elaborated by the author.

Figure 1. Schematic definition of the concept of *space economy*.

The Satellite Industry Association (SIA 2014, p. 6) adopts a definition of the global space economy as being constituted by two broad segments: the Satellite Space Industry and the Non-Satellite Space Industry. SIA issues annual reports about the satellite space industry, which provide the primary data used in this work. Since 2014, the annual report also includes an estimate for the nonsatellite space industry. According to the SIA space industry breakdown (Dolgopolov *et al.* 2020), the satellite space industry is further subdivided into the following segments: satellite manufacturing, launch industry, ground equipment, and satellite services. Table 1 describes each of these elements. The nonsatellite space industry consists of human spaceflight, nonorbital spacecraft, and government activities. Table 2 details and gives examples of the elements of this segment.

Table 1. Detailed description of the elements comprising the satellite space industry segment, according to the Satellite Industry Association.

Element	Description
Satellite manufacturing	The segment includes all commercially procured satellites for both government and commercial customers. Satellites designed and manufactured in-house by government agencies and universities are not included in this segment.
Launch industry	The segment includes commercially procured launch vehicle manufacturing and launch services. Government launches that are not commercially procured and those that deploy spacecraft other than satellites, for instance, International Space Station (ISS) cargo and crew missions, are not considered in this segment.
Ground equipment	The segment includes ground equipment that directly communicates with a satellite system. Essentially, it has three categories: (i) Network equipment, such as gateways, network operation centers, satellite news gathering equipment, flyaway antennas, and very small aperture terminals (VSATs); control stations; (ii) Consumer equipment, such as satellite TV and broadband dishes, receivers, modems, satellite radios, and satellite phones; and (iii) Satellite navigation equipment, which includes stand-alone and in-vehicle GNSS devices and components for navigation services in aviation, ground, and maritime transportation infrastructure, and other equipment.
Satellite services	The segment includes those services that directly exchange data with a satellite system to provide customers with one of the four types of services: (i) Consumer services, which include direct-to-home TV (DTH TV) broadcast services, direct audio radio satellite services (or satellite radio), and broadband Internet access services via satellite directly to residential and small business users; (ii) Fixed satellite services, which includes: a. Transponder leasing agreements, related to companies that operate satellites and lease or sell satellite transponder capacity to relay video signal, data/business services, and landline phone relay and cellular backhaul services; b. managed services, which include satellite-based data networks, providing data, voice, and video communications to widely dispersed or remotely located facilities through GEO satellites (C-, Ka-, and Ku-band), using VSATs; in recent years, it also includes broadband connectivity through terminals mounted on vehicles, vessels, and aircraft, and portable ones; (iii) Mobile satellite services (MSS), which make use of MSS frequencies (mostly L and S-band) and include: a. Mobile satellite telephony, which is voice and fax services provided to mobile subscribers who use handsets or terminals to link directly to Geosynchronous Equatorial Orbit (GEO) or Low Earth Orbit (LEO) satellites; b. Mobile data services, which include messaging, paging, and machine-to-machine services that utilize handsets or terminals connecting to satellites, and c. Internet of things communications. (iv) Remote sensing services include satellite imagery and closely related services, such as orthorectified scenes or other first-order processing; downstream value-added services or enabled products such as geographic information system technology, cartography, or data analytics are not included.

Source: Retrieved from Dolgopolov *et al.* (2020).

Table 2. Detailed description of the elements comprising the Non-Satellite Space Industry segment, according to the Satellite Industry Association.

Element	Description
Human spaceflight	All human-crewed spaceflight missions, commissioned either by government or private organizations, belong to this classification. Examples include the ISS crew missions.
Nonorbital spacecraft	All missions not aimed at deploying equipment in an orbital position fall in this category. Examples are ISS cargo missions and deep space missions.
Government activities	This category includes all space-related activities within government organizations and universities' budgets. It includes, for instance, all space equipment designed and manufactured in-house by government agencies and universities. All missions carried out by government organizations fall in this category.

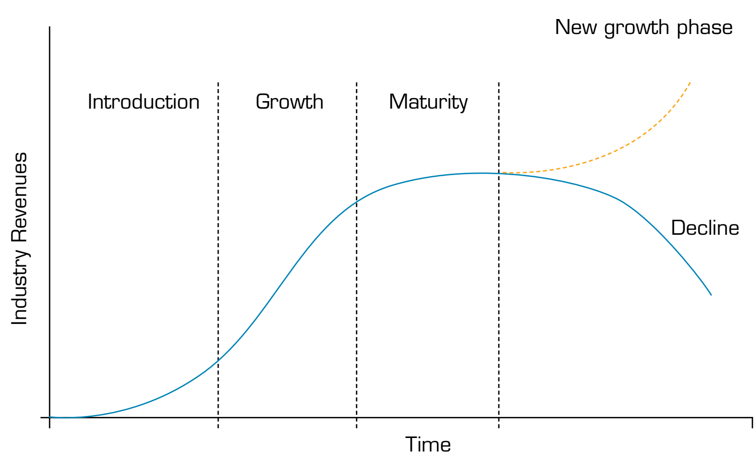
Source: Retrieved from SIA (2014, p. 6) and Dolgopolov *et al.* (2020).

Determining the precise boundary of an industry is unattainable and thus requires the exercise of specialized judgment (Low 1997, p. 439). One way around this conceptual difficulty is defining an industry as a group of organizations of the same form. Then, studying industry evolution amounts to studying the propagation of a specific organizational form (Low 1997, p. 440). This definition affords the basis for treating the industries of aeronautics, defense, and space as a single entity, the aerospace industry. Although there are statistics about the space and aerospace industries (AIA 2021), the space industry will be this article's central theme of concern.

INDUSTRY LIFE CYCLE MODEL

A central question in industry research is how to model the evolution of an industry from inception to eventual extinction in a given economy. To this end, the concept of life cycle has been borrowed from product research and extended to industry research, as reviewed by Klepper (1997). The essential proposition is that a set of sequential phases or stages can model industry evolution. The life cycle model of industry evolution gives an industry's possible course of expansion through a sequence of phases.

The industry life cycle model proposed by Porter (1980, p. 157), followed in this article, displays four stages: *introduction*, *growth*, *maturity*, and *decline* (Fig. 2). As indicated in the figure, the *decline* phase may eventually be overridden by a new growth period if a new or redesigned core product is introduced, or a new strategy is implemented.



Source: Adapted from Porter (1980).

Figure 2. Conceptual representation of the life cycle of an industry.

The proposal of a life cycle model to represent industry evolution derives from the practical observation that the nucleation of an industry sector from the inception of a new technology follows, in several cases, a paradigmatic pattern. The advent of a new technology enables the development of a product that is a novelty in a given market. The product usually classifies as a system.

Due to the limited market size, initial production is labor-intensive, small-volume, and carried out, in general, in production areas. Unit cost is usually high, and the use of the system is limited, owing mainly to its market novelty character and price. In the case of a successful product, over time, the scope of use broadens, and unit cost falls due to economies of scale. Eventually, with the concurrence of additional factors, including product research and development, and manufacturing process improvement, the system finds widespread application, finally establishing itself as the nucleus of a new industry. Table 3 describes the phases of the life cycle of an industry.

Table 3. Phases of the life cycle of an industry.

Phase	Market characterization	Production characteristics
Introduction	The market is limited, absorbing relatively small production volumes. Customer demand is limited due to a lack of knowledge about the new product's features and performance.	Short production runs, high skilled labor content, and high production costs are the main characteristics of the manufacturing process.
Growth	As market acquaintance with the product increases and the product finds new uses, product demand increases, and possibly, a series of product-enabled services come to light.	Medium-sized production runs; a shift toward mass production characterizes the manufacturing process.
Maturity	The direct use of the product and the advent of product-enabled services establish a new economic sector. Eventually, the potential of the market is reached,	The manufacturing process is characterized by automated mass production, low-skilled labor content, and low production costs.
Decline	One or more substitute products appear.	

Source: Adapted from Porter (1980, p. 159-161) and Corporate Finance Institute (CFI 2022).

As an example, consider the development of the automotive industry. One sees the inception of a disruptive technology, in the context of a society's socioeconomic life, that enables a new conceptual product, a transport vehicle, at a cost affordable to large segments of society. The vehicle in one configuration attends to personal use, while in other formats, it attends to the transportation of people and goods, i.e., vehicle-enabled applications, on an unprecedented scale. Hence, the advent of the vehicle concept sets the stage for the emergence of the automotive industry. Currently, the automotive industry, already in a mature stage, shows many ramifications. There are clusters of firms dedicated to vehicle production and distribution, while others deal with the services derived from the vehicles, i.e., the road freight transport industry and road passenger transport.

Taking the life cycle analysis to the space sector, the advent of the technology for placing an object in orbit, for either the gathering or the relaying of information, set the stage for the appearance of a new conceptual product, the artificial satellite system, which through different configurations, attends to different applications (SLH 2022). As with the automotive and transportation industry, the advent of a paradigmatic concept product, the artificial satellite system, enables the emergence of a new industry, the space industry. As regards the current structure of the industry, different ramifications are also observed. There are firms' arrangements responsible for the satellites' design, manufacturing, and orbital placement, and other chains that deal with the services enabled by the access to outer space provided by artificial satellites, such as Earth observation, telecommunication, and meteorology, to name a few (OECD 2022).

The industry life cycle concept is relevant in devising the strategic plan for organizations. To evaluate the threats and opportunities for an organization in the near future, it is fundamental to estimate how the industry environment may change in the considered planning window. The life cycle concept gives a framework for assessing the current stage of an industry in its evolution path. From an estimate of the industry stage, it is possible to approximate fundamental aspects of the industry in the near future by using characterizations as exemplified in Table 3. Most Industry growth curves follow an S-shaped curve (Polli 1969, p. 310). The stages are estimated by assessing industry revenue inflection points (Porter 1980, p. 157), but with some care.

Life-cycle patterns may vary in shape and duration, resisting generalizations (Kotler and Keller 2012, p. 317). As already pointed out, an industry may follow different patterns after reaching a primary maturity stage. For instance, an industry may enter a recovery phase rather than a decline phase after reaching maturity, as indicated in Fig. 2. Also, the period of each stage may vary from case to case. Despite such difficulties, the life cycle approach remains relevant in analyzing industry evolution. It may be considered a powerful concept. Industry evolution is an instance of a growth process and is, therefore, based on elements of growth theory, a well-established branch of science (Acemoglu 2012).

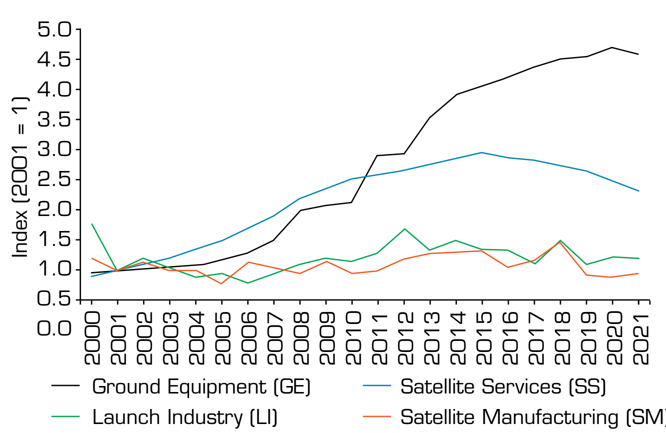
In the next section, the life cycle concept is employed in analyzing the evolution of the satellite space industry in the last two decades.

SATELLITE SPACE INDUSTRY EVOLUTION

In this section, a study of the evolution of the satellite space industry from 2000 to 2021 is carried out using data from SIA, which issues an annual report about the global space industry, with yearly revenue estimates for the satellite and nonsatellite space industries. The data relative to the nonsatellite space industry has been available since 2014. The focus of the present work is the satellite space industry data. As already mentioned, the satellite space industry is broken down into four segments: satellite manufacturing, launch industry, ground equipment, and satellite services, with definitions given in Table 1.

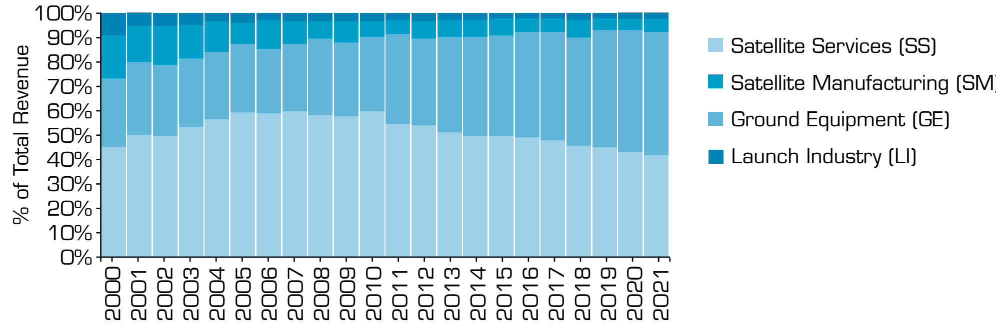
Every report gives the results relative to the previous year. There are two important notes about the data. The composition of the ground equipment segment has been redefined in the report published in 2017. The redefinition has been propagated backward until the year of 2012. The 2017 report also gives the ground equipment segment's percentual increase from 2011 to 2012, permitting backward propagation of ground equipment redefinitions up to 2011. In this way, the ground equipment numbers in the 2012–2016 reports have been superseded by those in the 2017 report. The other point concerns the data for the nonsatellite industry (NSI). Although one may find NSI data from the 2011 report onwards, NSI data have been considered for this study only from 2014 onwards. SIA data have been corrected for inflation using US consumer price indexes (BLS 2022), considering 2021 as the reference year.

Figure 3 shows the revenues of the satellite industry segments from 2000 to 2021, while Fig. 4 shows each segment's yearly relative contribution to the total revenue. The latter figure indicates that ground equipment and satellite services together dominate the global satellite industry, displaying a share of over 90% in the last decade. Moreover, despite some fluctuation, the participation of satellite manufacturing and launch industry has decreased over the years. Also, Fig. 3 shows that ground equipment and satellite services display remarkably higher revenues than satellite manufacturing and launch industry, mainly from 2007 onwards. To the aim of this research, it is relevant to delve into the structures of the ground equipment and satellite service segments.



Source: Elaborated by the author. Data from SIA (2006; 2012; 2017; 2018; 2019; 2020; 2021; 2022).

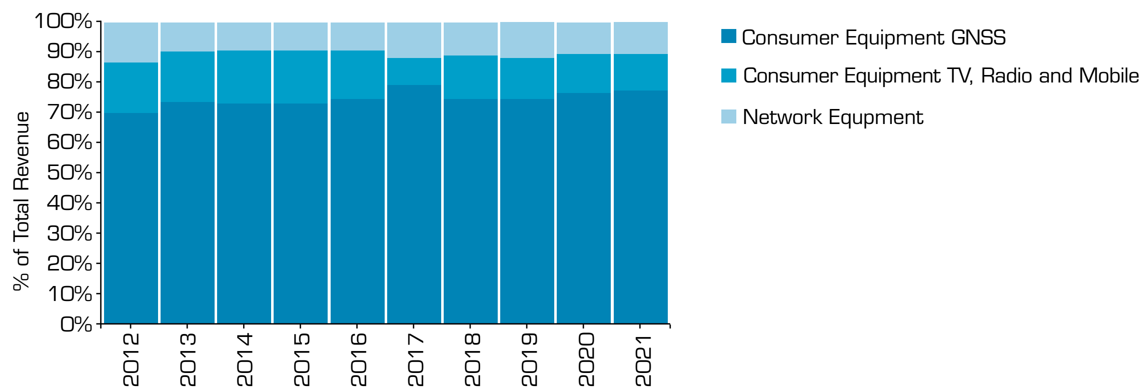
Figure 3. Revenue of segments of the Global Satellite Industry. Reference year: 2001.



Source: Elaborated by the author. Data from SIA (2006; 2012; 2017; 2018; 2019; 2020; 2021; 2022).

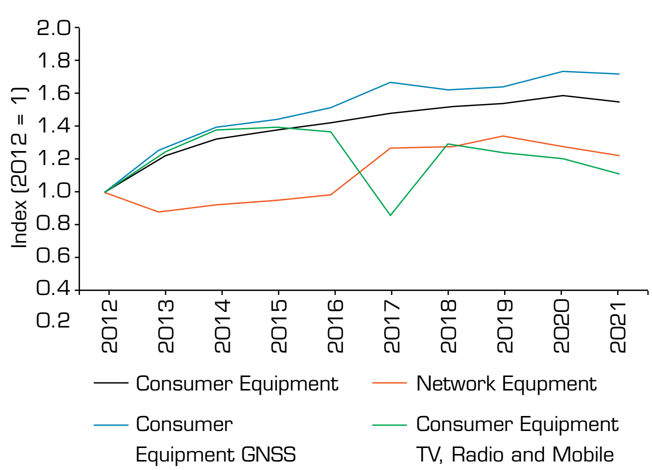
Figure 4. Segments of the global satellite industry in percentage of total revenue.

Figure 5 depicts the relative contributions of the ground equipment elements, defined in Table 1, to ground equipment's total revenue, from 2012 to 2021. Consumer equipment, mainly GNSS, consistently dominates the total revenue, with a share superior to 79% in the last decade. Thus, most of the accentuated growth exhibited by ground equipment comes from GNSS infrastructure, as depicted in Fig. 6, which compares the evolution of each element with the total revenue in the last decade.



Source: Elaborated by the author. Data from SIA (2017; 2018; 2019; 2020; 2021; 2022).

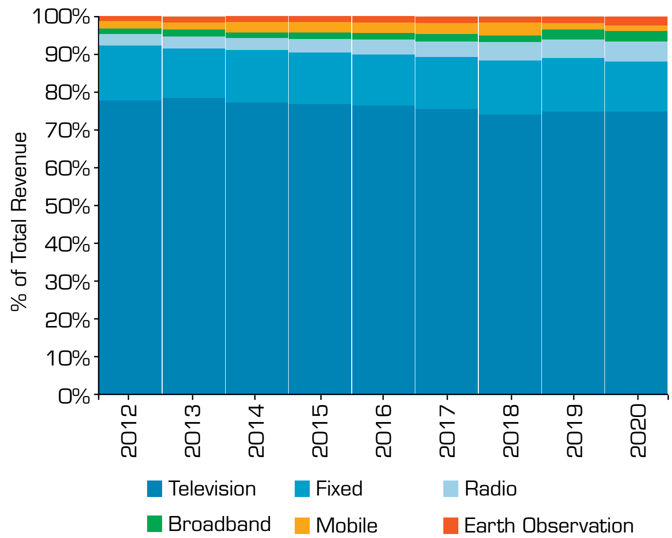
Figure 5. Elements of the ground equipment segment in percentage of total revenue.



Source: Elaborated by the author. Data from SIA (2017; 2018; 2019; 2020; 2021; 2022).

Figure 6. Revenues of the ground equipment segment and its elements. Reference year: 2012.

Regarding the satellite services segment, Fig. 7 shows the evolution of the revenue share of its components, which are described in Table 1. Consumer TV and fixed satellite services dominate the services segment, accounting for about 90% of the satellite services revenues in the last decade.



Source: Elaborated by the author. Data from SIA (2017; 2018; 2019; 2020; 2021; 2022).

Figure 7. Evolution of the revenue share of the elements of the satellite services segment in percentage of total revenue.

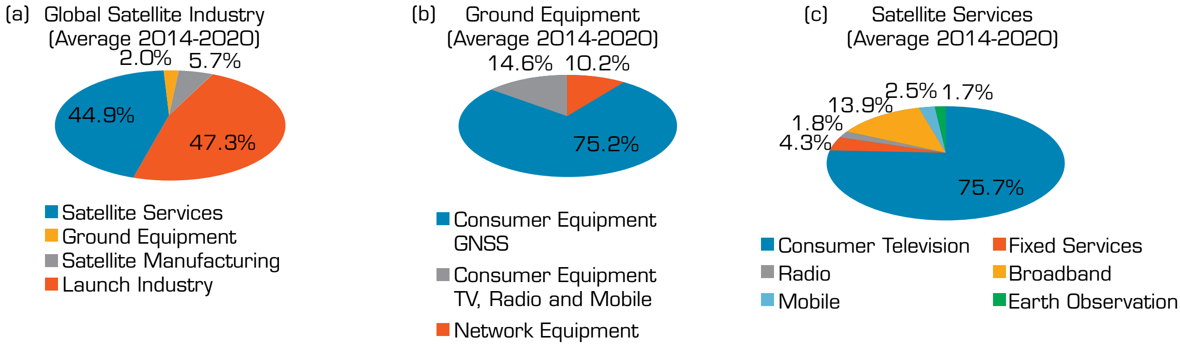
Table 4 and Fig. 8 summarize the results of the preceding analysis.

Table 4. Participation of the global satellite segments in the total revenue and share composition of satellite services and ground equipment. Average values computed for the period 2012–2020.

Industry	Segments	Elements
Global Satellite Industry	Satellite services (47.3%)	Consumer TV (75.7%) Fixed Services (13.9%) Radio (4.3%) Broadband (1.8%) Mobile (2.5%) Earth Observation (1.7%)
	Ground equipment (44.9%)	Consumer equipment GNSS (75.2%) Consumer Equipment TV, Radio, and Mobile (14.6%) Network Equipment (10.2%)
	Satellite manufacturing (5.7%)	
	Launch industry (2.0%)	

Source: Elaborated by the author.

From these results, one may draw the following conclusions regarding the expansion of the global satellite industry in the last two decades: (1) most of the expansion of the global satellite industry in the studied period comes from the growth of the ground equipment and satellite services segments; (2) the expansion of the ground equipment segment has been led by the growth of GNSS consumer equipment, followed by consumer equipment associated with TV, radio and mobile services; (3) the satellite services segment has been led by consumer TV followed by fixed services.



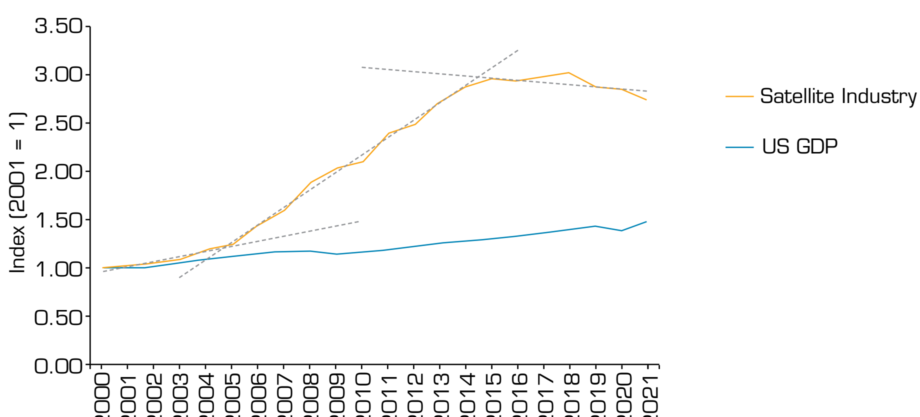
Source: Elaborated by the author.

Figure 8. Participation of satellite segments in the total revenue of the global satellite industry and share of ground equipment and satellite services elements. (a) Participation of satellite segments in the total revenue. (b) Share of ground equipment's elements in the total ground equipment's revenues. (c) Share of satellite services' elements in the total satellite services' revenues.

The satellite manufacturing and launch industry segments have experienced growth but at a much lower rate.

SATELLITE INDUSTRY LIFE CYCLE

Figure 9 compares the global satellite industry and the US GDP from 2000 to 2021. As already mentioned in the introductory section, global satellite industry revenues grew by 2.8 against 1.5 for the US GDP in the period considered. The behavior of the global satellite industry curve is suggestive of the different phases of an industry life cycle. In principle, three distinct stages are identified, corresponding to the *introduction*, *growth*, and *maturity* phases of the conceptual life cycle shown in Fig. 1. Table 5 gives the linear line-fitting parameters corresponding to these three regions.



Source: Elaborated by the author. Data from SIA (2006; 2012; 2017; 2018; 2019; 2020; 2021; 2022) and (BEA 2022).

Figure 9. Revenues of the global satellite industry and US GDP evolution. Dotted lines represent linear fittings. Reference year: 2001.

Table 5. Comparison between Satellite Industry and US GDP growth through linear fitting.

Period	Satellite Industry		US GDP		Ratio
	Inclination	Intercept	Inclination	Intercept	
2000-2005	0.0502	-99.3897	0.0316	-62.1793	1.6
2005-2014	0.1807	-361.1143	0.0127	-24.4785	14.2
2014-2021	-0.0204	43.9689	0.0203	-39.9712	-1.0

Source: Elaborated by the author.

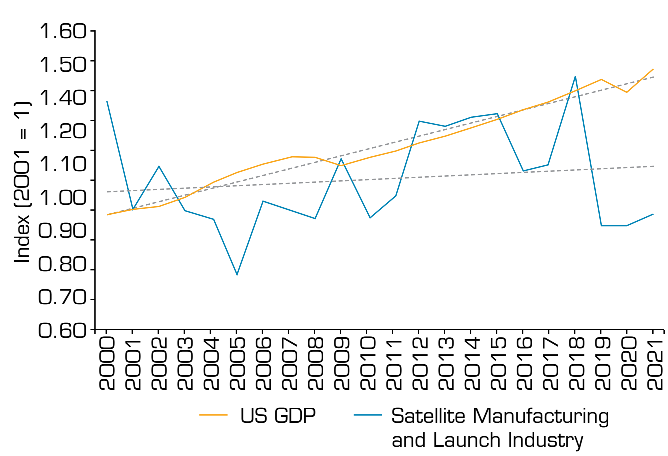
The inclinations give the average linear growth rate corresponding to the period presented in the first column. The last column shows the ratio between the growth rates for the global satellite industry and the US GDP in the indicated periods. If one assumes the validity of the life cycle interpretation, it is seen that the industry's growth in the *introduction phase* is moderately higher than that displayed by US GDP. This fact is compatible with the expected characteristics of this phase. In the next stage, the global satellite industry shows a remarkably larger growth rate than US GDP's growth rate. The computed factor of around 14 is also in line with the expected characteristics of the *growth phase* of an industry life cycle. Finally, in the last stage, which would correspond to the onset of the *maturity phase*, global satellite industry displays a growth rate lesser than US GDP. The restricted period and the fluctuations induced by significant external events, such as the abnormal epidemics economic period, might explain this result. In the long run, according to the life cycle framework, industry growth is expected to follow the GDP, with oscillations and possible secondary growth cycles, until the setting in of an eventual *decline phase*. The literature gives examples of observed products' life cycles, which could, to some extent, be generalized to industries (Kotler and Keller 2012, p. 310).

From the above assessment, one may tentatively state the following assertions regarding the global satellite industry life cycle: (1) the general behavior of the industry's revenue with time suggests that the global space industry may be transitioning from a *growth* phase to the first stage of a *maturity* phase; (2) by linking with the findings of the previous section, one may state that the transition of the global satellite industry from a *growth* phase to a *maturity* phase over the last two decades has been driven preponderantly by the expansion of consumer TV services and consumer GNSS equipment.

GLOBAL SATELLITE MANUFACTURING AND LAUNCH INDUSTRY LIFE CYCLE

If the global satellite industry is moving from a *growth* phase to a *maturity* phase, what might be stated regarding its different segments? The assessment in the previous section shows that the ground equipment and satellite services segments dominate the behavior of the global revenue curve shown in Fig. 9. Hence, these two segments may be considered to display a life cycle evolution similar to that of the global satellite industry. The life cycle behaviour of the combined satellite manufacturing and launch industry segments (SMLI) deserves attention and is studied in the following.

Figure 10 compares the growth of the combined satellite manufacturing and launch industry segments with the US GDP. The combined segments grew by 1.1, while the US GDP grew by 1.5, as given by a linear approximation in the considered period. Thus, as far as the measure provided by revenue figures is concerned, no evident life cycle pattern emerges from a revenue analysis of the SMLI segments.

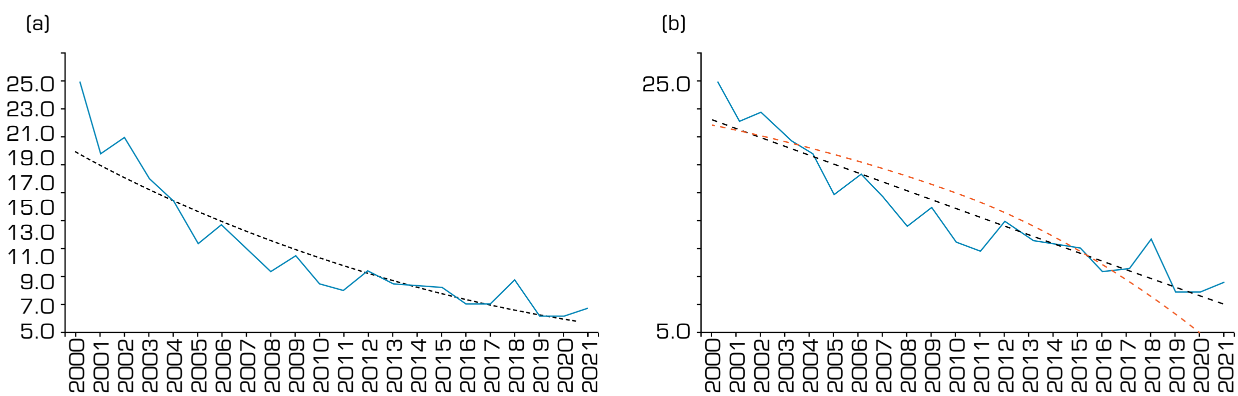


Source: Elaborated by the author. Data from SIA (2006; 2012; 2017; 2018; 2019; 2020; 2021; 2022) and U.S. Bureau of Economic Statistics (BEA 2022).

Figure 10. Revenues of the Satellite Manufacturing and Launch Industry segments compared with US GDP. Best-fit linear approximations are shown. Reference year: 2001.

As already glanced over in previous sections, industries nucleated from a conceptual product may evolve from activities directly stemming from the product, such as manufacturing and distribution, and from a collection of product-enabled services. In the case of the satellite industry, the correspondence would be given by the satellite manufacturing and launch industry segments on the one hand, and the ground equipment and satellite services segments, on the other. An essential question to the present analysis is how industry revenues distribute among these segments in a mature phase. In some industries, as the industry advances towards maturity, the revenues directly associated with the system that nucleates the industry decrease as a fraction of the total industry's revenues.

Figure 11 displays the percent participation of the combined satellite manufacturing and launch industry segments in the global satellite industry revenues, showing that the proportion of the revenues of the satellite manufacturing and launch industry segments decreases as the industry evolves. This fact may stem either from an increase in ground equipment and satellite services revenues or decrease in the market price of satellite manufacturing and launch industry or both simultaneously. The graph on the right gives the results in a logarithmic scale, showing that an exponential fit is superior in describing the observed behavior. The practical context does not favor a hypothesis that combines reducing the volume of operational SMLI components with an increase in satellite services and ground equipment elements. Since there has been a remarkable expansion in the volume of services, and core space hardware must be replaced over time, the observed SMLI revenue behavior might indicate the preponderance of decreasing costs of both satellites and launch services.

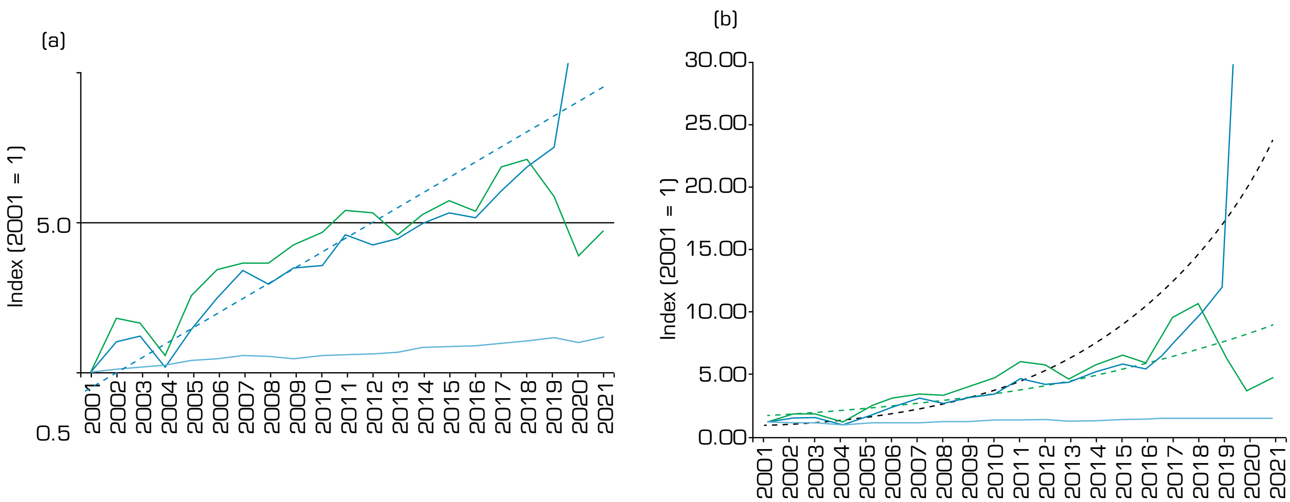


Source: Elaborated by the author. Data from SIA (2006; 2012; 2017; 2018; 2019; 2020; 2021; 2022).

Figure 11. Combined satellite manufacturing and launch industry segments revenue as a percentage of total global satellite industry revenue. (a) Linear scale. The black dotted line shows an exponential best fit. (b) Logarithm scale. The black dotted line shows an exponential best fit, while the orange dotted line shows the result of a linear fitting.

In order to investigate this hypothesis, alternative measures other than revenues might be sought to estimate industry growth. In the case of satellite systems, the number of satellites launched each year seems to be a natural choice for assessing the industry's production level. Another possible measure is the cumulative number of firms involved in satellite production or services. The cumulative number of countries using satellites for some purpose might as well be considered as another measure, yet of an indirect character.

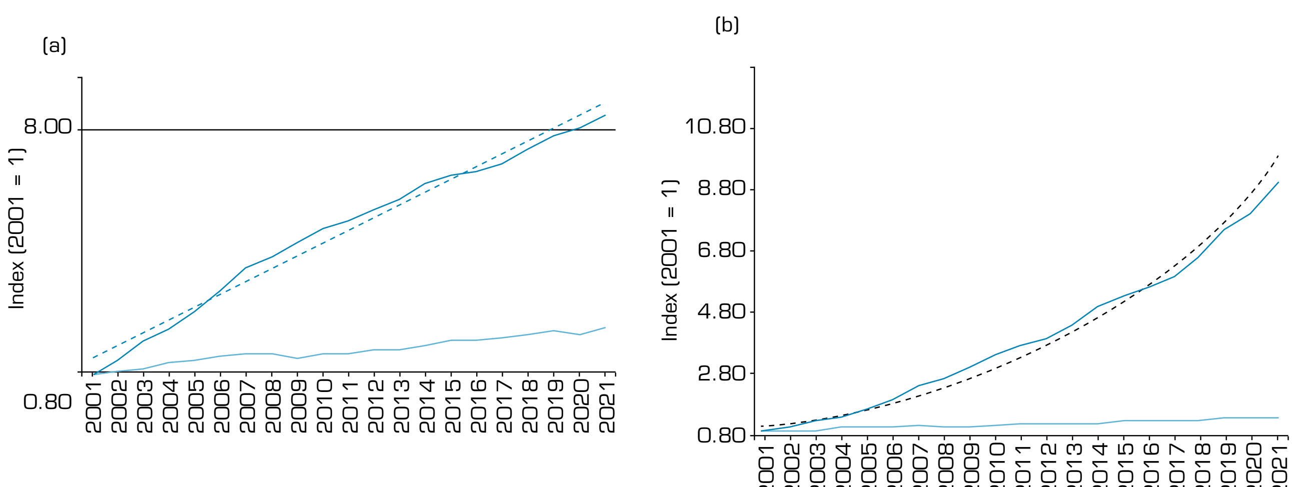
Data from the UCS (2022) have been used to implement these alternative metrics. Nanosatellites and picosatellites have not been included in the study. Only data relative to satellites with a mass superior to 25 kg were considered to avoid possible bias introduced by the emergence of small satellites as educational tools, which would disproportionately favor the hypothesis considered. Figure 12 compares the number of satellites launched per year with the US GDP from 2001 to 2021, taking values of 2001 as a reference. It also shows the number of satellites with a mass of over 500 kg. The dotted line is the result of an exponential best fit. Comparing with Fig. 11 and noting the linear versus logarithmic scales of the ordinate, it is seen that the number of launched satellites indicates a significantly higher activity of the satellite and launch industries than would be inferred from industry revenues. It is seen that the revenue per launched satellite is falling significantly, even if one considers satellites with masses over 500 kg.



Source: Elaborated by the author. Data from UCS (2022) and U.S. Bureau of Economic Statistics (BEA 2022).

Figure 12. Number of satellites launched per year with a mass above 25 kg compared with US GDP index. The green line represents the data for satellites with mass above 500 kg. The dotted lines give the best exponential fitting. Reference year: 2001. (a) Linear scale. (b) Logarithmic scale.

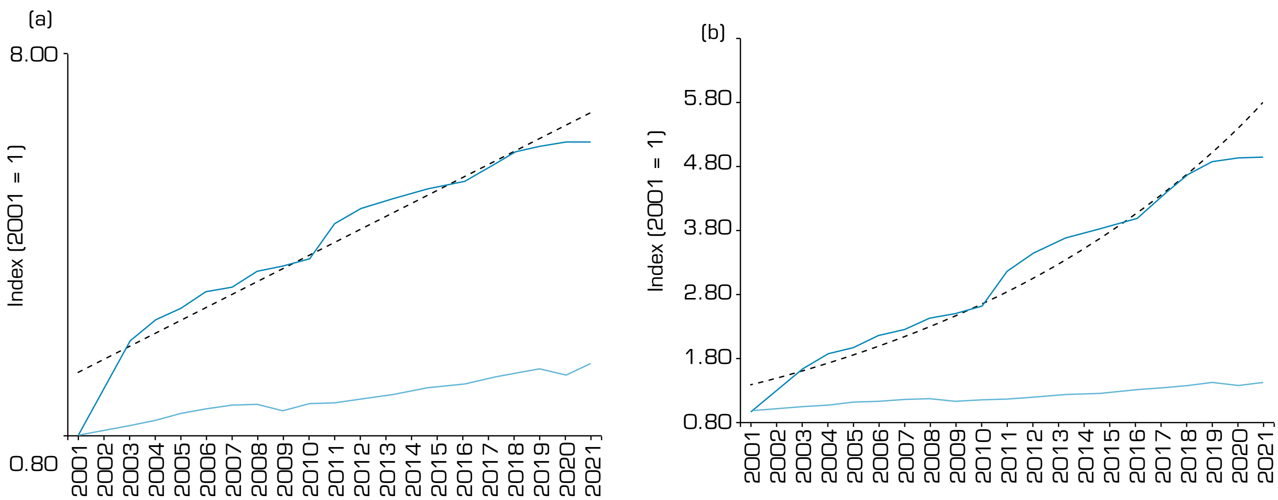
Figure 13 shows the cumulative number of contractors for satellites with a mass superior to 25 kg. This number relates to the expansion of the industry. According to the life cycle framework, the number of firms responsible for providing satellite systems is expected to increase significantly in the *growth* phase and stabilize during the *maturity* phase. The observed behavior shows that the growth in the number of firms entering the satellite industry is substantially higher than would be expected according to the average economic growth in the period of study, represented here by the increase in US GDP, suggesting a behavior compatible with a life cycle *growth* phase.



Source: Elaborated by the author. Data from UCS (2022) and U.S. Bureau of Economic Statistics (BEA 2022).

Figure 13. Cumulative number of contractors for satellites with mass above 25 kg compared with US GDP index. The dotted line gives the best exponential fitting. Reference year: 2001. (a) Logarithmic scale. (b) Linear scale.

Similar arguments apply to the cumulative number of countries involved with space activities. As the industry expands in a typical *growth* phase of its life cycle, this number is expected to increase at a rate larger than regular economic activity. Figure 14 shows that the cumulative number of countries that display operators or owners of satellite systems increases at a rate significantly higher than the corresponding average economic growth.



Source: Elaborated by the author. Data from UCS (2022) and U.S. Bureau of Economic Statistics (BEA 2022).

Figure 14. Cumulative number of countries of operator/owner of launched satellites per year with a mass above 25 kg compared with US GDP index. The dotted line gives the exponential best fit.
Reference year: 2001. (a) Logarithmic scale. (b) Linear scale.

This section has studied the 2000–2021 evolution of the satellite manufacturing and launch industry segments. The increase in the number of satellite systems deployed per year has been taken as a *physical* indicator of the satellite and launch industry activity growth. The yearly growth of the number of contractors of satellite systems and the annual increase in the number of countries that display operators or owners of satellite systems have also been taken as measures of industry growth. These indices might, in principle, compensate for any eventual bias of the previous index. The results show that the growth rate of the satellite manufacturing and launch industry segments is larger than that indicated by the revenue growth in the studied period, as summarized in Table 6.

Table 6. Comparison of different indicators for the growth of the satellite manufacturing and launch industry segments with US GDP.

Indicator	Increase in the period 2000–2021 *
i. Number of satellites launched per year	23.8
ii. Cumulative number of contractors of satellite systems	9.2
iii. Cumulative number of countries with operators or owners of satellite systems	4.9
iv. Revenue growth of the SMLI segments	1.1
v. US GDP	1.4

*Index with 2001 as the reference; i., ii. and iii.: exponential fitting; iv. and v.: linear fitting. Source: Elaborated by the author.

The results show that the observed SMLI revenue behavior may be explained by decreasing satellite and launch service costs over the studied two decades.

THE IMPORTANCE OF ENGAGING IN NEW INDUSTRIES

Emerging industries are either newly formed or reformed industries, resulting from different sources: technological innovations, changes in cost relationships, new consumer needs, or other economic or sociological changes. In essence, whenever a new product or service becomes a business opportunity, the emergence of a new industry is a possibility (Porter 1980, p. 215; Proctor 2014, p. 68).

New industries can revitalize economic growth and employment and induce the development of superior environmental technologies (Forbes and Kirsch 2011, p. 590). The wealth of a society is directly linked to the income level of households, the most significant component of which comes from wages. According to recent work, the business sector accounts for 72% of the GDP in OECD countries (Manyika *et al.* 2021). The study also estimated that direct labor income equals about 25% of company revenues. New industries, mainly those displaying high revenues, may thus significantly increment the income level of households.

Studies indicate that implementing space programs, related technologies, or associated activities may induce new sources of revenue for firms, usually beyond the space sector (Bach *et al.* 2002; Cohendet 1997; OECD 2007, p. 67). An OECD study covering the period from 1972 to 2017 identified at least 77 industries that benefited from the socioeconomic effects of space investments (OECD 2019, p. 43). Benefits include an increment of commercial revenues, an increase in employment level, gains in productivity and efficiency, social welfare improvements, and general macroeconomic benefits. The latter occurs at the national, regional, or local levels and relates to impacts on the gross domestic product, added value, and induced taxation (OECD 2019, p. 44).

The Brazilian space program formally began in 1961. Since its establishment, several achievements can be pointed out as paving the way for establishing a space industry in Brazil. There are initiatives related to the core elements of the space sector (satellites, launchers, launching and operations services) (INPE 2022a; IAE 2022a), efforts and activities aimed at personnel education and training (graduate and training courses, and training in direct core activities) (INPE 2022b; c), and provision of services in telecommunications, remote sensing, TV broadcasting, and data streaming, among others (Telebras 2022). The *Catálogo de Empresas do Setor Aeroespacial* (CESAER) currently lists 61 national companies that develop and manufacture aerospace products and provide services in the aerospace sector (IFI 2022). The Associação das Indústrias Aeroespaciais do Brasil (AIAB 2022) lists 39 firms as associates that supply small satellites, subsystem elements such as structures, on-board computers, and propulsion, payloads, sounding rockets, ground equipment, and various related services. Finally, the Associação Brasileira das Empresas de Telecomunicações por Satélite (ABRASAT) displays 25 associated companies headquartered in Brazil that hold the right to exploit Brazilian or foreign satellites and provide telecommunication services in Brazil (ABRASAT 2022).

In Brazilian government organizations, there have been, over the years, substantial investments in the infrastructure for the integration and tests of space systems; the same holds for satellite control, tracking, and data reception infrastructure (INPE 2022d). There is established experience in the engineering and design of space systems, including orbital platforms and vehicles (INPE 2022e; IAE 2022b; c). Brazil displays long-standing experience with sounding rockets (IAE 2022a). The Centro de Lançamento de Alcântara launching pad is close to the equator, a privileged position for launching geosynchronous satellites (FAB 2022). Also, there have been substantial investments in developing an industrial arrangement to manufacture space systems in Brazil. Recently, equipment for four satellites has been procured in this industrial arrangement (INPE 2022a; Oliveira 2014). Optical cameras, solar panels, telemetry, tracking, and control subsystems are examples of qualified equipment in recent missions. Currently, three remote-sensing satellites are in operation, whose subsystems, with the corresponding equipment, have mostly been procured among Brazilian companies (INPE 2022f).

Since the global satellite industry is still in a formation stage, possibly transitioning from a *growth* to a *maturity* phase, there are good opportunities for countries that display the resources to overcome barriers to entry. Dedicated and specialized infrastructure, scores of qualified personnel, and an industrial arrangement with already some experience with space systems constitute fundamental assets for overcoming barriers to entry. Finally, It should be noted that Brazil also displays a well-developed sector of space-enabled applications (ABRASAT 2022).

CONCLUSION

The emergence of new industries represents an opportunity for the economy of countries that display the necessary resources to overcome barriers to entry. There is plenty to be learned about how governments might stimulate the emergence of the space industry in their economies.

The main findings of the present study are: revenue data for the global satellite space industry from 2000–2021 show remarkable growth of the satellite space industry in the period considered; the ground equipment and satellite services segments together dominate the global satellite space industry's revenue growth behavior, displaying a share of over 90% in the last decade; consumer GNSS infrastructure and consumer equipment related to TV, radio, and mobile are responsible for about 90% of the growth exhibited by the ground equipment segment in the last decade; consumer TV and fixed satellite services dominate the satellite services segment, accounting for about 90% of the satellite services' revenues in the last decade; no evident life cycle pattern emerges from a revenue growth analysis of the joint satellite manufacturing and launch industry segments; other measures of activity, such as the number of launched satellites per year, the yearly growth of the number of contractors of satellite systems, and the annual increase in the number of countries that display operators or owners of satellite systems, indicate a significantly higher activity of the satellite and launch industries than would be inferred from industry revenues; the data show a remarkable decrease in the costs of both satellites and launch services.

The above findings support a characterization of the current global satellite industry as marked by decreasing costs of core elements and a large expansion of satellite-enabled services in the last two decades. This characterization suggests that the worldwide satellite space industry is transitioning from a *growth* to a *maturity* life cycle stage.

The possibility that the global satellite industry may be transitioning from a *growth* to a *maturity* life cycle phase places a window of opportunity for countries to engage in the emerging global space industry.

Once the satellite space industry reaches a full *maturity* life cycle phase, high entry barriers will become even more prominent. Engaging in the global satellite industry in the context of deliberate planning takes significant initial investments for a country. New entrants need unique infrastructures and capabilities. As examples, one may quote integration and test facilities; experience with control and reception ground stations; large teams of specialized personnel; a basic industrial arrangement with sufficient expertise in the philosophy of the project and manufacturing of space-qualified hardware and software; and other qualifications, in general, not readily available when a country is new to the space industry. Also, established international players will display a solid base of resources and knowledge, hence enforcing significant barriers to entry in terms of costs and other competitive factors, such as the quality and reliability of products.

Brazil displays a long-standing experience in all the factors mentioned above. Hence, Brazil has a favorable position for engaging in the international production chains of the emergent global satellite industry.

CONFLIT OF INTEREST

Nothing to declare.

DATA AVAILABILITY STATEMENT

The input data used in the calculations presented in the article are available in: https://doi.org/10.5281/zenodo.7511148.

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