Space Policy 46 (2018) 53–63

Contents lists available at ScienceDirect

Space Policy

journal homepage: www.elsevier.com/locate/spacepol

Climbing the Space Technology Ladder in the South: the Case of Argentina

Andrés López [a, b], Paulo Pascuini [a, b, *], Adrián Ramos [a, b]

[a] Universidad de Buenos Aires, Facultad de Ciencias Económicas, Buenos Aires, Argentina
[b] CONICET-Universidad de Buenos Aires, Instituto Interdisciplinario de Economía Política de Buenos Aires (IIEP-BAIRES), Buenos Aires, Argentina

A R T I C L E I N F O

Article history:
Received 15 December 2017
Received in revised form
2 May 2018
Accepted 2 June 2018
Available online 22 June 2018

Keywords:
Argentina
Space economy
Telecommunications
Innovation
Satellites

A B S T R A C T

The satellite industry is one of the few high-tech sectors where Argentina has generated its own innovation capabilities. This is the result of a process initiated more than 25 years ago in the realm of civilian space exploration, which in turn was possible because of the previous accumulation of knowledge and capabilities in military space projects as well as in another high-tech activity, the nuclear industry. Along these years, the country has been able to design and put into orbit observation and telecommunication satellites rapidly climbing the Space Technology Ladder (STL). This article analyzes this evolutionary trajectory, highlighting the key technological milestones, the role played by the main actors of the space sector, the linkages among them as well as with foreign partners, and the prospects of this activity in a developing country like Argentina.

1. Introduction

Argentina is one of the very few countries that have been able to climb up onto the last stages of what Wood and Weigel [1] define as the Space Technology Ladder (STL). The country has already built both low Earth orbit (LEO) and geostationary orbit (GEO) satellites, entering the exclusive 8-member club of those that have the capabilities to build their own GEO telecommunication satellites.[1] The Tronador project aims at producing vehicles for launching LEO satellites (the first launch is expected to happen by the end of 2020),[2] an achievement that would allow Argentina to join the 11-member club of those that have the capacity to manufacture that type of vehicles.[3]

This evolution seems to be relatively rapid. In 1991, the country created its National Space Agency, the National Space Activities Commission (Comisión Nacional de Actividades Espaciales, Spanish acronym CONAE). In 1996, the first LEO satellite was launched. In 2014, the first locally built GEO satellite was launched with the aim of providing telecommunication services (nowadays there are 2 in orbit and a third satellite was scheduled). As said before, by 2020 the country should master the capabilities needed for launching LEO satellites, 30 years after the creation of the CONAE.

These achievements would not have been possible without the experience and capabilities accumulated in 2 previous ventures. First, the satellite industry in Argentina is, to a large extent, an outcome of the technological successes of the local nuclear plans. INVAP, a company that has built and exported several turnkey reactors for research and for mass production of radioisotopes for medical use, has also designed and

* Corresponding author. CONICET-Universidad de Buenos Aires, Instituto Interdisciplinario de Economía Política, University of Buenos Aires, Faculty of Economic Sciences, Córdoba 2122, C1120AAQ, CABA, Argentina.
E-mail address: paulo.pascuini@fce.uba.ar (P. Pascuini).

[1] Argentina, China, the European Union, India, Israel, Japan, the Russian Federation, and the United States [23].

[2] No plans exist for creating GEO satellites' launching capabilities, the last step of the STL. Please note in this regard that even though Argentina could eventually develop a technological capability in this area, its latitude is not well suited for the launch of this type of satellites.

[3] China, France, India, Iran, Israel, Japan, North Korea, the Russian Federation, South Korea, the United Kingdom, and the United States [23].

https://doi.org/10.1016/j.spacepol.2018.06.001

manufactured all Argentina's LEO and GEO satellites. Second, from the '60s to the late '80s, Argentina's Armed Forces developed a series of projects related to the aerospace industry, mainly with military purposes. Therefore, we are dealing with a long-term process in which technological and productive capabilities, as well as a valuable stock of human capital, have been accumulated in some key organizations that would become the main actors of the space economy[4] in Argentina.

Take into consideration that both the satellite and the nuclear industry require the master and control of complex technological systems. Moreover, they both use and generate dual purpose (civilian and military) technologies. This poses another challenge for a developing country aiming at creating innovation and production capabilities in these industries, namely, that access to foreign knowledge is often subject to restrictions. In turn, capabilities accumulated in this type of areas create the basis for new "jumps" to other high-tech activities. This has in fact already happened, as INVAP began the manufacture of primary and secondary radars based on technological achievements developed during the process of designing and producing satellites.

The aim of this article is to examine the evolution and prospects of the satellite industry in Argentina. We will highlight the key technological milestones, the role played by the main actors of the space sector, and the linkages they establish. The analytical background will mainly rest on the neo-Schumpeterian literature on technological change. Our research is mainly based on interviews to key personnel of the organizations and companies that are part of the "space economy" in Argentina (see Appendix A). We have also reviewed the available literature and statistical data, which are not particularly abundant in the case of Argentina.

The article is structured as follows. Section 2 briefly presents the conceptual framework. Section 3 describes progress made with regard to Argentina's space activities on the basis of the STL framework and introduces the main organizations involved in the sector. Section 4 maps the evolution of technological and productive capabilities in the space industry as well as the linkages established both among domestic organizations and with foreign partners. Section 5 presents an alternative account of technological progress in Argentina's space sector based on a number of metrics and dimensions not considered in the 13 milestones of the STL framework.

2. Conceptual framework

2.1. The Space Technology Ladder

Wood and Weigel [1] propose a sort of "standard path" that a country would follow as it develops its space capabilities, the "Space Technology Ladder". The STL is composed by a list of milestones that are ranked according to their technical complexity. Within each milestone, there are different levels according to the national autonomy achieved at undertaking a given activity. In the analytical framework proposed by the authors, the space activity includes the areas of satellites and launch vehicles. The major categories of the STL, as well as the corresponding subcategories, are described.

- First category: the 2 possible levels/subcategories are (i) establishing the first Government Space Office and (ii) establishing the current National Space Agency.
- Second category: owning and operating a LEO national satellite. Subcategories here summarize the many ways in which a country can achieve this milestone, going from low to high national autonomy to execute this technical feat: (i) procure with training services: at this stage, countries buy a satellite from a foreign company with some knowledge transfer; (ii) build with support in partner's facility; (iii) build locally with outside assistance; (iv) build through mutual international collaboration ("mutual collaboration" refers to projects in which the financial and technical contributions of each partner are similar); and (v) build locally.
- Third category: owning and operating a GEO satellite. From straight forward procurement to local production, we can distinguish 4 subcategories: (i) procure; (ii) build locally with outside assistance; (iii) build through mutual international collaboration; and (iv) build locally.
- Fourth category: Satellites launching capabilities. 2 subcategories are distinguished here (i) launch LEO satellite and (ii) launch GEO satellite. Those achievements are reached when launching activities are based on locally mastered and controlled technology.

All milestones are ranked consistently according to their level of complexity within each category, but this is not necessarily so across categories. To make it clear, a country that operates a national satellite in LEO achieves a lower complexity milestone than a country that operates a GEO satellite. But to build locally, a LEO represents a greater amount of technical independence than to procure a GEO satellite from a foreign company. Table 1 provides a detailed view of the STL (note this table compiles and orders all subcategories of the different categories of the STL in one single list).

The STL framework is very useful for analyzing national trajectories in the space sector and to bring together all the steps involved in mastering the technology cycle in the space industry. However, as mentioned before, it should not be interpreted as a continuum of milestones of ever growing complexity and/or technological autonomy. It is not only the case that locally building a LEO satellite is clearly more challenging than buying a foreign GEO satellite. Some LEO satellites, depending on their characteristics, objectives, and type of instruments aboard, can be equally or even more sophisticated than GEO satellites. Moreover, LEO satellites in constellations may also be used for telecommunication purposes: designing, launching, and operating such constellations imply a higher level of complexity than releasing a single GEO telecommunication satellite.

The STL also has some limitations when applied to learning about technological progress in the space sector in a certain country. First, it does not inform about progress in technological sophistication within each milestone. For example, building more efficient GEO satellites,[5] launching heavier LEO satellites (or LEO satellites carrying more complex instruments), developing hybrid or even fully electric propulsion systems instead of chemical propulsion systems, etc. Likewise, launching a constellation of LEO

[4] "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 because 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." [24, p. 22]].

[5] Efficiency in a telecommunication satellite may be measured as the relation between weight and power.

Table 1
The Space Technology Ladder – detailed view.

The Space Technology Ladder	
13	Launch capability: satellite to GEO
12	Launch capability: satellite to LEO
11	GEO satellite: build locally
10	GEO satellite: build through mutual international collaboration
9	GEO satellite: build locally with outside assistance
8	GEO satellite: procure
7	LEO satellite: build locally
6	LEO satellite: build through mutual international collaboration
5	LEO satellite: build locally with outside assistance
4	LEO satellite: build with support in partner's facility
3	LEO satellite: procure with training services
2	Space agency: establish current agency
1	Space agency: establish first national space office

LEO, low Earth orbit; GEO, geostationary orbit.
Source: Wood and Weigel [1, p. 3]

satellites would be in the same stage than building a single LEO satellite, although the degree of technical difficulty of the former is clearly higher.

Second, there is no need for a country to go through each milestone. For instance, a country can attempt to master the launchers technology without having built a GEO satellite (it is the case of Brazil) or even a LEO satellite because launchers are based on a different set of technological and scientific abilities.

Third, the "build locally" stage does not imply that the whole set of pieces and instruments integrated in the satellite are domestically manufactured. Both the bus and the payload of the satellites may include imported inputs. In fact, in the current context of global fragmentation of technical and production capabilities, most satellites incorporate parts and instruments produced in different nations. For countries going through the first steps of the STL, acquiring a certain component abroad often has advantages in terms of lower costs, better quality, and/or faster delivery dates. However, a trade-off may emerge with the objective of designing and producing the same component at home in search of mastering the respective technology and generating knowledge spillovers. Therefore, one metric of national advance within the STL refers to the ability of building efficient satellites while at the same time integrating at least some locally produced key components and instruments.

Fourth, there are strategic steps of space projects which are not included in the STL, such as the capacity of building the ground stations. Fifth, the term "mutual collaboration" is somewhat loose—in fact most space projects involve collaboration among different countries even in the developed world. It may refer, for instance, to 2 countries designing and building different parts of a satellite. But collaboration also exists when a satellite completely designed and built in a certain country integrates into its payload instruments manufactured by a foreign country. There is also collaboration when a satellite is tested in a foreign country facility. However, all these examples illustrate very different kinds of collaboration (and different levels of domestic technological capabilities in the country under analysis). Furthermore, although mutual collaboration is below "build locally" in the STL, a country can manufacture a satellite integrating mostly imported components, while a mutual collaboration project may imply contributing with highly sophisticated technology developments to a bilateral project.

Finally, the STL does not capture the emergence of a relatively new phenomenon in the space industry, including (i) the growing diffusion of small satellites: small satellites are more affordable, but given their small size, they can carry fewer instruments. However, technological advances (e.g. miniaturization) may help to bypass that restriction. Fractionated mission architectures are also a way to take advantage of small satellites working in networks/constellations; (ii) the introduction of new processes aimed at applying mass production techniques to manufacture spacecraft and launchers; (iii) the increasing use of advanced manufacturing technologies in the space industry; (iv) the expansion of electric propulsion satellites which, thanks to their lower weight, may embark more payload (e.g. more transponders in the case of telecommunication satellites) [2].

In Section 3, we describe the evolution of Argentina under Wood and Weigel's version of the STL. In Section 5, we present an alternative account of the country's technological progress in the space sector based on the discussion of the STL framework made in the previous paragraphs.

2.2. Innovation in developing countries: the role of capabilities and linkages

As mentioned by Wood and Weigel [1], the STL builds upon the evolutionary-Schumpeterian literature and its view of technological learning. Companies/countries that aim at moving toward already developed industrial fields may acquire valuable knowledge from the access to foreign technology sources, especially in the first stages of the process. But to profit from those sources, absorption capabilities are needed. Those capabilities are mainly determined by the level of domestic efforts in research and development (R&D) activities, the availability of skilled personnel, and the existence of strong linkages among the different actors of the national innovation system (companies, universities, and research centers) [3,4].

Why are absorption capabilities important? First, if a country wants to take advantage of foreign knowledge, the initial gap cannot be very large [5]; therefore, those capabilities are crucial insofar because they reflect prior accumulated knowledge at national level. Second, technologies always have tacit components—i.e. they cannot be reduced to blueprints. Domestic capabilities are needed to assimilate and master that kind of knowledge [6]. Third, because of differences in available resources, inputs, market requirements, etc., foreign technologies need to be adapted to local conditions [7].

The same reasoning may be applied at company level. Although companies are the locus of innovation on market economies [8], isolated companies do seldom have all the assets and skills required for undertaking technological projects. First, they need to have access to external knowledge sources (e.g. patents, publications, databases, etc.). Second, collaboration activities with other agents (e.g. clients, providers, partners, universities, research centers, etc.) are often established to undertake innovation projects [9].

For companies to benefit from external sources of knowledge, they need to develop absorptive capacities to assimilate that knowledge for commercial means [10]. Many of these capacities are embedded in their products, processes, and people, which are the result of firm-specific evolutionary trajectories [11].

When it comes to the analysis of sectors, such as nuclear or space, there are at least 3 features that decisively impact on the type of required capabilities and the role of linkages. First, both sectors are characterized by the existence of access restrictions to existing knowledge as well as to some key components or inputs (e.g. fuels)—these restrictions are based on security and/or strategic reasons. Second, both sectors are based on "complex systems" technologies, characterized by the need of gathering knowledge inputs from different scientific and technological fields. Third, there are stringent quality requirements in the nuclear and space sectors because errors may be very costly (not only economically but also in terms of human lives), and if a component fails, its reparation or replacement is impossible or, at best, extremely expensive.

These features have an impact on the nature of linkages within the sector. First, they limit the extent to which a developing country may take advantage of foreign technology sources and cooperate with partners abroad. Second, they underscore the role of collaboration among domestic partners that may master certain knowledge fields and contribute with specialized inputs to the development of space projects.

Finally, capabilities and linkages are also relevant for further productive diversification along time. Hidalgo et al. [12] states that a country's possibility to move toward new products depends on its ability to manufacture similar products, i.e. products which require similar capabilities. This is because the latter are often local and/or company-specific and are unlikely to be obtained on the market (e.g. specialized human capital and knowledge).

In Section 4, we apply this conceptual framework to analyze Argentina's progress in the space sector. Our hypothesis is that while having access to foreign technology sources is a necessary condition to start climbing the STL, domestic capabilities play a crucial role for further escalating the ladder in a sector characterized by access restrictions to existing knowledge and by the prevalence of high complexity technological systems. These capabilities are embedded in specific organizations and are enhanced when efficient systems for creating, disseminating, and sharing knowledge exist. In turn, these capabilities and linkages within the domestic innovation system are not created overnight. They are the result of long-term evolutionary trajectories in which knowledge and skills accumulate, and trust relationships (including interpersonal ones) are built among the different organizations involved.

3. The evolution of Argentina's space activities

In 1960, the National Commission on Space Research (Spanish acronym CNIE) was created. CNIE was managed by Argentina's Air Force, and during its existence, 150 rocket launches were carried out. Later, at the end of the '70s, the Argentine Air Force started a missile project called Condor II. The project took impetus after the Malvinas (Falklands) War and was finally disabled because of international pressures in 1991—for more information see Blinder [13,14]. With the closure of the program, the CNIE was dissolved in 1991, and a civilian agency, the CONAE, was created that same year.

CONAE pioneered the process of modernization of the public science and technology (S&T) system in Argentina during the '90s. This was reflected not only in the elaboration of a strategic plan which clearly defined goals, activities, and functions but also in the early adoption of audit and evaluation initiatives [15]. CONAE is in charge of the National Space Plan, whose first version was adopted in 1995. Three revisions of the Plan were made later (the last one "Plan Espacial Nacional 2016–2027" has already been approved by CONAE's board in 2017 and is awaiting government approval). The basic objectives of the Space Plan are to encourage domestic technological developments and to carry out space-related research for peaceful purposes.

CONAE has around 250 employees and several facilities in the provinces of Córdoba, Rio Negro, Mendoza, and Buenos Aires. As seen in Fig. 1, its budget has steadily increased from 2006 onwards, and by 2013, it had multiplied by a factor of 5—in constant pesos—*vis-a-vis* 1998. Although in the following years—in a context of high fiscal deficits in Argentina—CONAE's budget declined; in 2017, it was still 4 times bigger than in 1998 in real terms.

Until 2017, CONAE had completed 4 satellite missions. The first one was the scientific satellite SAC-B, launched on November 4, 1996. A power failure prevented the separation that should have released the satellite from the Pegasus launcher XL, manufactured by Orbital Science Corporation. However, during the 12 h that the satellite was contacted since its launch, it was verified that it worked and responded to commands properly. The SAC-B was a minisatellite of 191 kg with a payload of 50 kg.

The second satellite launched was the SAC-A, which was conceived as a technological model for the more ambitious SAC-C project. Technical and human capabilities and locally designed telemetry, telecommand, and control equipment were tested in this mission. The SAC-A was a 68 kg microsatellite placed in orbit from the space shuttle Endeavor on December 3, 1998. The mission was successfully completed in August 1999.

The third satellite was the SAC-C, placed in orbit with a DELTA II launcher on November 21, 2000. The SAC-C was in orbit until August 2013. It was a 485 kg mini satellite, with a payload consisting of 2 cameras developed by CONAE and scientific instruments from different foreign countries agencies and organizations. Its objectives included obtaining data on agriculture and coastal management, monitoring emergences and natural

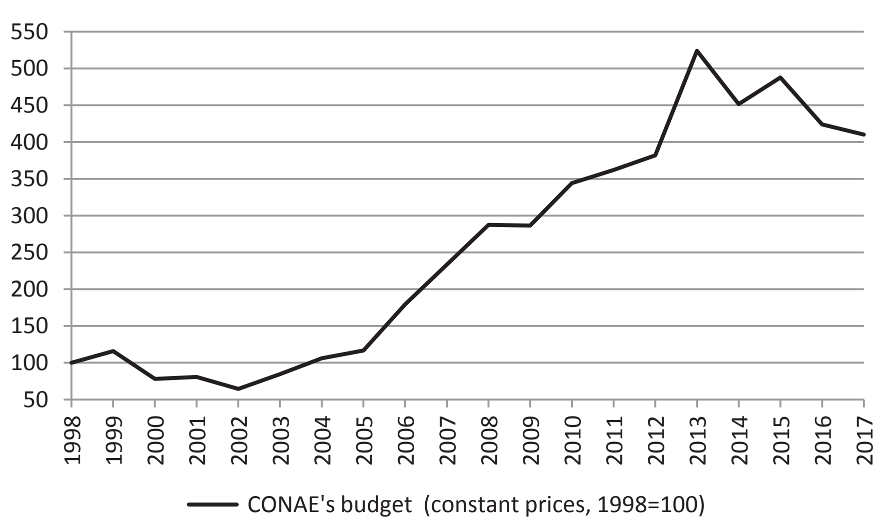

Fig. 1. CONAE's budget, 1998–2017 (constant prices, 1998 = 100). CONAE, National Space Activities Commission. Source: Prepared by the authors on the basis of data provided by the National Ministry of Science, Technology and Productive Innovation (MinCyT).

disasters, and generating scientific information about the geomagnetic field, the atmosphere structure and dynamics, climate evolution, and the Earth gravitational camp.

The last CONAE's completed mission so far was the SAC-D/Aquarius. It was put into orbit on June 10, 2011, through a 7320 Delta II launcher. The SAC-D/Aquarius successfully concluded its operational service on June 8, 2015. It was a 1600 kg large satellite. Among its main objectives, we can mention the measurement of sea salinity, the monitoring of Antarctic glaciers, and the generation of fire risk maps and soil moisture data that could be used for early floods warning.

At the moment this article was written (April 2018), CONAE was working on several projects, as follows:

Italian-Argentine System of Satellites for Emergency Management (SIASGE): this project, which is jointly developed with the Italian Space Agency (ASI), includes 2 satellites constellations for Earth observation with the aim of preventing, monitoring, mitigating, and assessing anthropogenic or natural disasters. The satellites will also generate agricultural plagues risk maps, as well as information that would allow for a more efficient application of fertilizers. One of the constellations (SAOCOM) is being manufactured in Argentina. It consists of 2 satellites. The first one, SAOCOM 1A, is expected to be released in September 2018, while the SAOCOM 1B probable launch date is late in 2019. Each one weighs about 3 tons, is 4.5 m high and its diameter is 1.5 m (therefore, they are large satellites).

SARE: they are lightweight satellites (250 kg approximately), which should be placed in orbit by the Argentine launcher Tronador with Earth observation purposes. There are 2 groups of satellites within this project. First, the Optical SARE series with a payload which will include panchromatic and multispectral cameras. Second, the Microwave SARE series, equipped with synthetic aperture radars. In both cases, a constellation of satellites will be launched with the aim of analyzing urban development, cartography, transport, and security issues, as well as generating information about agriculture, hydrology, land use, illegal fishing, and coastal emergencies, among others. The cameras resolution will be of approximately 1 m by 1 m.

SABIA-MAR: this is the so-called Argentine-Brazilian Satellite for Sea Information project which is carried forward jointly by CONAE and the Brazilian Space Agency (AEB). The objective of this project is to generate information for regional and international sea studies. SABIA-MAR will be a 2-satellite constellation. The CONAE has taken full responsibility for SABIA-MAR 1, whose launch is foreseen for the end of 2020, while AEB is responsible for SABIA-MAR 2. SABIA-MAR's payload will include 4 different cameras and a data collection system.

CONAE is also undertaking a research program that would lead to the development of fractionated spacecraft satellite architectures. The objective is to launch a series of small satellites, each one performing a separate function, which would navigate in clusters coordinated by wireless communication systems. It is expected that the abovementioned SARE project will be the first application of this technology.

CONAE's missions so far have been mainly related to scientific endeavors or to public policy objectives. But LEO satellites may also be employed for commercial purposes, for instance when aimed at providing useful images and information to improve agricultural productivity, one of the features of the so-called precision agriculture. A case of an Argentinean private company which has started operations in this area was mentioned in the following paragraph.

Although, as previously said, CONAE is in charge of the National Space Plan; the latter does not include telecommunication satellites. This area is managed by ARSAT, a state-owned company created in 2006. ARSAT objectives include (a) the local design, development, construction, launch, and/or commissioning of GEO telecommunication satellites in orbital positions assigned to Argentina under the International Telecommunication Union (ITU) procedures and (b) the corresponding exploitation, use, and provision of satellite facilities and the marketing of satellite-related services.

Before the creation of ARSAT, the private company Nahuelsat S.A. (a consortium of foreign aerospace companies) operated 1 satellite, launched in 1997 and manufactured abroad. This satellite navigated on 1 of the 2 orbital positions assigned to Argentina under the ITU regulations by that time.[6] Nahuelsat assets were transferred to ARSAT, which started operations with 2 rented satellites in 2007.

ARSAT's mandate included the local development and manufacturing of telecommunication satellites. Hence, in 2010, the ARSAT-1 project began. This satellite, whose footprint mainly covers Argentine territory, was launched in 2014. The same happened with the ARSAT-2 in 2015. Its footprint covers Argentina, the Andean Corridor, part of Brazil, and North America. Both satellites are operative and have sold their full efficient operational capacity (in the case of ARSAT-2, services have also been sold in the United States and Chile). In 2015, the company's board approved the project for the ARSAT-3 mission. In 2017, an intention letter was signed by ARSAT and the U.S. telecommunication company Hughes (which would contribute with financial resources and commercialize the satellite services). The intention letter established that INVAP would be in charge of construction, the satellite would be similar to ARSAT-1 and ARSAT-2, and the payload would be provided by the French company Thales Alenia Space. However, up to the moment this article was written, there have been no concrete advances with regard to the implementation of this agreement. Meanwhile, the ARSAT 3 project is delayed because of budget restrictions.

All the satellites put into orbit by CONAE and ARSAT were built by INVAP. This is a state-owned company, created in 1976 and fully owned by the province of Rio Negro. Its board includes 4 members appointed by the Government of the province of Río Negro, 1 named by the company's personnel and 2 appointed by the National Commission of Atomic Energy (Spanish acronym CNEA).

INVAP's inception dates to 1972, when a group of researchers working at the Group of Applied Physics of the Balseiro Institute, an internationally acknowledged academic center in the fields of experimental physics and nuclear engineering, embarked upon an initiative aimed at creating a technology-based company taking advantage of applied research capabilities available at the Balseiro Institute. INVAP was the final outcome of this project and would become the most respected high-tech organization in Argentina.

Initially, INVAP concentrated on the nuclear area, where it won international reputation as designer and supplier of systems for nuclear reactors and as provider for turnkey reactors for research and for mass production of radioisotopes for medical use. To mention a recent example, at the beginning of 2018, INVAP signed a contract to replace a high-flux reactor located in the town of Petten in the Netherlands, which supplies 60% of the radioisotopes market in Europe. In this tender, INVAP (associated with 2 Dutch companies) competed with well-established companies such as AREVA TA from France and Korea Atomic Energy Research Institute (KAERI) from South Korea.

As time passed, the company ventured in various sectors, including aerospace. This was the result of a proposal made by

[6] Although Nahuelsat obligations, according to the contracts signed with the Argentine government, included the launching of a second satellite, the firm never fulfilled this commitment.

CONAE, which at the beginning of its operations concluded that the only organization in Argentina that can carry out space projects was INVAP.[7]

According to the information published in the official INVAP's website [16] during the financial year 2015–2016, sales reached USD 282.57 million and profits amounted to USD 9.33 million; around 40% of the turnover was generated by the "Space and Government Projects" area. INVAP has more than 1400 employees, out of which about 85% are professionals and technicians.[8] Its headquarters are located in San Carlos de Bariloche (province of Rio Negro), and they have offices and subsidiaries in Buenos Aires, Australia, Brazil, Egypt, and the United States.

INVAP's businesses are organized around 4 main technical areas: nuclear projects, space and government projects, industrial projects and alternative energies, and Information and Communications Technology (ICT) and technological services. Although INVAP is completely owned by the province of Río Negro, its management mimics that of private companies, and the company does not receive any subsidy from the national or the provincial government.

At present, INVAP is able to manage and execute complete satellite projects, with the exception of the launch phase.[9] Its activities range from the concept of the mission to the management of the satellites operation. INVAP manufactures all components of the bus: structure, power, thermal systems, altitude's control, onboard computer, communications, and propulsion. INVAP has also been contractor of CONAE for the production of some scientific instruments included in the SAC missions and has built the ground satellite observation station located in the province of Córdoba.

The project aimed at producing launch vehicles is led by VENG S.A. (Spanish acronym of new-generation space vehicles)[10]. The company, controlled by CONAE, was created in 1998 and after several years of inactivity, picked up momentum with the signature of the contracts to develop the Tronador I and II rockets in the mid '00s. Different pilot tests and trials with prototypes have been made. A new stage of the project (called Tronador III), which is expected to have a launch capacity around 800–1000 kg, is now being developed. It is foreseen that the Tronador III will make its maiden flight from Puerto Belgrano, Buenos Aires province, by the end of 2020. If the project is successfully completed, it is estimated that VENG will be able to make between 5 and 10 launches per year, which will not only meet the needs of the National Space Plan, but it will also allow launches under cooperation agreements with other national space agencies.

Summing up what has been described here, Argentina has already reached level 2 of the STL by establishing a National Space Agency (within the first category of the ladder), level 6 (second category) by building a LEO satellite through mutual international collaboration, level 11 (third category) by building locally a GEO satellite, and hopefully will soon achieve level 12 (fourth category of the STL) by launching LEO satellites. This evolution can be seen in the following figure (See Fig. 2).

Finally, it is worth mentioning the case of Satellogic, a private company owned by an Argentinean entrepreneur and founded in 2010. Up to February 2018, Satellogic had launched 8 nanosatellites and microsatellites. The company currently has more than 60 employees. R&D activities are performed in Argentina, the satellites' integration is made in Uruguay, the software is developed in Israel, and the business management and sales teams are located in the United States (sales teams also exist in Colombia, Canada, and Israel). Satellogic benefited from subsidies granted by the Ministry of Science, Technology, and Productive Innovation, and, at its inception, it also profited from technological collaboration with INVAP. Satellogic aims at providing satellite information useful for crop monitoring as well as for other commercial and civilian objectives. The satellites produced by Satellogic are entirely based on off-the-shelf components. While a study of Satellogic's trajectory falls outside the scope of our research, its emergence is an example of some of the new developments in the space sector mentioned in Section 2, which could help to increase the diffusion of satellite-based services in the economy and the society as a whole.

4. A map of capabilities and linkages in Argentina's space sector

4.1. The accumulation and evolution of domestic capabilities

As said before, the success of Argentina's venture in the civilian space sector was enabled by capabilities and knowledge accumulated in 2 previous endeavors: the space military projects and the development of a local nuclear industry. Regarding the first of those endeavors, the key fact is that CONAE inherited the aerospace facilities of the Argentine Air Force and part of CNIE's civilian personnel linked to the Condor II project. This allowed CONAE to retain part of the capabilities developed at CNIE.[11]

In turn, as previously mentioned, the nuclear and the space sector share some characteristics related to (i) the existence of access restrictions to available knowledge and inputs; (ii) the stringency of the quality requirements; (iii) the need to manage "complex systems" technologies; and (iv) the capability to carry out large projects which integrate knowledge, components, and services developed by different providers, both inside and outside the organization leading the project.

Seijo and Cantero [17] analyze which specific technology areas were crucial for allowing INVAP to jump from the nuclear to the space area. They include electronics (integrated circuits design, production, and testing), monitoring and control systems, structural analysis of physical objects (e.g. vibration resistance), thermal and chemical analysis, quality assurance, software development, and special machining of high complexity components. All these capabilities were developed by INVAP first in the nuclear area, and then they were transferred, adapted, and subsequently improved when the company began its spatial activities. This was facilitated by the fact that INVAP is organized around a number of service areas whose human and physical resources may be used for any technological project undertaken by the different technical areas of the company.[12] Finally, the ability to forecast the effects of radiation is also shared by the nuclear and the space sector (i.e. potential damages caused by nuclear radiation to the components of a reactor and potential damages caused by cosmic radiation to the components of a satellite).

[7] CONAE's first and, so far, only president, Conrado Varotto, was one of the founders of INVAP.

[8] INVAP's payroll had reached more than 1000 employees in the late 80's, but the cancellations of the expansion plans in the nuclear area led to a dramatic fall in employment. Only 300 people were working at INVAP in 1993 [22]. Still in 2007, INVAP had around 400 employees, and its profits were close to zero. The remarkable growth in both variables from then on was an outcome of the state's decision to contract INVAP for a number of large projects not only related to the space but also in other areas such as radars and digitalization [26].

[9] INVAP was the first Latin American firm to be certified by NASA as a reliable supplier of space-related technologies, showing INVAP's capability to adapt the methodologies and processes followed by NASA in its space missions [17].

[10] The VENG endeavor is surrounded by a high level of secrecy, probably because of the fact that it involves the use and development of sensitive technologies.

[11] In fact, in 1981 a plan for building the first Argentine satellite was developed at the CNIE [27].

[12] These service areas include supply, international trade, administration and finance, quality, human resources and systems, security, and general services.

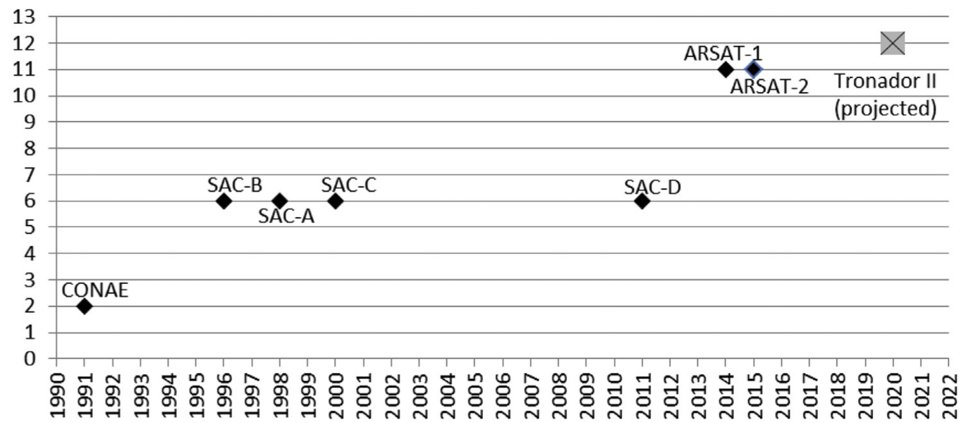

Fig. 2. Evolution of Argentina's space activity according to the 13 levels (left axis) of the STL. STL, Space Technology Ladder. Source: Prepared by the authors on the basis of Table 1 and Argentinean space milestones.

Later, the technological developments in the satellite industry have allowed INVAP to move toward a new area. During the preparation of the SAOCOM project, INVAP had to develop the capacity to understand and manage the so-called Synthetic Aperture Radar technology. Taking advantage of this knowledge, in the '00s INVAP began manufacturing primary, secondary, and meteorological radars by request of Argentina's Air Force (see Quiroga and Aguiar [18]).[13]

Although CONAE and INVAP are the main locus of innovation in the space sector, there are other public, private, and academic organizations that also contribute to the technological and productive developments in this area. According to an internal CONAE's report which we had access to, the agency has around 70 suppliers, out of which 10 are public- or university-based S&T organizations, and the rest of them are small and medium companies. The latter are mostly young technology-based companies (nearly 65% of them were created after 2000).[14]

CONAE and INVAP subcontract S&T institutions for the design and manufacture of solar panels, cameras, special materials, and components and also for specific research and testing activities. Private companies, in turn, manufacture different sorts of electronical, electrical, and mechanical components and are as well providers of software systems and analytical and testing services.

The Argentine Government is trying to promote innovation activities and domestic suppliers' development in the space sector (as well as in other “strategic” areas) through subsidies to public-private consortia granted by the Ministry of Science, Technology, and Productive Innovation. The Ministry of Production is also implementing a suppliers' development program that includes the aerospace industry and is based on subsidies, soft credits, and technical assistance.

The availability of high skilled personnel has obviously played a key role along the learning trajectory in the space area. The technical personnel working in space-related institutions in Argentina are mainly engineers and physics graduates from local state-owned universities; many of them also have master's and Ph.D. degrees from acknowledged foreign universities. In parallel, there are 4 master's degrees that are offered in Argentina by CONAE in partnership with different public universities. In contrast, CONAE and INVAP do seldom have personnel with degrees in areas such as business management, finance, marketing, or economics. As seen below, this is a serious weakness considering the challenges faced by the space sector in Argentina.

Argentina's space organizations have strong technological competences. However, they often lack high-quality managerial, organizational, and commercialization capabilities. This is reflected, for instance, in the delays observed in the SAC-D project[15] or in the fact that it took many months to sell the whole capacity of the ARSAT 2, when the usual practice in satellite telecommunications is that capacity is sold before the launching. CONAE and INVAP are technology-oriented organizations, but if Argentina aims at becoming a serious industry global player in the space area, they need to incorporate objectives related to efficiency and marketing of their products and services.

Finally, regarding state support for the space activity in Argentina, note must be taken that there is no legislation guaranteeing INVAP the exclusivity in the provision of satellites requested by CONAE or ARSAT, although the satellite telecommunication regulation in force establishes some conditions in which local manufacturers must be prioritized. Despite the fact that INVAP enjoys no legal monopoly, as seen before, all CONAE and ARSAT satellites have been committed to INVAP. This is the result of several factors. As mentioned, CONAE's Executive Director was one of INVAP founders. Hence, he was fully aware of INVAP's technological capabilities when he proposed the latter to embark upon the construction of the first Argentine LEO satellite. The success of the project confirmed INVAP's ability to design and manufacture satellites, so it was natural to grant INVAP the contracts for the following LEO projects. Later, at the time when ARSAT commenced the launch of a series of GEO telecommunication satellites, the national government decided to promote local production despite the fact that there could be cheaper suppliers on the market. Again, INVAP was a logical choice because it had already accumulated technological and manufacturing experience in building LEO satellites.

The state is the main or only customer of INVAP in most areas. However, this is not a peculiarity of the Argentinean case. The

[13] While primary radars are mainly dedicated to the control of Argentina's air space, including its frontiers, secondary radars aim at monitoring and controlling air traffic.

[14] The international experience shows that the creation of a “value chain” in the space sector usually involves efforts and investments that must be held for decades to be successful. In the case of India, for instance, according to Nagendra and Basu [25], these efforts have been going on for more than 4 decades and have resulted in the creation of several companies that provide goods and services for the national space program. However, India still does not have a private space company with a worldwide reputation, something that illustrates both the technological and the economic and market challenges to become a global player in this area.

[15] See https://spaceflightnow.com/news/n0912/26aquarius/.

Table 2
Government budget appropriations or outlays for R&D in exploration and exploitation of space (USD millions, 2010 constant prices, measured at purchasing power parity).

Country	Year	Value	Country	Year	Value
United States	2016	11.638.393	Belgium	2015	236.682
Russian Federation	2009	3381.625	Argentina	2012	202.01
Japan	2016	1922.643	Chinese Taipei	2016	120.702
France	2016	924.779	Netherlands	2016	150.5
Germany	2016	1591.017	Switzerland	2014	123.496
Italy	2015	892.503	Norway	2016	63.915
Korea	2015	567.095	Czech Republic	2016	34.876
United Kingdom	2015	442.219	Sweden	2015	28.137
Spain	2015	377.415	Denmark	2016	15.675
Canada	2013	276.932	Finland	2016	23.247

Source: OECD [21].[17]

public sector is a key customer in the nuclear and space sector in most countries with domestic capabilities in those areas, not only for economic but also for security reasons [2,19]. The state has also played a key role in promoting innovation in the space industry; again, this is the case in all countries involved in that industry [2]. Table 2 includes data on public resources for nonmilitary space-related research activities[16] in different countries. Argentina ranks 12 in this ranking, far from the global leaders, but well above several developed nations. According to data from the Ministry of Science, Technology, and Productive Innovation [20], the investment in R&D related to "exploration and exploitation of the space" was around USD 150 million in 2013, involving about 1000 researchers and interns and around 300 projects.

4.2. The role of linkages

4.2.1. Domestic linkages

There are strong linkages among the different actors of the space economy in Argentina. Some examples of these linkages include

(i) CONAE and INVAP closely cooperate in the R&D area, sharing both human resources and physical facilities [22].
(ii) Solar panels for LEO satellites are manufactured by a division of the CNEA. CNEA also undertakes the radiation tests performed on satellite components made by INVAP.
(iii) Some examples of local instruments and parts that were integrated in the missions concluded by the CONAE include the hard X-ray spectrometer developed by the Institute of Astronomy and Space Physics (SAC-B), the experimental solar cells produced by the CNEA (SAC-A), and the communications components designed by CONAE in collaboration with the Faculty of Engineering of the University of La Plata and the Argentine Institute of Radio Astronomy (SAC-A).
(iv) The VENG project, managed by CONAE, gathers 4 public universities (La Plata, Córdoba, Buenos Aires, and del Sur) as well as the CNEA. Special fuels for this project are being developed by Y-TEC, a partnership between the State oil company YPF and the National Council of Scientific and Technological Research. INVAP provides engineering and technical services to VENG, including the testing of launching facilities.
(v) In September 2010, the company CEATSA (high-technology testing center) was created. Its equity is shared by ARSAT and INVAP (89.5% and 10.5%, respectively). The company's objective is to provide advanced testing services to the satellite industry as well as to other sectors such as electronics, automotive, defense, energy and machinery. Prior to the creation of CEATSA, INVAP's satellites were tested in Brazil at INPE (National Institute for Space Research). CEATSA's facilities include a thermal vacuum chamber, acoustic test systems, mass properties testing equipment, and near-field horizontal scanner.

These and other linkages within Argentina's space sector are crucial for technological progress in this area, considering that no domestic organization masters the whole range of capabilities needed for building a satellite or a launch vehicle. As said before, space projects are based on "complex systems" technologies which require inputs from different knowledge fields which are available in specialized institutions (e.g. instruments, software developments, and specialized components). Moreover, domestic linkages are key for developing innovations in areas where access restrictions to existing technologies exist (it is the case of fuels for launch vehicles, for instance).

These linkages, in turn, were facilitated by the existence of previous personal connections among people belonging to the different actors of the space sector. Furthermore, labor mobility also helps in that direction because it is often the case that people working at CONAE or ARSAT are former INVAP members and vice versa. Linkages associated with the mobility of human capital also take place between the aforementioned institutions and the private sector. Such is the case of some local suppliers of CONAE and INVAP, which are spin offs of INVAP.[18] In other cases, these private providers were founded as a result of the capabilities accumulated in space projects. For instance ARSULTRA's partners after having participated in the SAC-D/Aquarius mission [23].[19]

4.2.2. Foreign linkages

All SAC projects have been undertaken in cooperation with the National Aeronautics and Space Administration (NASA), with whom CONAE signed a Framework Agreement on Civil Space Cooperation in 1991. This agreement was, in fact, a sort of compensation for Argentina's decision of putting an end to the Condor II project.

From then on, NASA has been in charge of the launching and monitoring of initial operational phases of all Satélites de Aplicaciones Científicas (SAC) satellites and has also been ready to provide contingencies support for those missions. NASA's instruments have also been a part of the payload of SAC missions. The most relevant example in this regard is that of the Aquarius instrument, which was the first equipment designed for navigating in a satellite with the objective of measuring the sea salinity for a better climate forecasting.

According to CONAE's personnel interviewed for this research, in the first stages, collaboration was relatively open. While no sensitive technology transfer was allowed, NASA's personnel was ready to give advice about specific questions, participate in the periodic revisions of the space projects, and to warn CONAE to avoid embarking upon misguided technological pursues. NASA's

[16] Some key players in this area do not report their budgets to Organisation for Economic Co-operation and Development (OECD) (e.g. China and India). Hence, they have not been included in the table.

[17] Data in Table 2 may differ from that informed by some national spatial agencies. However, we used this information because it is the best publicly available comparison data set.

[18] The founder and CEO of Mecánica 14 (a company dedicated to high precision machining) had previously worked for INVAP for several years. STI's (a provider of engineering services) CEO was former head of INVAP's electronic division.

[19] ARSULTRA provides high-tech hardware and software solutions for different industrial fields.

role was also influential for training human resources, transferring knowledge about different types of test specifications, and to help CONAE to learn about the planning, management, and monitoring of complex technological projects.

However, things changed in 1999 when the United States reinforced export controls on the satellite industry by transferring responsibilities in that area to the State Department under the International Traffic in Arms Regulations[20]. From that moment on, although collaboration continued, NASA's personnel ability to transfer knowledge was more severely restricted by security protocols.

The other 2 foreign agencies with which the main organizations of Argentina's space sector have strong linkages are those of Brazil and Italy. In the first case, it is worth taking into account that Brazil's progress in this sector has been limited so far. Brazilian efforts concentrated on the launchers area, but the lack of success and delays in the different projects finally led to abandon the whole program. Argentina's collaboration with Brazil has been mostly around the use of INPE's facilities to test LEO satellites. In turn, the SABIA-MAR project originally envisaged that both satellites would be designed and manufactured with the collaboration of Argentina and Brazil space agencies. However, as little progress was observed in the Brazilian side of the project, it was decided that each agency should build its own satellite. While the detailed engineering of the Argentinean satellite is now ready, to the best of our knowledge, no advances have been made in Brazil.

In the case of Italy, cooperation so far has included the provision of components and instruments for LEO satellites as well as the provision of research and training fellowships. The SIASGE project represents a higher level of collaboration between both agencies, as interactions along the design and manufacturing process of the SAOCOM have been intense and permanent. For this project, the Italian space agency is providing the 140 mini radar antennas which are the critical component of the payload.

5. Argentina's STL

There are many dimensions through which national technological progress in the space sector may be evaluated. The first is satellites' weight. Although small satellites may perform complex operations (especially when they are part of constellations or fragmented architecture systems), in the domain of single satellites, the heavier the weight the more complex their design and manufacture. A good approximation to the level of complexity of a satellite is the number of instruments it carries, and as a consequence, the higher the number of instruments, the greater the weight required by the satellite. Energy requirements are also larger. At the same time, more instruments complicate the management and processing of information traffic between the satellite and the ground segment. The evolution of the SAC series clearly shows that CONAE and INVAP have been able to launch heavier and more complex satellites along time. The SAOCOM project is a new step in this direction and is clearly the most technologically advanced satellite ever launched not only in Argentina but also in Latin America as a whole.

Second, the number of locally designed and manufactured instruments is another useful metric for analyzing the evolution of a country in the STL. In the first of the SAC missions, just 1 of the 4 scientific instruments included in the payload was developed in Argentina—2 other instruments were provided by NASA and the remaining 1 by an Italian research institute. In the last mission (SAC-D 2011), 5 out of the 8 scientific instruments were developed in Argentina (one in collaboration with the Canadian Space Agency), while the other 3 were provided by the United States, France, and Italy space agencies. In turn, while the Italian Space Agency (Italian acronym, ASI) provided the solar panels as well as some control instruments for the first SAC missions, the SAC-D employed local solar panels, and the satellite systems were wholly designed and produced in Argentina.

Progress in the design and manufacturing of LEO satellites in Argentina cannot be captured within the STL framework proposed by Wood and Weigel as this does not consider the above-mentioned metrics (i.e. weight, local provision of components, and instruments). Moreover, the last SAC satellite was more technologically challenging and had a higher level of local integration than ARSAT's satellites. In fact, many key components of ARSAT 1 and 2 were imported (including the whole payload as well as the solar panels). The decision to integrate foreign components instead of developing them locally is explained by the fact that business risks associated with telecommunication satellites impose a number of constraints. Delays in production times may result in the loss of the geostationary orbital positions assigned by the ITU. In turn, insurance companies impose restrictions associated with the record of the components of a satellite. In other words, there is not much room to include components or instruments in a telecommunication satellite that have not been tested in orbit before. Furthermore, the commercial telecommunication missions usually involve the fulfillment of contracts signed *ex-ante* with the clients by the satellite operator (in this case ARSAT). This implies that the costs of delay in placing the satellite into orbit or those associated with a failure in the satellite are much higher than those for scientific or observation missions. In fact, the loss of reputation due to delays or failures in the mission may imply costs which are hard to estimate for the satellite operator. Hence, the ARSAT platform was developed under the premise of minimizing risks and meeting deadlines, at the cost of a lower integration of local value added.

As regards of the comparison between ARSAT 1 and 2 and SAOCOM, the level of local integration is also higher in the latter case. Moreover, unlike the SAC series, in this case the weight metric would also show a higher technological complexity, since SAOCOM's wet weight will exceed the 3000 kg of ARSAT 1 and 2. In fact, the fuel represents about two-thirds of the wet weight of ARSAT 1 and 2, while fuel requirements in a LEO satellite are much lower. Thus, considering weight as a metric of complexity, SAOCOM is clearly more challenging than the GEO satellites launched by Argentina.

At this point it is worth reminding some observations introduced in Section 2 regarding the STL. The launching of ARSAT 1 implied reaching the "build locally" stage in GEO satellites, apparently more advanced than the "mutual collaboration" stage reached through the SAC series in the case of LEO satellites. However, as mentioned previously, the local contribution to SAC missions (as well as to the SAOCOM project) was clearly higher than in the case of the GEO satellites, both in terms of technology developments and integration of local components and instruments.

The satellites already launched by Argentina are not yet at the efficiency and/or technological frontier. For instance, in the case of telecommunications, a way to learn about the efficiency of a satellite is through the relation between weight and power. In the case of ARSAT 1 and 2 that relation is approximately 1 W per kilogram. According to the information gathered for this research, the international frontier is around 4 W per kilogram. INVAP authorities have informed us about the possibility of reaching that goal through the design and manufacture of a full electric platform for the new satellites that would eventually be demanded by

[20] This was a result of a series of explosions of U.S.-made satellites which had been launched in Chinese rockets. It was later discovered that sensitive technological information has been transferred to China [28].

ARSAT. This development process would take around 4 years, but at the time this article is written, budget restrictions prevent its kickoff.

Finally, although building a satellite is a huge challenge, this is mitigated by the fact that a large subset of its components may be acquired abroad, in particular with regard to the payload. In contrast, the technological autonomy required to carry out a launch vehicle project is much higher. This is because the risk that technology and materials related to launchers that may be used for military purposes is larger than in the case of satellites. A straightforward implication is that being able to develop launching capacities requires an almost complete technological autonomy because it is not possible to buy neither the technology nor the vast majority of the components (indeed this is a characteristic that is also shared with the nuclear area) abroad. This results in the fact that reaching the "launch capability" milestone of the STL requires full mastery over all the phases of the project and the development of most of its components, something that is not needed in the case of LEO or GEO satellites.

Despite the fact that designing and manufacturing a launch vehicle is not only more challenging but also involves a very different set of knowledge fields (e.g. fuels and special materials), it shares one feature with the satellite industry, namely the management of large and complex technological projects. Finally, the nuclear industry, which also shares the latter feature, is also heavily based on the use and control of special materials (e.g. resistant to very high temperatures). As a result, capabilities accumulated in that industry were instrumental for making progress in the VENG's project.

6. Discussion

Argentina has successfully climbed the STL in LEO and GEO satellites and is now pursuing the same endeavor in the more challenging launch vehicles technology. This was an outcome of a long-term process whose beginning was facilitated by the previous accumulation of capabilities in military-related space research as well as in the nuclear industry, a field with which the space sector shares a number of distinctive features. In a context in which access to foreign knowledge and components is often restricted by security reasons, linkages with partners abroad and access to foreign technology sources have been relevant, but they had to be complemented with the deployment of a dense collaboration network among domestic partners.

We have shown that Argentina climbed the milestones of the STL proposed by Wood and Weigel. We also demonstrated that it also climbed the technology learning curve in the satellite industry if other metrics absent in the STL are considered. This has been reflected on the design and construction of heavier satellites and the increasing integration of local components and instruments. The next objective in this process is to master the launch vehicles technology, in which access to foreign sources is even more restricted than in the case of satellites. This is an opportunity for further developing linkages with local suppliers and knowledge-based organizations.

This learning process has not been exempted of delays and setbacks, but in a country characterized by high economic and political volatility, the fact that plans in the space area have been maintained and deepened along the decades by different administrations with highly heterogeneous ideological views is in itself an evidence of the reputation gained by the main actors in this sector. In turn, the capability of putting scientific, observation, and telecommunication satellites in orbit is not only important insofar because it generates different kinds of spillovers (such as those that have led to the production of radars) but also because of its enabling role for the emergence of new business. The latter include, among others, those associated with the use of satellite images for agricultural production (under the concept of "precision agriculture") and the provision of telecommunication and geolocation services. Moreover, other social benefits include, for instance, a better control of natural resources, the provision of telecommunication services to remote areas that cannot be reached by optical fiber, a more rapid reaction to natural disasters, real-time climate monitoring, better forecasts and monitoring of fire risks and air quality, coastal supervision for the detection of oil spills, improved border controls, and the promotion and facilitation of scientific research.

Which are the main challenges ahead for space activity in Argentina? First, to gradually reduce the technological and efficiency gap with the frontier both in LEO as well as in GEO satellites. Second, to expand the economic impacts of space activity through the promotion of more linkages with current or new upstream suppliers which may provide specialized inputs and services, as well as through a more aggressive strategy aimed at disseminating the use of satellite-related services in sectors such as agriculture and others. Third, to explore the possibilities of exporting space-related technologies to other developing countries, following the trajectory of the nuclear industry.

To face these challenges, there are some conditions that must be met. First, although the space sector is increasingly able to generate revenue associated with the provision of different kinds of services, the continuity of state support for research activities is crucial in a field characterized by rapid technological progress. In this regard, current budget restrictions generate uncertainty about the future pace of space projects and may imply a potentially irreversible widening of the technological gap with the frontier. Second, while the main organizations of the space sector have strong technological capabilities, the same cannot be said about organizational, financial, and marketing competences. Consequently, there is a need for these organizations to incorporate, both in their staff and in their decision-making process, criteria and objectives associated with productive efficiency and commercial applications. This could help the space sector in Argentina to move from technological to economic success.

Declarations of interest

None.

Appendix A. Interviews

ARSAT S.A.

- Rodrigo De Loredo, President.
- Mariano Goldschmidt, Manager of Technological Development and Innovation.
- Guillermo Rus, former VP.

CEATSA

- Marcelo Famá, former General Manager.

CONAE (National Commission of Space Activities)

- Conrado Varotto, Executive Director.
- Fernando Hisas, Project Manager.
- Raúl Espiño, Project Manager.

- Oscar López, responsible for the formulation and monitoring of space projects co-financed by international credit organizations.
- Rafael Riva, Head of the Planning Unit.
- Ana María Hernandez, former Institutional Relations Manager.
- Roberto Perazzo, former consultant to the Presidency of CONAE.

CNEA (National Atomic Energy Commission)

- José Di Santo, Head of SAOCOM Satellite Mission Solar Panels Project.
- Claudio G. Bolzi, Head of Solar Energy Department and Deputy Head of SAOCOM Satellite Mission Solar Panels Project.

Frontec S.A.

- Gabriel Bisio, CEO.

INVAP S.E.

- Pablo Tognetti, Director (Former President of ARSAT)
- Sebastián Clasen, Manager of Planning and Control of the Aerospace and Government Area.
- Ignacio Grossi, Supply Manager.
- Tulio Calderón, Strategic Business Development VP.
- Vicente Campenni, Deputy General Manager.
- Dalila Grinkraut, Head of the Corporate Social Responsibility Area.
- Luis Genovese, Project Manager, Aerospace Area (Project Manager ARSAT-2).
- Eduardo Rodríguez Lubary, Head of Public Relations Area.
Ministry of Science, Technology and Productive Innovation
- Agustín Campero, Secretary of Technological Scientific Articulation.
- Fernando Ocampo, Project Manager at the National Directorate of Science Policy.

Ministry of Production

- Sergio Drucaroff, Undersecretary of National Procurement and Suppliers Development.

Servicio Satelital S.A.

- Gonzalo Berra, CEO.
- Eduardo Lema, Operations Director.

Telespazio Argentina S.A.

- Nicolás de Gracia, CEO.

U.I.D.-G.E.M.A. (Applied Mechanical Testing Group)

- Guillermo Garaventta, Researcher.
- Pablo Ringegni, Coordinator at U.I.D.-G.E.M.A.

References

[1] D. Wood, A. Weigel, Charting the evolution of satellite programs in developing countries – the Space Technology Ladder, Space Pol. 28 (1) (2012) 15–24.

[2] OECD, The Space Economy at a Glance 2014, OECD Publishing, París, 2014.

[3] C. Dahlman, R. Nelson, Social absorption capability, national innovation systems and economic development, in: B. Koo, D. Perkins (Eds.), Social Capability and Long-term Economic Growth, Macmillan, London, 1995, pp. 82–122.

[4] B. Lundvall, National Systems of Innovation. Towards a Theory of Innovation and Interactive Learning, Pinter, London, 1992.

[5] B. Verspagen, Uneven Growth between Interdependent Economies: an Evolutionary View on Technology Gaps, Trade and Growth, Universitaire Pers Maastricht, Maastricht, 1992.

[6] G. Dosi, Sources, procedures and microeconomic effects of innovation, J. Econ. Lit. (1988) 1120–1171.

[7] S. Teitel, Technology creation in semi-industrial economies, J. Dev. Econ. 16 (1–2) (1984) 39–61.

[8] D. Teece, Technological change and the nature of the firm, in: G. Dosi, C. Freeman, R. Nelson, G. Silverberg, L. Soete (Eds.), Technical Change and Economic Theory, Pinter, Londres, 1988, pp. 256–281.

[9] B. Cassiman, R. Veugelers, In search of complementarity in innovation strategy: internal R&D and external knowledge acquisition, Manag. Sci. 52 (1) (2006) 68–82.

[10] W. Cohen, D. Levinthal, Innovation and learning: the two faces of R&D, Econ. J. 99 (397) (1989) 569–596.

[11] A. Escribano, A. Fosfuri, J.A. Tribó, Managing external knowledge flows: the moderating role of absorptive capacity, Res. Pol. 38 (1) (2009) 96–105.

[12] C.A. Hidalgo, B. Klinger, A.L. Barabási, R. Hausmann, The product space conditions the development of nations, Science 317 (5837) (2007) 482–487.

[13] D. Blinder, Tecnología misilística y sus usos duales: aproximaciones políticas entre la ciencia y las Relaciones Internacionales en el caso del V2 alemán y el Cóndor II argentino, Revista Iberoamericana de Ciencia, Tecnología y Sociedad – CTS. Agosto, 2011.

[14] D. Blinder, Hacia una política espacial en la Argentina, Revista Iberoamericana de Ciencia, Tecnología y Sociedad – CTS. Mayo, 2015, pp. 65–89.

[15] D. Chudnovsky, Las nuevas políticas de ciencia y tecnología en la Argentina y el enfoque del sistema nacional de innovación, Rev. CEPAL 67 (Abril) (1999).

[16] INVAP, INVAP. http://www.invap.com.ar/. 2016 (accessed 6 December 2016).

[17] G.L. Seijo, J.H. Cantero, ¿Cómo hacer un satélite espacial a partir de un reactor nuclear? Elogio de las tecnologías de investigación en INVAP, Redes 18 (35) (2012).

[18] J.M. Quiroga, D. Aguiar, Abriendo la "caja negra" del radar. Las políticas de radarización para uso civil y de defensa en Argentina entre 1948 y 2004, H-industri@: Revista de historia de la industria, los servicios y las empresas en América Latina 19 (2016) 71–100.

[19] OECD, Innovation in Nuclear Energy Technology, 2007. https://www.oecd-nea.org/ndd/pubs/2007/6103-innovation-technology.pdf. (Accessed 10 April 2018).

[20] MinCyT, Ministerio de Ciencia, Tecnología e Innovación Productiva. http://www.mincyt.gob.ar/indicadores/indicadores-de-ciencia-y-tecnologia-argentina-2013-11318. 2015 (Accessed 26 January 2017).

[21] OECD.Stats, OECD.Stats, 2017. http://stats.oecd.org/. (Accessed 5 August 2017).

[22] R. Kozulj, M. Lugones, INVAP y el desarrollo de una trama de base tecnológica: evolución histórica y situación actual, in: M. Delfini, D. Dubbini, M. Lugones, I. Rivero (Eds.), Innovación y empleo en tramas productivas de Argentina, Prometeo, Buenos Aires, 2007, pp. 323–347.

[23] L. Drewes, El Sector Espacial Argentino: Instituciones Referentes, Proveedores Y Desafíos, ARSAT - Empresa Argentina de Soluciones Satelitales, Benavides, 2014.

[24] OECD, OECD Handbook on Measuring the Space Economy, OECD Publishing, París, 2012.

[25] N.P. Nagendra, P. Basu, Demystifying space business in India and issues for the development of a globally competitive private space industry, Space Pol. 36 (2016) 1–11.

[26] Repositorio UdeSA, Caso Invap, 2016. http://repositorio.udesa.edu.ar/jspui/bitstream/10908/12099/1/%5BP%5D%5BW%5D%20T.%20L.%20Adm.%20Grobocopatel%20Marra%2C%20Olivia.pdf. (Accessed 10 April 2018).

[27] M.N. Vera, C.R. Guglielminotti, C.D. Moreno, La participación de la Argentina en el campo espacial: panorama histórico y actual, Ciencia, docencia y tecnología 51 (2015) 326–349.

[28] K. Zinger, An overreaction that destroyed an industry: the past, present, and future and US satellite export controls, U. Colo. L. Rev. 86 (2015) 351.