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EVOLVING PUBLIC-PRIVATE RELATIONS IN THE SPACE SECTOR

LESSONS LEARNED FOR THE POST-COVID-19 ERA

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Building on OECD analysis, the paper has also benefited from insights collected from different OECD Space Forum workshops:

- *What's next for the space sector in the post-Covid 19 era?* October 2020.
- *Linking policies and indicators: A fresh look?* October 2019.
- *Economic models for the low-earth orbit and beyond,* October 2018.
- *Linking innovation and procurement in the space sector,* April 2018.

These events gathered in total more than 180 experts from ministries, space agencies and other administrations, international organisations, industry and academia. We warmly thank the experts who participated and recognise their contributions to this paper.

In connection with the more recent October 2020 workshop, a survey was circulated to selected public and private stakeholders, who kindly shared their views on the preliminary impacts of COVID-19 on the space sector and possible policy responses. We thank the survey respondents for their valuable inputs, which are included in the report.

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Evolving public-private relations in the space sector: Lessons learned for the post-COVID-19 era

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Where is the space sector headed? How can public and private actors work together to solve mutual challenges and sustain growth? What is the role of government programmes and funding? This paper addresses these and other questions by reviewing the evolving relationship between public and private actors in the space sector over the last two decades, based on case studies from North America, Europe and Asia. It provides new evidence for navigating the post-Covid-19 era, notably by exploring the range of government roles in supporting space sector innovation and expansion, from funder and developer of space programmes to partner and enabler of private sector growth.

Keywords: Space sector, public-private partnerships, innovation policies, public procurement, COVID-19 impacts

JEL codes: F01, H57, O30, Q55

Executive Summary

This paper documents the evolution of public–private relations in the space sector, in order to contribute new evidence on strengths and weaknesses of partnership models and lessons learned for navigating the post-COVID-19 era. It notably explores the range of government roles in supporting space sector innovation and expansion, from funder and developer of space programmes to partner and enabler of private sector growth.

Governments take on different roles vis-à-vis private actors in their efforts to support space sector development

The space sector is associated with high-risk and capital-intensive activities, with strong strategic interests, resulting in a key role of government in space technology development. Although starting as early as the 1980s, commercialisation trends are now accelerating in OECD countries, with government-centric space development moving to more decentralised approaches. The private sector is evolving from being exclusively a contractor to sharing more of the development costs, and taking on more financial risk and responsibilities in selected joint space projects. In that context, three general (often complementary) roles stand out today for public agencies, with government as lead developer, government as a customer, procuring finished goods and services, and government as a partner in different schemes where the private sector co-funds projects.

The prevalence of certain roles is primarily driven by public authorities' motivations to reduce costs of space programmes and increase returns on investment. However, there are also other considerations, such as technological transfer to launch new commercial activities or supporting private sector innovation in certain areas to fulfil government needs. A key inspiration comes from relatively new business models in the private sector, based on rapid evolutions in digital transformation, including in the space sector, and new commercial manufacturing schemes (see for instance OECD (2019[1])).

Private sector participation is growing, but government programmes and procurement still account for the lion's share of investments and represent a significant market for private firms

While private actors are playing an increasingly important role in space activities in OECD countries, governments provide the backbone of space funding. Governments invest in space capabilities to support broad socio-economic objectives and the development of scientific capabilities, for both R&D and operations. Still, as compared to other key public missions (e.g. education, environment, health), government investments in space activities remain modest and represented on average 0.03% of GDP for OECD countries in 2019 (some military space programmes may not be included in this estimate).

The digital transformation of the space sector is also ongoing, with strong impacts on incumbents and their business models, affecting their relationships with government customers. The sector has seen record levels of public and private involvement over the last decade, with more than eighty countries having registered at least one satellite in orbit, increasing private sector investments and a bustling start-up scene. The next decades may see the full deployment of mega-constellations of several thousands of satellites for communications and earth observations, the routine use of reusable launch technologies, and commercial missions to the Moon and beyond, with government still as a key customer. The transformation of the space sector was already ongoing *before* the onset of the COVID-19 pandemic and it has accelerated since.

It is yet unclear how the COVID-19 crisis will affect future institutional budgets. Levels of government investments have generally remained stable over the last two decades, including during the economic recessions in 2001 and 2008. However, this crisis is unprecedented in its scale and reach, with a high risk of long-lasting costs. At the same time, there is room for some optimism, as the COVID-19 crisis has also highlighted how space technologies can directly support societal needs, exemplified by the rollout of telemedicine and distance learning solutions using satellite communications.

In the coming years, policy actions will need to be carefully formulated to support innovative, but vulnerable, actors and to take advantage of the crisis to make positive long-term changes

Governments and space agencies have some work ahead of them to steer the space sector safely through the aftermath of the COVID-19 crisis, sustaining innovation and sector growth. Particular care will need to be taken of start-ups and small firms, which are traditionally most exposed during economic recessions. It will also be a challenge to take advantage of the crisis to make long-term positive changes. Governments are encouraged to act along three main lines.

- First, government agencies should apply the full range of procurement mechanisms and instruments at their disposal (i.e. traditional public procurement; anchor customer schemes, public-private partnerships) to benefit from private sector capabilities and commercial interests. In parallel, space agencies and other procurement agencies will need to have adequate and sustained skills and resources to negotiate contracts and carry out oversight (e.g. design instruments that address the different needs of actors including SMEs and start-ups, clarifying issues such as asymmetric relationships in collaborative projects).
- Second, the role of governments and public funding remains fundamental for the development of the space sector, particularly for innovation and entrepreneurship while the COVID-19-induced crisis is ongoing. Judging from previous crises, business R&D investments are likely to be reduced, and smaller firms and start-ups may have a harder time recovering than larger incumbents. To address these issues and ensure continued innovation, government organisations are encouraged to simplify funding practices and facilitate the participation of smaller actors. Long-established and sometimes cumbersome government practices are not the only obstacle to procurement changes and reform, as the private sector itself, especially large incumbents, is sometimes resistant to administrative change. By providing long-term visibility of the status and funding levels of space programmes, government agencies will enable firms to retain needed skilled staff and reassure investors.
- Finally, enabling future growth and innovation, especially when projecting beyond the COVID-19 crisis, will require predictable regulatory frameworks. This is particularly important for supporting emerging commercial activities, e.g. in the low-earth orbit (e.g. commercial spaceports, in-orbit servicing). And careful consideration will need to be given to the positive and negative effects of government policies and programmes in existing and emerging commercial markets, such as public-private partnerships co-existing with privately funded ventures.

As the private sector matures and diversifies, and more varied informal and contractual relationships are expected in the future, giving government agencies a wider set of tools to interact with these actors and enable economic growth will be key. This paper takes a first step in mapping these practices.

1. A central role of government in space sector development and sustainability

This section explores the central role of government in supporting the development of the space sector, by providing an overview of the current state of government space budgets, mapping the evolution of government R&D investments and presenting preliminary findings on the impacts of COVID-19 on the space sector.

1.1. Three different roles for government in space sector development

Governments continue to play a dominant role in the space domain. Since the beginning of the space age, large space programmes have been designed and developed in government space agencies, thanks to civil servants' expertise and public research facilities. Space activities, in the past and largely also today, are capital-intensive and associated with a high level of risk, especially in the development phase, and offer major strategic and dual use capabilities (Weinzierl, 2018[2]). However, the private sector has also been an integral part of space sector development, notably in OECD countries, providing contractors, R&D, equipment, components and services.

Over the last decades, the nature of this relationship has started to evolve, with the private sector sharing more of the development costs and taking on more risk and responsibilities. A clear shift can be detected in many space agency's objectives and policies, from reaching mission objectives in collaboration with a selected group of private contractors, to increasingly focusing on fostering entrepreneurship, innovation and commercialisation (Robinson and Mazzucato, 2019[3]). This translates into changing the relationship with existing private actors (e.g. more service buys, fixed pricing) and/or broadening procurement access and other programmes to a more diverse set of actors.

Another key driver for these developments has been the emergence of new business models in the space sector, inspired by assembly line manufacturing and the digital transformation, accompanied by a greater role of intangible assets (e.g. software, data) vis a vis physical assets. Examples in the space sector include not only the growing number of operators using low-cost cubesats[1], but also start-ups in space situational awareness and ground operations, which develop low-cost and low-maintenance ground equipment combined with user-friendly software solutions (OECD, 2019[1]). This has paved the way for service-based business models, as large incumbent space manufacturing firms have also started to modify their business models. Manufacturers have adopted different approaches to cutting costs, either by

[1] Cubesats are a class of nanosatellites that use a standard size and form factor, making them easier to mass produce and launch. The standard cubesat size is "one unit" or "1U", measuring 10x10x10 cm, and is extendable to larger sizes stacked lengthwise; 1.5, 2, 3, 6, etc.

outsourcing or offshoring certain activities, or by verticalising production (e.g. SpaceX launchers, consolidated production of Ariane 6 in Europe) (OECD, 2014[4]).

In this context, three general "government roles" stand out, with government as chief developer; government as customer; and government as a partner, as described in Table 1.1. Although all three roles are sometimes assumed in parallel by the same actor, depending on specific space projects as well as the maturity of the market and of the technology, there is a clear shift in OECD countries towards more decentralised space sector development, with governments acting as partners and customers, rather than main developers. It is important to note that this trend is not recent, as the US government has encouraged the purchase of commercial services since the early 1980s (see Box 1.1). However, the supply and use of services has diversified in the last ten years, and the government's take-up has accelerated.

Table 1.1. Roles of the government in space sector development

Role	Distribution of development costs	Selected instruments	Most common applications	Selected programmes
Government as developer	Government covers development costs (often with some outsourcing, but strong oversight)	In-house space agency development, R&D pre-procurement, cost reimbursement contracts with the private sector (More on this in Section 2.)	Public-good missions (e. g. science, exploration. navigation satellites, certain defence programmes)	NASA Space Launch System, James Webb Telescope. ESA/EC Galileo satellites
Government as customer	Government only pays for the final products and services. Private sector general covers development and operation costs	Procurement of services ("service buys"). (More on this in Section 2.2)	Mature commercial applications (e.g. telecommunications, earth observation) and space transportation	NASA commercial resupply contracts to the International Space Station, NOAA's commercial data purchase programme, ESA ClearSpace-1 mission
Government as partner	Costs are shared by government and private sector (e.g. 70-30, 50-50)	Fixed-price contracts, different types of public-private partnerships, "condominium satellites". (These instruments are further elaborated in Section 3.	Emerging applications with commercial potential (e.g. telecommunications, earth observation, on-orbit servicing)	ESA Ariane 6 launcher, ESA ARTES programme, Radarsat-2

In their role as developers, government agencies are responsible for funding and developing specific space technologies and applications, produced either fully in-house or via contractual relationships with private sector contractors, often heavily supervised. This is the historic model for space programmes, relying on government R&D facilities and expert staff (i.e. also the model for most military space programmes, particularly the ones for which a lot of R&D is needed). Governments carry development costs and risks, and cost-type contracts are common, were the procurement agency covers contractor costs. This type of model is common for major space programmes, such as NASA's Space Launch System or James Webb Telescope, and is also prevalent in countries with a mainly institutional market for space products (e.g. India, People's Republic of China (hereafter 'China')).

In their role as customers, government actors purchase readily available products and services in mature markets as part of their space programme. Some risks are transferred to the private sector, which covers development costs and operation costs (if relevant). The most prominent example of this model is NASA's commercial resupply contracts to the International Space Station, where NASA has selected three commercial companies to transport cargo to the International Space Station (following partnerships to develop the technology). Although these companies received government funding to support part of their R&D, they were able to build their own technical solutions to cover their customer's needs. There are also examples in other industry segments, such as the purchase of commercial weather data or commercial bandwidth for military telecommunications.

In their role as partners, government actors enter into different types of contractual arrangements with the private sector, acting more as partners in joint space projects. These arrangements vary in size and complexity, from R&D co-funding to public-private-partnership contracts worth several billion US dollars. Some risks are transferred to the private sector, such as cost overruns and delays (e.g. with fixed-price contracts). Partnerships with the private sector are becoming increasingly common in all space-faring countries, although the scope varies significantly. The development of the European launcher Ariane 6 is a partnership between the European Space Agency and Airbus/Safran (ArianeGroup) for example.

Box 1.1. Brief historical perspectives on commercial space

There is a large and growing literature on the history of commercial space and its potential, written by space industry experts and specialised journalists (e.g. Launius (2014[5]); Besha and MacDonald (2016[6]); Logsdon (2019[7]) Davenport (2020[8]) Berger (2021[9])). This brings valuable longer-term perspectives on the roles of public and private actors in space industry development and innovation.

Private actors (in particular wealthy individuals) have played an important part in the space sector ever since the beginnings of the space age, including in supporting developments in astronomy and space sciences (see MacDonald (2017[10]) on the development of the first large telescopes in the United States). When looking at more recent space industry developments, the late 1970s-1980s saw a liberal policy impetus to support commercial developments in North America and Europe. Many of the initial policy incentives drafted then, are being routinely used today. In Europe, the first large commercial undertakings were led by France's support of Spot Image and Arianespace in the 1980s, contributing later in the 1990s to make the European Space Agency-developed Ariane 4 launcher the world's leader in commercial launches (Varnotaux, 2015[11]). In the United States, several crucial presidential policy directives in the 1980s contributed to the future rise of commercial space programmes (Goldman, 1985[12]; Logsdon, 2019[7]).

In the 1990s and early-2000s, many new commercial actors entered the stage. Surrey Satellite Technology was created in 1995 as a spin-off of the Surrey University in the United Kingdom, and would become a leader in the small satellite revolution to come a decade later. KeyHole, an early innovator in earth observation, was bought by Google in 2004, leading to the game-changing GoogleEarth online services. The Amazon founder Jeff Bezos created Blue Origin in 2000, and Elon Musk established SpaceX in 2002. But these developments coincided with a strong crisis in commercial space in OECD countries, driven by an excessive speculation of Internet-related companies and major technology changes in telecommunications, with the rise of terrestrial, rather than space-based, cellular networks. In 1999, the Iridium constellation's financial woes represented one of the largest bankruptcies in US history, at the same time as several launch accidents occurred in Europe, North America and Asia. Major policy shifts demonstrated the dominant role of governments in restricting but also supporting private companies with contracts (i.e. foreign space technology transfers restrictions, European Space Agency's growing diversity of programmes engaging industry, strong role of defense procurement in the United States for launchers and space R&D) (Peeters, 2002[13]).

The late 2000s and 2010s saw a major shift in commercial space, with technology ruptures based on digitalisation and production transformation, more countries supporting commercial developments (Sridhara Murthi, Sankar and Madhusudhan, 2007[14]), and maturing commercial actors competing with long-term incumbents. New start-ups in the sector, building their business cases on big data and new manufacturing processes, were branded as "new space" actors (OECD, 2016[15]). The importance of commercial space solutions addressing both institutional markets, as well as business-to-business verticals, has continued growing in the early 2020s.

1.2. Public investment in space activities

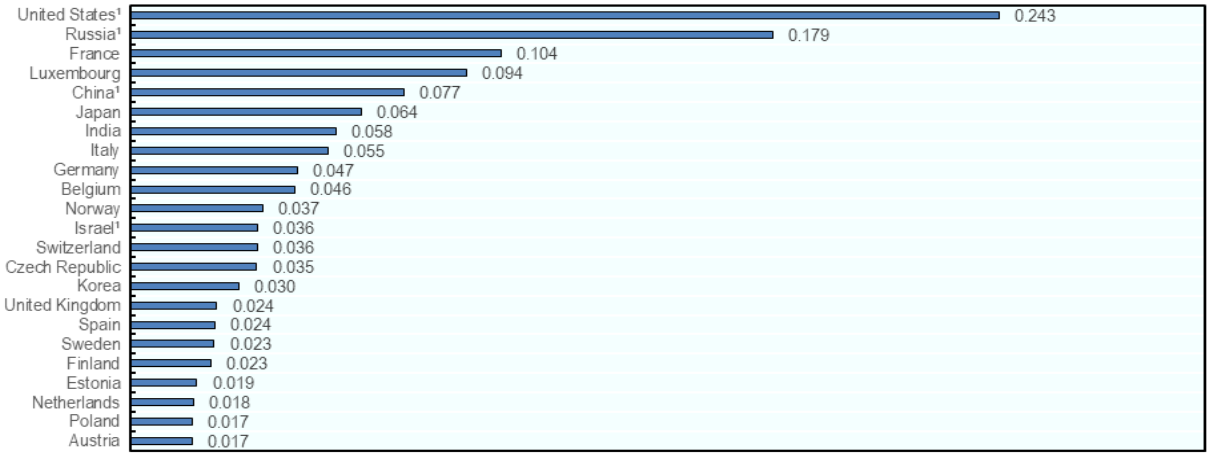
Before addressing the question of *how* governments spend their money on space activities, it is important to have a better understanding of *how much* government invest in this domain and how funding levels could be affected by the COVID-19 crisis.

As the cost of access to space has fallen and the number of space applications have multiplied over the last two decades, record numbers of countries are now engaged in different types of space activities (OECD, 2019[1]). Overall, government space investments have generally remained stable over the last two decades.

Public investments represent the bulk of funding in space activities, accounting for 0.1 to 0.2% of national GDP in the highest-spending countries (United States, Russian Federation, France), as shown in Figure 1.1.

Figure 1.1. Institutional space budgets of selected countries in 2019

As a percentage of GDP (%)



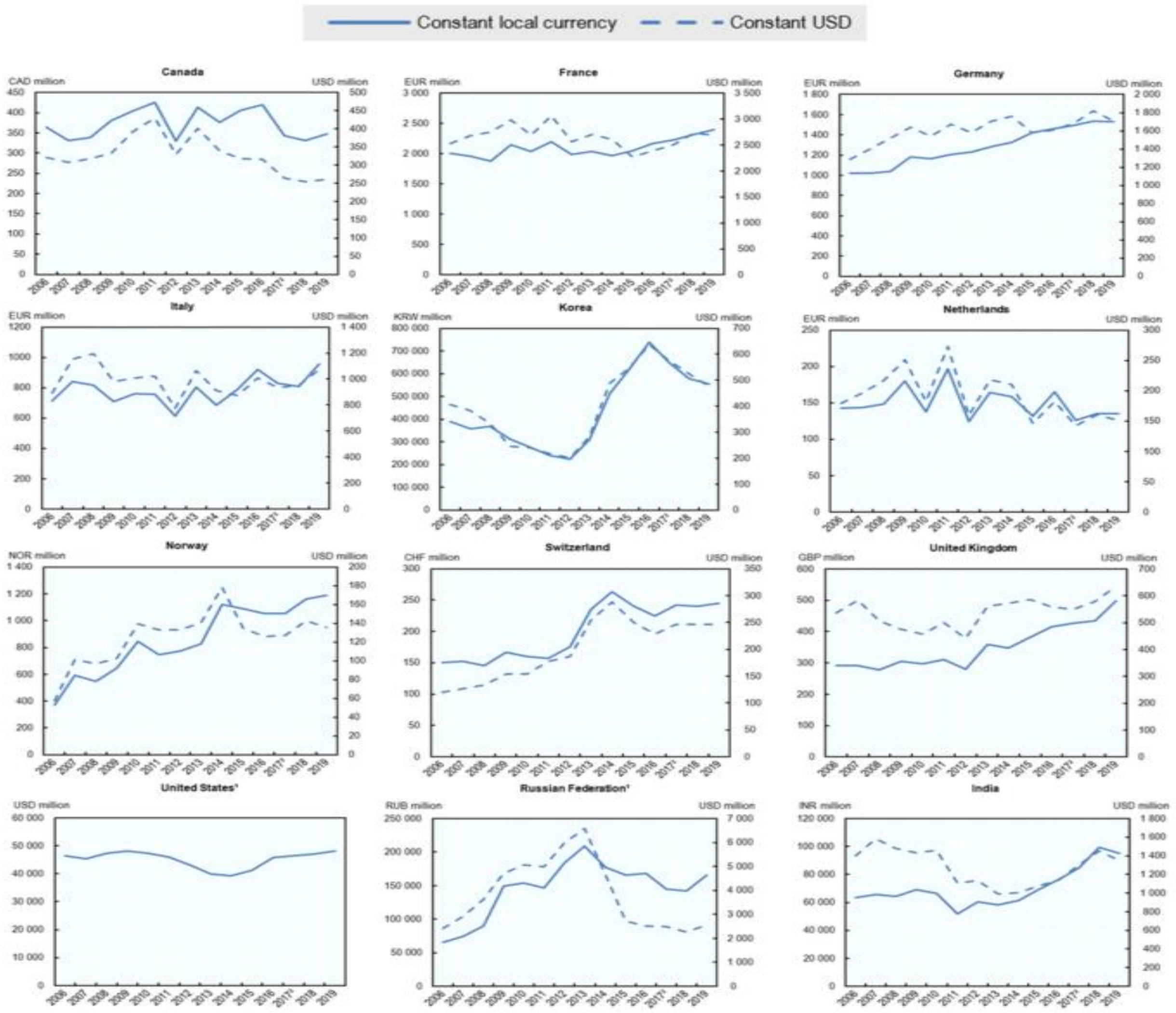
Notes: These estimates cover national budget estimates and contributions to international organisations for European countries (e.g. European Space Agency, Eumetsat). Additional regional and local government investments are not included. 1. Conservative estimates, including defence programmes when available.
Source: Government sources and OECD databases.

For the majority of OECD countries and other economies, public investment in space activities represented less than 0.05% of GDP in 2019. The OECD average is 0.03%. It is important to note that this figure only includes clearly identified space programmes and activities in national budgets, excluding non-disclosed programmes and additional investments at the regional and local levels. These data should therefore be regarded as conservative estimates.

Levels of public space investments have generally remained stable over the last two decades (Figure 1.2), and have proven relatively resilient to economic downturns, perhaps protected by space activities/ strategic importance and long R&D cycles.

Figure 1.2. Evolution in institutional budgets in real terms, selected countries

Baseline year 2015



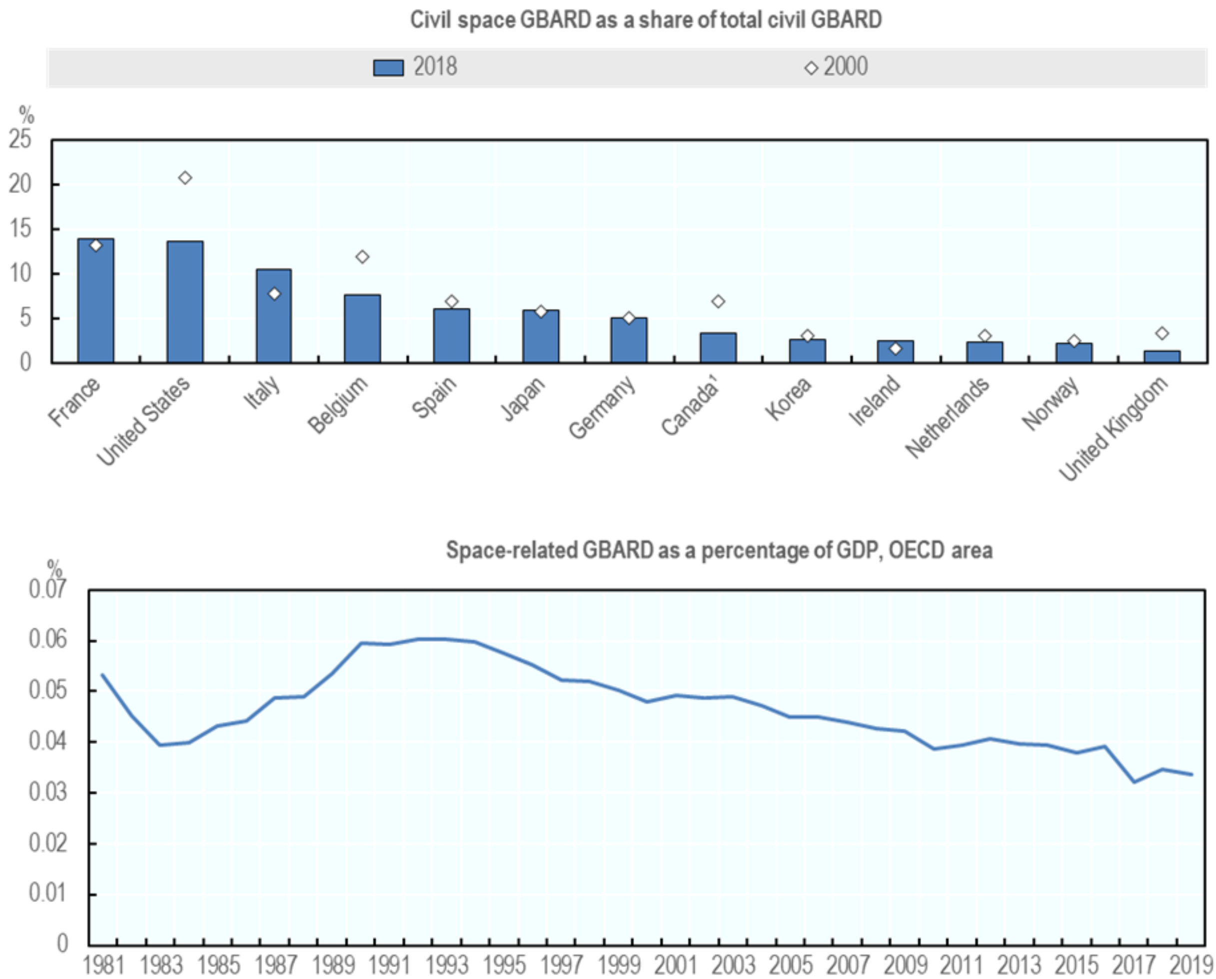
Note: 1. Conservative estimates
Source: Government sources and OECD databases.

Several countries increased their funding in the last fifteen years, sometimes in association with new policy strategies (e.g. United Kingdom) or accession to international space organisations and programmes. For instance, Norway and Switzerland have both joined the European Union Galileo/EGNOS programme, and Norway has also joined the EU Copernicus programme. Space technology R&D has historically required large upfront investments and long-term funding commitments. This is still very much the case for many space programmes, particularly for public good-related missions, such as satellite environmental monitoring, weather and major scientific missions. Although business enterprises play an increasingly important role in developing new space products and services, government R&D funding remains significant.

A useful indicator for tracking government-funded space R&D is government budget allocations for research and development (GBARD). Governments' R&D activities are classified according to 14 different socioeconomic objectives, one of which is 'the exploration and exploitation of space'. This category includes both fundamental and applied R&D activities and space-related infrastructure (laboratories, launch systems, etc.). But the data have some limitations, since civil space GBARD excludes all defence-related activities and potentially some of the R&D dedicated to earth observation, meteorology and environment monitoring (categorised under 'exploration and exploitation of earth'). Despite this caveat, GBARD gives an indication of how some space-related R&D budget allocations have evolved, as compared to other national priority areas and over time.

In 2018, France and the United States devoted 14% of their civil R&D budget to space R&D, followed by Italy (11%) and Belgium (8%) (Figure 1.3) (OECD, 2020[16]). This shows the relative importance of civil space R&D compared to other government R&D missions. Over time, space-related R&D allocations as a share of GDP have been steadily decreasing. This coincides with the first commercialisation efforts in the sector (starting with telecommunications operations) and indicates a greater implication of the private sector (OECD, 2004[17]).

Figure 1.3. The exploration and exploitation of space in civil government R&D efforts



Note: Does not include defence-related R&D. 1. Data from 2016.
Source: OECD (2020[16]), Main Science and Technology Indicators", *OECD Science, Technology and R&D Statistics* (database),
.

1.3. Supporting the space sector during the COVID-19 crisis

Compared to many other sectors, the space sector has so far proven relatively resilient to the COVID-19 crisis in most countries, and a majority of space sector firms seem to be able to cope. In the early months of the COVID-19 outbreak, space manufacturers and agencies actively contributed to the response efforts, by producing medical equipment and providing high-speed connectivity to distance learning solutions and to remotely located hospitals, residents and shops, as well as earth observation imagery for industry intelligence and monitoring of remotely located infrastructure (OECD, 2020[18]). The lockdown has so far mainly caused delays. For instance, the launch of European/Russian ExoMars mission has been delayed until 2022, with COVID-19 as a contributing factor.

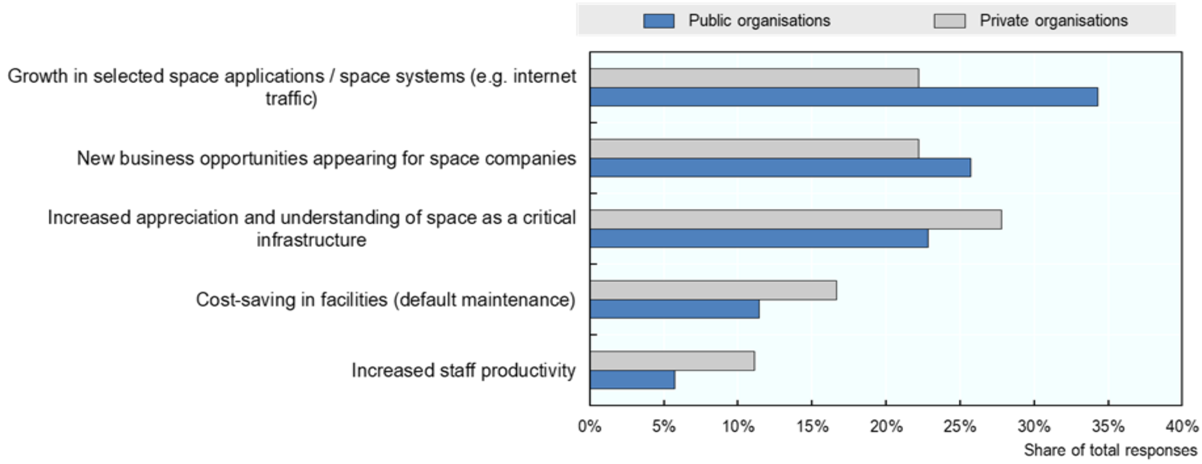
Indeed, the nature and size of impacts of the COVID-19 crisis on the space sector depends on a range of different factors (OECD, 2020[18]). First, the exposure to the COVID-19 crisis varies significantly across the different industry segments of the sector. The strongest effects so far, both positive and negative, have been found in space applications closest to consumer markets. Businesses providing connectivity to air and maritime transportation (e.g. passenger Wi-Fi) are the hardest hit. Meanwhile, demand for other satellite services and products has increased, such as connectivity to remote locations or earth observations imagery for industry intelligence and remote monitoring. Industry segments more strongly reliant on government procurement (e.g. space manufacturing and operations) seem so far less affected. These industry segments are typically part of national critical infrastructures, meaning that firms have been able to remain open during lockdowns and have seen no immediate changes in demand. In addition, most space manufacturing and operations are locked into multi-year budgets, which would tend to insulate them from immediate economic shocks.

Furthermore, there is a geographic dimension. Countries with a large domestic institutional market for space products (e.g. the United States or China) may be more resilient to the crisis, whereas countries and segments more dependent on exports (e.g. Canada, European countries) could see negative longer-term effects. Some regions and countries also seem to be recovering more quickly economically from the crisis (e.g. East Asia, United States).

Finally, irrespective of business segment and geography, the age and size of firms also plays a significant role (OECD, 2020[19]). Small- and medium-sized enterprises tend to have higher liquidity shortages and to be less diversified than larger actors, and start-ups also suffer from the inability to make new contacts and deals due to travel restrictions and the cancellation of conferences and fairs.

However, the crisis also brings new opportunities. In an OECD Space Forum survey circulated to selected stakeholders in September 2020 (see Box 1.2), both public and private respondents see several potential positive outcomes, including new business opportunities and a better appreciation and understanding of space as a critical infrastructure (Figure 1.4).

Figure 1.4. Potential positive outcomes of the crisis?



Note: Survey conducted the OECD Space Forum in September/October 2020. 25 organisations responded to the survey, 68% from public sector and 32 % from the private sector.

Box 1.2. The preliminary impacts of COVID-19 on the space sector

In an effort to better understand the socio-economic impacts of the COVID-19 crisis, the OECD Space Forum conducted a targeted survey among international stakeholders in September and October 2020, to collect first reactions about the effects of the COVID-19 pandemic on the space sector.

The questionnaire had three focus areas:

- Identifying key trends to prepare for the "post" COVID-19 era
- Identifying other side-effects related to the COVID-19 crisis
- Adapting administrative and policy responses to support the space sector

A total number of 25 organisations responded to the questionnaire. The majority of them (68%) came from public organisations (mainly space agencies), while private firms accounted for the other 32% of respondents.

Respondents were particularly concerned about future levels of government funding, and the possible decline in commercial demand for selected space products and services, as well as the effects this may have on the industrial base. SMEs and start-ups were considered more vulnerable to negative impacts. When it comes to operations, social distancing requirements also generated significant costs (e.g. health protection measures in manufacturing and launch).

In terms of longer-term impacts of COVID-19 on processes and ways of working, public organisations reported ongoing administrative and organisational changes.

Both public and private respondents identified several potential positive outcomes coming out of the crisis, including new business opportunities and a better appreciation and understanding of space as a critical infrastructure.

This crisis is unprecedented in its size and reach. In most economies worldwide there is a risk of long-lasting costs, with the level of output at the end of 2021 projected to remain below that at the end of 2019, and considerably weaker than pre-pandemic projections (OECD, 2020[20]).

In the longer run, experiences from the previous economic crises in 2001 and 2008 indicate that science, technology and innovation (STI) ecosystems more generally, could face a series of challenges, including increased financial constraints on public research institutions, decreasing business R&D expenditure and a widening gap between high-liquidity digitalised actors and the rest of the economy (Paunov and Planes-Satorra, 2021[21]). This, in turn, could increase economic disparities between regions and countries and impede scientific production in the most hard-hit countries. This is likely to affect institutional space budgets both directly and indirectly, something which could have knock-on effects on other parts of the space innovation ecosystem. Considering the high costs of entry to the sector, there is a risk that the crisis could lead to more industry concentration, eliminating in particular smaller and younger firms that are key sources of innovation, employment and economic growth (OECD, 2020[20]).

At the same time, some space agencies are cautiously optimistic about the future, as COVID-19 also has contributed to highlighting how space technologies can support society during a crisis, and more importantly, the role they can play in remodelling societies and the economy. For example, the South African government has announced significant investments in a Space Infrastructure Hub as part of the post-pandemic recovery (SANSA, 2020[22]).

Closer co-operation with the private sector is likely to be one of the key elements in recovering from the crisis. The next sections will review policy options for interacting with private actors in the years to come. Section 2 traces the evolution of government procurement practices, from developer to customer of products and services. Section 3 focusses on recent examples of different types of public-private partnerships and collaborations, providing some valuable lessons learned. Finally, Section 4 explores possible ways forward for policy-makers.

2. Governments evolving from chief developer to customer of space products and services

While private actors are playing an increasingly important role in space activities, governments continue to be the main drivers of space sector development. They do so by funding basic science and R&D, and by purchasing space products and services. However, in order to improve value for money, foster innovation and support commercialisation and entrepreneurship in the sector, the underlying models for dealing with the private sector are changing. In most OECD countries, government agencies are moving away from the role of chief developer towards a role of customer. Although this trend is not new, it has noticeably accelerated in recent years. This section looks more closely at this evolution, the instruments governments have at their disposal and the underlying motivations for change.

2.1. Government instruments for procurement and R&D support

Typical policy instruments for space technology development in OECD countries include grants and procurement mechanisms (Table 2.1). The use of these tools vary according to the nature and size of space programmes. Most space agencies and offices act primarily as R&D funding agencies, allocating grants to private and academic actors (e.g. the UK Space Agency, the Norwegian Space Agency). For larger space agencies that operate multiple missions, public procurement also plays an important role (e.g. the US National Aeronautics and Space Administration NASA; the European Space Agency ESA, the French space agency CNES).

Table 2.1. Selected government instruments for procurement and R&D support

Instruments	Description	Selected examples
General public procurement	Procurement of products and services from private contractors, academia and other sources	General and pre-commercial procurement is used in all countries with space programmes, for the purchase of space equipment and multiple services (e.g. engineering).
Pre-commercial procurement	Pre-commercial procurement refers to the purchase of products or services that do not yet exist in the market.	
Grants for business R&D	One of the most common tool for space agencies. R&D grants fund technology development at different readiness levels. Awards are generally granted on an open and competitive basis. Firm co-investment is normally required, but can be reduced/waived (e.g. for SMEs, start-ups)	Space programme in Horizon 2020 (European Union); space component in PIA (France); Space Components Initiative and Small Satellite programme (DLR, Germany); STAR-Exploration programme (Korea);; National Space Technology Programme (UK Space Agency)

Increasingly, procurement and grant instruments are designed in accordance with specific government objectives, such as targeting start-ups or small-and medium-sized enterprises. Fostering commercialisation and entrepreneurship is another emerging objective, which is shaping policy design.

Procurement programmes

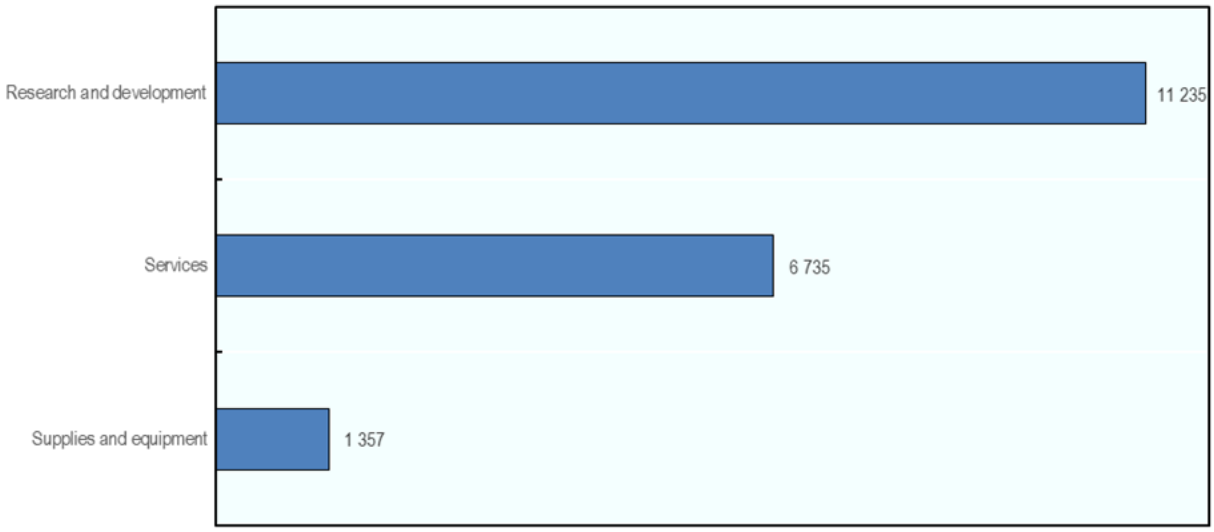
Procurement of research and development (R&D) goods and services accounts for the lion's share of large institutional space budgets, with two approaches that are increasingly used, often overlapping:

- General public procurement of innovative solutions: Government agencies act as early adopters, committed to purchase and deploy a critical mass of end products/services that are already in the market (or close to the market) but not fully commercialised yet (OECD, 2015[23]).
- Pre-commercial procurement: Government agencies support the development of technological space solutions that do not yet exist in the market, and for which new R&D is needed. This often involves prototyping and testing services for products or services. Pre-commercial procurement is particularly important in the space sector, where products and services are often custom-made for specific missions.

In the case of the United States, the National Aeronautics and Space Administration's (NASA) procurement accounted for more than 80% of the agency's budget in 2019, totalling USD 19.5 billion. The same year, procurement of R&D accounted for 58% of the total budget (NASA, 2019[24]). Government R&D procurement is therefore particularly important for technology development overall and for financing business R&D activities. In Canada, half of space-related business expenditure on R&D (BERD) is financed through external government sources (Canadian Space Agency, 2019[25]).

Figure 2.1. NASA procurement awards by type of effort, 2019

USD million



Note: NASA procurement refers to the purchase of R&D, services and equipment.
Source: NASA (2019[24]), *Annual Procurement Report: Fiscal Year 2019*.

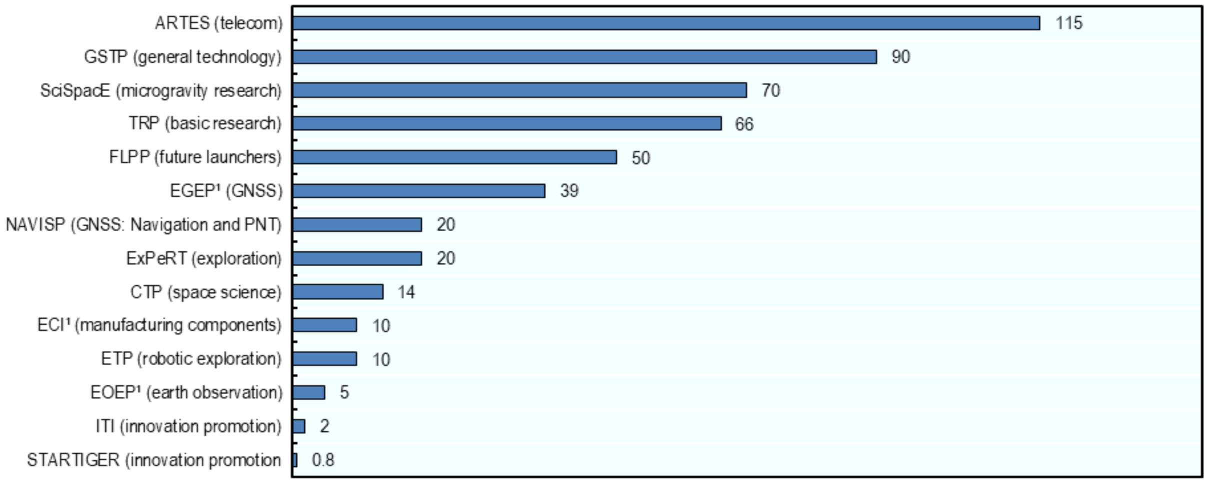
In Europe, the European Space Agency operated a budget of some EUR 5.7 billion in 2019, with most of the funds finding their way back to its contributing members in the form of contract. The procurement policy of the European Space Agency operates in accordance with the rule of "geographical return", whereby the share of a country in the weighted value of contracts should closely correspond to its share in Agency contributions by the end of a given period. The objective is to foster the growth and competitiveness of the European space industry (Germes, 2018[26]).

An important development in Europe is the emergence of a European Union (EU) space programme and its own procurement mechanism. Unlike the European Space Agency, EU agencies do not apply the rule for "geographical return", which could have a significant longer-term impact on the European space ecosystem. In the next multi-annual financial framework for 2021-27, a EUR 13 billion budget has been set aside for space activities, for navigation (Galileo/EGNOS), earth observation (Copernicus) and security aspects, mainly space situational awareness (GOVSATCOM) (European Parliament, 2019[27]).

R&D procurement programmes support technology at different levels of technological maturity. At the European Space Agency, early stage R&D is mainly funded through the Basic Technology Research. Programme (TRP), whereas the General Support Technology Programme (GSTP) and Advanced Research in Telecommunications Systems programmes (ARTES) provide funding for more advanced projects.

Figure 2.2. Selected ESA R&D programmes

2016, in EUR million



Note: 1. Average value. Budget allocated for several years.
Source: ESA (2017[28]), *European Space Technology Master Plan 2017*, Nordwijk.

R&D procurement programmes are sometimes designed to support different policy objectives. In the United States, NASA and other US federal agencies with large extramural R&D budgets are required to allocate 2.8% of their R&D budget to Small Business Innovation Research programmes (SBIR) and 0.3% for Small Business Technology Transfer programmes (STTR). In 2019, the Agency awarded USD 146 million in SBIR contracts and USD 20 million in STTR contracts (NASA, 2019[24]).

R&D grant programmes

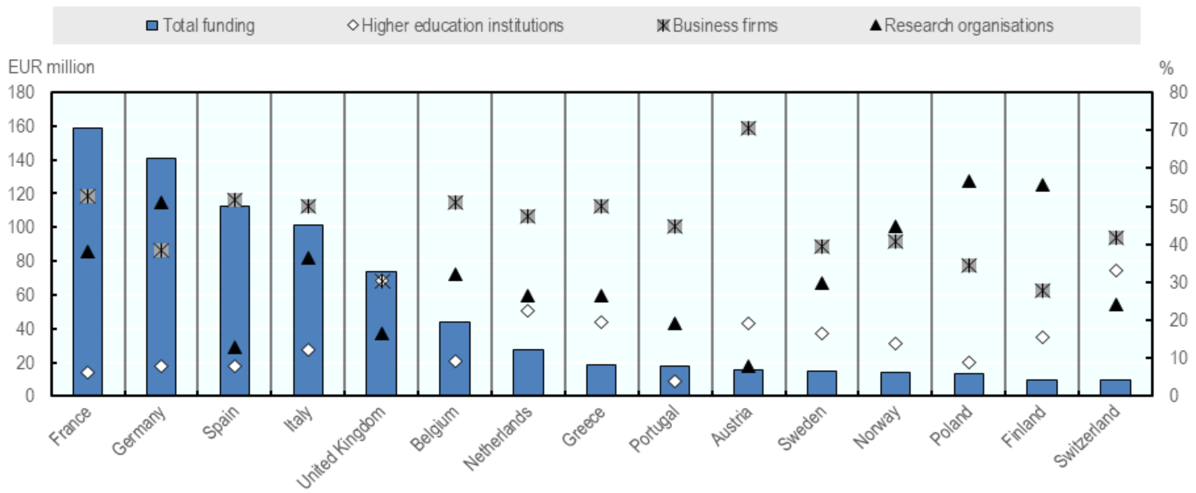
Unlike procurement schemes, R&D grants are from the onset designed as "transfer funding", i.e. not requiring any goods or service in return (OECD, 2015[23]). For R&D grants to the private sector, different levels of co-funding are normally required. Also, a s in other non-space sectors, grants are increasingly designed to contribute to other policy objectives, such as promoting innovation in small and medium enterprises (SMEs), collaboration among firms, entrepreneurship, or university-industry collaboration

One of the biggest R&D grant programmes at the international level is the European Union's six-year research programme (currently Horizon 2020 for the period 2014-20). It supports collaborative space research under the main pillar "Industrial Leadership", with a total estimated budget of some

EUR 1.4 billion (USD 1.6 billion) (European Commission, 2015[29]). The research themes are satellite navigation; earth observation; protection of European assets in and from space; competitiveness of European space technology; and science. EU member states, associated member states and selected developing countries can participate and receive funding. Figure 2.3 shows the preliminary distribution of grants through to April 2020 (left-side axis). Private actors typically account for 30-50% of awarded grants (shown in the axis to the right), but there are significant national differences. In Switzerland and the United Kingdom, higher education institutions account for more than 30% of space-related Horizon 2020 funding, reflecting their university-centred public research systems. In other countries, public research organisations play a bigger role (e.g. France, Germany, Norway).

Figure 2.3. Distribution of European Union Horizon 2020 space-related funding

By organisation type in selected countries. Funding in EUR million (left axis) and percentage of total funding allocated to organisations (right axis) through to 6 April 2020



Note: Horizon 2020 organisation classification types. The categories “Public entities” and “Other” are not displayed.
Source: French Ministry of Research and Education, (2020[30]), “Participations dans les contrats signés du programme-cadre pour la recherche et l’innovation (H2020) de la Commission européenne”, https://www.data.gouv.fr/fr/datasets/participations-dans-les-contrats-signes-du-programme-cadre-pour-la-recherche-et-linnovation-h2020-de-la-commission-europeenn

In Horizon Europe, the European Union research framework programme for 2021-27, space R&D funding will be mainly channelled through a “co-programmed” partnership on “Globally Competitive Space Systems” in the pillar for global challenges and European industrial competitiveness (European Commission, 2020[31]) . This partnership model, based on memoranda of understanding and/or contractual arrangements between the European Commission and the public/private partners, is expected to be more effective compared to traditional calls because they would “ensure industries working together across sectors and value chains, based on predefined targets” (European Commission, 2019[32]),

In addition to funding at the European level, several countries have their own (smaller) R&D programmes. Some of these programmes are often more modest, mainly mirroring contract funding from ESA (e.g. Norway and Switzerland), while others are becoming increasingly ambitious and targeting specific domains. In France, the two first rounds of the Future Investments Programme (PIA 1 and 2) have allocated more than EUR 700 million in grants to launcher and small satellite development between 2009 and 2016 (Cour des Comptes, 2015[33]). In Germany, annual R&D funding from the national space programme has grown from some EUR 1.9 million in 2000 to EUR 23.2 million in 2018, mainly focusing on affordable small satellite capabilities (Fischer, 2019[34]). In 2020, the UK Space Agency announced a new funding programme supporting the development of affordable solutions for space surveillance and tracking, addressing the growing problem of space debris.

2.2. Changes in government procurement and funding practices

Many space agencies are simplifying and shortening procurement procedures to facilitate the participation of start-ups and small and medium-sized enterprises (SMEs) and to accelerate the access to funding, through digital tools, e-tendering, etc.

Simplifying procurement practices to broaden access

Government agencies are increasingly using "new" procurement mechanisms, such as Other Transaction Authority agreements (OTAs) in the United States or simplified contracts at the European Space Agency. OTAs include for instance Space Act Agreements (used for the COTS programme) and Broad Agency Announcements, which are exempt from the administrative requirements of federal procurement laws and regulations (FAR) (see Table 2.2 below). The US Defense Advanced Research Projects Agency (DARPA) has reported that in some cases, by using open transaction authority agreements, project funding could come through in as quickly as 2-3 months. Interestingly, established actors, which have worked with traditional government procurement processes for decades, do not necessarily support the use of new procedures, as internal cumbersome administrative adaptation might be required, and smaller newcomers may be at an advantage (Kennedy, 2018[35]).

Table 2.2. Selected simplified procurement procedures applied by space agencies

Procedure	Agency	Description	
Open solicitations	DARPA, ESA, NASA	Firms have the opportunity to present proposals for new R&D. Calls can be periodic or permanent	
Other transaction authority agreements (OTA)	DARPA, NASA, NOAA	Legally binding contracts that are exempt from federal procurement laws and regulations (FAR), e.g. audit requirement, intellectual property, that can be structured in numerous ways with multiple actors	Non-reimbursable Space Act Agreements (SSA): collaborative agreements in which NASA and another party each contribute resources (personnel, facilities, expertise, equipment or technology) with no transfer of funds. Each party agrees to fund its own participation in the activity for their mutual benefit. Reimbursable SAAs: Payment of funds to NASA in exchange for the use of unique NASA resources (personnel, facilities, expertise, equipment or technology Broad Agency Announcements (BAAs): Competitive procedure used to solicit proposals for research and development projects. Co-operative research and development agreements (CRADAs): An agreement between a and a private company or university to work together on R&D. It is intended to speed the commercialisation of technology and protect the private company involved. A CRADA allows both parties to keep research results for a pre-determined period of time.
Simplified contracts	ESA	For low-to medium-size contracts. Simplified document covering eligibility and shortened bidding time limits	

Some of these trends have been accelerated by the COVID-19 crisis, which has forced space agencies to review their procurement practices, in particular vis-à-vis certain vulnerable actors, such as start-ups and small and medium-sized enterprises (SMEs) (OECD, 2020[18]). A German survey specifically targeting space start-ups revealed in summer 2020 that almost 40% of respondents reported the impacts of COVID-

19 to be “dramatic” and threatening the very existence of their firm, with 80% of the surveyed start-ups considering existing government support measures insufficient (BDI, 2020[36]).

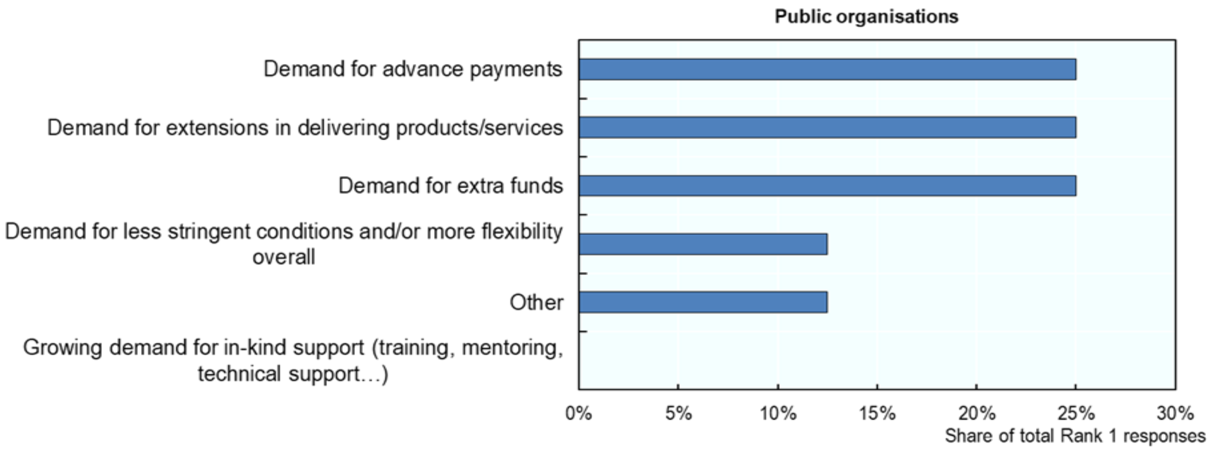
A major concern of start-ups is generally the lack of visibility of future contracts, with clients and private investors putting decisions on hold. In the context of the COVID-19 crisis, the restrictions on international travel and cancellations of conferences and trade fairs also made it much more difficult to make new business deals. These findings are echoed in similar industry consultations in Canada and France ((Satellite Canada, 2020[37]; CNES, 2020[38]).

Overall, evidence from this growing number of industry surveys and consultations in several OECD countries suggest that SMEs and entrepreneurs in the space sector may still be falling between the cracks of available government measures.

- All actors are concerned about the long-term impacts of the COVID-19 crisis on funding for government programmes and procurement, as this directly and indirectly supports and attracts an increasingly complex ecosystem of contractors, subcontractors, start-ups and private investors.
- SMEs have often problems identifying and navigating appropriate support programmes, finding them hard to understand.
- Eligibility is a problem for some actors. High collateral requirements remain a hurdle in several cases, and start-ups backed by venture capital firms often do not qualify for support.
- Procurement agency administrative processes are considered to be too slow to be effective.

In the OECD Space Forum survey circulated to space sector stakeholders in September 2020, public sector respondents reported that in response to the demands of industry actors (not only small firms), they had reacted rather quickly by promoting simplified and shortened administrative procedures, adapting eligibility criteria, and accelerated and advanced payments (Figure 2.4). Some of these practices are likely to continue after the crisis.

Figure 2.4. Changes in agency procedures following the COVID-19 crisis



Note: Targeted survey conducted by the OECD Space Forum in September/October 2020. 25 organisations responded to the survey, 68% from public sector and 32 % from the private sector.

Improving management of contracts and risk

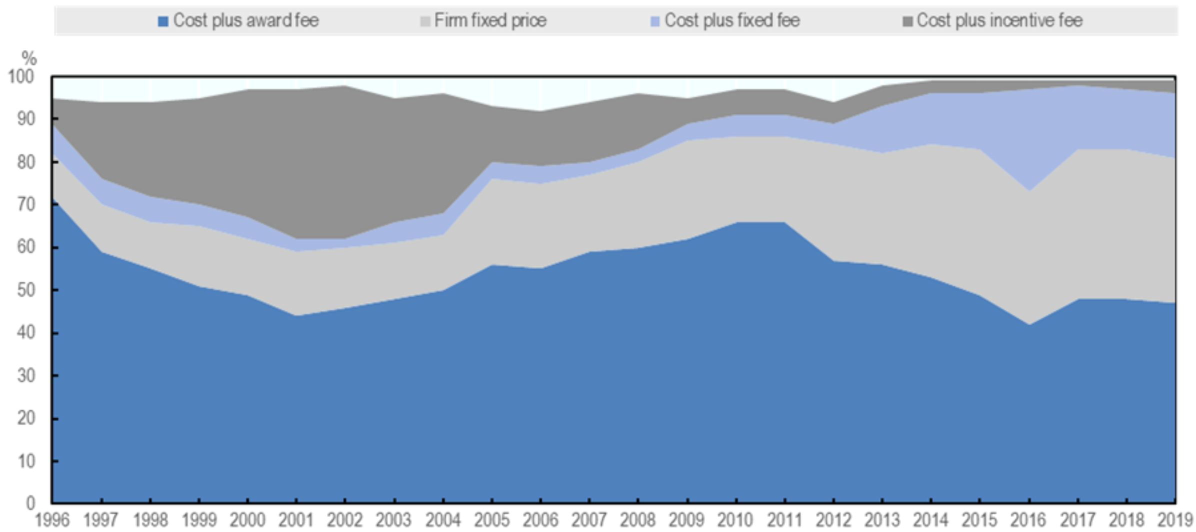
While easing contractual requirements vis-à-vis start-ups, space agencies are also making efforts to improve the management of risks, budgets and schedules of larger government missions (e.g. science), which generally rely on traditional procurement mechanisms. The Japan Aerospace Exploration Agency

(JAXA) has recently restructured its procurement and programme control mechanisms, after malfunctions in the recent ASTRO-H mission, with an increased use of firm fixed-price contracts. Departing from the traditional approach where the contractor was in charge of the whole design, test and manufacturing phases of the project, JAXA now performs initial R&D studies to assess the risks of the project and the contractor is in charge of the final manufacturing. ESA is also working in this direction, with an increased focus on adapting the procurement approach (phasing and price type) to the risk of the project (e.g. 'instrument first').

At NASA, there is a marked increase in the use of "fixed price" contracts, although different types of "cost-plus" contracts remain dominant (Figure 2.5). Cost-plus contracts cover the payment of allowed expenses *plus* an additional negotiated amount, sometimes representing the only source of profit for the contractor (GAO, 2007[39]).

Figure 2.5. Trends in NASA awards to business firms by contract type

Share of procurement dollars awarded to business firms



Source: NASA (2019[24]), *Annual Procurement Report: Fiscal Year 2019* and reports from previous years.

Cost-plus-award contracts, with award fees sometimes reaching 10% of the contract value, have been widely used by US agencies to procure non-routine services such as the development of new systems, but NASA has been criticised for not linking awards to contractor performance and project outcomes (GAO, 2007[39]; NASA OIG, 2013[40]). In contrast, fixed price contracts transfer more risks the contractor. In 2019, fixed price contracts accounted for 34% of NASA's total procurement dollars awarded to business firms (NASA, 2019[24]).

More outsourcing and service buys

Around the world, public agencies are gradually transferring activities and tasks to the private sector. An increasing share of government-funded R&D is performed in the private sector. Private actors are also increasingly involved in the production and, in some cases, product development, as space agencies turn their focus to other higher-risk, public-good missions such as science and exploration. In the early 2000s, some 35% of NASA's total R&D budget was performed by industry contractors, a share that had increased to 61% in 2019 (NCSES, 2020[41]).

In China, where the space sector is dominated by state-owned enterprises, private capital was allowed to enter the aerospace field in 2014 and the State Council encouraged the development of commercial space in the 2016 China Aerospace White Paper (Zhang, 2018[42]). In Korea, the Third Master Plan for Promotion of Space Development stipulates the gradual transformation of satellite and payload system projects to industry-led manufacturing systems, starting with three next-generation medium-size satellites for space science, resource management and environmental monitoring (Government of Korea, 2018[43]). The Indian Space Research Organisation (ISRO) is in a similar process, outsourcing the production of their polar small launch vehicle (PSLV) and satellites to private manufacturers (ISRO, 2019[44]).

In more mature industry segments, there is also a move towards service buys, where public organisations buy services from private operators without having to be concerned with building and operating the infrastructure. This has been common in satellite communications and earth observation (particularly military remote sensing), but there are fewer examples in other space applications. The United States is so far the only country with concrete examples of such practices in space transportation and exploration, meteorology and space exploration.

Table 2.3. Selected examples of US service buy programmes

Industry segment	Programme	Agency)	Description
Earth observation/ (meteorology)	Commercial Weather Data Pilot (CWDP)	NOAA	Programme testing the quality and use of commercial weather data
Space transportation	Commercial Orbital Transportation Services (COTS)	NASA	Transportation of cargo to the International Space Station
Space exploration	Commercial Lunar Payload Services (CLPS)	NASA	Moon landers that will carry NASA-provided payloads to conduct science investigations and demonstrate advanced technologies on the lunar surface

The most prominent example is perhaps the NASA commercial resupply services programme for transporting cargo to the International Space Station. Three firms, SpaceX, Orbital (Northrop Grumman) and Sierra Nevada have been awarded contracts for the 2019-24 period, with a total maximum contract value of USD 14 billion. In weather observations, the US National Oceanic and Atmospheric Administration (NOAA), has conducted a series of pilot programmes testing the quality and use of commercial weather data (the Commercial Weather Data Pilot CWDP). Even in space exploration, NASA envisages service contracts for the implementation of the different elements of its 2018-30 Exploration Campaign, which targets low-earth orbit (LEO) development and lunar and Mars exploration. More specifically, the agency plans to enlist commercial robotic lunar payload service contracts for surface delivery. Service contracts are also under consideration for the mid-to-large (500-1 000 kg) lunar lander (Tawney, 2018[45]). These contracts have in several cases been preceded by commercial pre-procurement and public-private partnerships.

In 2020, the European Space Agency signed a service contract with the Swiss company ClearSpace, to remove the upper part of a Vega secondary payload adapter (used to deliver multiple satellites to different orbits, once launched into space) in 2025. This end-to-end service contract is a move away from more ESA's more traditional agency-led procurement practices (ESA, 2020[46]).

3. Models for partnering with the private sector

As technologies and markets mature, different types of partnerships with the private sector are becoming increasingly common in most space-faring countries, although the scope varies significantly. This section reviews different approaches that governments have taken to partnering with private actors, beyond acting as a customer, and discusses lessons learned from these practices over the last two decades. The models range from partnering in R&D co-funding, to developing public-private partnerships to deliver a public asset or a service, or to shared use of space infrastructure (via "condominium" models and hosted payloads) (Table 3.1). The section ends with some recommendations on these models.

Table 3.1. Selected instruments for partnering with the private sector

Model	Key features	Selected examples
Partnering in R&D co-funding (section 3.1)	Various types of collaborative R&D carried out jointly and co-financed by public and private partners to develop a highly innovative product and/or to enhance the technological capabilities of the private partners.	ESA ARTES/Airbus European Data Relay System; Italian Space Agency/ Thales Alenia Space/Telespazio: Ital-GovSatCom, NASA/MadeInSpace: ISS Additive Manufacturing Facility
Public-private partnership (PPP) (section 3.2)	PPPs designed to deliver a public asset or a service, with models such as 'build-own-maintain', 'design-build-operate', typically employed in technologically and commercially mature segments of the space sector such as telecommunications or earth observation	Skynet 5 (UK), Arctic Satellite Broadband Mission (Norway), Radarsat-2 (Canada); Galileo concession project (Europe)
Shared use of space infrastructure (section 3.3)	The most recent models include hosted payloads and jointly-owned satellites ("condosats"). – Condominium" model: Joint ownership between public and private user, enabling the sharing of risk, market entry, etc. – Hosted payloads: The (public) utilisation of available capacity on commercial satellites to accommodate additional transponders and instruments	"Condominium" model: Monacosat, launched in 2016, jointly owned by Space Systems International (SSI) and Turkmenistan Hosted payloads: US Air Force CHIRP mission (remote sensing) and European Union's EGNOS (air traffic monitoring)

3.1. Partnering in R&D co-funding

Over the last two decades, the relationship between public and private actors has started to evolve, with the private sector sharing more of the development costs and taking on more risk and responsibilities. The main motivation from the government side is generally to increase value for taxpayers' money, but beyond the need to save costs, governments increasingly use these partnerships to "jumpstart" commercial activities to test and transfer technologies to the private sector (e.g. earth observation, in-orbit servicing). In the current economic situation, these arrangements are expected to multiply.

Several space agencies have recently engaged in what they refer to as R&D "partnerships". Sometimes also called "public-private partnerships", these projects actually correspond to various types of collaborative R&D, carried out jointly and co-financed by public and private partners (Table 3.2). A distinction is made in this paper between these arrangements and classic public-private partnerships

(PPPs) designed to deliver a public asset or a service, based on wider-reaching agreements and stretching to the operational phase (see next section on PPPs).

Table 3.2. Selected R&D partnerships in the space sector

Application	Collaborative R&D	Contract passed	Country/ region
Satellite telecommunications	Italian Space Agency/Thales Alenia Space/Telespazio: Ital-GovSatCom	2019	Italy
	ESA ARTES/Airbus: European Data Relay System	2011	Europe
	ESA ARTES/Avanti: Hylas-1 and Hylas-3	2006	Europe
	ESA ARTES/Imarsat: Alphasat	2007	Europe
	ESA ARTES/Hispasat: SmallGEO	2007	Europe
SAT-AIS	ESA ARTES /exactEARTH/ LuxSpace: ESAIL	2014	Europe
Deep space mining	Luxembourg government/Deep Space Industries	Failure, private party business failure	Luxembourg
Access to space	NASA: COTS	2005	United States
	DARPA: Experimental Spaceplane	2013. Failure, private party withdrawal	United States
	European Space Agency/ ArianeGroup: Ariane 6	2014	Europe
In-orbit servicing	DARPA/SSL: RSGS (GEO)	2016. Failure, new project underway	United States
	NASA/SSL: RESTORE-L (LEO)	2016	United States
In-orbit debris removal	JAXA/Astroscale	2020	Japan
Exploration	NASA/multiple partners: NextSTEP	Since 2015	United States
In-space manufacturing	NASA/MadeInSpace: ISS Additive Manufacturing Facility	Since 2016	United States
Space manufacturing	Indian Space Research Organisation (ISRO, /industry consortia: Satellite assembly, integration and testing	Since 2019	India

The objective of R&D partnerships may be to develop a highly innovative product and/or to enhance the technological capabilities of the private partners. The OECD distinguishes four types, based on the purpose and corresponding to main innovation policy measures (OECD, 2005[47]):

- Mission-oriented partnerships, corresponding to more cost-efficient direct R&D public procurement (steered towards government priority areas, such as science or defence);
- Market-oriented partnerships, corresponding to subsidisation of business R&D (supporting commercial applications);
- Industry-science-relation-oriented partnerships, corresponding to public execution of R&D; and
- Cluster or network-oriented partnerships, corresponding to infrastructural support to business R&D (e.g. PPPs for satellite assembly developed by the Indian Space Research Organisation).

There are several examples of mission- and market-oriented partnerships in the space sector.

Mission-oriented partnerships

Mission-oriented partnerships support government prerogatives and priority areas that were previously fully funded through public procurement (OECD, 2005[47]). The use of partnerships ideally produces value for taxpayers' money and more innovative products. Mission-oriented partnerships in the space sector support government missions such as exploration, space debris removal and military communications.

In the United States, NASA has several partnership programmes supporting government missions. The most prominent example of such partnerships is probably the NASA Commercial Orbital Transportation Services (COTS) programme, launched in 2006, which involved the development and demonstration of private sector transportation systems to low-Earth orbit. The programme saw the development of two new launch vehicles, their cargo carrier spacecraft, and the accompanying ground support systems in less than ten years. An important source of motivation for private sector participation in the COTS programme was the future possibility of being awarded International Space Station resupply contracts, , as described in section 2.2. Indeed, after the finalisation of COTS, NASA ordered eight flights valued at about USD 1.9 billion from Orbital and 12 flights valued at about USD 1.6 billion from SpaceX (NASA, 2008[48])).

Other US examples include the NEXTStep programme, in operation since 2015, which support the commercial development of selected capabilities in human space exploration (e.g. habitat systems, in-situ resource utilisation), with a 30% industry co-investment requirement and 2016-17 contract value of USD 65 million (NASA, 2016[49]). More recently, the fifth solicitation of NASA's "Tipping Point" programme awards contracts for technology demonstrations that will facilitate future lunar missions and commercial space capabilities. The combined contract value surpasses USD 370 million and the required industry contribution is 25% (NASA, 2020[50]).

There are also mission-oriented projects in other countries. In 2020, Japan announced the first-ever partnership for active debris removal. The first phase of the project involves the development of a spacecraft to demonstrate key technologies for rendezvous and proximity operations relative to non-cooperative targets. Japan's space agency, JAXA, will provide technical support in the form of research and development results, technical advice, and test facilities, while the private partner, Astroscale, will manufacture, launch and operate the spacecraft, with the launched planned for 2022 (JAXA, 2020[51]). In Europe, the PACIS projects develop secure mission control systems and operations centres for the future GOVSATCOM programme of the European Union.

Market-oriented partnerships

Market-oriented partnerships for innovation subsidise business R&D to support the development of commercial products and services. These arrangements are similar to traditional R&D business grants, but generally stipulate a greater transfer of risks to the private partner. In Europe, the majority of these partnerships aim to develop commercial applications, particularly in satellite telecommunications. The European Space Agency's Advanced Research in Telecommunications Systems (ARTES) programme has supported several partnerships for innovation, such as the European Data Relay System, Alphasat and smallGEO. Depending on the partner involved, co-sharing requirements can reach 50%. As part of Italy's Space Economy Strategic Plan, the country will introduce national mirror programmes for the European Union programmes Copernicus, Galileo (and, possible in the future, also GOVSATCOM), to develop technological capabilities and increase the competitiveness of Italian firms (Bartoloni, 2018[52]). In 2019, the country launched its first project, the satellite Ital-GovSatCom, a 50-50 partnership with a consortium of domestic firms, for secure telecommunications that can be used in different government missions and operations (ASI, 2019[53]).

In the United States, both NASA and the Defense Advanced Research Projects Agency (DARPA) have entered into partnerships with the private sector to develop commercial capabilities in on-orbit servicing (in both the geostationary and low-earth orbit), and also in small payloads transportation. These partnerships have sometimes faced difficulties, linked in part to the major technical challenges associated with developing new capabilities. In May 2017, Boeing won the bid for developing a prototype for the DARPA Experimental Spaceplane, a fully reusable, unmanned, vertical launch-horizontal landing, hypersonic aircraft. The partnership arrangement covered design, construction, testing and 12-15 flight tests, with the aim to fly ten times in ten days, scheduled for 2020 (DARPA, 2017[54]). Both DARPA and Boeing invested in the project, with DARPA providing up to USD 146 million, while Boeing's investments were not disclosed. In 2020, Boeing announced that they withdrew from the programme (Foust, 2020[55]). In 2019, Maxar (previously Space Systems/Loral or SSL) withdrew from the satellite-servicing partnership in the geostationary orbit. DARPA established a new partnership with Space Logistics in 2020. In this new deal, DARPA will provide the dexterous robotic payload. Space Logistics will provide the spacecraft bus, integrate the resulting robotic servicing spacecraft with the launch vehicle and provide the launch, as well as operations for the full mission duration (DARPA, 2020[56]).

Luxembourg's experience with partnerships in deep space mining illustrates some of the inherent challenges of involvement in leading-edge technologies. In 2016, the Luxembourg government, the newly-established company Deep Space Industries, and the national banking institution Société Nationale de Crédit et d'Investissement (SNCI), signed an agreement to explore, use, and commercialise space resources as part of Luxembourg's spaceresources.lu initiative. The initial commitment of the Luxembourg government amounted to approximately EUR 200 million, to cover R&D investments and company equity purchases (De Selding, 2016[57]). In the following years, deep space mining lost a bit of momentum, and Deep Space Industries was purchased by Bradford Industries in 2019. This firm entered into a new agreement with the Luxembourg Space Agency to develop critical low-cost spacecraft subsystems for deep space and earth-orbit missions (Luxembourg Space Agency, 2019[58]).

3.2. Partnering via public-private partnerships to deliver a public asset or a service

The OECD defines public private-partnerships (PPPs) as "long term agreements between the government and a private partner whereby the private partner delivers and funds public services using a capital asset, sharing the associated risks" (OECD, 2012[59]). This refers to PPPs designed to deliver a public asset or a service, with models such as "build-own-maintain", "design-build-operate", etc., typically employed in technologically and commercially mature segments of the space sector such as telecommunications or earth observation. These PPPs are inspired by decades of experience in ground infrastructure and utilities (roads, energy…), there are numerous examples of PPPs in military satellite communications, earth observation and one prominent failed PPP in satellite navigation (Galileo).

Table 3.3 provides an overview of selected public-private partnerships from the last two decades, showing a great variety in applications and scope. Case studies of several of these PPPs in telecommunications, earth observation and satellite positioning, navigation and timing are described below.

Table 3.3. Selected public-private partnerships in the space sector

Application	Infrastructure PPPs (system development and operations)	Contract passed	Country/ region
Satellite telecommunications	Ministry of Defence/Paradigm: Skynet 5	2003	United Kingdom
	Ministry of Defence/Telespazio: Sicral 1B and Sicral 2	2006	Italy
	German Armed Forces/MilSat Services: SatcomBw Stage 2	2006	Germany
	Norway/Inmarsat/US Department of Defense: Arctic Satellite Broadband Mission (ASBM)	2019	Norway
Earth observation	NGA/GeoEye and DigitalGlobe: Enhanced View	2010	United Kingdom
	Canadian Space Agency/MDA: Radarsat-2	1998	Canada
	DLR/Airbus: TerraSAR-X/TanDEM-X	2006	Germany
GNSS	European Commission/Eurely/iNavSat consortium: Galileo	1999-2007. Failed to reach agreement	Europe

PPPs in satellite telecommunications

Telecommunications represent the most mature sector for space-related PPPs. Developing and running a public satellite communication infrastructure remains expensive (satellite, launch and operations) with a long operational phase (typically 10-15 years), thus creating strong public incentives for cost-sharing (Venet and Nardon, 2011[60]). There are already well-established institutional and commercial markets for satcom services, which can attract private investors and a healthy number of private actors to ensure competition. It is therefore no surprise that it is in this sector that one can find examples of some of the largest and most successful space-related PPPs.

There are several examples of traditional infrastructure PPPs in the area of military satcom operations, including Skynet (UK), SatComBw (Germany) and Sicral 1-B, Sicral 2 (Italy). Of these, the PPP scheme for the development and operation of the UK Skynet constellation is by far the biggest and most complex. An interesting PPP underway is the Arctic Satellite Broadband Mission, which involves multiple Norwegian government actors, as well as Inmarsat and the US Department of Defense. These two projects are further elaborated below.

Skynet 5 (United Kingdom): In 2003, the UK Ministry of Defence signed a Private Finance Initiative (PFI) with the EADS subsidiary Paradigm Secure Communications (Airbus), at a forecasted cost of GBP 2.8 billion (UK National Audit Office, 2006[61]). This would cover the provision of next-generation satellite communication services (Skynet 5) to the UK Armed Forces for military operations and welfare communications (i.e. telephone calls, texts and e-mails to families of personnel). In exchange, Paradigm was guaranteed an annual income of some GBP 200 million until 2018 (later extended to 2022) and could sell spare satellite capacity to other customers (i.e. NATO members). The contract was restructured two years after the original deal, due to concerns about insufficient market capacity for space insurance. Airbus agreed to provide of a third satellite acting as physical insurance. At the same time, the duration of the contract was extended to 2022 and the total cost of the project increased by GBP 0.9 billion to a total forecasted cost of GBP 3.6 billion (UK National Audit Office, 2006[61]). Then, in 2012, Airbus added a fourth satellite to guarantee service delivery and increase excess capacity.

The project has been deemed successful at least from a private partner point of view. However, it has been argued that the outsourcing of operations to Paradigm in 2003 has undermined the technical expertise in the UK Ministry of Defence. Some government stakeholders maintain that fifteen years down the road, the Ministry has had difficulties in adequately preparing and formulating the contract requirements for Skynet 6 (Chuter, 2017[62]). For the extension of the Skynet fleet, the Ministry of Defence has reverted to traditional procurement. After two years of negotiations, the UK Ministry of Defence signed a GBP 500 million contract in 2019 with Airbus Defence and Space for the satellite Skynet 6A, which is planned for launch in 2025 (Airbus, 2020[63]).

Arctic Satellite Broad Mission (Norway): The PPP between the Norwegian government and Inmarsat, signed in 2019, aims to provide mobile broadband to the Arctic region (65 degrees north and above) for the first time (Space Norway, 2019[64]). For Norway, it represents a more affordable solution to provide connectivity to Norwegian civil and military operations than to build a public system, and the scheme allows Inmarsat to extend its Global Xpress Ka-band connectivity service beyond 75 degrees north, making it the first commercial provider of wideband connectivity (Iridium already provides narrowband services in the region) (Inmarsat, 2019[65]). The planned mission involves two satellites in high-elliptic orbit (HEO), and carries three communications payloads (two government, one commercial). One of the payloads belongs to the US Air Force. The satellite will be produced and launched by US firms (Northrop Grumman, part of Maxar) and SpaceX.

PPPs in earth observation

There are several examples of PPPs in the earth observation sector, with some successful and failed projects.

TerraSAR-X/TanDEM-X (Germany) and RADARSAT-2 (Canada): Both Canada and Germany have used PPPs to develop commercial capabilities in satellite radar imagery, notably via the TerraSAR-X/ TanDEM-X and RADARSAT-2 radar satellite missions, respectively. The two countries both shared development costs with the private partner, but chose slightly different approaches for ownership and operations. The German public partner, DLR, is responsible for the scientific use of the data, the planning and execution of the mission, the control of the two satellites and the generation of the digital elevation model. Airbus Defence and Space, the private partner, built the satellite and contributes to the development and utilisation costs (DLR, 2007[66]; Airbus Defence and Space, 2015[67]). The development of second-generation satellites, with German authorities stipulating higher private contributions, has been slowed by lower-than-expected revenues (De Selding, 2013[68]). In Canada, the private partner, MDA, got full ownership of the satellite, while providing the Canadian Space Agency with guaranteed access to data products and services worth CAD 446 million (Public Works and Government Services Canada, 2009[69]). An evaluation of the Canadian project was positive overall, but indicated that many government stakeholders regretted the limited control over the development process and lack of satellite ownership. In terms of returns on investment, it was deemed that the Canadian government paid less for the development of Radarsat-2 than they did for the previous mission, Radarsat-1, and also did not have to cover operation costs (Public Works and Government Services Canada, 2009[69]). In view of the technological risks and lessons learned from the previous Canadian PPPs, a more traditional public procurement arrangement was chosen for the next generation of Canadian radar satellites, i.e. the RADARSAT Constellation Mission (RCM) (Canadian Space Agency, 2017[70]).

EnhancedView (United States): In 2010, the US National Geospatial-Intelligence Agency (NGA) signed Service Level Agreements with two satellite operators (Digital Globe and GeoEye) worth USD 7.3 billion (EARSC, 2010[71]). The fixed-price contracts included the delivery of satellite imagery and value-added services to the US government for ten years. In the case of GeoEye, the contract also included a cost-share of USD 337 million for the development and launch of GeoEye-2 (EARSC, 2010[71]). The two companies reportedly committed more than USD 1 billion of private capital in investments to fulfil the different obligations in the programme (including in DigitalGlobe's case, the construction of WorldView-3). However, only one year into the programme, after the announcement of significant budget cuts, NGA chose not to renew its contract with one of the partners, GeoEye, making it a target for acquisition. Digital Globe purchased GeoEye in 2013.

PPPs in satellite positioning, navigation and timing

The European satellite navigation system Galileo started off as a PPP in 1999, but turned into a traditional procurement programme in 2007 and is an interesting case study for a failed public-private partnership.

The European Galileo programme was first conceived in the late 1990s, amid general market optimism and the desire of the European Commission to include private stakeholders in the process early on, motivated the choice for seeking a PPP concessions arrangement with the private sector. The original project cost estimate foresaw a total investment of EUR 3.3 billion, of which EUR 1.8 billion would be covered by the public sector partner (European Court of Auditors, 2009[72]).

The European Commission and the European Space Agency set up a dedicated structure, the Galileo Joint Undertaking (GJU), to manage the development and validation phase of the Galileo programme, which was also responsible for managing the tendering procedure. The tendering process ended with the two only competing consortia joining into a merged consortium, whose joint bid was accepted by the Galileo Joint Undertaking. In 2007, acknowledging that the concession negotiations with the merged consortium were still unresolved and that the project had a five-year delay and considerable cost overruns, the European Union Council decided to put an end to the PPP and fund the programme fully from the Community budget, with ESA as the delegated procurement agent (European Court of Auditors, 2009[72]).

The early stages of the Galileo programme has been subject to several evaluations. The evaluation of the European Court of Auditors (European Court of Auditors, 2009[72]) includes a careful analysis of the PPP. They report several shortcomings, which are summarised below:

- Inadequate preparation and conception of the PPP: The studies to select a PPP model neither evaluated the relative benefits of other PPP models nor took into account traditional public procurement models or a public sector comparator[2]. Furthermore, a realistic allocation of risk between public and private partners was not addressed in this early, preparatory stage. The GJU was understaffed and inexperienced. In addition, the bidding procedure appeared rushed, for both public and private parties, with the GJU not having enough time to define the concession approach and not allowing bidders enough time to develop a credible business plan. Initial tender documentation lacked specific objectives. As a consequence, industry bids did not contain firm pricing or commitments. When the two competing consortia merged, the competition for the market disappeared. As noted above, the initial preparations did not include an assessment of the cost of alternative arrangements.
- Inadequate PPP model: The chosen concession model was fundamentally different from other PPPs existing at the time (European Court of Auditors, 2009[72]). There were a range of issues; e.g. high technological risk (30 satellites in medium earth orbit with new components untested in space), significant uncertainty concerning monetisation (free signals of other GNSS systems); and finally, unlike traditional design-build-finance-operate PPPs, the private concession holder would have to commit itself to building, financing and operating a new system which was conceived by a public sector actor (ESA).

What slowed down and eventually ended the concession negotiations were the discussions about the transfer of risk from the public to the private sector. More concretely, this concerned the transfer of three types of risk:

- Market risk: There was a lack of private sector confidence that market revenue could be obtained in accordance with an agreed baseline market development scenario. Government was going to play an important role in market development.
- Design risk: The private sector wanted more assurance that the design (prepared by ESA) had no inherent problems that might result in a faulty or underperforming system (for which the concession holder would be responsible during operation). The division of duties between design and development (ESA), and deployment, operation and maintenance (concession holder) made a transfer of risk difficult. As a side note, in January 2017, it became known that the atomic clocks had failed on nine out of 18 Galileo satellites.
- The third-party liability regime: This referred to any potential extra-contractual liabilities towards potential victims of Galileo failures, for which no specific legal or insurance model was available.

Lessons-learned and guidance for future PPPs in the space sector

Some key findings from the different case studies are provided here, reviewing in particular public and private partners' specific responsibilities to make PPPs feasible. Building on the knowledge base in other sectors (see for instance (OECD, 2014[73]; 2008[74]), it also provides some recommendations for PPPs in the space sector.

[2] The hypothetical risk-adjusted cost of public delivery of the project.

Based on the different case studies, early and comprehensive preparation by both the public and private sectors is the key to successful public-private partnerships in the space sector. The tasks of the public and private partners described here should not be perceived as sequential; all are necessary for a successful partnership. When a project seems to be attractive enough to consider for a PPP, both public and private partners have specific responsibilities to make this PPP feasible.

Public partner responsibilities

Public partners need to invest significant resources in the preparation phases for the PPP.

- *Thoroughly evaluate the benefits of different PPP models and set up a public sector comparator, where relevant* - the PPP needs to be prepared well, and the different options and potential alternatives need to be considered. The Joint Undertaking model created for Galileo failed to evaluate the relative benefits of other PPP models or to take into account traditional public procurement models or a public sector comparator. When the negotiations failed, there were no other alternatives on which to fall back.
- *Ensure competition* – Competition is important for ensuring value-for-money and for guaranteeing continuity in the delivery of public services. Entering into non-competitive PPPs, for different reasons, can affect the success of the PPP, as in the case of Galileo. During the bidding process, the only two competitive bidders merged into one joint venture, and when the subsequent concessions negotiations stalled, the public party lacked alternatives. If there is no realistic competition, another procurement model should perhaps be considered.
- *Identify risk and transfer it to the partner best equipped to manage it* –The allocation of insurance risk was a central element in the private finance initiative (PFI) between the UK Ministry of Defence and Paradigm Secure Communications for the provision of satellite communications services for Skynet 5. Uncertainty about the health of the private space insurance market led the public party to request a renegotiation of the original contract, replacing the space insurance by a physical insurance (satellite) (UK National Audit Office, 2006[61]). Equally, the allocation of several types of risk (market risk, design risk, regulatory risk) halted the negotiations between the public and private parties in the planned PPP for Galileo in the early 2000s (European Court of Auditors, 2009[72]).
- *Clarify private investment opportunities and create incentives* – PPP preparations entail creating and constantly updating a plan for development, that early on identifies realistic private investment opportunities. The absence of private investors and venture capital can significantly limit the supply of eligible firms for a PPP. In the initial COTS programme, one of the original participants, the Kistler company, had to withdraw because it could not raise enough funds. Its technological readiness was also in question, but Kistler partially attributed its demise to a situation where NASA could not guarantee ISS cargo transportation contracts (NASA, 2016[75]).
- *The right public entity in place, with the right resources* – The public partner needs to make sure it has the appropriate expertise and resources to negotiate with the private party. In several of the case studies discussed in the previous sections (e.g. Radarsat-2, Galileo), adequate expertise and staffing of the PPP management staff was an issue. The GJU negotiating the PPP for Galileo was understaffed for most of its existence and lacked the necessary experience and expertise to negotiate with the consortium.
- *Ensure long-term stability and visibility* – partnerships that last 10-20 years will normally require large private sector investments and commitments, supplying an entire ecosystem of partners and suppliers. Furthermore, in many cases, the revenues generated in the PPP will represent a significant share of the private partner's total income, e.g. in the EnhancedView programme, NGA payments accounted for about 40% of GeoEye's annual revenues (Ananthalakshmi and Mandavia, 2012[76]). Government must ensure that it ensures long-term stability and visibility, not only to avoid private partner default but also to attract future private sector investments.

Private partner responsibilities

At the request of public agencies and administrations in the space sector, the private partner can be encouraged to submit unsolicited proposals conceptualising and designing the use of a public-private partnership.

- *Embrace transparency* - From the start, the private partner needs to be prepared for a transparent process. Any large-scale space project will attract much attention. Although parts of the process exist in which certain information is not disclosed, particularly during the competition over project bids, the PPP partner must be prepared to open itself to public scrutiny.
- *Establish market potential and build a viable business plan* – the private partner needs to identify the size of a potential market and identify all potential risks (to be carried by the private partner). Once a viable business plan is in place, it becomes easier to raise capital.
- *Establish financial feasibility* - While the public partner is establishing clear-cut goals and projects, the private partner will have to deal with its investors to explain the nature of the public-private partnership. Investors must be confident that their resources are being deployed effectively. As in all development processes, the developer must underwrite the market and determine interest.
- *Make use of available government technical expertise* – one of the findings of the Radarsat-2 evaluation was that the private partner, MDA lacked technical and engineering maturity and expertise in certain areas, and did not fully exploit the offers of assistance from the Canadian Space Agency staff. This contributed to some of the delay in implementation.

3.3. Shared use of space infrastructure

Another way of co-operating and pooling costs, is to better share and exploit existing infrastructure, and in that way extract value from surplus (public and private) capacity. The current satellite infrastructure, including both space and terrestrial networks, presents good opportunities for partnerships between public and private actors. Cost savings can result from sharing development, launch, and ground system costs with the host company. The most recent models include hosted payloads and jointly-owned satellites (“condosats”).

Hosted payloads

Hosted payloads refers to the (public) utilisation of available capacity on commercial satellites to accommodate additional transponders and instruments (Office of Space Commerce, 2020[77]). By “hitchhiking” on commercial spacecraft already scheduled for launch, government agencies can send sensors and other equipment into space on a timely and cost-effective basis, creating redundancy in case of accidents and making it more difficult for an adversary to defeat a capability (GAO, 2018[78]). This practice was explicitly promoted in the 2010 US Space Strategy, which encouraged federal agencies to “actively explore the use of inventive, non-traditional arrangements for acquiring commercial space goods and services to meet United States Government requirements, including [...] hosting government capabilities on commercial spacecraft” (United States White House, 2010[79]).

Below are selected examples of the use of hosted payloads in OECD countries, all involving commercial communications satellites. The majority of examples are in air traffic management, but there are also examples in military communications and remote sensing, science missions, vessels tracking, etc.

Table 3.4. Selected hosted payload missions

Payload	Application	Customer	Satellite operator	Launch date
WAAS	Air traffic monitoring	US Federal Aviation Administration	Telesat, Eutelsat and SES	2005, 2015 and 2017
AIS	Marine traffic monitoring	US Coast Guard	Orbcomm	2008
IRIS	Military communications	US Department of Defense	Intelsat	2009
CHIRP	Military remote sensing	US Air Force	AGS	2011
ADF UHF	Military communications	Australian Defence Forces	Intelsat	2012
EGNOS	Air traffic monitoring	European GNSS Agency	SES and Eutelsat	2012, 2014 and 2019
Aldo Paraboni	Technology demonstration, telecommunications	European Space Agency	Inmarsat	2013
GOLD	Space science (heliophysics)	US National Aeronautics and Space Administration	SES	2018
Distributed Space Weather Sensor System (D3S)	Space weather monitoring	European Space Agency	Airbus	2019
Space-based ADS-B	Air traffic monitoring	Aireon	Iridium	2019
A-DCS (Argos)	Collection and relay of meteorological and oceanographic data	US National Oceanographic Atmospheric Administration	GA-EMS	2021?
TEMPO	Air quality monitoring	NASA	Maxar	2022

Note: Only includes government payloads hosted on commercially operated spacecraft

Military applications

There are a few examples of military hosted payloads, including US, Australian and Norwegian missions. These are mainly in communications but there is also one in remote sensing (CHIRP).

- Since 2009, DOD has used three commercially hosted payloads, with three more missions planned or underway through 2022, e.g. IRIS and CHIRP missions.
- The Intelsat 22 satellite, launched in 2012, carries a communications payload for the Australian Defence Force (ADF UHF mission).
- ASBM, the Norwegian public-private partnership with Inmarsat for a high-elliptic orbit Arctic communications satellite, also hosts a payload for the US Air Force.

Air traffic management

Using global navigation satellite systems (GNSS) for air traffic management is becoming a standardised practice. The GNSS systems, such as the US Global Positioning System or the European Galileo system orbiting at an altitude of around 20 000-24 000 km, can be augmented regionally to improve the systems' accuracy, reliability and availability using other satellites which are not dedicated navigation satellites. Satellite-based augmentation systems usually require transmitters hosted on geosynchronous Earth orbit (GEO), which are located at a higher orbit of around 36 000 km.

In Europe and North America, these augmentation systems are hosted on commercial telecommunications satellites:

- The US Wide Area Augmentation System (WAAS): Transmitters are hosted on Eutelsat, SES and Telesat GEO satellites.
- European Geostationary Navigation Overlay Service (EGNOS): Transmitters are hosted on SES and Eutelsat GEO satellites.

Hosted payloads are also increasingly used to extend the reach and coverage of automatic-dependent surveillance-broadcast (ADS-B) technology, used to track air traffic in real-time. Limited to terrestrial receiver towers until recently, the first space-based ADS-B sensors were launched in 2019 on the Iridium NEXT communications satellites. The sensors are owned and operated by Aireon, a consortium of several air navigation managers (e.g. NAV CANADA, ENAV (Italy), NATS (United Kingdom) (Aireon, 2020[80]).

Scientific missions

Scientific missions are becoming increasingly diverse in their design to reduce costs and multiply observations. Hosted payloads is one of the strategies to achieve this. Two civil US agencies are making use of hosted payloads to fly instruments in different orbits:

- NASA has five commercially hosted payloads for monitoring environmental pollution, aerosol and carbon imaging, and measuring densities and temperatures in various Earth atmospheres. This includes the Global-scale Observations of the Limb and Disk (GOLD) payload flying on the SES-14 satellite. TEMPO, an air-quality measuring instrument, will be launched on a commercial Maxar satellite in 2022.
- NOAA's Argos Advanced Data Collection System (A-DCS) instrument will be hosted on the GA-EMS' technology testbed satellite. Argos is a satellite-based system, which collects, processes, and disseminates environmental data from fixed and mobile platforms.

Maritime vessel tracking

Maritime vessel tracking is benefitting from a number of technologies to allow the identification and tracking of ships at sea, contributing to avoid collision. These include in particular marine radar, used along the coastlines, and Automatic Identification Systems (AIS) on-board ships transmitting location signals at all times. The advent of satellite-AIS has revolutionised commercial intercontinental transport, with transceivers becoming compulsory on board vessels above a certain tonnage.

An early example of hosted payloads includes the AIS sensor from the US Coast Guard on an Orbcomm communications satellite launched in 2008. The AIS hosted payload was a programme sponsored by the US Coast Guard to demonstrate the reception and retransmission of AIS signals from orbit and gave Orbcomm a head start in the market for AIS data (Andraschko et al., 2011[81]).

Other technology demonstrations and space situational awareness

In recent years, the European Agency has provided instruments hosted on different satellites for technology demonstration and space situational awareness:

- The Inmarsat Alphasat satellite, launched 2013 carries four technology demonstrations developed through ESA Advanced Research in Telecommunications Systems programme (i.e. particularly the Aldo Paraboni, high-frequency Q/V-band communications payload).
- As part of its Space Situational Awareness programme, the European Space Agency is using hosted payloads schemes for the establishment of a Distributed Space Weather Sensor System (D3S). A radiation monitor is for example hosted on the Airbus-operated European Data Relay satellite EDRS-C, launched in 2019.

Joint satellite ownership

Often confounded with hosted payloads, this model involves joint ownership of a satellite, in order to save costs and/or gain access to new markets by partnering with the local country (Oberst, 2015[82]). It is mainly used in telecommunications and most commonly between two commercial operators, but there are also examples of public-private agreements (Table 3.5).

Table 3.5. Selected public/private "condosats"

Satellite	Company	Launch
ST-1 and ST-2	SingTel / Chunghwa Telecom (Chinese Taipei)	1998 and 2011
OPTUS C1	AUSSAT (Singtel) commercial and government payloads	2003
Azersat 1 / Africasat-1A	Azercosmos, operating under Azerbaijan's Ministry of Communications / Measat	2013
Eutelsat 25B / Eshail 1	Es'Hail (Qatar) /Eutelsat	2013
MonacoSat / TurkmenSpace	SSI-Monaco / NSSC (Turkmenistan)	2015

Source: Based on Oberst (2015[82]), "Models of ownership: Condominium and hosted payload satellites".

Preliminary lessons learned on hosted payloads

Shared infrastructure solutions bring benefits to both the public and private partners. For the satellite owner, hosted payloads is an opportunity to compensate for some of the high upfront costs of the satellite. The public partner not only saves money by not developing a dedicated satellite, but also time. Hosted payload programmes last about 3-4 years from concept to launch, compared to 5-10 years for government projects (Andraschko et al., 2011[81]). The US Department of Defense estimates that it has saved "several hundred" million dollars from using commercially hosted payloads (GAO, 2018[78]).

Still, hosted payloads remain uncommon, mainly due to some resistance on the government side (Andraschko et al., 2011[81]; GAO, 2018[78]). For instance, commercial projects advance at a quick pace, which may force government agencies to adapt their procedures to meet all the requirements in terms of quality and mission assurance. There may also be cybersecurity concerns (Werner, 2019[83]). Finally, it can also be a challenge to marry the location and coverage area of the host satellite with the mission requirements of the hosted payload. Many of the same challenges are valid also for condosat arrangements.

With the costs of access to space falling, some alternatives such as using smaller and cheaper satellites with a more timely access to orbit, could be anticipated for selected missions, but hosted payloads have already brought concrete benefits.

3.4. Key considerations for partnering with the private sector

Partnering with the private sector can be beneficial for government actors, contributing to commercialising public R&D in some cases, and saving time and costs. Nevertheless, for the partnerships to be successful, careful preparations and consideration of all viable alternatives are important. This is especially the case in the space sector, where government procurement plays such an important role and commercial markets remain immature for many industry segments.

The following points, adapted from OECD public-private partnership "pre-test questions" (Burger and Hawkesworth, 2011[84]) cover the most important issues that need to be answered before deciding upon a partnership model, especially as concerns the treatment of risk and competition:

- Can risks be defined, identified and measured? If not, there is room for conflict in the contract if the risk materialises, or the private partner might be unwilling to take on this risk.
- Can the right type of risk be transferred to the private sector (e.g. penalties of late delivery)? If only one type of risk is transferred (e.g. construction and delivery of an asset, but not the operational risks), then it may not make much sense to create a PPP. Endogenous risks (risks that the private partner can manage) need to be transferred to the private sector. If also exogenous risks are

transferred (risks that can be managed by the government partner or not at all), then the private partner needs to be compensated.

- Is the size of the risk large enough to serve as an incentive towards value for money? If there is only a small difference between actual and expected costs and revenues, then this may not justify the creation of a PPP.
- How much competition is there for the market? If there is not enough competition in the bidding phase, a PPP may not be the best option.
- How much competition is there in the market? If competition and contestability during the operation phase do not exist, a PPP might not be the best option as it will probably not deliver better value for money.
- How large are the benefits from combining the construction phase and the operating phase of the project in a whole-of-life contract? If there is only a limited scope for future cost savings, then a PPP may not be the best option.
- Can the quality and quantity of service output that the private partner must deliver be clearly measured in order to deal with possible cost and quality trade-offs? Future cost reductions may in some cases lead to a decrease in quality. Profitability, not quality, is generally the primary objective of private partner, so the quality (or quantity) of future output needs to be clearly defined, quantified, measured and linked to the payment of the service, to prevent a reduction in the quality of service.
- How much innovation is required? Sometimes the government chooses to leave the product design to the private sector in a PPP, if the public sector cannot specify the design itself, or if it cannot specify it in a cost-efficient way. If the government can clearly specify the design and the quality of the asset ex ante (but not the quality of the output), then traditional procurement may be more appropriate.
- What is the availability in the public sector of the skills needed to operate the asset? A PPP is a better option if the government does not have the required skills to construct and operate the project. However, it still needs skilled staff to monitor the private partner and manage its own responsibilities and risk.
- How rapidly and significantly does the technology needed for the project change? One should be careful about using PPP contracts in projects where the technology involved is subject to frequent and significant change, especially when considering that a typical PPP contract lasts 25-30 years. Changes in technology can affect the nature of the asset, both during both construction and operation phases, and influence customer preferences, thus generating both supply-side, redundancy and demand-side risks.
- How much flexibility does the government want to change the output specifications of the service to be delivered? The flexibility of the contract affects the allocation of risk; a rigid contract transfers more risk to the government whereas in a more flexible arrangement, more risk is carried by the private partner.

4. Ways forward in the post-COVID-19 era?

Governments and space agencies have the opportunity to steer the space sector safely through the aftermath of the COVID-19 crisis, sustaining innovation and sector growth, by easing the development of certain win-win approaches and adapted procurement practices.

As the private sector matures and diversifies, government agencies are developing a wider set of tools to interact with these actors and enable economic growth. This paper takes a first step in mapping these practices, whereby governments take on different roles:

- Government as a developer, where public agencies play the key role in funding, developing and supervising entire space missions. This approach is common for strategic and/or mission-oriented programmes (e.g. defence, science).
- Government as a customer, where public agencies purchase readily available products and services from a mature private market. Commercial market support and development becomes a key priority, in order to ensure value for taxpayers' money.
- Government as a partner, where public agencies act as partners in joint projects with the private sector, sharing funding and transferring risks.

In order to learn from good practices and more robustly underpin future policy interventions, governments may consider some of the following policy options, which are based on key findings in this paper and further ongoing analytical work by the OECD.

4.1. Employing the full range of procurement mechanisms and instruments

Government agencies have a broad range of procurement mechanisms and instruments at their disposal to make use of private sector capabilities and commercial interests.

- With revamped public procurement practices and more service buys, new partnerships are being set up with the space industry throughout OECD countries. Space agencies and other procurement agencies will need to have adequate and sustained skills and resources to negotiate contracts and carry out oversight.
- Although risk-sharing practices with the private sector are likely to become more common, some areas will remain reserved for traditional public procurement. It is part of the strategic work of space agencies to distinguish "core" activities from those that can be carried out by the private sector alone, or in partnership with the public sector.
- As the space ecosystem grows bigger and more diverse, space agencies and administrations need to identify and consider the complementary strengths of big and small actors and design policy instruments that address the different needs of these actors, clarifying issues such as asymmetric relationships in collaborative projects, intellectual property rights, etc.

- Agencies need to consider the impact of their policies on the incentives of other space actors. Privately funded projects are generally much easier to finance when there is an anchor customer assuring a secure line of revenues.

4.2. Keeping up innovation and entrepreneurship during the crisis

As noted in sections 1.3 and 2.2 , the long-term impacts of COVID-19 could be severe for a range of public STI missions, including space activities. Furthermore, judging from previous crises, business R&D investments are likely to be reduced, and smaller firms and start-ups may have a harder time recovering than larger incumbents (OECD, 2020[18]; 2020[19]; 2020[20]). To address these issues and ensure continued innovation, government organisations are encouraged to:

- Simplify agency funding practices, to facilitate the participation of smaller actors. Long-established and sometimes cumbersome government practices are paradoxically not the only obstacle to procurement changes and reform. The private sector itself is sometimes resistant to administrative change, especially large incumbents.
- Some of the most innovative actors in the space industry (e.g. start-ups and small and medium-sized enterprises) are also the ones most vulnerable to economic shocks. Their needs need to be specifically addressed in policy considerations (e.g. limited cash flow, supply chains issues).
- Provide long-term visibility of the status and funding levels of space programmes, enabling firms to retain needed skilled staff and reassure their investors. The role of governments and government funding remains fundamental for the development of the space sector.
- Reinforce existing measures such as business incubation centres and product testing and demonstration schemes, addressing particularly the needs of SMEs and entrepreneurs.
- Save and share costs where possible. The coming years may be difficult for both public and private actors. Space organisations are encouraged to actively seek out mutually beneficial arrangements, including collaborative R&D, hosted payloads and public-private partnerships.

4.3. Enabling long-term, sustainable growth

The use of outer space has intensified over the last two decades, producing new opportunities for both government missions and economic growth. This brings with it additional challenges of managing the outer space environment and resources and other externalities associated with space activities, and creating framework conditions that attract private investments and new actors. Governments could consider some of the following policy actions:

- Create predictable and flexible regulatory frameworks. This is particularly important for supporting emerging commercial activities, e.g. in the low earth orbit (commercial spaceports, in-orbit servicing, debris removal, etc.).
- Consider the positive and negative effects of government policies and programmes in existing and emerging commercial markets, such as the free release of data from government missions competing with proprietary private data, or public-private partnerships co-existing with privately funded ventures. As governments enter into more partnerships and more pro-actively support entrepreneurship in the space sector, these effects to be carefully considered and accounted for.
- Reinforce programme management and data collection efforts, to reliably measure and evaluate outcomes. The use of standard methodologies and indicators, that ensure comparability across sectors and over time, is likely to strengthen the credibility of results vis-à-vis decision makers.

- With the rise in the number of launches and size of satellite constellations, there are growing concerns about the stability of the orbital environment, see for instance (Undseth, Jolly and Olivari, 2020[85]). Government programmes can address these issues through targeted R&D programmes, procurement and partnerships.

Annex A. Selected case studies of public-private partnerships in the space sector

Over the years, the amount of government sector experience with PPPs has increased considerably, as has the evidence-base for policy analysis and evaluation. This paper presents a selection of case studies to identify valuable lessons learned and potential policy implications that can be useful for exploring public-private collaboration modes for future space activities.

As the following sections will show, the number and relative success of PPPs vary considerably across industry segments, depending to a large extent on the maturity of the industry in question (e.g. maturity in technology, number of active firms, availability of a commercial market). But it is important not to ignore the role of the government actor in carefully preparing the PPP process and creating incentives for private sector participation and third-party financing in high-risk ventures (e.g. assuming role of anchor customer role).

Telecommunications

Telecommunications represent the most mature sector for space-related PPPs. Public satcom infrastructure remains expensive (satellite, launch and operations) with a long operational phase (typically 10-15 years), creating strong public incentives for cost-sharing. There are also established institutional and commercial markets for satcom services, which can attract private partners. Finally, there are a healthy number of private actors to ensure competition (Venet and Nardon, 2011[60]). It is therefore no surprise that it is in this sector one can find examples of some of the largest and most successful space-related PPPs.

There are several examples of traditional infrastructure PPPs in the area of military satcom operations. Examples include Skynet (UK), SatComBw (Germany) and Sicral 1-B, Sicral 2 (Italy). Of these, the PPP managing the development and operation of the UK Skynet constellation is by far the biggest and most complex. An interesting PPP underway is the Arctic Satellite Broadband Mission, which involves multiple Norwegian government actors, as well as Inmarsat and the US Department of Defense. These two projects are further elaborated below.

The European Space Agency ARTES programme has also supported several PPPs for innovation (e.g. the European Data Relay System, Alphasat, smallGEO), involving the public-private co-funding and co-development of commercial satcom projects.

Table A A.1. Skynet 5, United Kingdom

Mission description	Partners	Responsibilities	Benefits	Outcomes
Two GEO satellites, later extended to four, providing communications services for military operations and welfare operations. Mission life and govt. costs: 2003-22 (GBP 3.6 billion)	UK Ministry of Defence	Guarantee annual payment of GBP 200 million for mission duration.	Reduced costs and use of public human resources	Project considered successful from private point of view. Model has not been reproduced for mission upgrade.
	Paradigm Secure Communications (Airbus Defence and Space)	Design, build, launch and operate satellites until end-of-life in 2022; upgrade and support ground infrastructure; supply new remote terminals	Guaranteed long-term income. Able to sell spare capacity to other customers	

Source: UK National Audit Office (2006[61]), Ministry of Defence: *Major Projects Report 2006*, https://www.nao.org.uk/wp-content/uploads/2006/11/060723i.pdf and (Amos, 2010[86]).

The contract was restructured two years after the original deal, due to concerns about insufficient market capacity for space insurance. Airbus agreed to provide of a third satellite acting as physical insurance. At the same time the duration of the contract was extended to 2022 and the total cost of the project increased by GBP 0.9 billion to a total forecasted cost of GBP 3.6 billion (UK National Audit Office, 2006[61]). Then, in 2012, Airbus added Airbus added a fourth satellite to guarantee service delivery and increase excess capacity.

The project has been deemed successful at least from a private partner point of view. However, it has been argued that the outsourcing of operations to Paradigm in 2003 has undermined the technical expertise in the UK Ministry of Defence. Some government stakeholders maintain that fifteen years down the road, the Ministry has had difficulties in adequately preparing and formulating the contract requirements for Skynet 6 and this growing lack of expertise on the public side could make future PPPs less successful.

For the extension of the Skynet fleet, the Ministry of Defence has reverted to traditional procurement. After two years of negotiations, the UK Ministry of Defence signed a GBP 500 million contract in 2019 with Airbus Defence and Space for the satellite Skynet 6A, which is planned for launch in 2025.

Table A A.2. Arctic Satellite Broadband Mission, Norway

Mission description	Partners	Responsibilities	Benefits	Outcomes
Two satellites in high-elliptic orbit (HEO), carrying three communications payloads (two government, one commercial). This would represent the first-time provision of mobile broadband to the Arctic region (65 degrees north and above) Mission life:15 years with launch in late 2022, Govt. costs: Not disclosed	Norwegian Ministry of Defence and Space Norway	Purchase and operate satellites	Represents a more affordable solution to provide connectivity to Norwegian civil and military operations	n.a. Satellite launch late 2022.
	Inmarsat	Lease commercial transponder during mission life	Extends its Global Xpress Ka-band connectivity service beyond 75 degrees north	
	US Air Force (hosted payload)		Payloads parts of Enhanced Polar System-Recapitalization (EPS-R) system providing secure anti-jamming communications for war fighters	

The agreement brings benefits for all partners. For Norway and the United States, ASBM is a more affordable solution than stand-alone satellites. Inmarsat will be able to extend its Global Xpress Ka-band connectivity service beyond 75 degrees north, making it the first and only commercial provider of wideband connectivity (Iridium already provides narrowband services in the region). The satellite will be produced and launched by US firms (Northrop Grumman, part of Maxar) and SpaceX.

Earth observations

There are several examples of PPPs in the Earth observation sector. The case studies include two successful and one failed PPP, including the development of radar satellite missions for Germany and Canada (TerraSAR-X/TanDEM-X and Radarsat-2, respectively) and the US EnhancedView programme of the National Geospatial Intelligence Agency.

Table A A.3. TerraSAR-X/TanDEM-X, Germany

Mission description	Partners	Responsibilities	Benefits	Outcomes
High-definition radar imagery satellites for digital elevation models Mission life: 11 years with launch in 2007 (TerraSAR-X) and 2010 (TanDEM-X) Govt. costs: EUR 147 million, 80% (TerraSAR-X) and EUR 85 million, 70% (TanDEM-X)	German Aerospace Centre (DLR)	Shared satellite development costs, respectively; development of the ground segment and first five years of operation. Government retains ownership of the satellites	Cost savings on development and operation costs.	Lengthy preparation process. Has contributed to developing a more competitive earth observation industry in Germany.
	Airbus Space and Defence	Shared satellite development costs, operation costs after first five years	Cost savings on development and operation costs. Exclusive commercial utilisation rights	

Source: DLR (2007[66]), "TerraSAR-X – first satellite funded by public and private sector", http://www.dlr.de/en/Portaldata/28/Resources/dokumente/re/TerraSAR-X_PPP_engl.pdf.

The preparation of this PPP lasted five years. This included an initial study of market prospects and expert consultations, followed by a time-consuming identification of the most suitable technology to fly on the mission, combining affordability and technical capabilities. There were also significant legal challenges, as there was no pre-existing procedure for this type of cooperation in Germany (DLR, 2007[66]).

Table A A.4. Radarsat-2, Canada

Mission description	Partners	Responsibilities	Benefits	Outcomes
Sun-synchronous radar imagery satellite Mission life Seven years, starting in 2007 Govt. costs: CAD 434 million (80% of total costs)	Canadian Space Agency	Shared satellite development costs	Cost savings Guaranteed access to data products and services worth CAD 446 million	Project provided value for money, but dissatisfaction on government side due to limited control of development and no satellite ownership. Model not reproduced for follow-on mission.
	MDA	Develop, own and operate satellite and related infrastructure (including data distribution)	Satellite ownership	

Source: Public Works and Government Services Canada (2009[69]), *Evaluation of the RADARSAT-2 Major Crown Project*, https://open.canada.ca/data/en/dataset/7102cdcd-0298-42ab-b0cc-518054b4bb0f.

An evaluation of the project carried out by Public Works and Government Services Canada found that several aspects of the PPP had worked well, e.g. the programme management office established to manage the PPP 'enjoyed exceptional stability and continuity' and was generally sufficiently staffed. Furthermore, the risk management processes in CSA were also deemed highly satisfactory.

Some steps in the preparation process were criticised. It was observed that the master agreement lacked clarity and detail in defining the common objectives relating to the potential pressures on project scope, costs, and time. In particular, unclear objectives regarding data policy and operations transitions were considered a challenge, in part due to lacking Agency expertise in data policy (Public Works and Government Services Canada, 2009[69]).

A majority of government stakeholders found it unsuccessful from a public partner point of view. Government ended paying for most of the system, while having very limited control over the development process and not owning the satellite (Public Works and Government Services Canada, 2009, p. 21[69]). The report noted, however, that in terms of value for money, the Canadian government paid less for the development of Radarsat-2 than they did for the previous mission, Radarsat-1, and also did not have to cover operation costs (Public Works and Government Services Canada, 2009[69]).

A more traditional public procurement arrangement was chosen for the Radarsat Constellation Mission (RCM) (Canadian Space Agency, 2017[70]).

Table A A.5. EnhancedView, United States

Mission description	Partners	Responsibilities	Benefits	Outcomes
Service level agreements for the delivery of satellite imagery and value-added services. Duration: Ten years (one base year plus nine one-year renewals) Govt. costs: Total announced contract value of USD 7.3 billion	National Geospatial-Intelligence Agency (NGA)	USD 337 million in cost-share for one satellite (GeoEye) Guaranteed annual payments	Cost savings, added flexbility	Programme interrupted due to announced govt. budget cuts. The two firms merged in 2013.
	Digital Globe and GeoEye	Develop, own and operate satellite and related infrastructure	Guaranteed long-term income	

Source: EARSC (2010[71]), "GeoEye Wins National Geospatial-Intelligence Agency Enhanced View Award", http://earsc.org/news/geoeye-wins-national-geospatial-intelligence-agency-enhanced-view-award.

In 2010, the US National Geospatial-Intelligence Agency (NGA) signed Service Level Agreements with two satellite operators (Digital Globe and GeoEye) worth USD 7.3 billion (EARSC, 2010[71]).

The fixed-price contracts included the delivery of satellite imagery and value-added services to the US government for ten. In the case of GeoEye, the contract also included a cost-share of USD 337 million for the development and launch of GeoEye-2 (EARSC, 2010[71]). The two companies reportedly committed more than USD 1 billion of private capital in investments to fulfil the different obligations in the programme (including in DigitalGlobe's case, the construction of WorldView-3). However, only one year into the programme, the US Congress announced significant budget cuts, which eventually led to the merger of the two companies in 2013.

Satellite positioning, navigation and timing

The European satellite navigation system Galileo, which started off as a PPP in 1999 but which turned into a traditional procurement programme in 2007, provides an interesting case study for a 'failed' PPP in the space sector.

Table A A.6. Galileo concession project

Mission description	Partners	Responsibilities	Benefits	Outcomes
30 MEO navigation satellites.	European Commission	Design and develop satellites and infrastructure	Value for money	Project failed after several years of negotiations in 2007. The European Union Council decided d fund the programme fully from the Community budget, with ESA as the delegated procurement agent.
Mission life: Govt. cost: EUR 1.8 billion (54%)	Eurely/iNavSat consortium	Build, finance and operate satellites	20-year concessions contract	

Source: (European Court of Auditors, 2009[72]), Special Report No 7: The Management of the Galileo Programme's Development and Validation Phase, https://www.eca.europa.eu/Lists/ECADocuments/SR09_07/SR09_07_EN.PDF.

The early stages of the Galileo programme and the failure to negotiate a PPP have been subject to several evaluations. The evaluation of the European Court of Auditors (European Court of Auditors, 2009[72]) includes a careful analysis of the PPP. They report several shortcomings, which are summarised below:

- Inadequate preparation and conception of the PPP: The studies to select a PPP model neither evaluated the relative benefits of other PPP models nor took into account traditional public procurement models or a public sector comparator. Furthermore, a realistic allocation of risk between public and private partners was not addressed in this early, preparatory stage. The GJU was understaffed and inexperienced. In addition, the bidding procedure appeared rushed, for both public and private parties, with the GJU not having enough time to define the concession approach and not allowing bidders enough time to develop a credible business plan. Initial tender documentation lacked specific objectives. As a consequence, industry bids did not contain firm pricing or commitments. When the two competing consortia merged, the competition for the market disappeared. As noted above, the initial preparations did not include an assessment of the cost of alternative arrangements.
- Inadequate PPP model: The chosen concession model was fundamentally different from other PPPs existing at the time (European Court of Auditors, 2009[72]). There were a range of problematic issues; e.g. high technological risk (30 MEO satellites with new components untested in space), significant uncertainty concerning monetisation (free signals of other GNSS systems); and finally, unlike traditional design-build-finance-operate PPPs, private concession holder would have to commit itself to building, financing and operating a new system which was conceived by a public sector actor (ESA).

What slowed down and eventually ended the concession negotiations were the discussions about the transfer of risk from the public to the private sector. More concretely, this concerned the transfer of three types of risk:

- Market risk: There was a lack of private sector confidence that market revenue could be obtained in accordance with an agreed baseline market development scenario. Government was going to play an important role in market development.
- Design risk: The private sector wanted more assurance that the design (prepared by ESA) had no inherent problems that might result in a faulty or underperforming system (for which the concession holder would be responsible during operation). The division of duties between design and development (ESA), and deployment, operation and maintenance (concession holder) made a transfer of risk difficult. As a side note, in January 2017, it became known that the atomic clocks had failed on nine out of 18 Galileo satellites.
- The third-party liability regime: This referred to any potential extra-contractual liabilities towards potential victims of Galileo failures, for which no specific legal or insurance model was available.

Access to space

There are a few examples of PPPs for access to space, all PPPs for innovation, supporting government missions and/or developing private sector capabilities. The most prominent example is the NASA initiative to support commercial orbital transportation services (COTS).

Table A A.7. NASA Commercial Orbital Transportation Services (United States)

Mission design	Partners	Responsibilities	Benefits	Outcomes
The NASA Commercial Orbital Transportation services (COTS) programme, launched in 2006, involved the development and demonstration of private sector transportation systems to low-Earth orbit. Project duration: 10 years Govt. costs: USD 788 million (about 50% of development costs)	NASA	Shared space vehicle development costs	Value for money, timeliness, innovation, foster private sector capabilities	The project saw the development of two new launch vehicles, their cargo carrier spacecraft, and the accompanying ground support systems in less than ten years
		SpaceX and Orbital	Possibility to be awarded NASA International Space Station resupply contracts	

Source: NASA (2014[87]), Commercial Orbital Transportation Services: A New Era in Spaceflight, https://www.nasa.gov/sites/default/files/files/SP-2014-617.pdf

An important source of motivation for private sector participation in the COTS programme was the future possibility to be awarded NASA International Space Station resupply contracts. (Indeed, after the finalisation of COTS, NASA ordered eight flights valued at about USD 1.9 billion from Orbital and 12 flights valued at about USD 1.6 billion from SpaceX (NASA, 2008[48])).

However, during the early stages of COTS, NASA could not guarantee follow-on ISS resupply service contracts (NASA, 2014[87]). This led to the withdrawal of the company Rocketplane Kistler from the programme, which did not succeed in attracting sufficient outside investment. Most companies seeking outside or corporate investment raised the issue that the demand risk was too high, barring corporate investment (NASA, 2014[87]).

Table A A.8. DARPA: Experimental Spaceplane (XS-1), phases 2/3 (United States)

Mission design	Partners	Responsibilities	Benefits	Outcomes
Develop a prototype for the DARPA Experimental Spaceplane, a fully reusable, unmanned, vertical launch-horizontal landing, hypersonic aircraft. Govt. costs: USD 146 million Test flights scheduled for 2020	DARPA	Co-fund R&D	Value for money. Foster private tech. development	Project failed. Boeing withdrew from the project in 2020.
	Boeing	Build and test spaceplane		

Source: Foust (2020[55]), "Boeing drops out of DARPA Experimental Spaceplane program", *Space News*, https://spacenews.com/boeing-drops-out-of-darpa-experimental-spaceplane-program/.

In May 2017, Boeing won the bid for developing a prototype for the DARPA Experimental Spaceplane, a fully reusable, unmanned, vertical launch-horizontal landing, hypersonic aircraft. The PPP arrangement covered design, construction, testing and 12-15 flight tests, with the aim to fly ten times in ten days, scheduled for 2020 (DARPA, 2017[54]). Both DARPA and Boeing are investing into the project, with DARPA providing up to USD 146 million. Boeing's investments were not disclosed. In 2020, Boeing announced that they withdrew from the programme (Foust, 2020[55]).

GEO in-orbit servicing

NASA and DARPA have both created public-private partnerships to support the development of in-orbit servicing technologies, DARPA in the geosynchronous orbit, and NASA in the low-earth orbit. The DARPA PPP focuses mainly on R&D, but also covers the operations phase.

Table A A.9. DARPA Robotic Servicing of Geosynchronous Satellites Programme (United States)

Mission design	Partners	Responsibilities	Benefits	Outcomes
Support the development and on-orbit demonstration of technologies to enable cooperative inspection and servicing of satellites in geosynchronous (GEO) orbit. Govt. costs: USD 15 million for R&D + launch costs	DARPA	Shared R&D funding, provides robotic module. Funds the demonstration launch	Reduced-priced servicing of govt. satellites and access to commercial servicing data	Failed project Private partner withdrew in 2019. A new partnership was established with Space Logistics (Northrop Grumman) in 2020.
	Space Systems Loral – SSL (Maxar)	Provides satellite bus and is responsible for system integration. Spacecraft ownership and operation if demonstration is successful.	Can provide commercial services	

Source: (DARPA, 2017[88]), "DARPA selects SSL as commercial partner for revolutionary goal of servicing satellites in GEO", https://www.darpa.mil/news-events/2017-02-09.

In 2019, Maxar (previously SSL) withdrew from the partnership. DARPA established a new partnership with Space Logistics in 2020. In this new deal, DARPA will provide the dexterous robotic payload. Space Logistics will provide the spacecraft bus, integrate the resulting robotic servicing spacecraft with the launch vehicle and provide the launch, as well as operations for the full mission duration (DARPA, 2020[56]).

Active debris removal

In 2020, JAXA and Astroscale agreed on in the first public-private partnership for active debris removal.

Table A A.10. Commercial Removal of Debris Demonstration, Phase 1 (Japan)

Mission design	Partners	Responsibilities	Benefits	Outcomes
Development of spacecraft to demonstrate key technologies for rendezvous and proximity operations relative to non-cooperative targets. Govt. costs: Not disclosed Timeline: Launch in 2022	JAXA	Provide technical support in the form of research and development results, technical advice, and test facilities	Value for money. Obtaining movement observational data to better understand the debris environment	n.a. Contract signed in 2020.
	Astroscale	Manufacture, launch and operate the satellite	Technology development, commercial positioning	

Source: JAXA (2020) (2020[51]), "JAXA concludes partnership-type contract for Phase I of its Commercial Removal of Debris Demonstration (CRD2)", https://global.jaxa.jp/press/2020/03/20200323-1_e.html.

The agreement covers the technology demonstration and data acquisition phase. The project's second phase, the actual removal of a Japanese upper stage rocket body, will be tendered separately (Astroscale, 2020[89]).

Other space applications

In addition to the case studies described above, there are numerous examples of more explorative public-private partnerships:

- **Space exploration**: Since 2015, NASA has established several innovation PPPs to support the commercial development of selected capabilities in human space exploration (e.g. habitat systems, in-situ resource utilisation) in cooperation with private stakeholders. For Habitat Systems for example, in the second phase of the programme, six participating companies (e.g. Bigelow Aerospace, Boeing) were given 24 months to develop ground prototypes and/or conduct concept studies for deep space habitats. The total value of NASA's fixed-price contract awards is estimated at USD 65 million for 2016 and 2017. The corporate share of co-investment is 30% (NASA, 2016[49]).
- **Deep space mining**: In 2016, the newly-established company Deep Space Industries, the Luxembourg government and the national banking institution, Société Nationale de Crédit et d'Investissement (SNCI), signed an agreement to explore, use, and commercialise space resources as part of Luxembourg's spaceresources.lu initiative. The initial commitment of the Luxembourg government amounted to approximately EUR 200 million, to cover R&D investments and company equity purchases (De Selding, 2016[57]). In the meantime, deep space mining lost momentum, and Deep Space Industries was purchased by Bradford Industries in 2019. The firm entered into a new agreement with the Luxembourg Space Agency in 2019 to develop critical low-cost spacecraft subsystems for deep space and earth-orbit missions (Luxembourg Space Agency, 2019[58]).

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