5 Strengthening assessment of the impacts of the space economy

The number and quality of indicators measuring the socio-economic effects of space activities have grown over the years, but challenges remain in achieving comparability and linking back to overlying policy objectives. This chapter addresses some of these issues by clarifying current terminology based on the evaluation literature, reviewing selected examples of indicators and identifying potential future needs.

Introduction

Public expenditures on space programmes are often justified by the capabilities and improvements they bring in the provision of public services, national security, and government-led scientific services (e.g. meteorology and environmental monitoring). Furthermore, applications that rely on satellite data and signals drive efficiency savings across a broad range of activities and help to create new commercial markets (OECD, 2021[1]). The space economy is therefore increasingly seen as a possible driver of future prosperity.

The term *impact assessment* describes a set of analytical tools used to understand the negative and positive effects of a particular policy so that the resulting impact can be evaluated. Impact assessments assist public policymakers in demonstrating the socio-economic effects of space activities but are also used in private sector decision taking. They may be performed *ex ante* to assist policymakers and decision makers by exploring the range of potential future effects of a policy decision and the magnitude and direction of their likely impacts. They may also be conducted *ex post* to provide a measure of the success or failure of interventions already implemented.

The OECD Space Forum has identified multiple space economy evaluations and impact assessments that have been conducted over the past two decades in OECD member countries and partner economies (see Annex Table 5.A.1 for a selection of studies). Many areas of the space economy have been subject to such analysis and some areas have been focused on multiple times in different contexts.

Past studies have been conducted on the impacts of:

- entire national space programmes, as conducted in e.g. Canada, Denmark, India, Norway and the United Kingdom
- specific sets of applications or activities, e.g. earth observation, space exploration, launchers, as conducted in organisations in e.g. Europe, United States and Australia
- specific programmes, e.g. Landsat in the United States or Eumetsat's EPS/Metop 2 programmes
- government facilities, e.g. National Aeronautics and Space Administration (NASA) and European Space Agency (ESA) centres.

The number and types of recorded effects and estimated impacts of space activities have therefore grown substantially in recent years. However, challenges remain in producing findings that are reproducible over time, comparable with other areas of the economy and across countries. More effort also needs to be devoted to assessing both the positive and negative effects of space policy implementation.

This chapter aims to address some of these issues by clarifying the terminology adopted in the field of impact assessment, discussing the effects of the space economy on society, introducing how such effects may be measured and identifying potential future needs for conducting effective analyses.

Brief introduction to assessing impact

The variety of statistics on space activities is broader than ever before (OECD, 2020[2]). The indicators constructed from them provide information that may be used to monitor the performance of space activities across a range of measures of interest to space economy analysts. However, understanding the societal value of the space economy requires frameworks used to estimate the magnitude of and compare both the positive and negative effects of space activities. This section describes the vocabulary used and the methodologies employed internationally that allow for assessments of impact to be conducted and repeated over time.

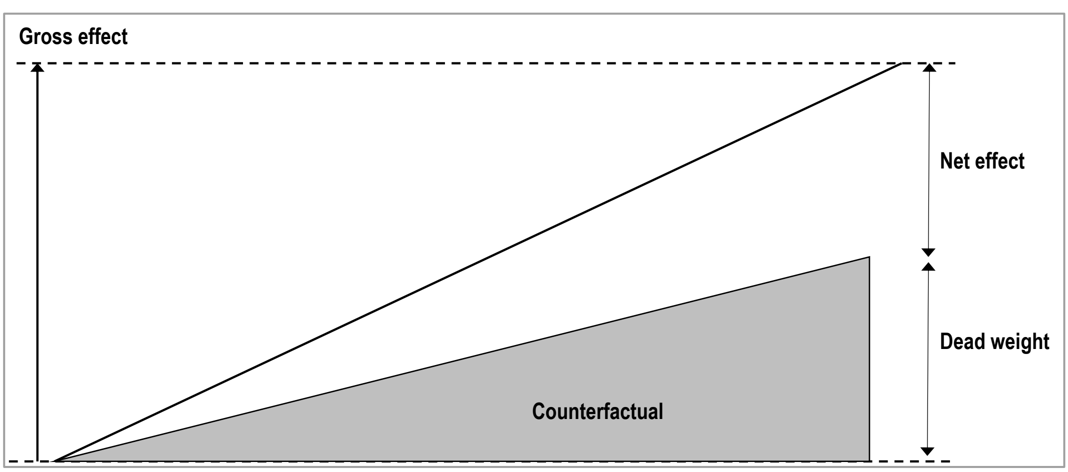
Terminology of impact assessment

When conducting evaluations of the space economy, terms such as "'outputs", "outcomes" and "impacts" are often used interchangeably, and tend to overlap (see OECD (2021[3])). The following standard definitions can be found in the literature:

- Outputs refer to what is produced directly or immediately by an activity. Depending on their nature, outputs may or may not be straightforward to measure. Outputs may for example refer to the goods or services produced by government agencies, or the private sector measured in quantities produced, the goods and services produced by the space business enterprise sector measured in total revenues, the number of scientific papers in refereed journals, or the number of annual space launches.
- Outcomes refer to the effects that are ultimately achieved by an activity, positive and negative, intended and unintended. In other words, they are defined as the effects arising from the delivery of outputs on social, economic, environmental or other important areas.
- Impacts refer to the much broader results of achieving the ultimate goals of a programme or policy, taking into account the positive and negative effects, as well as the intended and unintended effects. For example, the contribution of public spending on the space economy in improving the economic performance of broader areas of the overall economy, once all other potential contributions to economic performance in those areas have been controlled for.

Measuring impacts is complex, as an exhaustive analysis of the effects of a particular policy or decision requires taking into account what could have happened in the absence of the policy or decision having taken place. This requires accurate attribution of effects to a given action, estimates of the extent to which an action may have displaced other potential positive outcomes and a clear understanding of the negative consequences (whether intentional and mitigated against or unintended and unmitigated) (OECD, 2015[4]). In the evaluation literature, causal impacts refer to the "difference between potential outcomes under observed and unobserved counterfactual treatments" (OECD/Eurostat, 2018[5]). In this chapter, the term "effect" will encompass both outcomes and impacts to take into account the overlaps (Figure 5.1).

Figure 5.1. Gross and net effects



Source: OECD (2015[4]), "Causality problems", https://www.oecd.org/sti/inno/What-is-impact-assessment-OECDImpact.pdf.

Dealing with effects that are difficult to quantify

In many cases, it can be difficult to express the effects of space activities in quantitative units. Earth observation, national security applications, space exploration and science, for example, are all associated with considerable intangible social and strategic benefits. Examples include:

- The advancement of technology and knowledge: This includes breakthrough missions, from the European Space Agency's Rosetta mission to Comet 67P/Churyumov-Gerasimenko to the first images of Pluto (NASA's New Horizons).
- Culture and inspiration: The Moon landing is one of the most iconic events of the 20th century and is thought to have inspired an entire generation of scientists.
- International partnerships and means to address global challenges: The space sector is characterised by high levels of international co-operation, illustrated by the International Space Station, the co-ordination of meteorological missions or the development and provision of instruments on exploration missions (OECD, 2014[6]). One of the first emblematic joint space missions took place in 1975 during the Cold War, when an American spacecraft docked for the first time with a Russian spacecraft. In addition to the political significance of the event, it was a major engineering accomplishment, as both the US and the Russian systems relied on domestic hardware and standards.
- Space-based systems provide significant military capabilities: both in terms of tactical weapons and providing operative support.

Effects that are difficult to quantify are often highlighted as qualitative case studies. Certain impact assessment methodologies may be better suited to evaluating qualitative effects than others. Multi-criteria analysis, for example, has been used to score the significance of different types of effects including those that are not quantified. A 2019 application of this method in an assessment of ESA's science programmes identified important effects across scientific, social, economic and strategic areas in education, international cooperation, scientific production and quality, scientific interest, inspiration and awareness (PwC, 2019[7]).

Due to the broadly intangible nature of many of the effects associated with it, a substantial share of space economy impact assessments relies on hybrid or partial approaches. The estimated effects tend to be based on a combination of survey data, ad hoc data collection, interviews and expert opinions. The reasons for this fall into a couple of categories. Firstly, there is a lack of easily accessible and distinct economic statistics on the space economy with space activities dispersed in multiple, aggregated statistical categories of economic activities (Chapter 2). Secondly, as already mentioned, the nature of several of the most important effects of the space economy make them difficult to incorporate in quantitative frameworks as they do not relate to goods and services traded in markets.

Methodologies for evaluating positive and negative effects

Chapter 4 discussed space economy surveys, which may provide data to quantify the positive effects of space activities such as business enterprise revenues and employment, investment in space infrastructure and new science and technology. Impact assessment involves comparing positive effects such as these with any potential negative ones. A number of standard methodologies exist to identify and compare realised or potential effects and the overall impacts of future or past policy interventions.

Table 5.1 lists some of the most common approaches to assessing impact.

Table 5.1. Methodologies used in impact assessments and examples from evaluations of the space economy

Methodology	Description	Indicators	Examples in the space sector
Cost benefit analysis (CBA)	Cost benefit analyses quantify benefits and costs in monetary terms and compare them over time. Results are compared to a counterfactual "do-nothing" scenario.	Monetised benefits and costs, including intended and unintended economic, social and environmental effects.	CBAs have been used in ex ante evaluations, like the impact study for the global monitoring for environment and security programme (GMES, currently Copernicus) (Booz & Company, 2011[8]); the use of satellite imagery for safeguard tasks at the International Atomic Energy Agency (IAEA) (Andersson, 1999[9]); and the case for a second generation of the EPS/MetOP weather satellites (EUMETSAT, 2014[10]). India has also conducted a CBA of its space programme (Sridhara Murthi, Sankar and Madhusudhan, 2007[11]). A major Italian CBA highlights the role of public policies in the space sector (Università di Milano and Agenzia Spaziale Italiana, 2021[12]).
Cost effectiveness analysis and cost utility analysis	A variety of cost benefit analysis, cost effectiveness analyses take the benefits of the intervention as a given and compares different policy options.	Cost effectiveness ratios, e.g. quality-adjusted life years (QUALYs) and disability-adjusted life years (DALYs).	Few examples are available in the literature for space activities. Perhaps the most prominent cost-effectiveness analysis in the space sector is the feasibility study of the Space Shuttle System (Mathematica, 1972[13]).
Input-output modelling	Input-output models trace the activity generated by a project or intervention in other parts of the economy. Common models: IMPLAN and RIMS-II.	GDP and employment multipliers, comprising direct, indirect and induced effects; contributions to GDP, employment and government revenues.	Economic impact analyses are frequently used to study the impacts of space programmes on employment and other economic activities in the whole economy. They are particularly common in North America, where the space manufacturing and launch activities have distinct industrial classification (NAICS) codes. Examples include (FAA, 2008[14]; Goss Gilroy Inc., 2010[15]; CSA, 2019[16]; PwC, 2014[17]; London Economics, 2015[18]; Florida Tech, 2022[19]).
General equilibrium modelling	More dynamic and complex than input-output modelling. Simulations are run to assess the impacts of different policy options on the economy. Examples of models applied in the space sector: E3ME (Europe) and Tasman Global (Australia).	GDP and employment multipliers; contributions to GDP, employment, government revenues, productivity, pollution, etc.	Examples include (Eftec, 2013[20]) for determining satellite telecommunications' contributions to sustainable development; (PwC, 2019[21]) for assessing socio-economic benefits of selected ESA earth observation activities; and for computing the value of earth observations and augmented GNSS in Australia (ACIL Allen, 2015[22]; 2013[23]).
Multi-criteria analysis	Multi-criteria analysis allows systematic decisions to be made in cases where quantification of impacts is difficult.	Effects of policy options receive weighted scores according to predetermined criteria. And options are ranked according to their final score.	Recent examples include (PwC, 2019[7]; Euroconsult, 2019[24]) for the socio-economic assessments of ESA's science programme and communication satellites for safety and security.

Selected effects and approaches to their measurement

This section outlines the rationale for studying the impact of the space economy and summarises approaches to their evaluation. It focuses on the analysis of four categories of effects and methods that are generally considered in impact assessments of the space economy. The first considers the effects of space programmes on organisations operating in the space economy, the performance of which is increasingly used as a justification for public expenditure on space programmes. The second relates to the economic value generated by space activities and their linkages with activities in the rest of the economy based on input-output analysis. The third focuses specifically on the effects of technology originally developed by space activities and subsequently transferred into other areas of the economy. And the fourth explores burgeoning efforts to understand the role and value of satellite-derived information products on society as a whole.

The effects of participation in space programmes on organisations' performance

A growing number of studies evaluate the effects of government space programmes on participating organisations and their performance, in terms of knowledge, networks, revenues, academic reputation, etc.

Space programmes are often evaluated in terms of their impact on research. A qualitative study of the effects of Norwegian participation in European Space Agency Science projects suggests that involvement led to increased experience, knowledge and contacts. In turn, these improvements enabled participation in new projects, better international recognition (supported by scientific publications in prestigious journals, grants and awards) and furthered knowledge transfers to other projects and activities (Høegh Berdal, 2018[25]). The report asserts that participation in ESA science projects has been essential in shaping the solar physics scientific community in Norway as it is today, for example. More broadly, a 2019 assessment of eight ESA science missions (four past missions: XMM-Newton, Rosetta, SOHO, and the participation of ESA to the Hubble Space Telescope (HST); and four future missions, i.e., JUICE, ARIEL, SMILE and the participation of ESA to the James Webb Space Telescope (JWST)) found strong effects in terms of scientific quality and international collaboration (PwC, 2019[7]).

The effects of space programme participation are felt beyond research. An evaluation of Swiss R&D funding instruments for space activities considered both higher education institutes and business enterprises (Barjak, Bill and Samuel, 2015[26]). The survey results reveal that more than 80% of the academic respondents assessed ESA projects and complementary national activities as contributing positively to academic reputation, the size of the global academic network, employees' competencies, and the recruitment and training of staff (Figure 5.2). But, in addition, around 60% of respondents representing business enterprises reported that participation had led to better outcomes across a range of business metrics including quantity of products sold and diversification of clients and markets.

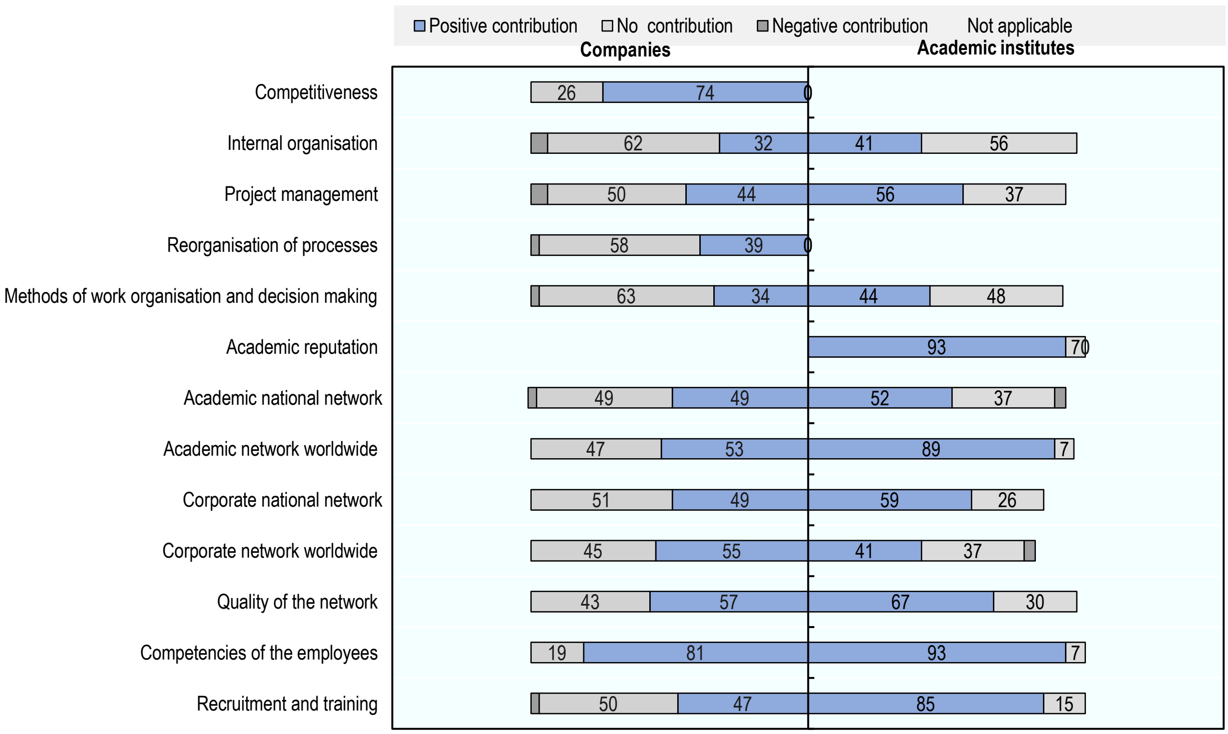
In OECD countries, space programmes have always sought the involvement of organisations operating in sectors beyond the government and higher education sectors, with a particular focus on the participation of business enterprises. The motivations for and expected outcomes from the participation of business enterprises in space programmes have been described in multiple previous analyses. A study from the early 1990s of firms participating in ESA projects, for example, outlined multiple positive effects including: better access to new markets, effective technological and scientific networks, the development of more capable staff and more advanced managerial expertise (BETA, 1991[27]). The Norwegian study outlined above found that firms receiving contracts associated with ESA Science programmes reported significant technological effects and the opening of new market opportunities (Høegh Berdal, 2018[25]).

Assessing the impacts of space programmes on business enterprise activity often involves tracking and quantifying the positive effects and contrasting them with likely outcomes in absence of the space programme. A core objective of impact assessments of this type is to capture and quantify technological, reputational, networking and other spillovers from space programme participation on the business performance of organisations from any sector. Frequently, some measure of output is used as a proxy for the combined influence of all of the above effects. A common approach is to estimate *additional revenues* attributable to participation in the space programme.

The section below considers first the effects of space programme participation on firms operating primarily in the business enterprise sector. It then focuses on the effects of participation on the business enterprise activity of organisations operating primarily in the higher education sector, and finally ends with a few examples of the potential negative effects of space programmes overall.

Figure 5.2. Organisation-related outcomes of ESA projects and complementary national activities by sector in Switzerland

Share of respondents (%)



Note: Academic institutes: n≥ 22, companies: n≥ 34.
Source: Based on Barjak, Bill and Samuel (2015[26]), "Evaluation of the existing Swiss institutional R&D funding instruments for the implementation of the space-related measures", https://www.sbfi.admin.ch/dam/sbfi/fr/dokumente/evaluation_of_theexistingswissinstitutionalrdfundinginstruments.pdf.download.pdf/evaluation_of_theexistingswissinstitutionalrdfundinginstruments.pdf.

Effects on firms operating primarily in the business enterprise sector

Several members of the European Space Agency (ESA) have conducted assessments of their domestic firms' participation in ESA programmes. Examples exist from Norway (Norwegian Space Agency, 2018[28]), Denmark (Ramboll Management Consulting, 2008[29]) Portugal (Clama Consulting, 2011[30]) and the United Kingdom (Technopolis, 2019[31]; London Economics, 2018[32]) to name a few. The data used in such analyses are mostly collected from the business enterprise sector through surveys and interviews, where firms self-assess the additional revenues resulting from space programme participation.

Several sources of additional revenues are identified and made explicit in these studies, mainly resulting from technology and expertise developed through the realisation of contracts awarded through government space programmes. Examples include additional revenues from existing products that would not have been sold without participation, revenues from new products that would not have existed without participation, revenues generated from network or reputation effects caused by participation, and the revenues in firms producing intermediate inputs for those participating.

An alternative approach to collecting self-reported information on additional revenues from firms is to compare enterprises awarded contracts through space programmes with those that are not involved but produce similar goods and services. Multiple assumptions are required for this comparison to hold true that are unlikely to be reflected in reality. A major simplifying assumption is that firms in the two groups have similar characteristics and capabilities on average, a constraint that is unlikely to hold under scrutiny and may lead to inaccurate results.

Finally, an evaluation survey of the United Kingdom's funding of space activities through ESA's programme of Advanced Research in Telecommunications Systems (ARTES) programme found that participation in the programme led to new and strengthened partnerships, new and improved skills, knowledge and capabilities and increased visibility and reputation of UK capabilities (Technopolis, 2019[31]). As a result, 56% of respondents reported that their organisations were generating additional revenues attributable to participation in the ARTES programme and a further 29% reported the expectation of generating additional revenues in the succeeding years. Only 13% of survey respondents expected no additional income from participation in the programme.

Effects on the business enterprise activity of organisations operating primarily in the higher education sector

Business activity is not restricted to firms that operate solely in the business enterprise sector, as seen in Chapter 3. The effect of participation in space programmes on activities of organisations in the higher education sector has also been studied in evaluations.

Take, for example, the involvement of Cardiff University in Wales, United Kingdom, with the Herschel Space Observatory. The Herschel SPIRE project was an ESA-funded astronomical satellite that launched in 2009 and operated until 2013 with Cardiff University leading a consortium of 18 institutions. Cardiff University is primarily a higher education institute that also conducts business enterprise activity, either through research performed under commercial contracts or through the incubation and spinning-off of new businesses. The effects of participation in the Hershel SPIRE project have been shown to be relevant to the activities conducted by Cardiff University in both sectors in which it operates. In addition to the enhanced scientific reputation brought about by leading a major space programme project, the university generated positive effects to its business enterprise activity through the development of three spin-off firms and new follow-on contracts with its commercial partner Airbus valued at GBP 4 million (Sadlier, Farooq and Romain, 2018[33]).

Potential negative effects of space programmes

Space programmes for the most part are funded through government spending and some of this expenditure flows towards the business enterprise sector. As previously noted in Chapter 3, government grants and procurement sometimes represent the main source of income for certain industry segments, e.g. in 2018, sales to the government sector accounted for 57% of the total revenue of the upstream segment in Canada and 71% in Europe (Eurospace, 2020[34]; CSA, 2019[16]). And, as outlined above, business enterprise participation in space programmes has been shown to result in positive effects beyond sales for the business enterprises involved.

Assessment of the impact of public expenditure requires an understanding of both the positive and negative effects of a particular intervention so that the two can be compared. But the potential negative effects of space programmes on the business enterprise sector overall and/or on society as a whole are rarely discussed in evaluations of the space economy. Such negative effects may include, but are not limited to, the unintentional "crowding-out" of business enterprise activity that would exist without public intervention and the potential for public resources to be misallocated. Consider, for example, the effects on the terrestrial telecommunications industry, resulting from the development of satellite communication technologies and public expenditure on their development. While the overall societal impact of satellite communications is considered to be positive, it does not necessarily come without negative effects such as unemployment and economic decline in competing activities.

An increasingly pressing example of the unintended consequences of space programmes relates to space debris and its potential effects on the provision of satellite data (Undseth, Jolly and Olivari, 2020[36]). Much of the activity associated with space programmes since their commencement in the 1950s has involved the deployment of satellites and other instruments into orbit. Satellites have many uses and have important applications in society (see the section: The societal effects of information generated from satellite data*)* for a discussion on one such use case). Due to dramatic reductions in the costs of launching and operating satellites and to the benefits associated with their use, organisations from all sectors of the space economy and in many countries are targeting the deployment of ever-increasing numbers of satellites in low-earth orbit. However, this does not come without risk.

Space debris refers to manmade objects, fragments and elements that result from space operations, ranging from specks of paint and lens caps to rocket bodies and other large objects. Atmospheric drag and other natural phenomena eventually pull debris closer to Earth where they burn up upon entering the atmosphere, but this can take anything from a couple of years to several centuries. There is no atmospheric drag in geostationary orbit, so debris remain there unless moved to dedicated "graveyard" orbits. The accumulation of space debris is a growing problem following several fragmentation events and increased launch activity to the low-earth orbit. In a worst-case scenario, a self-generating cascade of on-orbit collisions could lead to the disruption or loss of certain low-earth orbits (the so-called Kessler syndrome). The costs to society of such an event would likely be very large given the combined value of the positive effects associated with the use of satellites (OECD, 2020[37]). But little attention has been focused on maintaining the sustainability of satellite operations in the environment in which satellites are placed.

Current launch activity to critical orbits is dominated by the business enterprise sector. Mega-constellations of satellites are planned for low orbits including, for example, the OneWeb constellation or SpaceX's Starlink telecommunications project. The objectives of such commercial activity are to provide internet access to places where connection to ground networks is prohibitively expensive. This is likely to have substantial positive effects. But, no matter how large space is, increasing numbers of satellites and space debris will increase the likelihood of collisions and other risks from occurring (IADC, 2013[37]; Liou, Johnson and Hill, 2010[38]; Boley and Byers, 2021[39]).

The unintended negative effects of space programmes are rarely treated in space economy impact assessments. Data on orbital debris (see Figure 5.3) and information on compliance with debris guidelines and regulations are collected by civil and military space organisations alike (the US Space Force Space-Track website, ESA's Annual Space Environment Report (ESA, 2021[40]) and NASA's Orbital Debris Quarterly News (NASA, 2022[41]), for example). But the datasets required to conduct effective assessments are rarely made publicly available. Perhaps because of this, the negative effects of space debris were identified in only one study of the space economy referenced in this chapter (Eftec, 2013[20]).

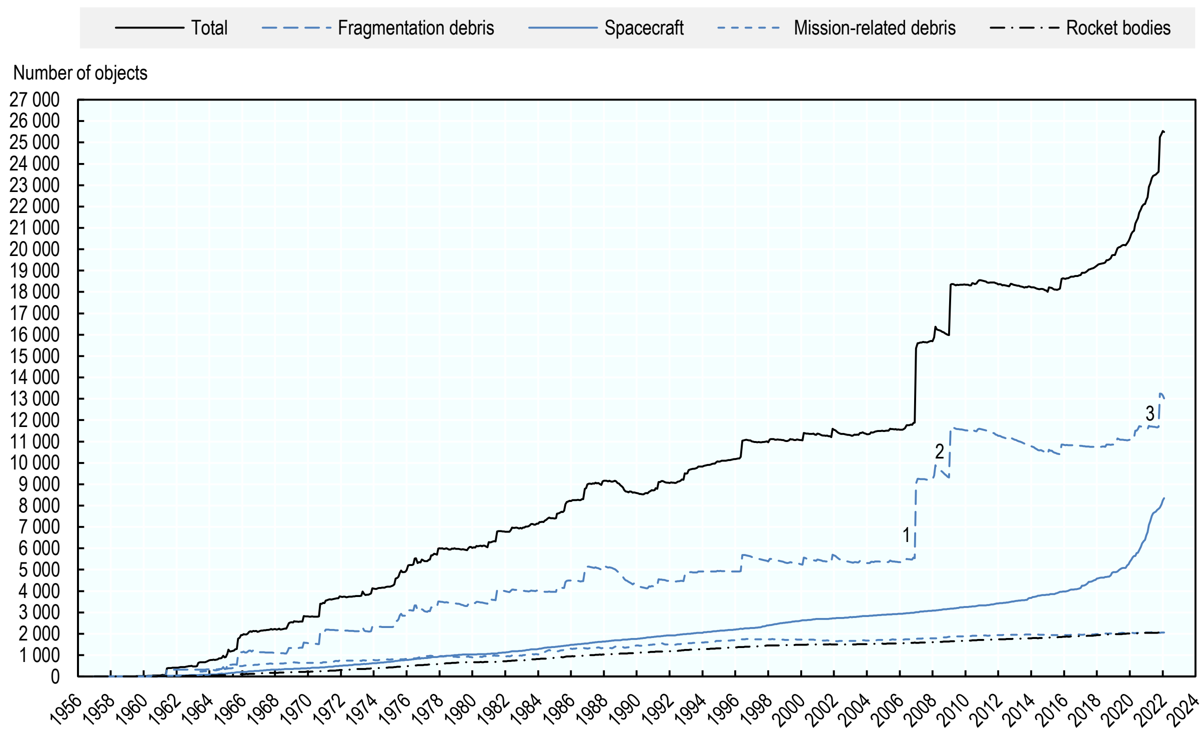
The direct, indirect and induced economic effects of space activities in the general economy

In order to measure the economic effects of space activities in the context of the broader economy, analysts may use a framework known as input-output (IO) analysis. IO analysis is based on the input-output tables (IOTs) that are often, but not exclusively, produced by national statistical offices (OECD, 2021[3]).

Official IOTs are derived from the supply-use tables (SUTs) used in national accounting to measure gross domestic product (GDP) in a robust manner. They represent a transformation of the activity by product nature of the SUTs into an activity by activity or product by product set of analytical tables. In doing so, it is possible to see the effects that particular changes in one part of the economy have on others. An increase in output in Industry X will require an increase in the outputs of all industries that produce goods and services used as intermediate inputs in Industry X and so on. As a result, IO analysis is often used to understand the importance of interrelationships between particular activities and the rest of the economy.

Figure 5.3. The number of space debris objects has accelerated since 2007, potentially threatening the provision of satellite data and signals

Historical increase of the catalogued objects based on data available on 1 March 2022



Notes: The three upward jumps in fragmentation debris correspond to (1) the anti-satellite test conducted the People's Republic of China in 2007, (2) the accidental collision between Iridium 33 and Cosmos 2251 in 2009, and (3) the anti-satellite test conducted by the Russian Federation in November 2021. More Cosmos 1408 fragments are expected to the added to the catalogue in the coming weeks and months.
Source: NASA (2022[41]), *Orbital Debris Quarterly News*, https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/ODQNv26i1.pdf.

IO analysis is a useful tool upon which to estimate the value of the economic effects of a policy intervention and to use as the basis for economic impact assessment. A space economy IO analyst might, for example, consider the effects of the output generated by space activities on the output of economic activities in the rest of the economy.

Economic effects in input-output analysis are frequently broken down into three categories:

- In a study that considers the value to the overall economy of the output generated by the space economy, *direct effects* represent the value of the goods and services produced by the organisations conducting space activities.
- To produce their output, such organisations will require and purchase intermediate inputs. The value of the intermediate goods and services required by space activities are known as *indirect effects*.
- Finally, any production requires a supply of labour which is rewarded through wages and salaries. The subsequent value generated through the sales of goods and services paid for from income earned both directly and indirectly from space activities are called *induced effects*.

The total economic value of a particular policy intervention is therefore the aggregate of the direct, indirect and induced economic effects. It is, however, not necessary to take into account induced economic effects.

In the Netherlands, input-output analysis has been carried for activities in the space economy without including the broader effects on production via wages and salaries (Dialogic and Decisio, 2016[42]).

Space economy input-output analysis in practice

The Canadian Space Agency (CSA) has, in co-operation with Innovation, Science and Economic Development (ISED) Canada, developed a methodology to estimate the indirect and induced effects of production in the space economy using input-output (IO) analysis.

The analysis relies upon official statistics and IO tables constructed by Statistics Canada. As the statistics produced by Statistics Canada are often too aggregated for space activities to be visible, a series of weightings are applied in order to approximate the space-related components in isolation from the rest. The weightings are based on the share of employment in space activities – ascertained from an annual CSA survey of space economy organisations (CSA, 2022[43]) – and in the categories recognised by Statistics Canada (which are based on the NAICS statistical classification). A similar process is used to approximate the magnitude of the interrelationships between space activities and the rest using Statistics Canada's input-output tables.

The results of CSA's 2019 economic impact assessment suggest that Canadian space activities directly employ 10 541 jobs to produce CAD 1.30 billion worth of goods and services. From the industries that supply space activities with intermediate inputs, the IO estimates suggest that Canadian space activities demand CAD 0.60 billion worth of output. In turn, the organisations providing intermediate inputs to Canadian space activities support an additional 6 482 jobs. The people employed in these jobs, both those directly and indirectly supported by Canadian space activities, consume CAD 0.57 billion worth of goods and services in the economy overall. This household spending supports 5 856 further jobs. The total estimated output effect of Canadian space activities is therefore CAD 2.5 billion and the total estimated employment effect is 20 891 jobs (Table 5.2). The advantage of this analysis is that it relies on official statistics augmented by information gathered by the long-standing annual Canadian Space Agency survey.

Table 5.2. Economic impact of space activities in Canada, 2019

Indicator	Direct impact (space sector)	Indirect impact (supply industry)	Induced impact (consumer spending by employees)	Total size of effects	Multiplier
Value of final goods and services	CAD 1.3 billion	CAD 0.6 billion	CAD 0.57 billion	CAD 2.5 billion	1.90
Employment	10 541 jobs	6 482 jobs	5 856 jobs	22 879 jobs	2.17

Source: Canadian Space Agency (2022[43]), "The state of the Canadian space sector 2019", https://www.asc-csa.gc.ca/eng/publications/2020-state-canadian-space-sector-facts-figures-2019.asp#annex-b.

Input-output analysis frameworks are also regularly used to estimate the economic impacts of individual NASA centres (e.g. (NASA, 2018[44]; 2022[19])). In 2019, the agency commissioned a report to estimate the overall economic impact of NASA spending on the US economy (Highfill and MacDonald, 2022[46]; Voorhees Center, 2020[47]). Using information from BEA's supply-use tables, the study identified the direct, indirect, and induced effects of NASA spending on the US economy and state economies across all industries. In addition to NASA's direct budget expenditures, the study considered the new demand for goods and services resulting from NASA's expenditures, including products purchased along NASA's supply chain (indirect) and products purchased by the employees and business owners from NASA and its supply chain (induced). The study found that that NASA spending in the fiscal year 2019 had an overall impact of USD 64.3 billion in output and USD 35.3 billion in value added, which translates to 312 630 jobs and USD 23.7 billion in labour income. Most of the economic impact is attributable to indirect and induced effects. Only 5% of jobs and 12% of labour income can be directly attributed to NASA employees and their income.

Space economy input-output analyses typically focus on effects on output, employment, and government revenues. But they are often complex to realise, as reliable data may not be available for all three of these metrics due to the challenges associated with measuring the space economy outlined in Chapter 2. In the absence of detailed space economy statistics, the use of proxies is common and calculations tend to be based upon the results of ad-hoc surveys of space economy organisations or simple averages taken from broader categories of economic activity.

This makes it difficult to compare the findings of space economy IO analyses over time, with other areas of the economy and across countries. Furthermore, IO analysis should not be used uncritically. IO tables do not take into account supply-side constraints, some of which are crucial factors in the performance of the space economy such as the availability of skilled labour. This implies that, if the economy is operating at or near capacity, the realised effects are likely to be smaller than the results of an unsophisticated IO analysis would suggest. Finally, input output tables and multipliers should not be used out of context (i.e. in a different region or country), with different structural relationships between suppliers and a higher (or lower) dependence on traded products.

Extending input-output analysis to account for the environmental implications of space activities

Space economy studies have tended to focus on economic metrics such as output and employment. But input-output analysis is also a useful framework for understanding the use of natural resources in production and the discharge of pollutants into the environment as a result of industrial activity. An increasingly important extension to traditional IO-based economic impact assessment is the inclusion of alternative variables such as energy use. Space manufacturing, including product testing, is an energy-intensive activity. Several space agencies, including the German Aerospace Centre (DLR), ESA and NASA, increasingly provide environmental performance data for their facilities. Typically, water consumption, energy consumption and CO_2 emissions are measured among other variables (ESA, 2017[47]; DLR, 2018[48]). Figure 5.4 displays a visualisation of environmental monitoring conducted by the DLR of its facilities in Germany.

In general, environmentally extended IO tables account for both the natural inputs to an activity (whether they be material resources, renewable resources or other inputs such as soil nutrients) and the flow of residuals into the environment that results from that activity (such as air emissions, solid waste and wastewater). This physical information is then combined with the monetary information of the standard IO tables in order to provide an integrated summary of the environmental effects of a particular area of the economy. This method could be used to, for example, analyse the direct, indirect, and induced effects of space activities on generating greenhouse gas emissions. The results of which could be used to compare both the total positive economic effects (in terms of output, employment and government revenues) with the total negative environmental effects (in terms of greenhouse gas emissions, for example).

The specific effects of technology transferred from the space economy to the general economy

Space technology transfers to different sectors of the economy have evolved from being an accidental by-product of space research to a routine means of maximising the value of space research and development expenditure.

Many space technologies originate in the context of government-funded space programmes. Technological transfer and commercialisation (TTC) have therefore often been part of routine objectives since the 1960s and 70s. But in the last decade, the number and diversity of programmes and policies to transfer and commercialise space technologies has grown. Promoting different uses of space technologies is becoming an increasingly crucial task in space agencies' programme of work in many countries. Selected TTCs help broaden the benefits of public space R&D investments indirectly to the wider economy. This maximises the returns associated with the initial scientific and technology-intensive programmes, beyond simply fulfilling their primary mandates (e.g. achieving a successful space mission), although an economic framework of analysis is needed to assess their actual impacts.

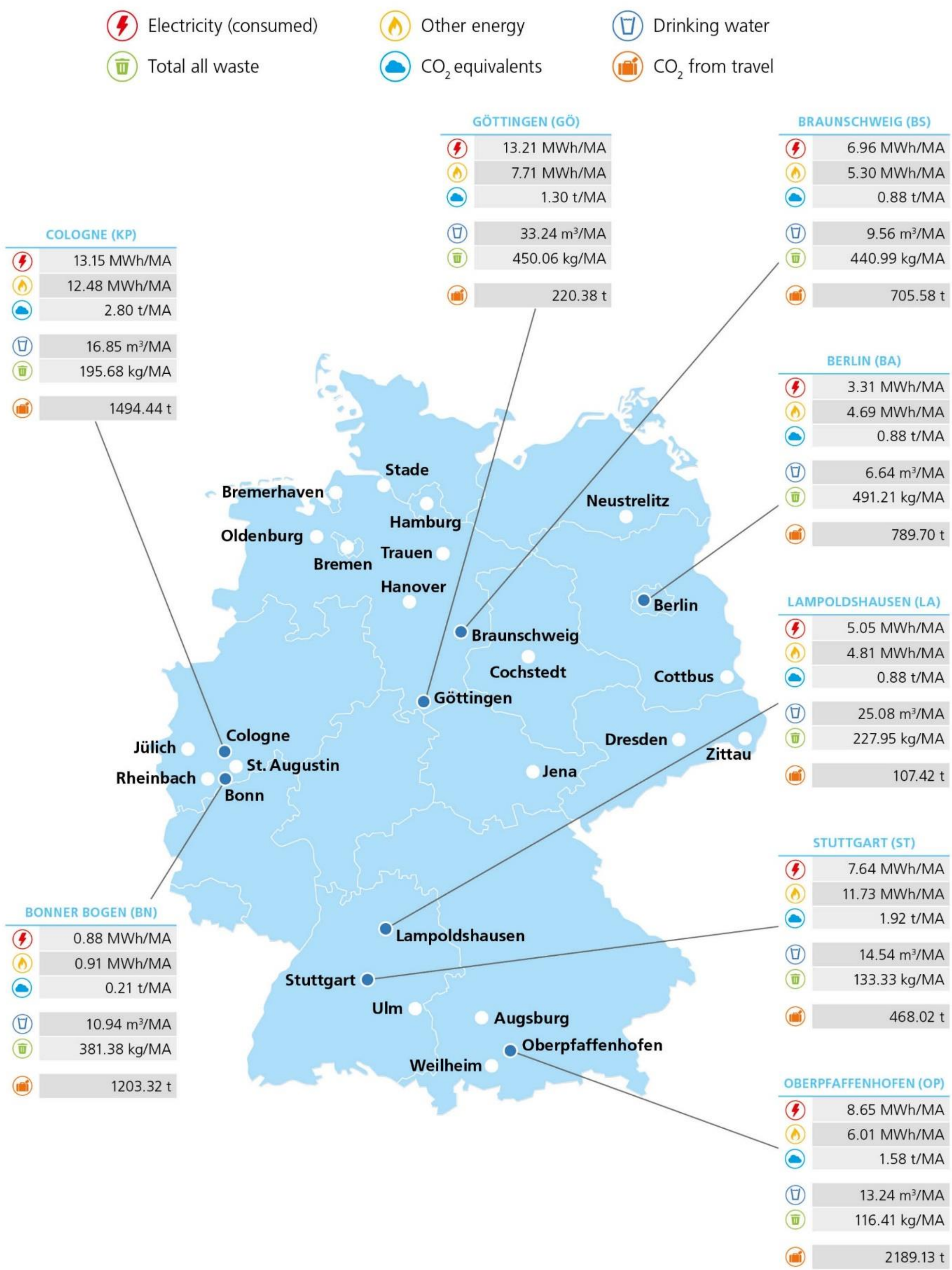
The OECD has examined space technology transfers and their commercialisation, focusing on transfers from publicly funded programmes to different sectors of the economy and comparing practices from Europe, North America and Asia (Olivari, Jolly and Undseth, 2021[50]). Space technological transfers and commercialisation are described in the analysis as the movement of know-how, skills, technical knowledge, procedures, methods, expertise or technologies from a public research organisation (e.g. space agency, space research centre) to another organisation operating in a different sector (e.g. a firm in the business enterprise sector).

Keeping track of the effects of space technology transfers is today mostly done through much broader evaluations of space activities and assessments of the commercialisation of government intellectual property in general.

In the United States, federal agencies tend to measure the benefits of their technology transfer programme via the number of patents and licensing income (Choudhry and Ponzio, 2020[50]). In order to complement this information, other ad-hoc studies are regularly conducted. For instance, an evaluation of Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programmes at NASA also provide useful insights (National Academies of Sciences, Engineering, and Medicine, 2016[51]). NASA and other US federal agencies with extramural R&D budgets exceeding USD 100 million are required to allocate 2.8% of their R&D budget to Small Business Innovation Research programmes. Another 0.3% for Small Business Technology Transfer programmes are required if their R&D budgets exceed USD 1 billion. A survey among recipients of SBIR and STTR funding from NASA found that participation in the programmes contributed to developing new markets, reputational effects, access to other federal agencies' programmes (outside the space programme), and connections to key stakeholders in core technical areas (including agencies, prime contractors, investors, suppliers, subcontractors, and universities) (National Academies of Sciences, Engineering, and Medicine, 2016[51]).

In Korea, on the occasion of the 30-year anniversary of the Korea Aerospace Research Institute (KARI) in 2019, the organisation conducted a large impact assessment of the institute's R&D activities over the last three decades. This included a systematic analysis of technological transfer activities, their outputs and outcomes covering all KARI aerospace programmes. The results show that since 2001, there have been a total of 326 technology transfers (an average of 18.1 transfers per year of which 81.3% were transfers of "technology" (as opposed to know-how)). The average improvement in annual sales of recipient firms attributable to the institute's R&D activities was valued at KRW 390 million (USD 330 000). Technology transfers were directly related to 20.3% of these additional sales (Park, 2020[52]). Furthermore, the utilisation by "internal" and "third party" actors of KARI facilities indicated significant growth in external usage over the years.

Figure 5.4. Environmental compliance of DLR institutes



Source: Grunewald, M. (2019[53]), "Sustainability indicators at DLR research institutes".

Using government intellectual property commercialisation assessments to understand the effects of space technology transfers

When technology transfer occurs, intellectual property is one of the key elements to consider. A number of administrations and agencies have attempted to assess the benefits derived from the commercialisation of space-related patents through licensing.

Comstock and Lockney (2011[54]), for example, analyse the positive effects generated by the commercialisation of government intellectual property at NASA. The authors considered 187 transfers recorded in NASA's annual *Spinoff* publication between 2007 and 2011. They report benefits as revealed by recipient firms according to a consistent set of indicators, although only a minority of case studies report numeric data. The benefits range from new or additional jobs in the firms to revenues and environmental benefits (Table 5.3). Focusing on the economic effects of technology transfers from NASA's life sciences programme, Hertzfeld found substantial returns to the 15 firms that were surveyed based on their commercialisation of new products under NASA licenses (Hertzfeld, 2002[55]). All firms reported profitable product lines and provided evidence of positive effects extending to the users of their products.

Table 5.3. Selected benefits of NASA technological transfers

Indicators	Quantifiable benefits	Share of case studies with numeric data
New or additional jobs	1 665 new jobs collected from eight transfer stories (e.g. composite manufacturing).	4%
New or additional revenues	USD 532 million (mainly single year of sales) from nine transfer stories.	5%
Productivity/efficiency gains	NASA's research on winglet design (blended winglets) is estimated to have generated aircraft fuel cost savings of more than USD 4 billion over the 2006-10 period (see also environmental benefits).	2%
Lives saved	659 lives saved attributed to two tech transfers, including 450 lives saved attributed to Apollo-era lift raft technology used to manufacture rescue rafts.	1%
Lives improved	30 million lives improved attributed to 4 NASA tech transfers, notably unique nutritional supplements used in baby formula and new materials used in surgical implants.	2%
Environmental benefits	NASA's work on winglet design is estimated to have saved 21.5 million tons in CO_2 emissions over the 2006-10 period.	n.a.

Notes: n.a.= Not available. Data based on 187 tech transfer stories collected between 2006 and 2010.
Source: Comstock and Lockney (2011[54]), "A sustainable method for quantifying the benefits of NASA technology transfer", https://spinoff.nasa.gov/pdf/AIAA 2011 Quantifying Spinoff Benefits.pdf.

The European Space Agency support commercialisation of space technologies and services in general, including the commercialisation of its intellectual property via a network of 22 business incubation centres (BIC) in its member states. A 2020 assessment suggests the initiative has resulted in the creation of more than 700 firms since the launch of the first centres in 2003 and supports on average some 180 start-ups annually (ESA, 2020[56]). Other assessments suggest the performance of each BIC centre vary considerably depending on the metric under consideration. The ESA BIC in Harwell in the United Kingdom reported a firm survival rate of 92% since the creation of the incubation centre in 2011 (O'Hare, 2017[57]). The Bavarian ESA BIC, established in 2009, had in 2018 incubated a total of 130 start-ups, creating 1 800 jobs and generating EUR 150 million in annual turnover (ESA BIC Bavaria, 2021[58]).

Since its opening in 2016, ESA BIC Switzerland has supported 40 start-ups nationwide and invested a total of more than EUR 6 million non-dilutive funding from ESA. Start-ups in ESA BIC Switzerland have raised more than EUR 170 million in third party funding and created more than 300 domestic jobs. At least five of these start-ups have reported CHF 1 million (USD 1 million) in annual revenues and some have been supported by major organisations such as IBM. Perhaps the best-known alum of ESA BIC Switzerland is ClearSpace, which has received a contract of EUR 86 million from ESA to demonstrate the first space debris clearance mission (Startupticker ch, 2021[60]).

Challenges associated with understanding the effects of space technology transfers

The review of different types of positive effects generated by technological transfers shows that there is considerable anecdotal evidence of "success stories". There is also a growing amount of qualitative data, generally suggesting relevant impacts on recipient organisations, including academic organisations and firms.

However, the challenge remains to identify benefits that can be aggregated, analysed and compared. As shown in Table 5.3, only a tiny percentage of the NASA case studies reviewed by Comstock and Lockney provided quantitative data. Similarly, the type and amount of reporting from the European Space Agency Business Incubation Centres differs considerably from one centre to another.

The methodological challenges associated with identifying the different types of benefits from space technology transfers are the same as for many other government R&D programmes (Gaster, 2017[60]):

- **Lags:** There is sometimes a considerable time lag between the initial investment and the realised outcomes, sometimes several decades. Time lags are particularly relevant for space activities, exacerbated by long technological development lead times and small markets with limited commercial opportunities.
- **Limited institutional memory of firms:** Memories or records of past government projects may be limited, especially if they date back several years. This is perhaps particularly the case for small- and medium-sized enterprises, which are more susceptible to failure or acquisition than bigger firms.
- **Self-reported data:** Most outcomes mentioned in this section are self-reported, mostly via ad-hoc surveys and studies. Some organisations may make mistakes or inflate results, and there is no way to measure benefits over time unless there are repeat studies using the same indicators.
- **Problems of causality and quantification:** How much of an organisation's revenues can be attributed to a single project? Firms often need support from several projects and organisations to commercialise their products. Similarly, how much of a mature firm's revenues should be attributed to government funding (potentially received decades earlier)?

Some of these issues may be addressed by improved agency data collection and management practices, by creating incentives for self-reporting (e.g. associate it with future governmental funding), providing clear guidelines for the type of data to report and introducing follow-on surveys (National Academies of Sciences, Engineering, and Medicine, 2016[52]).

There are already ongoing efforts to harmonise knowledge transfer metrics across countries in Europe (Olivari, Jolly and Undseth, 2021[49]). Table 5.4 below shows the indicators used by the European Association of Knowledge Transfer professionals, for surveying technology transfer offices across Europe. This provides an exhaustive overview of typical indicators for mapping collaboration and intellectual property commercialisation. Some space agencies already follow this approach and are adopting some of these metrics.

The societal effects of information generated from satellite data

The deployment of large-scale government missions such as Global Navigation Satellite System (GNSS) constellations and GNSS-augmented missions in Europe, Asia and Oceania, as well as the European Copernicus programme, suggest that access to satellite data will continue to grow in the coming decades. As OECD Space Forum research suggests (OECD, 2019[61]; 2008[62]), many economic activities encompassing most sectors of the economy use a range of applications built upon satellite data in order to improve the information available to them in decision making. The benefits associated with the use of information generated from satellite data are broad and touch upon many areas of the economy.

Table 5.4. Selected general metrics used by technology transfer offices

Indicator	Description
Gross revenues from intellectual property rights (IPRs)	Overall revenues obtained by an agency through the concession of IPRs on its technologies (the aggregate include revenues from patent licenses as well as royalties and eventual income coming from the sale of equity in spin-off firms and/or start-ups linked to the transfer)
Gross revenues from patent licenses	Income earned by a firm for allowing its patented material to be used by another firm under the effects of a specific licence
Gross revenues from running royalties	Revenues tied to the turnover of a product sold (directly or indirectly) by a licensee
Number of active patent families	Number of patents families covered by the TTO's portfolio of active patents
Number of collaborative research agreements	Number of collaborative research agreements concluded by the TTO
Number of consultancy agreements	Number of consultancy agreements concluded by the TTO
Number of contract research agreements	Number of contract research agreements concluded by the TTO
Number of invention disclosures	An invention disclosure is a document that provides a complete description of something novel and non-obvious. It clarifies the characteristics of the novelty in such a manner that a third party could reproduce the invention described. The disclosure represents the first official recording of the invention and, if done properly, can establish an irrefutable date and scope of the invention
Number of licenses granted	Number of licenses granted and their nature (technology, software, research)
Number of patents granted	Number of patents the TTO has been granted
Number of priority patent applications	Number of new patent applications filed where the application is the first (or priority) application for a technology
Number of spin-off firms generated	Number of new spin-off firms generated, which operate using intellectual capital originated in the TTO. Spin-off firms count for their activity on a formal agreement with the TTO to use and exploit IPRs for the development of new products or services
Number of start-ups generated	Number of start-ups supported by the TTO. To note that start-ups do not count on IPR developed within the TTO to perform their activity and do not have any formal use agreement on specific technologies developed therein
Share of licensed patent families	Percentage of the total number patent families touched by the TTO's portfolio of active patents, which are currently licensed

Note: TTO=Technology transfer office
Source: Adapted from ASTP (2021[63]), "ASTP survey report on knowledge transfer activities in Europe", https://www.astp4kt.eu/about-us/kt-news/astp-survey-report-on-knowledge-transfer-activities-2020.html.

In the past five years, several initiatives, such as the GEOValue community, the NASA-funded VALUABLES Consortium and the Sentinel Benefits studies funded by the European Space Agency and the European Union, have contributed to producing more evidence in this area (GeoValue, 2021[65]; Valuables Consortium, 2021[66]; EARSC, 2021[67]). All these groups aim to collect and provide accessible case studies, community-accepted methodologies and peer-reviewed publications. In the United States, interagency discussions between key institutional operators and users of earth observation satellites, i.e. NASA, the United States Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA), are also contributing to exchanges of best practices. An international community of practitioners is forming, consisting of academia, national and international organisations, with the support of the Group on Earth Observations (GEO) and the OECD Space Forum, which hosted a GEOValue workshop in 2016 together with NASA and USGS.

The value chain approach to understanding the use of satellite data in society

The links between satellite data and better decisions can be studied using different approaches (Bernknopf et al., 2019[67]), including the concept of stylised value chains. The value chain begins with the transformation of unprocessed satellite data into information that is more readily usable, often through the development of data products and web applications (applications herein). Applications based on satellite data may be built by developers working in any sector operating in the downstream segment of the space economy as defined in Chapter 2. The rationale for devoting resources to the development of applications from satellite data may differ between sectors. Business enterprises seek to generate profit from the services their applications provide while government sector developers will often be motivated by the provision of public services. This section focuses on the societal effects of any satellite data application of the use in decision making and developed by any sector.

Illustrations of the value chain approach to understanding the societal effects of satellite data are commonplace. By way of example, a series of briefings on satellite data value chains are provided by a study conducted by the European Association of Remote Sensing Companies (EARSC et al., 2016[68]). Over 20 use cases outline the value chains of applications built upon data flowing from the European Union's Copernicus-Sentinel satellites. Examples of activities relying upon applications built upon satellite data include the management of farms, forests, floods and maritime navigation. The types of beneficiaries and the value generated at different stages of the value chain are assessed for each use case.

One such case study outlines the societal value of natural gas pipeline monitoring services in the Netherlands. The application developer supplements high-resolution commercial satellite data with Copernicus-Sentinel data in order to provide information services on the state of gas pipelines. The application developer is rewarded through the revenue it receives from selling its product to pipeline maintenance companies and to municipality governments. Through the use of the application, pipeline maintenance companies are better able to target their resources, conduct their activities more efficiently, and avoid costs in the process. And municipalities are better able to plan their expenditure on pipeline maintenance and ensure efforts are focused on priority areas that require the most attention. Ultimately, society benefits through the reduced risk of pipeline defects causing problems with the gas network, less disruption from unnecessary operations and maintenance, and a more efficient use of government revenues. Table 5.5 outlines the results of this case study including estimations of the monetary value of such positive effects across the different parts of the value chain.

Table 5.5. Pipeline infrastructure monitoring in the Netherlands

	Service provider	Primary users	Secondary beneficiaries	End use beneficiaries	Total
Actors	Private provider of InSAR maps	Infrastructure management companies	Municipalities	Wider public	n.a.
Benefits	Employment and revenues	Better maintenance and assets management	Better planning of maintenance activities	Household risk reduction and less disturbance from maintenance work	n.a.
Estimated annual benefits (2016)	EUR 0.5 million	EUR 11.1 million	EUR 3.3-6.6 million	n.a.	EUR 15.2-18.3 million

Note: n.a.= Not available.
Source: EARSC et al. (2016[68]), "Assessing the detailed economic benefits derived from Copernicus earth observation (EO) data with selected value chains: Pipeline infrastructure in the Netherlands", http://earsc.org/news/satellites-benefiting-citizens-the-case-of-pipeline-infrastructure-in-the-netherlands.

Using information theory to quantify the positive societal effects of satellite data

In general, the developers of applications directly benefit from the use of satellite data through the revenues generated by the provision of their services. The value of such transactions can be observed in the market prices paid by consumers – one way of calculating the total market value being to multiply the market price of a particular application by the quantity of application units sold. However, the remaining links in the value chain are characterised by non-market effects that are difficult to assign with a monetary value. While the value chain concept provides a framework for making explicit the links between satellite data and various forms of value, it does not provide a methodology for estimating monetary values for the non-market effects.

Consider, for example, weather forecasting, the producers of which are a major user group of satellite data. The value of satellite data in weather forecasts extends far beyond the revenues generated by the developers of weather applications as they market their products (Anderson et al., 2015[70]; Kull et al., 2021[71]). To focus on just one non-market effect, the information provided by weather forecasts enables decisions to be made that help society avoid costs that would have been incurred in the absence of the weather forecast. Examples of this scenario include early warning systems for flooding and heatwaves that enable preventative action to be taken and the costs associated with unmitigated disasters to be avoided (EUMETSAT, 2014[10]). There is no set of readily observable market transactions for the avoided costs of a natural disaster mitigated by decisions made due to the information provided by weather forecasts. So, the value of all the costs avoided in such an event must be estimated.

The non-market effects of the use of satellite data applications are often quantified using methods originating in an area of economics known as *information theory* (Macauley, 2005[72]; Pearlman et al., 2016[73]; Straub, Koontz and Loomis, 2019[74]). The theory proposes that data has little intrinsic value and only realises its full value once it is used as information (akin to the Copernicus-Sentinel satellite data informing decision making in pipeline maintenance in the Netherlands outlined above EARSC et al. (EARSC et al., 2016[68]). Furthermore, information developed from data is only likely to be required if some ambiguity in the potential outcomes of a decision exists. If there is no ambiguity, or uncertainty, then there would be no need for data to inform the decision-making process. The value of information (VOI) is therefore calculated as the difference between some measure of the outcomes associated with a decision based on the information under scrutiny and an estimate of the outcome that would have occurred had a decision been made without the information. It follows that information is higher in value when used to inform decisions that have important potential effects and are characterised by high uncertainty. In 2022, the European Space Agency commissioned a pilot study on the value of satellite observations (from the ESA Aeolus mission) to meteorological institutes, supported by the European Centre for Medium-Range Weather Forecasts (ECMWF).

Non-market effects of satellite-derived information

In practise, it is often useful to break down the value of information by the sector of the beneficiary. For example, the information generated from satellite data applications is often used by the business enterprise sector to improve decisions. The effects of better decision making in firms tends to be measured through gains in productivity (in whatever measure chosen) over counterfactual estimates of productivity in a scenario where satellite data does not exist or is of poorer quality. Often the magnitude of such effects reflects the degree to which a particular economic activity relies upon the information taken from satellite data applications – where the greater the uncertainty, the greater the reliance on the information – and the economic size of the particular area of the sector.

By way of example, applications based on data from GNSS have generated important positive productivity effects in road and maritime transportation industries by improving navigation and route planning. Productivity gains accrue to transportation companies as they are better able to plan routes in order to reduce their fuel consumption and optimise the time spent on delivery, thereby saving on expenses that would have occurred in absence of the satellite signals. But more efficient transport provision also has profound implications for every part of the economy that uses transportation services – which is to say all other economic activity involved in the manufacture and retailing of goods – through lower transport margins in the final prices of products. This suggests the value of this particular application extends far beyond that accruing to the developers of satellite signal-derived navigation aids and their immediate users. Table 5.6 provides estimations of the total value of information generated from the Global Positioning System (GPS) in business enterprises across a range of economic activities in the United States taken from a 2019 study by the Research Triangle Institute.

Table 5.6. Estimated benefits to business enterprises derived from the use of the Global Positioning System

Sector	Contribution of GPS (precision, navigation and timing)	Estimated cumulative monetary benefits, United States (1984-2017)
Telecommunications	• Improved reliability and bandwidth utilisation for wireless networks	USD 686 billion[1]
Telematics (fleet management, logistics)	• Improved vehicle dispatch • Navigation aids • Reduced use of fuel • Reduced labour costs	USD 325.2 billion
Surveying	• Increased accuracy of services • Reduced labour costs	USD 48.1 billion
Oil and gas	• Increased oil and gas yield • Increased accuracy • Enables deep water operations • Reduced labour costs	USD 45.9 billion
Electricity	• Improved system reliability and efficiency	USD 15.7 billion
Mining	• More efficient allocation and dispatch of equipment • Increased ore yield • Increased accuracy of site surveying and digging • Reduced labour costs	USD 12.3 billion
Agriculture	• Increased crop yield • Reduced use of seeds, fertilizer, water • Reduced labour costs	USD 5.8 billion

1. Valuated using willingness-to-pay.
Source: Based on O'Connor et al. (2019[74]), "Economic benefits of the Global Positioning System (GPS): Final report", https://www.rti.org/sites/default/files/gps_finalreport.pdf.

The business enterprise sector satellite data value chain is complex and contains many aspects that are difficult to quantify. But examples of the use of satellite data by the government sector also abound (ACIL Allen, 2015[22]; 2013[23]). The effects of improved public policy making as a result of the information developed from satellite data can be even more difficult to value monetarily than those apparent in the business enterprise sector due to their public good nature and sheer scale. Consider, for example, the role of government organisations in monitoring the environment and implementing policies to safeguard it – activities that generate many non-market effects and are regularly explored in the evaluation literature.

Satellites may carry atmospheric sensors capable of collecting data used to measure the level of air pollutants (CEOS, 2015[76]; Sullivan and Krupnick, 2018[77]). Once processed, this data may be developed into applications used to monitor air quality at local scales. Such information allows regulators to track pollution levels and provides evidence on whether or not they are below the level that regulations stipulate they must be. In some cases, sensors are able to monitor areas of just a few square kilometres which is smaller than most municipalities. The availability of the satellite data displaces some of the costs of constructing and maintaining an elaborate ground-based sensor network. In some cases, satellite-based measurements may even act as a substitute to in-situ sensors.

Perhaps the most profound effects of the decisions made using information generated from atmospheric sensors concern public health and safety. A 2018 Resources for the Future study suggests that the information provided by satellite-derived air pollution monitoring systems in the United States saves roughly 2 700 lives annually over and above an alternative scenario where monitoring does not occur (Sullivan and Krupnick, 2018[77]). The statistical value of the lives saved amounts to over USD 24 billion each year. In Europe, the value of avoided hospitalisations as a result of poor air quality warnings based on satellite data and sent to vulnerable people has been projected to accumulate to between EUR 8.3 million and EUR 21 million by 2035 (PwC, 2017[78]).

Strengthening space economy impact assessments

The sections above outline the current state of understanding with regards to the economic and social effects of the space economy across four major areas. Efforts in multiple countries and by international organisations mean the number and quality of publicly available assessments of the overall impact of space activities are increasing. However, space economy impact assessment remains a challenging field. Overall, the results of many impact assessments conducted in the sector tend not to be robust over time, comparable with other sectors or across countries.

The following analysis considers the field of space economy impact assessment as a whole. The major challenges associated with it are highlighted and various recommendations for changes are provided that may assist space economy analysts with achieving robust evaluations.

Key take-aways: Addressing the challenges associated with space economy impact assessment

The information required to conduct space economy impact assessments is generally not readily available and is often gathered on a case-by-case basis: This includes information developed from official economic statistics (as discussed in previous chapters in this *Handbook*), information on how space activities might relate to market outcomes, and information concerning how the use of particular space economy goods and services might affect society more broadly. Without regular and standardised reporting of the type of data required to create such information, space economy analysts must collect it themselves ex post and/or rely upon proxy measures. Furthermore, the effects of space activities are likely to vary in the time it takes for them to be realised. This means that information collected in the present may poorly represent the full value of space activities through time.

Information is particularly scarce with regards to the non-market effects of space activities: The most common approaches to evaluating the non-market effects outlined in this chapter include the estimation of replacement/substitution costs (e.g. aerial surveys), production factor costs (e.g. reduced labour costs) and cost avoidances. Other approaches, such as contingent valuation (willingness-to-pay) have also been used. Estimating this type of information and developing the adequate level of data can be a long, complex and costly exercise. For example, a 2018 study estimating the value of GPS to the United States lasted three years and combined insights from almost 200 experts (O'Connor et al., 2019[75]).

As a result, space economy impact assessments, tend to be highly subjective and lack coherence with other areas: Results are often heavily reliant on case studies and expert opinion which can make it difficult to test them for validity and compare with other areas. Robust counterfactuals are not always developed, which increases the risk that the effects under assessment are poorly estimated. For example, when estimating the additional revenues from a new satellite data derived service, only the revenues that can be attributed to satellite data in isolation of all other data sources should be counted.

Countries may consider the following recommendations

Develop overall results-oriented evaluation frameworks supported by adequate resources: Countries are encouraged to develop frameworks that align policy objectives with indicator needs. In this way, there is more clarity about *what* to measure and a better guarantee that the ensuing assessment informs policy decisions. However, expanded data collection requires substantial resources. In order to leverage these efforts, the use of internationally recognised definitions and standard indicators makes it possible to compare findings and outcomes across agencies, sectors and countries. Although there is a push for the increasing quantification of indicators, it is also important to recognise that not all aspects can be treated in a quantitative way. Qualitative impacts of space activities and programmes should be included in the analysis and accounted for in the most objective and systematic manner possible.

Reinforce efforts in the collection of space economy statistics to improve impact assessments: Many countries have made great progress in economic measurement, notably by estimating contributions of the space economy to national GDP or supporting the collection of economic data from industry. However, reporting on the effects of participation in space programmes can be challenging for both smaller and larger organisations due to the difficulties of estimating counterfactuals. In order to decrease reporting burdens placed on participating organisations, few space agencies request data from their contractors in the first place and some organisations may have little obligation or incentives to provide information. Annual surveys of participants in space programmes from all sectors will systematically capture longer-term effects.

Document and share methodologies widely: Ensuring that methodological choices are transparent and well documented should enable reproducibility of results, while improvements in evaluation design could make findings more persuasive to decision makers. The OECD Space Forum will continue to work with ministries, space agencies, other administrations, academia, industry associations, business enterprises, and other international organisations, to better measure the impacts of space investments on society and the economy.

Annex 5.A. Space economy evaluation studies

The number of evaluations and impact assessments on space activities keep growing across OECD countries and beyond, as governmental agencies try to track the socio-economic effects of space programmes. A few of these studies are referenced below for information purposes. The proposed list is far from exhaustive.

Annex Table 5.A.1. Selected evaluations and impact assessments of space activities

Country/Region	Organisation	Selected publicly available reports conducted internally or commissioned
Australia	Department of Industry, Innovation, Climate change, Research and Tertiary Education	Augmented global navigation satellite systems (ACIL Allen, 2013[23]) Earth and marine observations ((Nous Group, 2019[78])
	Geoscience Australia/FrontierSI	Geospatial information: (ACIL Tasman, 2008[79]) Earth observation: (ACIL Tasman, 2010[80]; ACIL Allen, 2015[22]; Deloitte Access Economics, 2021[81])
Canada	Canadian Space Agency	Space sector: (Euroconsult, 2015[82]) and State of the Canadian Space Sector reports Canada-ESA Cooperation agreement: Canadian Space Agency (2009)
Denmark	Danish Agency for Science, Technology and Innovation	Space sector: (London Economics and Rambøll Management Consulting, 2016[83]) ESA membership: (Ramboll Management Consulting, 2008[29])
Europe	European Space Agency	ESA programmes: (Bramshill Consultancy Ltd, 1999[84]; BETA, 1991[27]; Euroconsult, 1985[85]) Ground systems engineering and operations: (PwC, 2019[86]) Science: (PwC, 2019[7]), Earth observation: (PwC, 2006[88]; 2019[21]; EARSC et al., 2018[89]; 2016[90]; 2016[91]; 2015[92]) Satellite communications: (Euroconsult, 2019[24]; Euroconsult et al., 2019[93]; Eftec, 2013[20]) Launchers (PwC, 2014[17]; Bramshill Consultancy Ltd, 2001[93]) International Space Station: (PwC, 2016[94]) Space situational awareness: (PwC, 2016[95])
	European Space Agency facilities	ESTEC, The Netherlands: (General Technology Systems, 1991[96]) ESOC, Germany: (Accenture, 2008[97])
	Eumetsat	EPS/Metop 2: (EUMETSAT, 2014[10])
	European Union	EU space activities: (Booz & Company, 2014[98]) Earth observation/Copernicus: (European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, 2016[99]; 2019[100]; 2017[77]; Booz & Company, 2011[8]) GNSS/Galileo-EGNOS: (PwC, 2001[103])
France	INSEE, French Guiana	Kourou Space Centre: (INSEE, 2017[102]) and similar report in 2009
Italy	Italian Space Agency (ASI) and Università di Milano	Cost-benefit analysis highlighting the role of public policies in the space sector (Università di Milano and Agenzia Spaziale Italiana, 2021[12])
India	Indian Space Research Organisation (ISRO)	Cost-benefit analysis of the Indian space programme (Sridhara Murthi, Sankar and Madhusudhan, 2007[11])
Netherlands	Ministry of Economic Affairs and Climate Policy	Space programmes: (Dialogic and Decisio, 2016[42]; Dialogic, 2020[103]) Space research: (Dialogic, 2021[104])

Country/Region	Organisation	Selected publicly available reports conducted internally or commissioned
Norway	Norwegian Space Agency	Space programmes: (PwC, 2012[105]) ESA membership (Norwegian Space Agency, 2018[28]) and similar reports ESA voluntary programmes and national programme: (Menon Economics, 2016[108]) ESA science programme: (Høegh Berdal, 2018[25]) Copernicus/Galileo/EGNOS membership: Oslo Economics (2019[107])
Portugal	Foundation for Science and Technology, FCT	ESA membership: (Clama Consulting, 2011[30])
Sweden	Swedish Space Agency	National earth observation programme: (Technopolis, 2013[108])
Switzerland	Swiss Space Office	Institutional R&D funding instruments: (Barjak, Bill and Samuel, 2015[26])
United Kingdom	UK Space Agency	Space sector: (London Economics, 2015[18]) ESA ARTES programme: (Technopolis, 2019[31]) National programmes: (Technopolis, 2018[109]) Spillovers: (London Economics, 2018[32])
	Innovate UK	Earth observation: (London Economics, 2018[110])
United States	Bureau of Economic Analysis	US space economy: (Highfill, Jouard and Franks, 2020[111])
	NASA	NASA programmes (Tauri Group, 2013[112]; Highfill and MacDonald, 2022[45]; Voorhees Center, 2020[46]) Earth observation: (Macauley, 2005[71]), (Bernknopf et al., 2018[113]), (Bernkopf et al., 2019[114]), (Sullivan and Krupnick, 2018[76]) Life sciences R&D: (Hertzfeld, 1998[115])
	NASA/NOAA	Space weather: (Teisberg, Weiher and Bardach, 2000[116])
	NASA facilities	Kennedy Space Center, Florida: (Florida Tech, 2022[19]) and previous years Marshall Space Center, Alabama: (NASA, 2017[117]; 2018[44]) and previous years
	Federal Aviation Authority	Commercial space transportation: (FAA, 2010[118]) and similar reports in 2001, 2003, 2006
	Office of Science and Technology Policy/USGS	Earth observation/Landsat: (Loomis et al., 2015[119]; Miller et al., 2013[120]; Straub, Koontz and Loomis, 2019[73]; NGAC, 2014[121])
	National Institute of Standards and Technology	GPS: (O'Connor et al., 2019[74])
International	International Space Exploration Coordination Group (ISECG)	Space exploration: (ISECG, 2013[122])
	International Space Station Program Science Forum (ASI, CSA, ESA, JAXA, ROSCOSMOS)	International Space Station: (ISS Program Science Forum, 2019[123]) and previous editions in 2015 and 2012

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