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An attempt to measure the return on public investment in the Brazilian Space Sector

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Abstract: The space sector is responsible for generating products with high added value and diffusing effect on practically all sectors of the economy. Recent transformations have changed the sector dynamics with greater participation of the private sector. Although the government is still the largest financier of projects, mainly for significant missions, changes in the sector have been driving technological decisions for solutions to the problems proposed for the private sector's responsibility. Even with these characteristics, the sector is not yet consolidated, from the point of view of structuring data, to allow the evaluation of public investments made robustly. Thus, in this work, it was decided to adopt a multiplier methodology developed for the European Union countries, resulting in a direct return of 3 times and an indirect return of 6 times for each Real (BRL) invested by the public sector.

Keywords: Public Investment; Space Sector; Return Rate

JEL Code: H30; H54; O23

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1. INTRODUCTION

Several countries have started to invest in the space sector in recent years. Even those countries with no history in the sector have realized the benefits of space technology: from the generation of direct benefits to diffusion to other sectors of the economy.

In the 1960s, a restricted group of countries dominated space technology and competed to access space autonomously. We currently have a large group of countries that have mastered certain technologies. The focus is on exploring outer space, usually carried out through large agreements between countries to support such projects' financial resources.

The main countries in the space sector, such as the United States, China, Russia, Japan, and India, invest billions of dollars annually. They have a concrete industry and are engaged in projects, dominating practically the entire value chain of the sector, that is, the segments satellites, ground, launchers, and applications.

However, smaller countries with scarcer resources, such as South Africa, Peru, Southeast Asian countries, and others, have directed their investments towards the purchase of space products for national security or autonomy in the generation of telecommunications data or Internet access. Part of these investments includes the attempt to internalize the acquired technology. This behavior is because space technology generates considerable spinoffs and impacts virtually all economic sectors.

Although the positive effect of space technology on the economic sectors are well known, as the generation of spinoffs and spillovers by the space sector, studies that effectively demonstrate the economic impact of the investments made are still scarce.

These studies are important to guide and justify the high resources allocated by governments in the development and incentive to the national space industry, to the detriment of other sectors.

In the Brazilian case, in addition to the lack of studies of this type, the characteristics of the space sector impose even greater difficulties when compared to other countries: the existence of a small and restricted industry; the lack of a specific and detailed classification for space products; and the fact that space products are not the main delivery of a large part of the national industry. These are just a few factors that demonstrate the difficulties in measuring the benefits generated by the space sector in Brazil.

In this sense, the objective of this work is to propose the use of an existing methodology, in an attempt to measure the impacts generated on the economy by public investments made in 2020 by the Brazilian Space Agency (AEB), through the analysis of the three largest projects: o CBERS-4A satellite; the Amazonia-1 satellite and the VLM-1 launch vehicle.

2. CONCEPTUALIZING SPACE ECONOMY

Before measuring the impact of space activity, it is necessary to conceptualize the terms "space sector" and "space economy."

For the OECD (2014), in the work Handbook on Measuring the Space Economy, “the space sector includes all actors involved in the systematic application of engineering and scientific disciplines to the exploration and utilization of outer space, an area that extends beyond the earth's atmosphere.” Nevertheless, this definition is currently extremely limited, given the development of space services and applications.

The space sector's influence expands beyond direct applications, as companies in non-space sectors can benefit directly from space services, and indirectly, through knowledge and technological spillovers.

Past studies such as Size and Health and Case for Space (London Economics 2014) have focused on the space industry alone, i.e. companies that manufacture, launch, and operate space equipment. However, an additional group of organizations uses the signals and data offered by these companies to develop value-added applications, such as Earth observation images and broadband satellite services. This group is not part of the space industry but still obtains revenues generated by equipment and/or services that depend on the space industry’s operation continuity. In order to include this group of companies, a broader term, space economy, is used.

> “The space economy is much wider than the space sector and can be defined using different angles. It can be defined by its products (e.g. satellites, launchers...), by its services (e.g. broadcasting, imagery/data delivery), by its programmatic objectives (e.g. military, robotic space

> exploration, telecommunications...), by its actors/value chains (from R&D actors to users), and by its impacts (e.g. direct and indirect benefits...). One drawback is that narrow definitions might ignore important aspects, such as the R&D actors (laboratories and universities), the role of the military (as an investor in R&D budgets and customer for space services), or ignore scientific and space exploration programs altogether". (OECD 2014, 19).

The definition adopted by London Economics (2014) is the one that will be adopted in this study:

> "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 utilizing 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. It follows that the Space Economy goes well beyond the space sector itself since it also comprises the increasingly pervasive and continually changing impacts (both quantitative and qualitative) of space-derived products, services, and knowledge on economy and society". (London Economics 2014, 11).

3. THE WORLD SPACE SECTOR

Space technology is already part of modern life: weather forecast available at any time, location-based services on smartphones, events broadcast live, and broadband connection availability in rural areas that are difficult to access. Space technologies have become an integral part of citizens' daily lives, even though they are unaware of such technologies.

The characteristic of space technology is to be broadly transversal. It is present in several areas such as aviation, research, agriculture, fishing, monitoring, communication, geological exploration, transport, energy, financial sector, defense, emergency services, and response to disasters, among others. Given the wide spectrum of use of this technology, these services' availability and continuity have great economic importance. The potential for developing new applications and services can influence the innovation process, generating important spillovers for all economic sectors.

Considering these characteristics, as shown in Figure 1, the global space economy reached US$ 366 billion in 2019 (Bryce 2020), with prospects of reaching US$ 1 trillion (Morgan Stanley 2019) to US$ 2,7 trillion (CNBC 2017) dollars up to 2040. The space applications segment, such as telecommunications, remote sensing, and national security, is responsible for a large part of the space economy and is the most dynamic in the space sector. It requires less investment and provides a shorter return in a period of time.

A country with the territorial dimensions of Brazil demands many solutions from space. Monitoring of borders, land or sea, fleet control, disaster management, communications in distant locations, solutions for distance education are just some segments strongly dependent on space technology in Brazil.

In terms of evolution, the economy's digitalization is one of the main items that will demand solutions to be provided by the space sector in the coming years. Several space applications can provide solutions to health and distance education issues, so required today due to the pandemic of the SARS CoV-2 virus. The 5G technology is also a factor that will respond to the increased demand for high speed connections in an environment where remote work has become a reality.

The ground equipment makes up another large part of the slice. After all, they are necessary to ensure the correct reception and retransmission of satellite data in its various applications.

The launch segment was responsible for only US$ 4.9 billion in 2019, due to the entry of private companies that started to commercially explore access to space and thereby drastically lowered the price of launch services.

Government budgets and resources for commercial space flights accounted for US$ 95 billion of space economy in 2019. A select group of countries, including the United States, Russia, and China, are responsible for much of that budget and maintain programs more complete spatial.

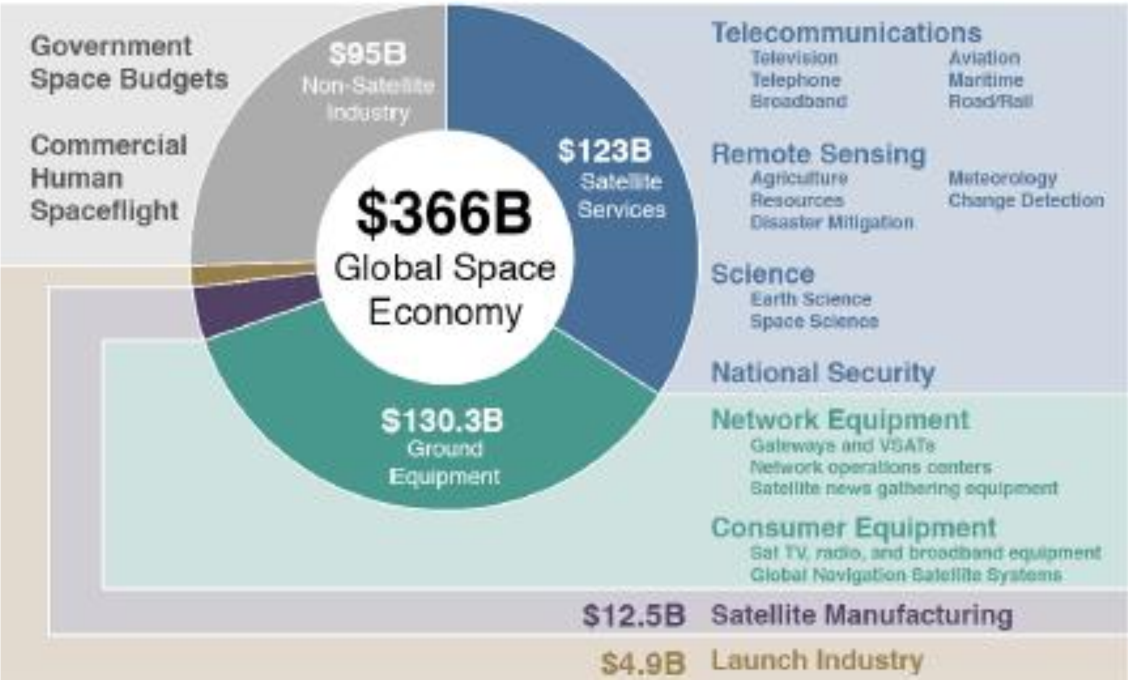


Figure 1 - The Satellite Industry in Context

Source: Bryce 2020

The satellite manufacturing industry accounts for US$12,5 billion. The process of components miniaturization has caused a reduction in the average weight of satellites in recent years and transformed the dynamics of the space sector.

Figure 2 shows the predicted increase in the number of satellites launched for the next decade. The rise in demand for satellites will have a positive effect on the launch market. This projection has even stimulated the development of small launch vehicles dedicated to the launch of nanosatellites or nanosat. These types of launch vehicles seek a niche market focused on customers who do not want to wait for the launch window of large vehicles.

A large vehicle needs to fill its total launch capacity to maximize its profits, which forces customers to wait a time to confirm its launch. As the number of commercial launchers is still small, this makes the waiting time even longer. Thus, smaller vehicle developers aim at a market for timely launches and for customers willing to not wait too long for the launch to take place.

According to Figure 2, for the period between 2020 and 2029, the launch segment is expected to reach US$ 18 billion per year (Euroconsult 2020). The average number of satellites launched in the same period will be 1,011 against 181 satellites from 2010 to 2019. And this segment has attracted the participation of several private companies, which enter the market with the aim of meeting the increased demand for launches.

As an example, in 2018, SpaceX performed 15 commercial launch operations (SpaceX 2018). In 2017, this company launched 18 launch vehicles and recovered 14 reusable engines (The Economist 2018). Blue Origin plans to launch the first tourists into space shortly soon (Wattles 2017). It should be noted that the development of reusable engines was an important milestone for the development of the launch vehicle segment, as it significantly reduced the cost of access to space.

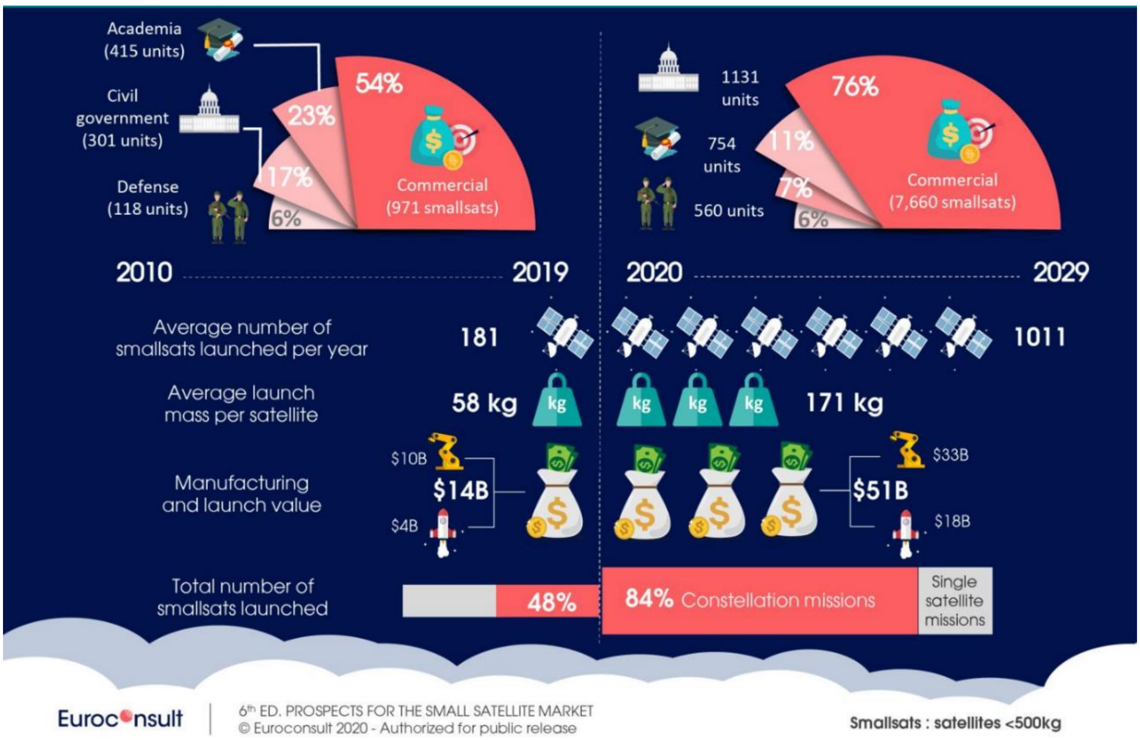


Figure 2 - Small Satellite Market until 2029

Source: Euroconsult 2020

Historically, governments have been the main investors in the space sector. The budget of space agencies totaled US$ 70.8 billion (Euroconsult 2019), with only NASA (American Space Agency) responsible for US$ 20 billion of this total. Adding the US Department of

Defense budget for space, the volume of resources destined by the United States for space is more than US$ 40 billion, as can be seen in Figure 3. Next, considering the amount of investment, we have China (US$ 5.8 billion), Russia (US$ 4.170 billion), France (US$ 3.158 billion), in terms of individual countries. The ESA (European Space Agency), with a total budget of US$ 6.68 billion, for the year 2020 cannot be left out (ESA, 2020).

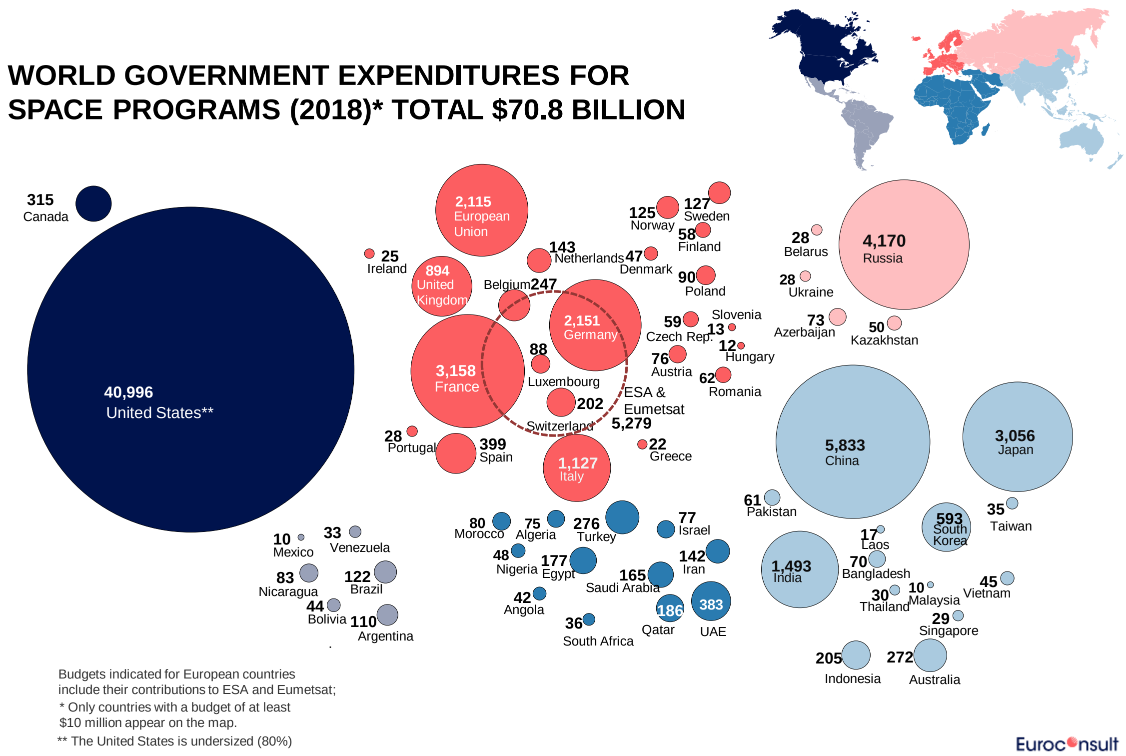


Figure 3 - Budget for Space Programs

Source: Euroconsult 2019

In recent years, there has been an increase in the number of countries interested in investing in the space sector, precisely because of the sector's capacity to interact and generate spinoffs and spillovers. Even with limited budgets, several countries have bet on the space sector as a driver for innovation and socio-economic development. Only in Latin America, we have initiatives in the space sector by Argentina, Paraguay, Peru, Chile, and Bolivia, besides Brazil.

4. TRADITIONAL SPACE X NEW SPACE

The space sector has undergone major changes in recent decades. Called the Traditional Space (or Big Space), this sector for a long time was dominated by state investments, with large projects of high cost and duration, such as the Shuttle, the International Space Station, and the Hubble telescope. In addition to being the main investors, governments also played the role of defining the requirements and the way of carrying out technological development.

In the 1980s, the microelectronics revolution allowed the miniaturization of several components and technologies, including space ones, initiating the so-called “New Space.” More than just revolutionizing the sector from a technological point of view, the "New Space" also brought changes in organization and state / private participation, allowing the emergence of new business models.

> “New Space” is “*a sectorial dynamic encompassing various interrelated trends which, together, are driving the emergence of a new approach to space activities characterized, in particular, by a more prominent and leading role for the private sector and by more private, market-oriented activity*” (Tugnoli, Sarret; and Aliberti 2018).

The term "New Space" is often compared to the so-called "Traditional Space.” The first is the result of the emergence of new business models and the progressive transformation of the traditional way of conducting activities in the space sector. The second is characterized by a set of activities led and financed by governments. Among the public sector initiatives that benefited from the emergence of the “New Space,” stands out the evolution of legal and regulatory frameworks that allow the greater participation of the private sector in space activities.

The beginning of this transformation is due to the progress of initiatives aimed at the private market in different segments of the space sector, such as the development of launchers, Earth observation, telecommunications, and space exploration. However, much of the space activity continues to be led by governments due to the high volumes of resources that are still needed, with the private sector being contracted as part of public programs.

These new initiatives are the result of the emergence of companies that enter the space sector as startups and large information technology companies that seek to explore the applications market. These new businesses propel public and private funds towards innovative models that present disruptive solutions. The space industry is becoming increasingly knowledge-intensive and generates high-skill jobs.

On the economic side, the emergence of a large number of small launcher development initiatives responds to the demand arising from the growth of nano and microsatellites in “New Space”. It is important to note that the new companies are not only focused on the launch vehicle and satellite segments but also on the development of new services and applications.

In this new model, private participation increases considerably, mainly because of the cost reduction provided by the miniaturization of the components. The projects have shorter deadlines and lower costs, making them more accessible to private companies, which previously were not able to bear the risks associated with the projects.

The satellites’ average weight is also reduced, which largely ceases to weigh tons, reducing their service life. Thus, it is necessary to replace these in a shorter period of time. Large satellites can have lifetimes of around 20 years, while nanosatellites have much shorter lifetimes, as short as 2 years, for example. The increased number of smaller satellites launched contributes to a higher cadence of demand for products in the industry, which positively influences the generation of employment and income.

Such changes are reflected in the performance and dynamics of the space sector itself. As can be seen in Figure 4, there is greater participation by the private sector. The role of the State is shifting to defining high-level requirements while the how to do it becomes the responsibility of the private sector. Costs are also shared and no longer just borne by the government.

Government support has traditionally been a critical factor in technological change linked to the space industry. Private companies in the United States, for example, had access to the technical archive of the U.S. Space Agency (Bockel 2018). These favorable conditions were essential for companies to make technological leaps (Chaikin 2012). Cooperation between government scientists and private industry has triggered convincing advances in a number of sectors, with applications in several areas other than space (Werner 2015).

Governments have also played an important financial role, supporting the space sector in various ways, such as research grants, contracts, and other agreements with the private sector (Bockel 2018). The U.S. Space Agency (NASA) uses direct contracts with the industry in a systematic way. One example is the development of a vehicle capable of carrying cargo and astronauts to the International Space Station (ISS) and the vehicle that will carry out the return mission to the Moon in 2024. The entry of the developed technologies into the market may still need government support because the costs and risks can be so high that companies cannot afford to undertake on their own (OECD 2016). This situation has been changing as companies begin to envision the possibility of profits in the space sector.

Program Characteristic	Legacy Space	New Space
Owner	Government	Industry
Contract Management	Prime Contractor	Public-Private Partnership
Customers	Government	Government and Industry
Space Agency´s Role	Government defines “what” and “how”	Government defines “what” and industry defines “how”
Requirements Definition	Government defines detailed requirements	Government defines top-level capabilities needed
Costs Structure	Government incurs total costs	Government and industry share cost

Figure 4 - Characteristics of the former and new space sector

Source: Adapted by the author from the work of Martin 2017

Traditionally, investors considered commercial opportunities in the space sector as high risk, high cost, and characterized by long periods to earn a return on the investment, which made it unfeasible for the private sector to operate on its own (Wakimoto 2018). Typically, companies operating in the space sector were dependent on government procurement and contracts. Until 1982, the United States government was responsible for launching all civilian and commercial cargo within its borders. Launch vehicles were produced under contract with the American government, and the bidding process for these contracts tended to be uncompetitive due to the limited number of companies operating in the space sector (Berger 2017).

Several major changes, however, have reduced barriers to entry and increased private sector interest in space. Improvements in management practices and technological development are reducing launch and satellite costs. The standardization of production imposed by SpaceX for its launch vehicles has had a significant impact in reducing production costs (Chaikin 2012). As stated earlier, the development of reusable engines has also had a substantial effect on the industry, placing SpaceX as one of the leading companies in the space sector. The price reduction provided has practically transformed access to space into a commodity.

The increase in private participation is also affecting several markets around the globe. While the United States is still the main private market in the space sector, Europe has increased its role, and European companies have started to compete with American companies. At the same time, developing countries are making significant advances in their own space programs (Bockel 2018). Countries without a history in the space sector have made investments and advanced rapidly in developing launch vehicles and space exploration missions , such as the United Arab Emirates, which launched its first satellite in the 2000s and is already planning missions to Mars.

In the current scenario, the State starts to finance large space projects that, due to their characteristics, cannot be carried out entirely by the private sector, still needing large amounts of public investment. However, the form of these investments changes dramatically. For example, NASA commissioned on the market the development of a vehicle capable of taking its astronauts to the International Space Station. Two companies qualified for the supply and received funds from the American agency, generating competition between them. Private institutions apply not only to receive a public contract but also because they see lucrative opportunities in the space sector. New markets (tourism and space exploration) and products (reusable engines) can be explored by these companies in a sector with positive growth prospects.

5. THE BRAZILIAN SPACE SECTOR

The Brazilian space sector emerged in the 1960s, before China or India. The development of space activities related to launch vehicles was under the responsibility of the Air Force, which resulted in import restrictions for the main components of the time. Later, in 1971, satellite-related activities were assigned to the National Institute for Space Research (INPE).

Public Finance Notebooks, Brasília, v. 21, n. 2, p. 1-29, sep. 2021

In the 1970s, the Brazilian Commission for Space Activities (COBAE) was created, responsible for updating the National Policy for the Development of Space Activities and for coordinating civilian and military sectoral programs. During the 1960s and 1970s, the SONDA program started the quest to nationalize rocket production and, later on, launch vehicles in Brazil.

Also during the 1970s, the Brazilian Complete Space Mission (MECB) was instituted to launch a national satellite from a national launch vehicle of a national launch center. Thus, in 1983 the Alcântara Launch Center (CLA) was opened, located in Alcântara, Maranhão State. Brazil already had a launch center located near the city of Natal, the Barreira do Inferno Launch Center. However, due to the city's growth and its proximity to the center, the associated risks in case of failure to launch large vehicles made it impossible to use the center. INPE, responsible for the development of satellites, completed both the SCD-1 and SCD-2. MECB was hampered by the accident with the vehicle developed at the time by Brazil, called VLS (Satellite Launch Vehicle), in 2003.

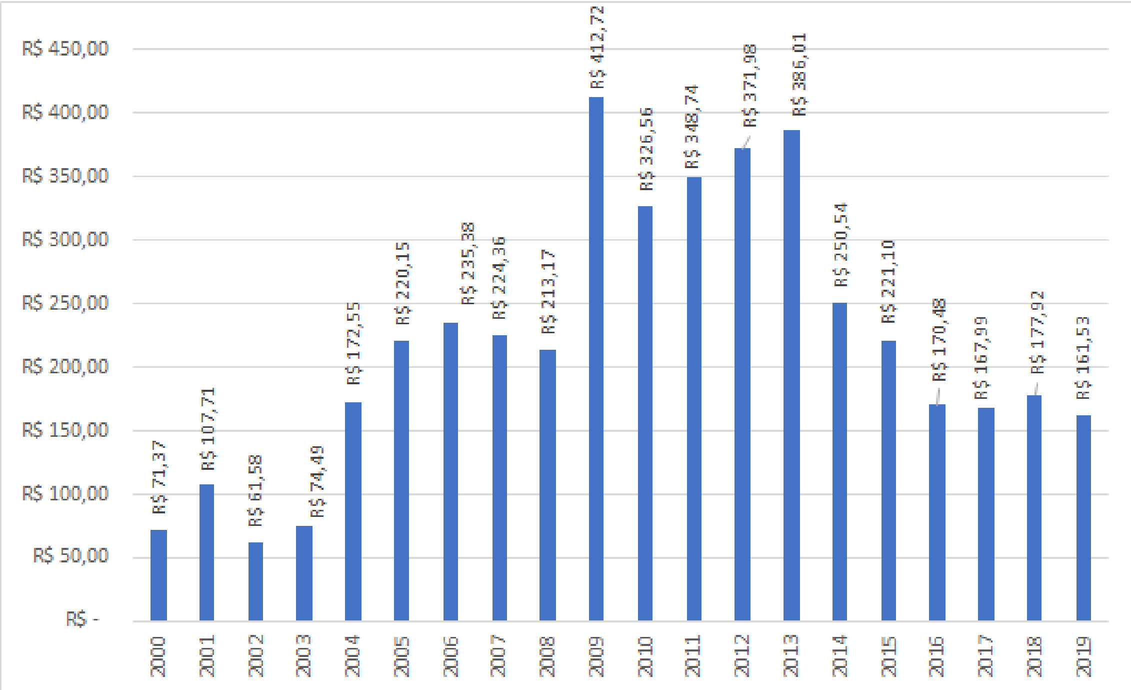
With the goal of having a civilian institution leading the space sector in Brazil, the Brazilian Space Agency (AEB) was created in 1994. AEB would be a central organization of the space system, while the Brazilian Air Force would continue to deal with the development of launch vehicles and INPE, with satellites. In Brazil, the space sector is currently organized through the National System for the Development of Space Activities (SINDAE), with AEB as the central organization and with INPE and IAE as executing agencies. Representatives from industry and academia also participate. This model is currently being restructured. Following the North American model, the proposal is to create the National Space Council (CNE), presided over by the Casa Civil (Secretary of the Interior), with the responsibility of defining the strategic guidelines of the Brazilian Space Program. It is also planned to create the Space Executive Committee (CEE), which will act at a more operational level and will be chaired by the AEB.

Several projects developed over time have shown good results, such as the space probes (SONDA family) and the data collection satellites (SCDs). However, subsequent projects have not achieved the same success. An example is the Satellite Launching Vehicle (VLS), which was discontinued after the accident in 2003, and replaced by the Microsatellite Launching Vehicle (VLM-1) project, still under development.

Public Finance Notebooks, Brasília, v. 21, n. 2, p. 1-29, sep. 2021

On the satellite side, Brazil signed a cooperation agreement with China that resulted in the launch of the CBERS series satellites (China-Brazil Earth Resources Satellite), which was launched in December 2019. However, projects in partnership with other countries were not completed, such as the SABIA-mar, which was to be manufactured with Argentina. The main reason for the paralysis of these projects is the continuous reduction of resources allocated to the Brazilian Space Program (PEB), as shown in Graph 1.

Another project hampered by budget restrictions was the joint venture between Brazil and Ukraine for the production of a launch vehicle using the Alcantara Launch Center (CLA). The company called Alcantara Cylcone Space (ACS) ended its activities without completing the works of the launch center and without the completed vehicle.



Graph 1 - Budget of the Brazilian Space Agency (Current Commitments - in BRL million)

Source: Elaborated by the author from data of Brazilian Space Agency (AEB)

The constant budget reductions experienced by AEB have drastically affected the Brazilian space industry, which has always been dependent on government projects. There are currently not enough resources to start new projects in the sector, but only for the completion of those in progress, such as the VLM-1 and the Amazonia-1 satellite. Then, there is a need for the involvement of private actors in developing new initiatives in the sector.

The Brazilian space industry consists of few companies and many suppliers that do not work exclusively with the space sector, which makes it extremely complex to identify which companies manufacture goods and services for the sector, the amounts invested, the production and benefits generated. There is not even a specific code for space activities in the national classification of economic activities (CNAE), a problem found in other countries.

According to Vellasco (2019, 62), the Brazilian space sector is formed by small and medium sized companies that play the role of subcontractors, supplying components and subsystems to the satellite programs and national launchers. INPE and IAE act as prime contractors, and national private companies are subcontracted by them. The Brazilian model still operates in Traditional Space, with major projects being defined and conducted by the State through the associated research institutes.

In order to bring the dynamics and logic of New Space to Brazil, AEB has been working to create better conditions for private participation in the Brazilian space sector. The goal is to create an attractive and uncomplicated business environment for companies interested in investing in Brazil. Thus, AEB, in conjunction with the Ministry of Science, Technology, and Innovations (MCTI), has been leading a working group to create the General Law on Space Activities in which incentives, benefits, and simplifications for the space sector will be available.

6. HOW TO MEASURE THE RETURN RATE ON INVESTMENT

The space sector characteristics induce investments by the State, mainly due to the generation of externalities and spinoffs. Another important factor is the need for the State to increasingly guarantee a range of space services that can be considered public goods, such as, for example, the internet access network, satellite positioning systems, and the telecommunications network.

The State’s role is also important to manage the high risks associated with space technological development, with long-term and high-cost projects, such as the American initiative to create a vehicle to transport astronauts to the International Space Station or the lunar module for the 2024 return to the moon project. Historically, space Research & Development programs have generated more spillovers than direct benefits, hence the need for state support to develop large projects (NASA Spinoffs 2020).

Several studies have been carried out to estimate the return on public investments in the space sector. However, the definition of "Space Sector" itself is complex. In addition to the satellite and component manufacturing segments, launch vehicles, ground segment and applications, there are also issues associated with innovation, technology transfer and education, making the space sector the most transversal and complex of the economic sectors.

Several authors have made efforts to measure the return on investments in the area. However, due to the characteristics aforementioned, results are still scarce, and many suffer from methodological problems and theoretical definitions.

One example is a study developed by London Economics (2015) to measure public investment return in the space sector. In this study, public investment in the space sector was defined as the direct investment of public resources in programs, projects, or infrastructure related to the space sector. In addition, to measure the impact of public investment in the space sector, the London Economics (2015, 4-5) study used the following definitions:

- Return Rate: can be divided into three sub-items:
    - Public (Social) Return Rate - the net social benefit/cost of investing public resources, measured as the impact on the aggregate domestic economic result and other benefits from investments.
    - Direct Return Rate - the net benefits/costs of private investments measured as the impact on the output or productivity of the investing organization.
    - Spillover Return Rate - the net benefits/costs of private investments, measured as the impact on the output or productivity of other organizations and other benefits generated by the investments.
- Lag: time in years before the impacts started.
- Duration of benefit: time in years (from the end of lag) that the impact lasts.
- Inertia: the returns that could occur without public investment.
- Crowding in: the increase of investments from private companies, third sector, and public external in projects, as a proportion of domestic public investments.

- Crowding out: the decrease of investments from private companies, third sector, and external public sector in projects as a proportion of domestic public investments.
- Other quantitative results: quantitative measures of the impact of key results and results adjusted for the effects of inertia, such as employment, spinoffs, marketed products and scientific articles.
- Other benefits: additional social impacts associated with public investments in the space sector, related to the benefits of spillovers, such as employment, economic multiplier, consumer surplus, environmental impacts, and social impacts.

So far, there is no standardized methodology for calculating the return rate on public investments in the space sector. Several studies have used different methodologies (London Economics 2015), making an international comparison of the obtained results very difficult. Unfortunately, not all studies are robust enough, from a methodological point of view, to allow the generation of an annual return rate. London Economics' work (2015) consisted of identifying the best jobs so that it was possible to generate a yearly return rate.

The work of London Economics (2015) consisted of identifying the best studies so that an annual return rate could be calculated. Currently, the OECD (Organization for Economic Cooperation and Development) has an initiative trying to standardize space sector impact studies. However, it is still a preliminary attempt.

Thus, the study conducted by London Economics (2015, 9) adopted the multiplier methodology, that is, the return on each £ 1 of public investment, calculated using the following formula:

$$Multiplier = \frac{NPV}{DEL}$$

NPV = net present value, defined as the total benefits updated less the total costs (public and private) updated.

DEL = total updated domestic public investment.

The formula is the multiplier or return rate, which can be interpreted as an average of the economic benefit generated for the economy after an initial public investment of £1. The main gain from working with the multiplier methodology is its easy understanding and application.

On the other hand, its calculation is not so simple, mainly due to the difficulties in obtaining the necessary information.

Considering the existence of all information, the multiplier can be calculated using the following formula (London Economics 2015, 11):

$$NPV = \frac{(BD + BS) - (IP + IA)}{IP}$$

Being:

BD = Direct Benefits

BS = Spillovers Benefits

IP = Public Investment

IA = Leveraged Investment

The calculation will be impaired if the necessary information is missing or poor. In this case, the multiplier will probably take on lower values than would be calculated for situations where all the information is available.

Direct benefits capture the impact on the output or productivity of the private organizations that made the investment, while the benefits generated by spillovers measure the broader effects and the impact on on the output or productivity of other organizations as a result of private investment. The sum of direct and spillover benefits is equal to the total social benefits that are used to calculate direct return and spillover rates (London Economics 2015, 11).

$$Direct\ Rate\ of\ Return = \frac{(Direct\ Benefits) - (Leveraged\ Investments)}{Leveraged\ Investments}$$

$$Spillover\ Rate\ of\ Return = \frac{(Spillover\ Benefits) - (Leveraged\ Investments)}{Leveraged\ Investments}$$

Although there are robust and consistent return rates methodologies applied for investments in science and technology (S&T), there are still many difficulties associated with calculating such rates for the space sector, largely due to the characteristics of this sector itself, as pointed out by Bruston (2014 apud London Economics 2015, 11-12):

- Fragmented data structure: the space sector is not recognized as a category in the International Standard Industrial Classification (ISIC). Nor it is recognized in the classification adopted in Brazil, the CNAE. For example, information from the space manufacturing sector could be encoded as belonging to the electronic equipment sector. The lack of a classification does not allow statistical data from the space sector to be isolated as an economic activity on its own. Thus, the measurement of activities must be done by approximations, or through direct surveys of companies, which also generates two main problems: (a) the reliability of data provided by companies; and (b) the identification of the companies that will be surveyed.

- Wide and long-term dissemination of the impacts of space activities, which are:
    - Transversal and favor a large number of applications with the generation of social and economic benefits by several other economic sectors; and
    - Widespread over a long period of time, which complicates too much the task of defining the return on investments.
- Late acceptance of the need for planning to evaluate: it makes the space sector unaccustomed to the routine collection of information that could support studies of socioeconomic impact.
- Classified and sensitive information: the nature of government activity in the sector also poses difficulties in data availability, especially in the case of military activities. Thus, many data may not be available for carrying out impact studies.
- Presence of small and new businesses: the downstream market for space applications is growing rapidly. Such companies are small and focused on the market for space applications. Two factors hamper the attempt of measuring the economic activity of these small and new organizations:
    - Most of these companies are exempt from presenting statutory reports and market information, limiting the information available; and
    - For those who are required to submit, there may be a delay in publishing the information.
- Small suppliers: space production chains depend on suppliers for whom the space industry represents a very small proportion of their total production. Identifying and measuring these suppliers' contribution is an extremely complex task, probably possible only through the application of specific questionnaires. And, in this case, it is dependent on the company's agreement to participate and provide the data;

- Lack of international comparability: there is no defined standard for the generation of national statistics, that vary in definition, coverage, and methodology, which limits international comparison. There is still no international standard for defining data.

Thus, the study conducted by London Economics (2015) evaluated the various studies that aimed to measure the rate of return on public investments made in the space sector. The evaluation mainly took into consideration the methodological limitations of the studies, the methods adopted due to the lack of necessary information; the assumptions used; and quantitative methodological rigor. Based on this analysis, the works were classified according to the robustness of the evidence, being classified from 1 to 5, as defined below (London Economics 2015, 13-14):

- 1 - The parameters do not provide useful information for the proposed study.
- 2 - The parameters are of little use for the proposed study. This is due to the fact that the methodological justification is weak.
- 3 - The parameters can be used to refine the estimation to be done in the proposed study. The methodology is more reliable than in the previous item.
- 4 - The parameter will be used in the study because it is consistent with the definitions already established and has a robust methodology.
- 5 - The parameters result from a comprehensive analysis of the return on investment and use a robust methodology.

It is worth noting that no study analyzed was classified as grade 5.

After a detailed analysis of the studies, London Economics (2015) identified nine studies that attempted to calculate the impact of public investment for the member countries of the European Space Agency (ESA). The nine studies are presented in the table below, listing the main characteristics, weaknesses and strengths, besides classifying them according to the methodology mentioned above. It is important to emphasize that the studies considered only public investments made. It is important to mention that one of the studies cannot be published due to restrictions on access and disclosure.

Author(s) and year	Country	Public Rate of Return	Caveats & Weaknesses	Strength Assessment *
Belgian Federal Science Policy Office (2012)	Belgium	2.3	Cursory report, severely limited in scope. No description of methodological approach.	●○○○○
Ramboll Management (2008)	Denmark	3.5	Limited coverage of influencing factors	●●●○○
Clama Consulting (2011)	Portugal	1	Limited coverage of influencing factors	●●●○○
Rosemberg et al. (2015)	[redacted]	[redacted]	[redacted]	[redacted]
London Economics and PwC (2012)	Norway	2.5	Partial estimate of benefits	●●●●○
Triarii (2005)	Netherlands (ESTEC)	2.4 (2004) 3.3 (2011)	Limited coverage of influencing factors, simplification of benefit appraisal	●●○○○
High Tech Systems and Materials top team (2012)	Netherlands	4.3	Simplification of benefit calculation, lack of methodological detail	●●●○○
BETA/CETAI (1989) and CETAI/BETA (1994)	Canada	2.5 (1979-1988) 3.2 (1989-1992)	Limited coverage of benefits, methodological explanation and influencing factors. Relatively dated.	●●○○○
BETA (1980, 1988, 1989)	All Member States	1.9 (1980) 2.2 (1988)	Limited coverage of benefits, methodological explanation and influencing factors. Relatively dated.	●●○○○

Note: All Rates of Return are public Rates of Return, as only public investment constitutes Member State contributions. Influencing factors refer to key parameters affecting the size of the Rate of Return estimated, such as lag, duration of benefits, deadweight etc.
* London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Figure 4 - Summary and Evaluation of Return Rate Studies for ESA Member Countries

Source: London Economics 2015, 21.

Considering the most robust studies, presented in Figure 4, London Economics (2015, 21) calculated an estimate for the aggregate return rate for countries participating in the European Space Agency (ESA) as being between 3.0 and 4.0 (direct) and 6.0 to 12.0 (indirect). This fee can be considered as an annual fee.

Although the rates are applied to countries that contribute to ESA, we will use the return rates as a proxy to estimate the effects on the Brazilian space sector. According to the authors:

> (…) there is nothing to dispute the applicability of generic science and innovation estimates, or the above space-specific estimates, as a conservative default. Ultimately, we recommend that evaluators employ, in order of preference: program-specific information; space-specific estimates on returns where supported by evidence; and

> generic science and innovation estimates on returns as a conservative fallback (London Economics 2015, ii).

In this sense, this work will apply the estimated rates of return for three projects financed by AEB: CBERS 4-A, Amazônia-1, and VLM (Microsatellite Launch Vehicle).

7. PUBLIC PROJECTS IN THE BRAZILIAN SPACE SECTOR

In order to guarantee the execution of projects and activities of the Brazilian Space Program (PEB), AEB decentralizes budgetary credits to the institutions of the National System for the Development of Space Activities (SINDAE).

The decentralization of credits emerged with the State Administrative Reform (Decree nº 825/1993), instituting two types of decentralization: internal and external[3]. However, it was only with the Decree No. 6170 / 2007 that the Term of Decentralized Execution (TED) was defined as an instrument for carrying out budget transfers at the federal level. The purpose of the act was to provide agility in the decentralization of budget credits between entities or agencies that are part of both Fiscal and Social Security Budgets, aiming to execute actions of interest to the decentralizing unit.

Whereas about 80% of the AEB's budget allocation, approved in the Annual Budget Law (LOA), is assigned for SINDAE members through TED for the achievement of PEB projects and activities, AEB decided to improve the internal rules, publishing a specific act for this matter, the Ordinance AEB nº 254/2018. This regulation brought agility and practicality to the internal procedures, thus seeking to guarantee efficiency and effectiveness in the PEB execution (Harada e Freitas 2019).

With the new rules defined by the Decree nº 10.426 / 2020, in which the Ministry of Economy foresees standardization of procedures for the TED, the Agency decided to update the regulations and published the Ordinance AEB nº 269/2020, adapting to the new legislation. Like as the previous ordinance, the current one foresees for possible cases of transfers among SINDAE entities, the competencies of interested parties, and the models and documents necessary to execute the instrument.

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[3] Internal decentralization: between managing units of the same organ/ministry or entity integrating the fiscal and social security budgets.
External decentralization: between managing units of a body/ministry or entity of different structures.

Activities and projects such as the development of satellites and launch vehicles are carried out through the celebration of TEDs, with the National Institute for Space Research (INPE) for satellites and the Aeronautics and Space Institute (IAE) for launch vehicles. In 2019, the decentralized value for entities such as INPE, the Department of Aerospace Science and Technology (DCTA), and universities was around BRL 125 million, which corresponds to 85% of the AEB's budget (excluding social charges, personnel expenses, and fringe benefits).

In this paper, we will analyze, using this instrument, the three major AEB projects carried out in recent years: CBERS-4A, Amazônia-1, and VLM-1.

The CBERS-4A Satellite is the sixth cooperation satellite between China and Brazil and was launched on December 20, 2019, from the Taiyuan Satellite Launch Center in China. It is a medium resolution remote sensing satellite, equipped with optical payloads with resolutions in the range from 2 to 60 meters. The satellite configuration is close to the previous satellites, except for the imaging camera with higher quality than the previous ones (INPE 2020). Being a joint Brazil - China project, the division of responsibilities remained at 50% for each country, as well as responsibility for the supply of subsystems and equipment.

Amazonia-1 will be the first Earth Observation satellite fully designed, integrated, tested, and operated by Brazil. It is a five-day revisit polar orbit satellite with a wide-view optical imager capable of observing a range of approximately 850 km with a resolution of 60 meters (INPE 2020). The satellite is expected to be launched in 2021.

VLM-1 aims to launch three-stage microsatellites in low equatorial orbit (LEO). It is a binational project developed between the Aeronautics and Space Institute (IAE) and the DLR-Moraba, belonging to the German Aerospace Center (DLR) (IAE 2020). The project is expected to be completed in 2022.

It should be noted that the origin of the amounts invested in these projects is the General Budget of the Union. That is, the expenses and revenues are presented by the Executive Branch and approved by the National Congress in an ordinary law, the Annual Budget Law (LOA).

The projects' analysis will take place through the decentralization of budget credits, through TED, by the AEB to INPE and to the IAE, discounting the indirect costs associated with the projects.

Public Finance Notebooks, Brasília, v. 21, n. 2, p. 1-29, sep. 2021

Considering the Decree nº 10.426 / 2020, which provides for procedures for the decentralization of credits in the Public Administration, indirect costs are the amounts intended for the maintenance of the institutes, such as rent, maintenance, and cleaning of facilities, electricity and water supply, data communication and telephony services, administration fees and for technical, accounting and legal consultancy. This way, only the values for research and development in the space sector will be identified.

The following table lists the projects and respective final values excluding the indirect costs:

Project	Type of expense	Annual Budget Law (LOA) 2020	Indirect Costs	Final Values
CBERS-4A	Costing	R$ 2.633.330,00	R$ 938.000,00	R$ 1.695.330,00
	Capital	R$ 2.088.756,00	R$ -	R$ 2.088.756,00
	Total Value	**R$ 4.722.086,00**	**R$ 938.000,00**	**R$ 3.784.086,00**
Project	**Type of expense**	**Annual Budget Law (LOA) 2020**	**Indirect Costs**	**Final Values**
AMAZONIA-1	Costing	R$ 14.515.074,00	R$ 3.170.000,00	R$ 11.345.074,00
	Capital	R$ 28.432.147,00	R$ -	R$ 28.432.147,00
	Total Value	**R$ 42.947.221,00**	**R$ 3.170.000,00**	**R$ 39.777.221,00**
Project	**Type of expense**	**Annual Budget Law (LOA) 2020**	**Indirect Costs**	**Final Values**
VLM-1(*)	Costing	R$ 4.500.412,00	R$ -	R$ 4.500.412,00
	Capital	R$ 9.483.103,00	R$ -	R$ 9.483.103,00
	Total Value	**R$ 13.983.515,00**	**R$ -**	**R$ 13.983.515,00**

Table 1 - AEB's investment projects for 2020, values to be excluded and Final Values

Source: Integrated Planning and Budgeting System (SIOP). Elaborated by the author.

(*) In LOA 2020, VLM-1 expenses are borne by two budgetary actions, 21AG - Development of space systems and 21AI - Infrastructure and space applications. The indirect costs of this project are computed in action 21AI.

Considering the final values for the three projects realized by AEB, in the year 2020, the return rate calculated by London Economics (2015) for each one applies as per Table 2.

It is understood that Brazil' situation is completely different from the countries that are part of the ESA. However, the characteristics of the space sector are the same, regardless of the country being analyzed:

- The space sector in Brazil is also a technological frontier sector;
- Projects are long-term, high-cost and high-risk;

- They generate impacts in several other economic segments;
- The investments are made by the public;
- INPE and IAE operate as prime contractors, subcontracting the industry for the projects development; and
- Most companies in the space sector in Brazil do not operate exclusively in the space sector but rather as a secondary source of operation, again making difficult the access to data on production, employment, exports, and imports.

It is also worth noting Brazil's the specific calculation would have the same complicating factor as the lack of specific codes in the National Classification of Economic Activities (CNAE) that allows us to identify space products more easily. Another difficulty is the failure to identify which companies belong to the space sector. There is still no complete mapping of the space industry in Brazil.

Therefore, we opted to apply rates already calculated for the projects financed by AEB during the year 2020. Thus, the rates were applied for direct impact on the order from 3 to 4 times, for indirect impact, on the order from 6 to 12 times, and for total impact.

For the case of direct impact, in a more conservative scenario (considering the effect of 3 times for each BRL invested) the total investments made in 2020, in the order of BRL 57,544,822.00, generated a return of BRL 172,634,466.00. It is more interesting to adopt a conservative scenario in the Brazilian case due to the operation of public institutes as prime contractors and the non direct contracting of the industry. It is also noteworthy that, in the case of CBERS-4A, public investment is only 50% of the satellite since its development would be 50% of China's responsibility.

In the indirect impact, the return to the conservative scenario (considering the multiplier of 6 times for each BRL invested) added up to BRL 345,268,932.00. Indirect impacts measure the effects generated by spatial sector investments in other economic sectors. Of the three projects, Amazônia-1 is the one that has most of its components produced or developed in Brazil, which contributes to the greatest generation of indirect effects.

Thus, being conservative, the total invested by AEB in 2020, disregarding indirect costs of BRL 57,544,822.00, generated a total effect of BRL 517,903,398.00. In other words, a total effect of 9 times on the initial amounts invested. In a more optimistic scenario, the total effect would be BRL 920,717,512.00, an effect of 16 times over the initial value. It can be seen that even in a conservative scenario, the numbers show the real impact of the space sector on the economy and as a driver of socioeconomic development.

Project	Total Investment	Direct Impact	
		3x	4x
CBERS-4A	R$ 3.784.086,00	R$ 11.352.258,00	R$ 15.136.344,00
AMAZONIA-1	R$ 39.777.221,00	R$ 119.331.663,00	R$ 159.108.884,00
VLM-1	R$ 13.983.515,00	R$ 41.950.545,00	R$ 55.934.060,00
Project	**Total Investment**	**Indirect Impact**	
		6x	**12x**
CBERS-4A	R$ 3.784.086,00	R$ 22.704.516,00	R$ 45.409.032,00
AMAZONIA-1	R$ 39.777.221,00	R$ 238.663.326,00	R$ 477.326.652,00
VLM-1	R$ 13.983.515,00	R$ 83.901.090,00	R$ 167.802.180,00
Project	**Total Investment**	**Total Impact**	
		Minimum	**Maximum**
CBERS-4A	R$ 3.784.086,00	R$ 34.056.774,00	R$ 60.545.376,00
AMAZONIA-1	R$ 39.777.221,00	R$ 357.994.989,00	R$ 636.435.536,00
VLM-1	R$ 13.983.515,00	R$ 125.851.635,00	R$ 223.736.240,00
TOTAL	**R$ 57.544.822,00**	**R$ 517.903.398,00**	**R$ 920.717.152,00**

Table 2 - Direct and Indirect Impacts of Public Investment in the Space Sector.

Source: Elaborated by the author based on data from the Brazilian Space Agency.

One factor that should be taken into consideration and that can diminish the total calculated effect is the fact that payments related to launches of both CBERS-4A and Amazonia-1 will be made to companies abroad, which does not generate the effects internally in the country.

Hence the importance of developing a competitive national launch vehicle in order to attract investments and resources that can generate a positive chain effect in Brazil.

8. CONCLUSION

The space sector is recognized as one of the most transversal and highest added value sectors. Several countries have made investments in this sector to promote socioeconomic development, and the prospects for the space sector are extremely positive, reaching more than US 1 trillion dollars as early as 2040.

It is also important to mention the increase of private participation in the space sector, resulting in a sharp change in the dynamics of this sector. The government now defines the high-level requirements while industry becomes responsible for defining the method to achieve the proposed goal.

The changes are so intense that private companies, which previously could not foresee profit opportunities, started to invest on their own to create new products and markets for the coming years.

Thus, due to its characteristics, it is expected that the returns, direct and indirect, of the investments made in the space sector can generate many benefits for other economic sectors.

In the absence of detailed information on Brazil's space sector, such as a specific economic classification code, information on production, exports and employment, it was decided to use the impact rates, direct and indirect, calculated for countries belonging to the Agency European Space Agency. Understanding that the space sector has the same characteristics, regardless of the country, the countries' rates can be used as a proxy for Brazil.

Thus, considering the three largest projects financed by the Brazilian Space Agency, namely CBERS-4A, Amazônia, and VLM-1, it is concluded that, in a conservative scenario, the investments made by AEB generate a return of 9 (nine) times the initial values, while in a more optimistic scenario, the return can reach around 16 (sixteen) times the initial values. Thus, reinforcing the effects and impacts of the space sector on other economic sectors. It is also noted that a large part of the impacts occurs on indirect effects, precisely because of the characteristic of the transversality of space technology.

9. BIBLIOGRAPHIC REFERENCES

Brazil. *Lei de Licitações* (Public Biddings Law) n° 8.666/1993.

Brazil. Decree nº 9.283/2018.

Berger, Eric. 2017. How America's two greatest rocket companies battled from the beginning. *ArsTechnica*, 2 August 2017. https://arstechnica.com/science/2017/08/how-americas-two-greatest-rocket-companies-battled-from-the-beginning/. Access: September, 2020.

Bruston, J. 2014. Space: the last frontier for socio-economic impacts evaluation? Yearbook on Space Policy 2011/2012 – Space in Times of financial crisis, p.183-191. Access: September, 2020.

Bryce. 2020. Global Space Economy. https://brycetech.com/reports/report-documents/2018_Global_Space_Economy.pdf. Access: September, 2020.

Chaikin, Andrew. 2012. Is SpaceX Changing the Rocket Equation?, Air & Space, January 2012, https://www.airspacemag.com/space/is-spacex-changing-the-rocket-equation-132285884/?all. Access: September, 2020.

CNBC. 2017. The space industry will be Worth nearly $3 trillion in 3 years, Bank of America predicts. https://www.cnbc.com/2017/10/31/the-space-industry-will-be-worth-nearly-3-trillion-in-30-years-bank-of-america-predicts.html. Access: September, 2020.

Euroconsult. 2019. Presentation given at the 3rd Brazilian Space Industry Forum. Held in November 2019. http://forumindustriaespacial2019.aeb.gov.br/. Access: September, 2020.

Euroconsult. 2020. Prospects for the Small Satellite Market. Available in: www.euroconsult-ec.com.

Harada, Márcio Akira and Freitas, Lúcia Helena Michels. 2019. *Aplicação do Termo de Execução Descentralizada no âmbito do Programa Espacial Brasileiro* (Application of the Decentralized Execution Term - TED in the scope of the Brazilian Space Program). Annals: VI Brazilian Forum on Public Administration (EBAP). GT 6: Planning and Public Budget.

IAE – *Instituto de Aeronáutica e Espaço* (Institute of Aeronautics and Space). VLM-1. http://www.iae.cta.br/index.php/todos-os-projetos/projetos-aeronautica/projetos-vlm-1. Access: September, 2020.

Public Finance Notebooks, Brasília, v. 21, n. 2, p. 1-29, sep. 2021

INPE – *Instituto Nacional de Pesquisas Espaciais* (National Institute for Space Research). CBERS. http://www.cbers.inpe.br/. Access: September, 2020.

INPE – *Instituto Nacional de Pesquisas Espaciais* (National Institute for Space Research). Mission Amazônia. http://www.inpe.br/amazonia1/. Access: September, 2020.

London Economics. 2014. The size & health of the UK Space Industry. https://www.gov.uk/government/publications/uk-space-industry-size-and-health-report-2014

London Economics. 2015. Return from public space investments: an initial analysis of evidence on the returns from public space investments.

https://londoneconomics.co.uk/blog/publication/return-from-public-space-investments-an-initial-analysis-of-evidence-november-2015/

Martin, Gary. 2017. New Space: the emerging commercial space industry. SSP14. https://ntrs.nasa.gov/citations/20170001766. Access: September, 2020.

Morgan Stanley. 2020. Space: Investing in the Final Frontier. https://www.morganstanley.com/ideas/investing-in-space. Access: September, 2020.

NASA Spinoffs. Nasa Spinoffs. https://spinoff.nasa.gov/.

OECD. Organization for Economic Co-operation and Development. 2014. The Space Economy at a Glance 2014", OECD iLibrary, 23 October 2014. http://www.oecd-ilibrary.org/economics/the-space-economy-at-a-glance-2014_9789264217294-en;jsessionid=7df9497ffpkpr.x-oecd-live-02

OECD. Organization for Economic Co-operation and Development. 2016. Space and Innovation. http://www.oecd.org/futures/space-and-innovation-9789264264014-en.htm

SpaceX. 2018. SpaceX Updates: Launch Manifest, 5 September 2018, https://www.spacex.com/missions. Access: September, 2020.

The Economist. 2018. The Falcon Heavy's successful flight is another vindication for Elon Musk. 6 February 2018. https://www.economist.com/news/21736429-and-another-headache-spacexs-competitors-falcon-heavys-successful-flight. Access: September, 2020.

Public Finance Notebooks, Brasília, v. 21, n. 2, p. 1-29, sep. 2021

Tugnoli, Matteo; Sarret, Martin e Aliberti, Marco. 2018. European access to space: business and policy perspectives on micro launchers. Springer.

Vellasco, Fabiany Maria Made. 2019. *O desenvolvimento da indústria espacial brasileira: uma abordagem institucional* (The development of the Brazilian space industry: an institutional approach). Master's Dissertation. Enap. Brasília, 2019.

Wakimoto, Takuya. 2018. How to reduce US space expenses through competitive and cooperative approaches. The Space Review, 22 January 2018, http://www.thespacereview.com/article/3412/1. Access: September, 2020.

Wattles, Jackie. 2017. Blue Origin CEO: We're taking tourists to space within 18 months., CNN, 5 October 2017, http://money.cnn.com/2017/10/05/technology/future/blue-origin-launch-human-space-tourism/index.html. Access: September, 2020.

Werner, Debra. 2015. SpaceX Leaves Searing Impression on NASA Heat Shield Guy. SpaceNews, 9 March 2015. http://spacenews.com/spacexs-high-velocity-decision-making-left-searing-impression-on-nasa-heat-shield-guy/. Access: September, 2020.