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SPACE TECHNOLOGY TRANSFERS AND THEIR COMMERCIALISATION

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Space Technology Transfers and their Commercialisation

This paper examines space technology transfers and their commercialisation, focussing on transfers from publicly funded space programmes to different sectors of the economy. It notably compares practices from Europe, North America and Asia for the first time. It identifies the conditions for enabling successful space technology transfers, as well as the most common channels for commercialisation. The paper also reviews methodological issues in measuring and assessing the benefits of transfers, and provides recommendations to develop improved and internationally comparable evidence. The analysis benefits from original content and endorsement from some of the most active space agencies in OECD countries and beyond.

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- OECD Space Forum Workshop on "Linking Policies and Indicators: A Fresh Look", OECD, Paris, held on 2 October 2019;
- Space Agencies Technology Transfer Officers (SATTO) group's 'Meeting on Technology Transfers from Space' – organised by the SATTO Group and held at the premises of the International Space University (ISU), in Strasbourg, on 21 February 2019;
- OECD Space Forum Workshop on "the Transformation of the Space Industry: Linking Innovation and Procurement", OECD, Paris, 27 April 2018;
- OECD Space Forum / SATTO joint Workshop on "Technology transfer and commercialisation (TTC) from space programmes: enabling conditions, processes and economic impacts", held at the French space agency CNES on 21 June 2017.

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Table of contents

Tables

Figures

Boxes

Executive Summary

This paper examines space technology transfers and their commercialisation, focussing on transfers from publicly-funded programmes to different sectors of the economy, comparing practices from Europe, North America and Asia for the first time. It identifies the conditions for enabling successful space technology transfers, as well as the most common channels for commercialisation. The paper also reviews methodological issues in measuring and assessing the benefits of transfers. Finally it provides recommendations to develop improved and internationally comparable evidence.

Defining space technology transfers: Within the specific context of this paper, space technological transfers and commercialisation (TTCs) are defined as the movement of know-how, skills, technical knowledge, procedures, methods, expertise or technologies from one public research organisation (e.g. space agency, space research centre) to another organisation (e.g. a firm), generating value and economic development outside the space sector. This narrow definition involves the adoption of a specific knowledge of space technologies, initially developed thanks to public investments, enabling the recipient to eventually develop new or improved processes, products or services.

Space technology transfers to different sectors of the economy have evolved from being primarily by-products of space research, to routine means of multiplying the value of the original R&D investment. Many space technologies originate in the context of government-funded space programmes. Technological transfer has therefore often been part of routine objectives from the onset of space activities, 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).

Despite this decades-long focus on technological transfers, processes through which TTCs in the space sector occur are often still poorly defined and understood. While there are hundreds of case studies describing successful technology transfers, relatively few examples of systematic collection of socio-economic impacts exist. Although there is more knowledge now on the type of space programmes that generate transfers and common recipient sectors, it has proven challenging to detect and measure their socio-economic impacts.

The technology transfer process is not automatic and depends on several concurrent factors and strategic decisions taken by the actors involved. Specific drivers can affect the likelihood that a technology transfer takes place, as well as the channels through which transfers usually occur, and, ultimately, the realisation of positive impacts. Some of these impacts have been qualitatively documented in studies over the years. However, more should be done to improve the tracking of outcomes, data collection processes and analysis of existing data, while promoting comparability and learning from other sectors.

Several channels for the transfer of technologies produced by public space research organisations exist. Space TTCs mostly occur through:

- Collaborative research through participation by e.g. academia or private firms in government-led programmes and projects (with different funding arrangements, often including some degree of firm co-investment);
- Commercialisation of government intellectual property, typically through the licensing of patents or firm creation;
- Other channels, including labour mobility, scientific publications, facility sharing, conferences, etc.

Measuring trends in TTCs and assessing their benefits is complex. Some of the main challenges hindering evaluation and assessment efforts include:

- Time lags between the initial investment and the realised outcomes.
- Limited institutional memory of firms, in particular in small- and medium-sized enterprises (SMEs).
- A predominance of self-reported outcomes, typically via ad-hoc surveys, which means data are not always reliable – organisations may make mistakes or inflate results.
- Problems of causality and quantification, particularly in terms of the attribution of observed economic results to specific programmes, projects or even government space funding.

In OECD countries, policy frameworks to promote technology transfers build on regulatory, financial and "soft" instruments. These policies have three main objectives: defining clear regulatory frameworks, facilitating the diffusion of technologies produced by research organisations in the market, and promoting science-industry co-creation. Space agencies use a combination of regulatory, financial and soft policy instruments to support the transfer and commercialisation of space technologies, examples of which include:

- Regulatory instruments: definition of intellectual property rights arrangements and adoption of patenting and licensing strategies
- Financial instruments: provision of subsidies for innovation and R&D, public-private co-funding schemes, start-up programmes, as well as funding of infrastructures.
- "Soft" instruments: creating networking and training opportunities involving the private sector

Supporting the development of comparable metrics across countries represents one way to improve evidence on the benefits of transfer and commercialisation of space technologies. Some space and non-space organisations already propose a number of metrics for their own uses (e.g. licensing revenues), but improved international comparability would improve the evidence base and benefit all stakeholders.

Acronyms

AIS	ActInSpace
ASI	Agenzia Spaziale Italiana
BIC	Business Incubation Centre
CSA	Canadian Space Agency
CNES	Centre National d'Etudes Spatiales
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EO	Earth observation
ESA	European Space Agency
GSTP	General Support Technology Programme
ICT	Information and Communication Technology
IP	Intellectual Property
IPR	Intellectual property rights
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
KARI	Korea Aerospace Research Institute
MPE	Max Planck Institute for Extra-terrestrial Physics
NASA	National Aeronautics and Space Administration
NCR	National Research Council
NOSA	Norwegian Space Agency
NSO	Netherlands Space Office,
NSTP	National Space Technology Programme
OECD	Organisation for Economic Co-operation and Development
RAL	Rutherford Appleton Laboratory
R&D	Research and Development
SATTO	Group of Space Agencies' Technology Transfer Officers
SBIR	Small Business Innovation Research
S&T	Science and Technology

SME	Small and medium-sized enterprise
SSO	Swiss Space Office,
STEAR	Strategic Technologies in Automation and Robotics
STI	Science, Technology and Innovation
STTR	Small Business Technology Transfer
SXS	Space Exchange Switzerland
TTC	Technology Transfer and Commercialisation
TTO	Technology Transfer Office
TTPO	Technology Transfer Programme Office
UKSA	United Kingdom Space Agency

1. Concepts and definitions

1.1. Rationale for the paper

Technology transfers and commercialisation (TTC) is the process through which a form of knowledge originating in one organisational setting finds an application in another organisational setting. This knowledge can take the shape of know-how, skills, technical information, procedures, methods, expertise or technology (Roessner, 2000[1]). The concept of "know-how" is comprised itself of a complex set of scientific principles, strategies, problem-solving capacity, workers' expertise, and organisational practices (Bach, Cohendet and Schenk, 2002[2]).

Technology transfers have grown in recent decades as an important source of innovation, growth and job creation, and the space sector is no exception. There is evidence - some well-founded, some anecdotal - that the socio-economic benefits of space technology transfer and commercialisation can be significant not only in the space sector itself, but also in other sectors of the economy.

This has led governments in OECD and other space-faring countries to encourage the transfer and commercialisation of space technology, often publicly-funded, through a wide and diverse range of measures. To a large extent, however, public policy is still discovering how best to support space TTCs. This is due to a range of challenges hampering effective TTC policymaking. This includes the absence of broad agreement on a definition of what should constitutes TTCs in the space context, a lack of systematically researched evidence on what support measures and tools produce the desired benefits, the lack in many cases of a workable general framework for supporting technology transfers, and the relative scarcity of regular evaluations on the effectiveness of support programmes. As a result of these shortcomings there is often insufficient information, data and knowledge guiding public decision making in this field.

This paper examines the transfer and commercialisation of space technologies from public research organisations and projects to various sectors of the economy, building on experiences from North America, Europe and Asia. This paper aims to support the exchange of best practices and encourage mutual learning to eventually facilitate better tracking of the impacts of space technology transfers and commercialisation, particularly the ones that result from publicly funded space programmes.

This paper is organised as follows: Section 1 reviews relevant concepts and definitions. Section 2 focuses on the determinants and channels through which space technologies usually diffuse to other sectors. Section 3 discusses issues in tracking transfers and analysing their benefits. Section 4 highlights a possible way forward to improve international comparability.

1.2. Defining technology transfers and commercialisation

Technology transfers are seen as a strategic tool to stimulate innovation, by means of industry-science collaborations (OECD, 2016[3]; 2013[4]; 2019[5]). Studying these transfer mechanisms is important to understand the path these ideas and knowledge take from inception – often by governments, research institutions, but also private actors – to the their transfer to other sectors and/or concrete application. But it is a complex process that depends upon a range of different factors, including the technology itself, the R&D programme, the nature of recipient actors, as well as the institutional and regulatory frameworks in place.

Within the specific context of this paper, space technological transfers and commercialisation (TTCs) are defined as the movement of know-how, skills, technical knowledge, procedures, methods, expertise or technologies from one public research organisation (e.g. space agency, space research centre) to another organisation (e.g. a firm), generating value and economic development outside the space sector. This narrow definition involves the adoption of a specific knowledge or space technologies, initially developed thanks to public investments, enabling the recipient to eventually develop new or improved processes, products or services.

There are also different types of technological transfers within the space community itself (e.g. universities involved in space programmes commercialising their research), between firms (e.g. transfers between multinationals and their affiliates), and between countries (i.e. international technological transfers, as part of space cooperation programmes or foreign direct investments schemes). These other types of technology transfers are not directly within the scope of this paper and could be the subject of future research.

The process of technology transfer, as analysed here, entails a phase of technology commercialisation, which can take place in various ways. The process of commercialisation expresses the further valorisation of the technology transferred by the actors receiving it. Their role is to identify a market opportunity and eventually develop and advertise new products or services. This requires testing the technology in specific applications, adapting and upgrading it to respond to the needs of the target market and getting a market value out of the process.

In the space sector, the term "spin-off" is sometimes used as a synonym for technology transfer. A number of space agencies (e.g. NASA, CSA, DLR) define "spin-offs" as technologies initially created to meet the agency's objectives, which incorporated internal expertise, and then were commercialised as a product or service to serve other uses outside of the agency. At NASA, the creation of transfers spurred from agency-funded research is encouraged via partnerships with other actors, through licensing, funding agreements, assistance from experts and the use of NASA facilities (OECD, 2016[6]). However, in the context of this paper, spin-offs refer to a technology transfer process achieved through the creation of a new firm (Verbano and Venturini, 2012[7]). The OECD generally identifies spin-offs as "small, new technology-based firms whose intellectual capital originated in universities or other public research organisations" (OECD, 2016[6]). This is in line with the definition in the knowledge transfer field: a spin-off is a firm expressly established to develop or exploit intellectual property (IP) created by a public research organisation and with a formal contractual relationship for the use of this IP. From this perspective, the number of spin-offs produced within an economy can be a good indicator of its ability to commercialise the outputs of public sector investments in research. This general definition of spin-offs, i.e. a small and new technology-based firm, will be used in the paper.

1.3. The importance of "spin-ins" in space innovation

In this paper, the space sector is predominantly seen as a source of knowledge and technologies to be transferred. However, the space sector is a large user of external, or "spin-in", technologies. Spin-ins often play an instrumental role in initiating the virtuous cycle that leads to OECD TTCs and the generation of socio-economic benefits. This section briefly introduces the spin-in concept, which could be developed further in future work on space TTCs.

The first generation of launchers and satellites are clear outcomes of technology spin-ins, as their development strongly benefited from the latest technological advancements in sectors like aeronautics, missile defence and general electronics. The ICT sector is also an important source of transfers, with many information technologies feeding into space applications. Human space exploration has been an opportunity to conduct life science experiments in space, leading to a number of spin-in of bio-medical, testing instruments and devices. The joint OECD / SATTO workshop held in Paris in 2017 particularly recognised the importance of the International Space Station for testing terrestrial technologies now used in space missions. In addition, spin-ins make it possible to generate more complex space solutions and missions, which may result in new transfers outside the space sector, as described in the Italian example in Box 1.1. The INNOspace Masters is an annual innovation competition organised by the German Space Agency, in collaboration with the European Space agency which leads to technology transfers from the space sector, as well as many spin-ins (DLR, 2018[8]).

Space programmes work as integrators of terrestrial technologies, typically by adapting their characteristics and designs to the challenges of the space environment (London Economics, 2018[9]). This is facilitated by the typical configuration of space R&D programmes, involving large networks of multidisciplinary teams working together for long periods of time. This environment creates a unique context to catalyse long-term knowledge accumulation that can later find an application in other domains. This process of adaptation generates new technologies, which can then "return to earth" with a much wider portfolio of potential applications (Simpson, 2010[10]).

Box 1.1. The role of spin-ins: an example from the Italian Microfluidics project

Verbano and Venturini (2012[7]) analysed the organisational aspects and determinants of technology transfers in Italy. They investigated two different transfer cases supported by the National Research Council (NRC) and the Italian Space Agency (ASI) applying space technology for different purposes – i.e. the Microfluidics and the Mach-Zehnder projects. Both of these projects involved technologies developed in a non-space sector, which were then applied and improved in space, and finally adapted and patented for commercial uses outside the space sector, following a sort of "earth-space-earth" path (Verbano and Venturini, 2012[7]).

In the Microfluidics project, ASI asked a firm to develop a micro-propulsion system to control and regulate a satellite's tilt for the space mission Miosat. The ASI satellite experienced orbital disturbances but its main propulsion system was unable to readjust correctly. The firm developed a new micro-propulsion system able to resolve the issue experienced by ASI by using microelectromechanical (MEMS) technology originating in ICT and software applications. This new technology was then transferred to the biomedical sector and applied by a medium-size firm operating in healthcare and membrane filtration. The transfer was driven by a specific request of the recipient and co-ordinated by the National Research Council (NRC).

The main effects generated were an increase in technological and organisational knowledge, as well as in reputation, for the final recipient as well as for the initial firm, based on interactions with ASI and the NRC.

Source: Verbano, C. and K. Venturini (2012[7]) "Technology transfer in the Italian space industry: Organisational issues and determinants".

The processes of spin-ins and technology transfers originating from the space sector are highly interdependent. When technologies from other sectors enter the space sector they either exit it without any modifications, or are improved and redesigned before finding new applications outside of space. Bach, Cohendet and Schenk (2002[2]) describe this process by introducing the concepts of short and long loops. They assume three classical types (or levels) of knowledge: scientific knowledge, technological knowledge and knowledge incorporated in existing products, components, devices, software, etc. Short loops take place when knowledge spins in and off at the same level (i.e. scientific, technological or product level). In contrast, long loops occur when knowledge spins in at one level, is transformed at another level, and then spins off. For space, they see three possible types of long loops: scientific level to technological level, scientific level to product level, and technological level to product level (Bach, Cohendet and Schenk, 2002[2]).

Spin-ins remain important for innovation in the space sector. As the space industry integrates advances in information technologies, manufacturing (e.g. 3-D printing, miniaturisation) and artificial intelligence, further space innovations are regularly triggered, as the development of very small satellites has demonstrated (OECD, 2019[11]).

2. Determinants and channels of space technology transfer

This section identifies and maps different determinants and channels of technology transfers and commercialisation in the space sector.

2.1. Determinants for space technology transfers

The space sector is part of a much wider science and innovation ecosystem, with differing, sometimes competing technology transfer and commercialisation schemes even at national levels. It is not uncommon that space agencies, ministries and other administrations involved in space technology transfers link with othper technology transfers offices (TTOs) in universities and the private sector. Typical policy frameworks for these transfers in OECD countries have three main objectives (Guimón and Paunov, 2019[12]):

- Provide a regulatory framework that mitigates information asymmetries to ensure legal certainty and create incentives, by defining clear rules for property rights transmission and making transfers an integrated goal of procurement mechanisms;
- Facilitate the penetration and uptake of technologies produced by public research organisations in the market: This can be achieved by combining financial instruments and mentoring/networking mechanisms, and by providing specific lines of support at different stages of the technology transfer life cycle. TTOs are crucial “matchmakers”, coupling the “supply” of technologies with the “demands” from the market and society;
- Encourage science-industry co-creation, which is “process of the joint production of innovation between industry, research and possibly other stakeholders, notably civil society” (Kreiling and Paunov, 2021[13])]. It is often based on medium-to-long term relationships between science and industry. Standard strategies include the provision of conditional grants, requiring the creation of consortia between science and industry partners, for example via collaborative and contract research, as well as consulting agreements, or public-private partnerships, such as joint laboratories between science and industry (Guimón, 2019[13]).

Different types of policy instruments are used to reach these objectives, many of which are outside the realm of space agencies. Table 2.1 provides an overview of some of the most common instruments to support technology transfers, including regulatory, financial and “soft” instruments. Many of the "soft" instruments are very important and effective (e.g. workshops, training programmes), however it is often complex to measure the value created by such programmes.

Table 2.1. Selected policy instruments supporting technology transfers

Type of policy instrument	Description
Regulatory instruments	
IP rights regime	Ownership of IP resulting from public-private research. Allocation of IP revenue from publicly funded research
Open access and open data provisions	Requirements to provide in open access results of publicly funded research openly and to make the data available
Regulation of firms ("spin-offs") founded by researchers and students	Conditions for parent organisation's involvement as shareholder, distribution of revenue, implications for employees' salaries, contractual possibilities for other staff to participate in spin-offs, etc.
Financial instruments	
R&D and innovation subsidies or grants	Direct financing of collaborative projects, ranging from generic to mission-oriented calls, and from small scale, challenge-driven competitions to large consortia.
Tax incentives	Tax credits (i.e. indirect financial instruments) for firms that engage in collaborative research or purchase services from research organisations.
Grants for IP applications	Grants covering the costs of registration in patent offices, as well as the protection of other forms of IP (e.g. trademarks, copyright, industrial designs) to encourage researchers to disclose and commercialise their intellectual property.
Financial support to host industry researchers	Financial support schemes for research organisations to host industry researchers temporarily.
Innovation vouchers	Financial support for firms (especially small and medium enterprises (SMEs)) to purchase R&D services from research organisations.
Public-private joint research centres	Joint research centres co-funded by the public sector and a firm. Sometimes called collaborative, co-created, or competence centres.
Performance based-funding	Funding targeting universities and government research organisations, rewarding linkages with industry, e.g. providing earmarked funding based on number of contracts with industry, IP licences, spin-off firms, etc.
Funding of infrastructures and intermediaries	E.g. technology transfer offices (TTOs), science parks, clusters and business incubators and accelerators.
Public procurement	Sourcing of goods and services by public authorities from universities, public research institutions (PRIs) and private firms
"Soft" instruments	
Training programmes	Training delivered by government agencies covering different aspects of knowledge transfer
Networking	Events, workshops, and fairs where firms can express their technology needs and scientists can present the results of their research.
Collective road mapping and foresight exercises	Initiatives bringing together actors from business and research organisations to identify technological opportunities and priorities for future research and technology development.

Source: Adapted from OECD (2019[14])"Policy instruments and policy mixes for knowledge transfer", http://dx.doi.org/10.1787/d8dd671d-en.

A technology transfer can be complex and depends on several concurrent factors and strategic decisions taken by the different actors involved in the process. The nature of the technologies concerned, their maturity or technological readiness levels, as well as the characteristics and level of interaction among recipients and grantors of technology and know-how, are all critical factors that may affect the likelihood of the transfer taking place. Additionally, collaboration platforms and dedicated infrastructure, the presence and design of institutional frameworks and legal arrangements between space and non-space actors, as well as the intensity and frequency of interactions, can all play a role in a successful transfer.

There are four main determinants for technology transfer, based on the nature and characteristics of the initial R&D programmes and the transfer recipients:

- **Objectives of the initial R&D programme**: Space programmes developed for a specific mission, that also contain a "demand-pull" component are the most likely to stimulate the transfer of technologies beyond their initial space R&D objectives. A programme can be considered demand-pull when its goals are aligned with the needs of targeted communities (OECD, 2017[15]). The closer the gap between the design of the programme and its goals on one side, and the needs of the potential users' community on the other, the higher the probability of interactions and transfers of technologies (e.g. imagery sensors useful for both a space mission and for medical applications) (Amesse, Cohendet and Poirier, 2002[16])..

- **Technological content of the programme**: The characteristics of the technologies embodied in the originating space programme are highly correlated with the path and the channels through which a potential technology transfer might take place (Raykun, 1996[17]). The most important features of the technologies in this sense are their versatility, their maturity (emerging or more advanced) and the extent to which they are generic or specific. As a general rule, a technology transfer is more likely if the technology is versatile (e.g. semiconductor R&D transferred from the Japanese space programme (Venturini, Verbano and Matsumoto, 2013[18])) and its technology readiness levels are not too low at the beginning of the initial R&D programme (Bach, Cohendet and Schenk, 2002[2]).
- **Nature of the network of recipient actors:** The characteristics of the network of actors involved in a R&D programme matter, as the intensity of the linkages among them can pave the way for the creation of channels for technology diffusion (Cummings and Teng, 2003[19]). In other words, the connections and their strength are fundamental for diffusing innovative ideas. The exchange of information and knowledge among actors, their coordination and reciprocal trust considerably affect the diffusion of new technologies coming from a space programme (ESA, 2019[20]). The continuous exchanges among potential technology recipients accelerate the processes of technological validation as well as the discovery of new potential and unexpected areas of application. The strategic and commercialisation abilities of each actor plays a key role (Petroni, Venturini and Santini, 2010[21]).
- **Internal organisational structure of the recipient actor:** This is particularly relevant for organisations working under complex decision-making systems (e.g. large space agencies and firms). Areas of work with completely different tasks can benefit from the same technology by finding their own context-specific application depending on the internal structure of the organisation (Cusumano and Elenkov, 1994[22]). Therefore, the flexibility of each actor to adapt and welcome new technologies is important (Susanty, Handayani and Henrawan, 2012[23]).

These four determinants are important for technology transfers and commercialisation from space programmes.

2.2. Channels for space technology transfers

Depending on the nature of the initial public R&D programme, transfers occur through different channels. Table 2.2 presents the most common mechanisms for knowledge transfers, categorised in two main groups (OECD, 2019[5]):

- Formal channels*:* processes involving detailed transactions among the research and industry counterparts, such as signed contracts and agreements that can be tracked and counted.
- Informal channels*:* processes involving less traceable agreements among the parts involved, in the form of tacit transfers.

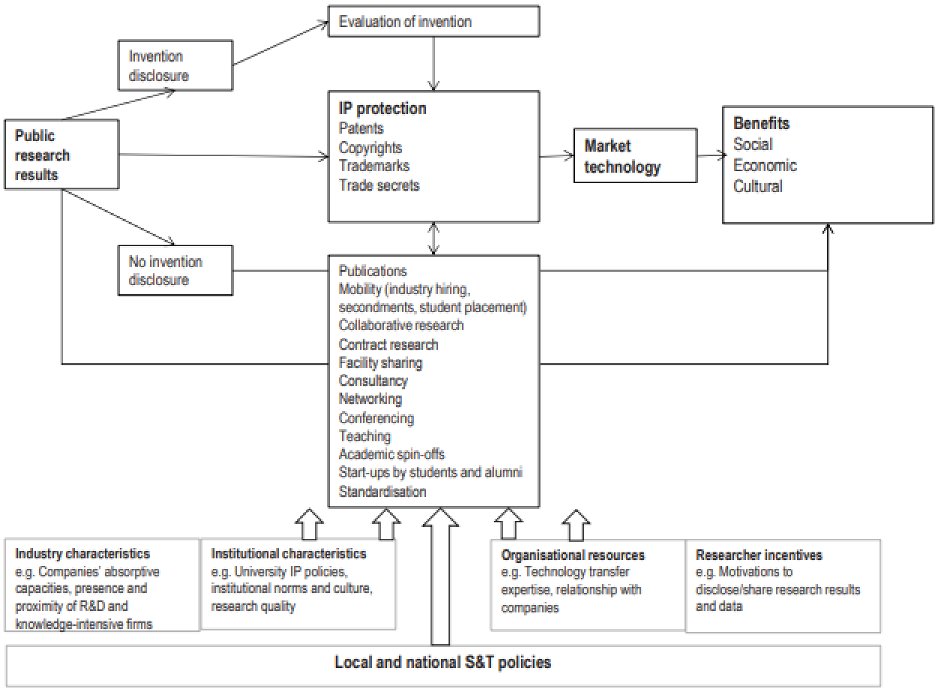
Table 2.2. Main channels for public R&D technology transfer to other actors: formal and informal mechanisms

Channels		Description
Formal	Collaborative research	Small and big research projects carried out jointly by public and private actors, with different funding models (they can be fully or partially funded by industry). This also includes public-private co-publications.
	Contract research	Specific channel where a private actor commissions to a public research organisation a research project with the goal to generate knowledge or a new technology necessary to solve a problem.
	Academic consultancy	Provision of advisory services by a public research institution to industry counterparts, to support the development of new technologies/knowledge.
	Intellectual property rights transactions	The licensing and selling of IP generated by academic and public organisations to industry.
	Research and labour mobility	Mobility of personnel between research institutions and firms. This may involve industry hiring or training workers, student placements, personnel intersectoral mobility, etc.
Informal	Scientific publications	Widely used, in particular by universities, to transfer knowledge. To be distinguished from joint publications between public and private actors, which belongs in the collaboration category.
	Conferencing and networking	Informal interactions between researchers and industry actors in the context of conferences and similar events. Knowledge is transmitted in various ways, through presentations, demonstrations, informal trainings, at a relatively low cost.
	Networking facilitated by geographic proximity	Informal interactions between public research staff and industry researchers, facilitated by locating science parks near university campuses, or firms' laboratories within university campuses.
	Facility sharing	Public and private actors sharing of infrastructure, e.g. laboratories and equipment, typically owned by research organisations.
	Courses and continuing education	Trainings offered by research organisations, often universities, to private actors, as well as university lectures by industry representatives

Source: Adapted from OECD (2019[5]), *University-Industry Collaboration - New Evidence and Policy Options*, https://doi.org/10.1787/e9c1e648-en.

A technology or know-how can be shared via diverse types of channels with different degrees of formality (Figure 2.1). Disclosing an innovation might require formal contractual arrangements, such as patenting and licensing contracts, or lead to the creation of spin-off firms. Knowledge transfers may take place through "softer" and less formal channels, such as scientific publications, collaborative research or secondments (OECD/Eurostat, 2018[24]). Other factors also play a role, such as the characteristics of participating actors, the existence of intellectual property rights' regulations and science, technology and innovation (STI) policies, the availability of incentives given to research institutions to disclose their inventions and the availability of resources and expertise (OECD, 2013[25]).

Figure 2.1. The technology transfer process in public R&D



Source: OECD (2013[25]), *Commercialising Public Research. New Trends and Strategies*, https://dx.doi.org/10.1787/9789264193321-en.

The formalisation of technology transfer and commercialisation activities in space agencies depends on the size of the agency and the nature of the agency's tasks. Large, R&D-performing and procuring agencies, such as NASA, ESA or JAXA, have dedicated technological transfer offices and/or industrial department offices. In the case of NASA, individual centres also have their own technological transfer office (e.g. JPL, Marshall, Glenn Centres). ESA's Technology Transfer and Business Incubation Programme Office (TTPO) uses a network of technology brokers across Europe (currently 22). In JAXA, the Business Development and Industrial Relations Department is responsible for promoting the development and expansion of the aerospace industry by supporting the industry's R&D activities, introducing the use of technology to non-aerospace firms and promoting the use of non-aerospace technology in the aerospace sector ("spin-in"). Smaller agencies may have a unit or a technology transfer officer dedicated to technology marketing (e.g. Intellectual Property Management and Technology Transfer in the Canadian Space Agency). In some cases, TTC activities may also include the provision of business development services (e.g. KARI's STAR Exploration programme, DLR's Technology Marketing Office, ESA BICs).

Space R&D broadly follows the same channels for technology transfers as other types of public R&D, with some specificities. For instance, patenting is less common in the space sector as compared to other sectors, because of confidentiality precedence for some dual-use space systems and because some products cater to very small and specialised markets making patent protection strategically less attractive (National Academies of Sciences, Engineering, and Medicine, 2016[26]), (OECD, 2014[27]).

Space R&D, especially in the domains of spaceflight and on-orbit applications (e.g. launch, earth observation, space exploration) has some specific characteristics that may affect how technology is transferred:

- Some space activities are closely associated with military programmes, where the transfer of technologies and knowledge is strictly controlled and regulated.

- Space R&D projects are often long-lasting and collaborative: Projects in space science and space exploration involve multiple public and private actors, sometimes from different countries, and may last several years, which affects technology transfers both within and outside of the space sector (see Box 2.1).
- Testing is an important part of space technology development and a potential source of technology transfer. In many cases, government testing facilities, such as wind tunnels, vacuum chambers, cryogenic chambers, etc., are important for prototype development and flight qualification. Bigger firms may have certain in-house capabilities, but small- and medium-sized enterprises are big users of government facilities and services.
- Finally, space agency practices differ concerning the ownership of space R&D conducted with universities and the private sector. As an illustration, NASA procures some USD 10-11 billion worth of R&D each year, almost 60% of its total budget, mainly from the private sector (NASA, 2019[28]). The European Space Agency redistributes a majority of the national contributions it received in the form of industry contracts. This impacts the later phases of technology transfer to non-space actors.

Box 2.1. Space exploration as a driver of international co-operation

During the Cold War, major scientific and engineering breakthroughs took place in different parts of the world, often in isolation, as military R&D and industrial secrecy forced to preserve their own technological advances. International conferences of scientists have prospered since 1991 and the end of the cold war, allowing researchers to collaborate on and disseminate scientific advances. Knowledge flows and dual-use technological transfers have also increased from OECD countries and the Russian Federation to other parts of the world. This has sometimes caused tensions concerning the transfer of sensitive technologies (i.e. rockets carrying satellites are based on missile technologies), and a tightening of technology export controls.

One of the first emblematic joint space missions took place in 1975, when an American Apollo spacecraft, carrying a crew of three, docked in orbit for the first time with a Russian Soyuz spacecraft with its crew of two. Russian cosmonauts and American astronauts met for the first time in orbit. In addition to the political significance of the event, it was a major engineering accomplishment as, at the time, both the US and the Russian industrial chains relied entirely on domestic hardware and national standards. Bilateral working groups were set up for the first time to develop compatible rendezvous and docking systems in orbit, which are still in use today.

Source: Adapted from OECD (2014[27]), *The Space Economy at a Glance 2014*, https://dx.doi.org/10.1787/9789264217294-en.

Given their strong R&D focus with pre-existing portfolios of technologies, software and patents, facilities and expertise, space agencies make use a number of channels to support technology transfers and commercialisation. Each of these channels responds to different space agency's objectives, challenges and characteristics of the institutional framework within which they operate (Venturini and Verbano, 2014[29]). In this context, space TTCs may occur through primary channels, including:

- Promoting the exploitation of intellectual property developed through public space R&D and held by private organisations
- Patenting and licensing the outcomes of public space R&D;
- Creating ad-hoc platforms to promote exchanges between space and non-space actors to trigger opportunities of mutual learning (for example via collaborative research and contract research projects, labour mobility);

- Promoting cross-sectoral outreach events and gathering involving space and non-space professionals (for example conferences, professional gatherings, hackathons, competitions, seminars).

Patenting and licensing

Although patenting levels are lower than in many other sectors, patenting and licensing the outcomes of public space R&D remains one of the most common channels adopted by space agencies and technology transfer offices to promote the commercialisation of inventions. NASA's patent portfolio contains more than 1 200 patents that are available for different types of exclusive and non-exclusive licenses fees (NASA, 2015[30]). The German Aerospace Centre (DLR) also uses licenses to promote all of the agency's inventions that have commercialisation potential (DLR, 2017[31]). There are many other approaches, with some illustrations provided below:

- Within NASA, every civil servant, contractor or grantee must disclose any new technology, invention, idea, concept or software discovered, through so-called New Technology Reports (NTRs). The agency then reviews every invention to check its technical readiness, market viability and patentability. Only technologies that are deemed marketable within the following seven years are patented and receive the Technology Transfer Program's commitment, which actively supports the commercialisation phase. NASA also asks the inventor to be ready to work with potential licensees and support commercialisation efforts. Once licensed, patents generate royalty income (NASA, 2017[32]). All patented technologies available for licensing appear in the NASA Patent Portfolio online catalogue (NASA, 2020[33]).
- DLR's policy is to patent all of its inventions demonstrating a commercialisation potential. Inventions are then proposed to potential users through licenses or by developing cooperation arrangements and service contracts. DLR may assume part of the risk derived from the commercialisation of the inventions, for example by advancing funds. It is estimated that market revenues will eventually repay the investments made by the agency (DLR, 2020[34]).
- The European Space Agency (ESA) patents between ten and twenty inventions every year. ESA's Patents Group (managed by the Technology Transfer and Patents Office) oversees the resulting portfolio of inventions, which currently comprises around 530 patent applications and patents. Intellectual Property rights can then be made available to European space firms via a system of free but non-exclusive licenses. For firms that intend to commercialise the technology beyond the space sector, some fees are due, as a different licensing scheme comes into play for non-space applications or for uses outside ESA member states (ESA, 2020[35]). ESA only claims ownership of intellectual creations produced by its staff within the scope of their duties. Ownership of intellectual creations produced by ESA staff "on the side" or produced by private contractors are held by the creators (ESA, 2019[36]). ESA does however retain some rights to use intellectual property for R&D purposes within its Member States, and the right to distribute it further to other firms in Europe. This is an important point for contractors to know.
- In Canada, the Intellectual Property Management and Technology Transfer office manages the portfolio of the Canadian Space Agency's available technologies. Patented technologies are made available to interested researchers or entrepreneurs under specific licensing agreements (see below) (CSA, 2020[37]). Pilot projects have demonstrated that Canadian SMEs need support to increase their own intellectual property protections and to conduct technology transfers of their own portfolio of technologies, sometimes initially developed under contracts for CSA.
- Finally, the European Union is a large funder of space R&D in Europe, and it retains ownership of all tangible and intangible assets created or developed under its Galileo and European Geostationary Navigation Overlay Service public procurements (GSA, 2016[38]). In the framework of the European Union Horizon 2020 space programme, intellectual creations are owned by the

creator(s), with the obligation to protect (e.g. through patents, trademarks, etc.), exploit (for further research and/or commercially) and disseminate the results (European Commission, 2018[39]).

License agreements can also vary quite significantly within space agencies, according to the type of licensee and the licensed asset. NASA, for instance, negotiates licenses case by case, prescribing conditions for the commercialisation of the asset, the duration of the agreement, the royalties and periodic reporting (NASA, 2017[40]). Three types of licenses exist within (NASA, 2019[41]):

- Evaluation licenses: They grant the users the possibility to "test drive" the commercial viability of NASA technologies with minimal risk and up-front commitment.
- Standard commercial licenses: They provide the licensee with the right to make and sell products based on NASA technologies, requiring detailed commercialisation plans and financial documentation.
- Start-up licenses: They permit small businesses to use technologies produced within the agency for commercial use without sustaining any up-front costs, while securing the intellectual property needed to build competitive market space.

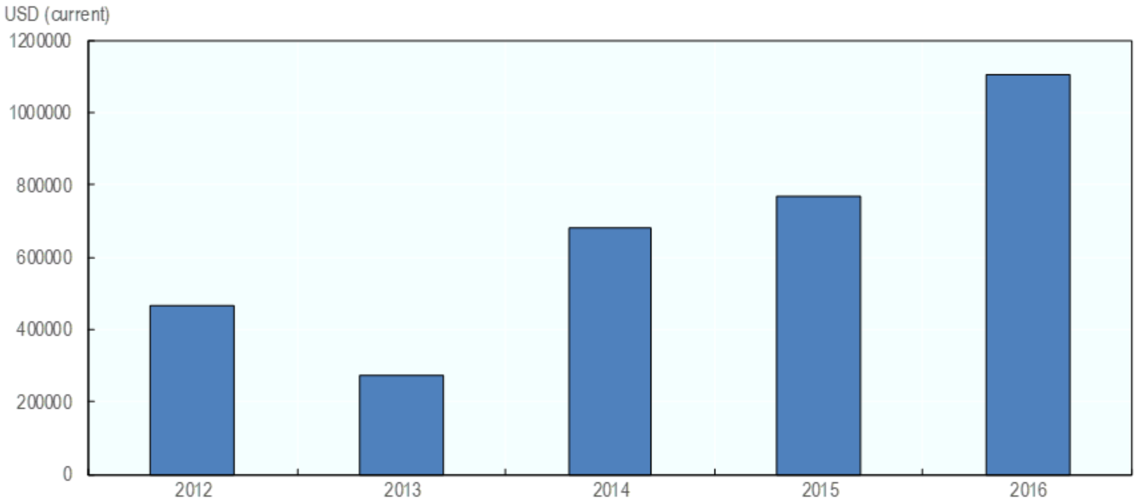
In the United States, software is patentable, with software patents typically referred to as computer implemented processes. NASA offers licenses on all software created by or for the Agency, as well as software derived from work performed by NASA employees, contractors and grantees. Such licenses take the form of software releases and might be of four different types: General Public Release, Open Source Release, US Release Only and US and Foreign Release (NASA, 2019[41])

Licenses might also differ according to the nature of the asset and the goal of licensee. The Canadian Space Agency distinguishes four types of licenses (Canadian Space Agency (CSA), 2018[42]):

- Commercialisation licenses: Providing access to intellectual property rights and to the available expertise for the purposes of manufacturing.
- Research-based R&D licenses: Used to support R&D objectives, where the goal of the recipient is research-based – i.e. discovery of a new product or simply the enhancement of an existing product or process.
- User licenses: Permitting or granting the right to access data and information then used for purposes other than commercialisation or research – i.e. typically useful in the case of the development of software programmes.
- Licenses for educational and training purposes: Released to educational institutions to permit the use of technologies for educational purposes.

In recent years, several agencies have seen a significant increase in licensing activities. Licensing revenues more than tripled between 2015 and 2017 at the DLR (DLR, 2018[43]) and doubled at the Korea Aerospace Research Agency (KARI, 2017[44]) (Figure 2.2). The number of executed licenses at NASA increased by 293% between 2011 and 2017, while software releases grew by 145% over the same period (NASA's Office of Inspector General, 2019[45]; NASA, 2017[32]). It is worth to note that not all space agencies have a mandate to generate revenues. Licensing out can be considered as a way to better support the ecosystem and new firms. For example, CSA negotiates flexible terms and conditions that accommodates licensees needs and takes into account their resources (most of licensees are Canadian SMEs).

Figure 2.2. Increase in KARI licensing revenues



Source: Adapted from KARI (2017), "Space technology transfer and commercialisation in KARI"

Infrastructure and collaborative platforms

Sharing existing infrastructure or establishing ad-hoc collaborative platforms such as government testing facilities and services, clusters, incubators and other collaborative platforms; and cross-sectoral outreach is a common way to create opportunities of cooperation between space and non-space actors and trigger knowledge exchanges. More in genral, such platforms work across the private and public sector to manage, co-ordinate, and catalyse innovation (Winickoff et al., 2021[47]).

Shared infrastructure and collaborative platforms may be used to facilitate the access of third parties to a space centres' facilities and services and engage industry in long-term R&D cooperation projects (through contract research or collaborative research mechanisms for example) or involve academic institutions and promote cross-sectoral labour mobility opportunities. Benefits of these mechanisms are associated with the opportunity to share development costs as well as risks among different actors, while maximising the potential of technology commercialisation. Some of these infrastructure and collaborative platforms are detailed below.

Government testing facilities and services

In countries with space programmes, many space agencies and public research organisations have sophisticated ground- and space-based testing infrastructure (e.g. wind tunnels, propulsion test cells, vacuum chambers, cryogenic chambers, microgravity, acoustic and vibration testing facilities, as well as computer simulation facilities and services) at their disposal, often representing several decades of public investments (OECD, 2016[6]).

These resources may be made available to external businesses and academic users on favourable terms, fostering collaboration. The goal is to stimulate innovation and the development of private sector products and services, in particular those of start-ups and SMEs, through the provision of testing and demonstration services. Several space agencies also offer opportunities for flight demonstration on government space missions. Selected OECD space agencies providing such services include those from Canada, France, Germany, Japan, Korea, the United Kingdom and the United States. The European Space Agency also provides access to testing services for its member countries.

Selected programmes include:

- The NASA Flight Opportunities programme (suborbital research flight programme), the Cubesat Launch Initiative (free launch opportunities for research cubesat missions) and the reimbursable and non-reimbursable Space Act Agreements. These initiatives provide external users with access to government space infrastructure and services (including astronaut time). Nanoracks is one of the firms benefiting from such an agreement by providing commercial launch and research services on the International Space Station.
- In Europe, the UK Wind Tunnel Facility project (providing access to selected wind tunnels free of charge), and the German Galileo Test and Development Environments project (GATES), which provides an artificial test bed for Galileo satellite navigation applications and services. Furthermore, the ESA's General Support Technology Programme (GSTP) gives firms, in particular SMEs and academic institutions, hosted payload flight opportunities on suborbital rockets, launchers, satellites and the International Space Station (ISS).
- In Korea, the STAR-Exploration programme provides access to manufacturing facilities and equipment for start-ups so they may develop prototypes.

Clusters, incubators and collaborative platforms

Clusters, incubators and collaborative platforms play an important role in space innovation and technology transfers. They also contribute to the growth of space ecosystems and outreach to other economic sectors, especially when clusters and incubators are opened to space and non-space firms. With the convergence of technologies, having diversity within a cluster could contribute to further technology transfers (Kreiling and Scanlan, 2020[46]). In recent years, there has been a marked increase in the number of centres and initiatives supporting commercialisation and collaborative R&D.

Many countries and regional authorities have supported the development of space-related clusters over the years, sometimes creating them from scratch with incentives for research centres and industry to relocate, or building on existing industry clusters. For instance, aerospace clusters have traditionally formed around research institutes or university centres. There are now a growing number of clusters nationally, such as the French Aerospace Valley near Toulouse, the Italian aerospace clusters of Lazio and Torino, the Korean high-technology clusters in Daejeon, the clusters in German Bavaria or Bremen. The UK space industry cluster is located in Harwell. The European Centre for Space Applications and Telecommunications, the UK Satellite Applications Catapult, the Rutherford Appleton Laboratory (RAL) and the UK ESA business incubator centre are all within walking distance to one another. In the United States, many clusters are closely connected to either NASA research centres, or large aerospace groups. There are also increasing international interactions between clusters.

There are also a growing number of business incubator and accelerator services in the space sector:

- The European Space Agency, in co-operation with its member states, has created a network of ESA national business incubator centres or BICs to cater to the needs of entrepreneurs. Twenty-two ESA BICs currently exist, spread across 19 European countries (see also the next section for discussions on benefits).
- The Italian Amaldi Foundation, established in 2017 by the Italian Space Agency and the Hypatia Research Consortium, is a technology accelerator, working to enable technology transfers from the space sector to the rest of the economy. The Foundation's mission is to discover areas of technological excellence, develop synergies between space and non-space actors, and deliver innovative financing instruments to support TTCs (ASI, 2020[47]).
- The Technology Marketing Office of the German Aerospace Centre (DLR) provides substantive support to both in-house and external entrepreneurs who want to commercialise DLR technologies.

This includes help with business plans, finding suitable financing and granting access to existing DLR infrastructure and equipment.

Other collaborative platforms are being set up throughout OECD countries to enable space technology transfers and the development of commercial space applications in various non-space domains.

- The Norwegian Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA) is a research network established in 2014 by the Norwegian Research Council, with 6 public research partners and 12 industry partners. The objective of this centre is to conduct research on methods and technologies that can reliably detect, monitor, integrate and interpret multi-sensor data describing the physical environment of the Arctic. This descriptive information is then incorporated into models to perform predictions of sea ice state, meteorological and oceanographic conditions on both short and long timescales.
- The French Booster programme funded by the public-private co-ordination group CoSpace and CNES supports the development of space applications in different areas. Four boosters have been established in conjunction with existing technology clusters: the Booster Morespace in Bretagne, focusing on ocean-related applications, and Boosters Nova near Toulouse, PACA in Provence and Seine Espace near Paris, the latter three targeting several sectors such as “smart cities”, the environment and energy.
- Switzerland is in the process of setting up the Space Exchange Switzerland (SXS), to be hosted by a higher education institute and meant to support and complement government activities, such as facilitating space-related professional training, organising outreach activities and regular national events. Another Swiss programme entitled Multidisciplinary Applied Research Ventures in Space (MARVIS) is a novel competitive funding instrument designed to investigate promising interconnected subject areas related to space and create key competencies in these areas with a time horizon of 6 to 7 years. This is an important tool to prepare and integrate the Swiss space ecosystem in the larger international market, while promoting space technology transfers in a variety of ways (SERI, 2021[48]).
- Australia has had several space-related Cooperative Research Centres (CRCs), which are government-funded consortia of universities and other research organisations that partner with industry to develop know-how and technologies in specific areas. The CRC-SI for spatial information ran from 2003 to 2018, with the objective to conduct collaborative research and education in the spatial disciplines. The CRC-SI aimed to accelerate the take-up of spatial science by key end users, spawning major innovation and productivity advances in key industry sectors (CRCSI, 2020[49]). A SmartSat CRC was established in 2019 and focuses on advanced telecommunications and IoT connectivity, intelligent satellite systems and Earth observation next generation data services (SmartSat CRC, 2020[50]).
- In New Zealand, Xerra is one of four regional research centres, established in 2017 and working to identify knowledge gaps and conduct industry-led, self-funding research in the fields of earth observation (EO), geospatial science and remote sensing technologies, with a pathway to commercialisation (Xerra, 2020[51]).

Outreach towards different economic sectors

Space research transfer often takes place through gatherings of experts from space and non-space sectors, through formal and informal events. These events include conferences, professional meetings, expositions and seminars (Ponomariov and Boardman, 2012[52]). Sometimes they also take place through the creation of new fora and associations within existing organisations, periodically attracting actors with different industrial backgrounds, as well as academia.

The number of such gatherings is growing year after year, with space agencies trying to engage with industrial partners from other sectors to boost the diffusion of space technologies with several types of initiatives. They offer a valuable opportunity for space organisations to present the outcomes of their work to space and non-space actors, demonstrate technologies and eventually trigger commercialisation ideas. They also offer a chance to identify and analyse future opportunities and scenarios for the space sector as well as to study the potential contribution of space technologies to support pressing socio-economic needs.

- The French Space Agency (CNES) launched "Space'ibles" in 2017, a multi-disciplinary observatory analysing the medium to long-term future of the space sector. The observatory has more than 60 partner organisations, of which two thirds are non-space (Lafaye, 2018[53]). It organises events to promote interactions between space and other industry sectors.
- Similarly, the INNOspace Initiative, started in 2013 by the German Space Agency, promotes innovation and encourages the adoption and commercialisation of space technologies by non-space actors, as well as encouraging spin-ins (Zeitler, 2013[54]). An important component of the initiative is the organisation of several inter-sectoral symposia, bringing together specialists from the space industry with experts from other industrial sectors. The goal of the networks is to transfer knowledge and technologies along the whole value chain by connecting firms, research institutes, universities, associations and public players from space and non-space sectors (i.e. cross-sectoral INNOspace Networks: Space2Motion, Space2Agriculture and Space2Health, each dedicated to a specific non-space sector).

Prizes and hackathons are also increasingly common instruments used to enable the commercialisation of space inventions.

- ActInSpace (AIS), is an international hackathon promoting original applications of space technologies. The competition, taking place every two years, has been running since 2014. Open to people from all professional and educational backgrounds, AIS is a competition that aims to develop entrepreneurial ideas and to create links between space and non-space professionals. It proposes to participant teams a number of challenges to be solved through the application of space data and technologies patented by CNES, eventually leading to the design of new products and services. Winning teams must propose their start-up projects to a jury of international experts in technology transfers and business development. Teams interested in further developing their business ideas can then receive direct support by CNES and take advantage of the ESA BIC system. Since 2014, 36 start-ups have been created through AIS, of whom 75% are still operative (CNES, 2020[55]).
- Part of the INNOspace Initiative by the German Space Agency is also the INNOspace Masters, started in 2015. The programme works as an annual innovation competition organised by the German Space Agency at DLR, in collaboration with the ESA BICs Hessen, Baden Württemberg and Bavaria, the space manufacturers Airbus and OHB as well as DB Netz AG (responsible for the German rail infrastructure). The best submissions are awarded prizes to be used to translate the ideas into proper innovation and transfer projects with the support of the INNOspace Masters partners (DLR, 2018[8]).

3. Tracking and measuring the socio-economic benefits of space technology transfers

In OECD countries and beyond, policy-makers aim to improve the management and accountability of government spending. Identifying and measuring socio-economic returns of government space activities is part of these efforts. This section presents different selected means used to track and measure the benefits of space technology transfer and commercialisation, highlighting some underlying methodological challenges and possible ways forward to encourage international comparability.

3.1. Tracking space technology transfer and commercialisation

Promoting the diffusion and transfer of space technologies originating from publicly funded space programmes has been a longstanding priority for many space agencies. Throughout NASA's history, many acts and memoranda have encouraged technology transfers, starting with the agency's initial mandate from Congress, issued in 1958, up until the more recent Technology Transfer Commercialisation Act of 2000 (Hertzfeld, 2002[56]), the Presidential Memorandum of 2011 and NASA Presidential Directives (NASA, 2017[57]). As another illustration, the original mandate of the Canadian Space Agency in its founding Act in 1990, explicitly states the importance of promoting the transfer of space technologies to industry (Canadian Space Agency (CSA), 2017[58]).

Several space agencies and other government space organisations have spent years developing either ad-hoc or systematic monitoring frameworks to track space technology transfers derived from their publicly-funded programmes. Hundreds of technological transfers have taken place, and case studies have been collected by space agencies to document successful transfers from space programmes to other sectors. Although there are no standard definitions across OECD countries, nor indicators using the same methodologies to track and compare space technology transfers between countries yet, there are some common trends that can be identified in terms of the typical indicators used.

Indicators tracking space technology transfer and commercialisation from the channels of dissemination that were identified in the previous section. They are valuable for policy because they provide insight into public R&D commercialisation, but they do not specifically gauge the efficiency and effectiveness of technology transfer processes and the actual returns on investment.

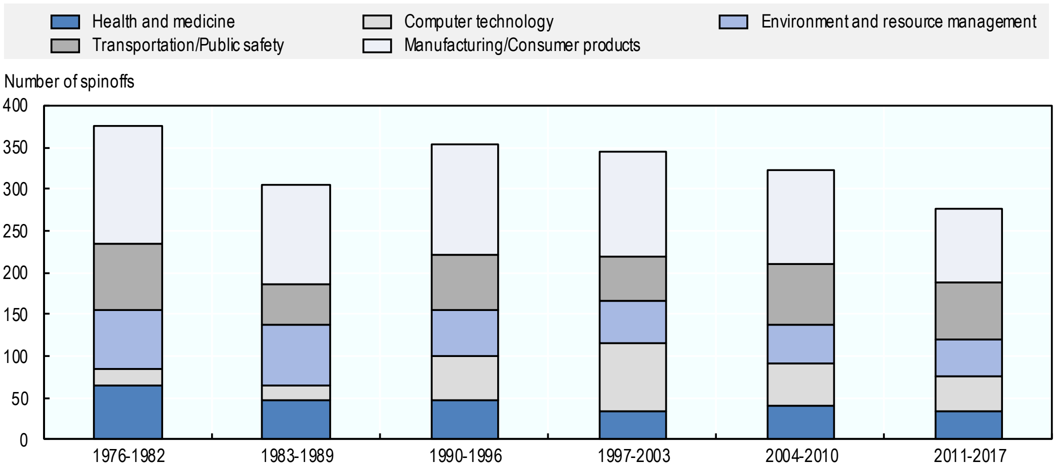
The indicators cover primarily:

- Licensing activities: the number and types of licenses awarded every year provide useful information on the trends in technology transfers, but also the revenues that may be derived from the licensing schemes (see Patenting and licensing). One inherent constraint of these indicators is that it often takes many years before a technology finds a new commercial application, and the often small numbers of licenses do not reflect the many activities taking place at the space agency level;

- Number of start-ups created (or "spin-off" firms): Although this is an indicator appreciated by policy-makers, since it often translates into job creation, it remains quite limited as it does not take into account the life-expectancy and sustainability of the new firms.
- Top recipient economic sectors of space technology transfers.

Knowledge is growing about the most common recipient sectors of space technology transfers, as well as the type of space programmes that generate transfers. For instance, NASA's tracking of more than 2 000 successfully developed US commercial products between1976 and 2018 shows that a majority of US space technology transfers occurred in the sectors of manufacturing and consumer products, computer technology and environment and resource management (Figure 3.1).

Figure 3.1. NASA technology transfers to different economic sectors



Note: NASA's "spin-offs" refer here to licenced NASA intellectual properties in non-space sectors.
Source: OECD calculations based on NASA spin-offs database (2018).

In Europe, studies by the European Space Agency in the 1990s showed that space technology transfers to private firms were primarily targeted towards software development, engineering, energy, medical applications, transport and security (ESA, 1999[59]). A review of ESA Business Incubation Centres' programmes from 1990 to 2006 found that transfers from the space sciences and launchers programmes produced the highest number of new commercial products, followed by human spaceflight and telecommunications (Szalai, Detsis and Peeters, 2012[60]).

Selected illustrations from different countries of transferred space technologies and their applications to various sectors, such as health and medicine or transport, are shown in Table 3.1.

Table 3.1. Selected examples and applications of space technology transfers

Space programme	Technologies transferred	Applications outside the space sector	Areas of application
Italian Mach-Zehnder project	Microinterferometer, technology to analyse planetary gases	First: technology for the monitoring of air quality and the presence of atmospheric pollutants Second: technology for monitoring fermentation and various chemical processes in wine production	Environmental monitoring and agriculture and food sectors
NASA investments in life sciences research	Investments in life sciences research and development of related technologies	Development of more efficient medical and research equipment and research activities	Health and medicine
Italian Microfluidics project	Micro-propulsion system to control and regulate a satellite's tilt	Technologies for healthcare and membrane filtration and research activities	Health and medicine
German Research from the Max Planck Institute for Extra-terrestrial Physics (MPE) on ROSAT X-rays	Mathematical algorithm (SIM) used to analyse data from X-ray satellite ROSAT	Development of a computer-aided early recognition system (MELDOQ) to recognise melanomas through digital image analysis	Health and medicine
German DLR Institute for Robotics and Mechatronics work on remotely controlled robots for the International Space Station (ISS)	Development of robots remotely controlled from Earth or from the ISS giving the operator the impression of being there (e.g. telepresence)	MIRO is a robot remotely controlled by doctors to perform a surgeon's movements with high precision through numerous sensors via partial or total automation	Health and medicine
French CNES human spaceflight	Ultrasound probes tested by universities during the first French human spaceflights	Development of innovative echocardiography probes	Health and medicine
Canadian Space Agency's technology tested on the International Space Station (ISS)	Portable Canadian technology that analysed cells and hormones in blood or other biological samples.	Microflow could be used to perform rapid, real-time testing and analysis anywhere in the country, including areas with limited medical equipment, such as remote communities or those affected by natural disasters	Health and medicine
Carré Technologies of Montreal, Quebec, developed Bio-Monitor for the Canadian Space Agency (CSA)	A new wearable technology has been designed to fit into an astronaut's daily routine aboard the International Space Station (ISS) while monitoring and recording vital signs.	An early version can improve the performance of sport athletes. Future versions have the potential to help Canadians who are bedridden, housebound, or living in rural communities with limited access to medical support. It can also be worn by workers in dangerous environments such as mines, industrial sites, or factories.	Heath and medicine/sports
ESA's Rosetta mission	Technology used in the Ptolemy Instrument for analysing comets	Development by a UK firm of a detector that enables the hospitality industry to reproducibly and accurately monitor for the presence of bed bug infestations	Hospitality industry
ESA work on robot calibration	Creation of a new system, the so-called Rodym, exploiting multiple cameras to measure the movement of infrared LED markers on space robots	Rodym is now part of many car manufacturers` production lines to enhance precision, with significant returns in terms of higher production rates and better quality control	Transports and manufacturing

Source: OECD (2019[11]), *The Space Economy in Figures. How Space Contributes to the Global Economy*, https://dx.doi.org/10.1787/c5996201-en, based on different reports referenced in the publication.

Beyond these indicators, the actual performance of the technology transfer offices, incubators and accelerators themselves may come under scrutiny. A wide variety of indicators exist and may include: the number and satisfaction rating of training programmes and outreach events conducted to promote space technology transfer; the number of experts from different sectors that participated in those programmes;

the number of SMEs or other non-space private actors using infrastructure and test laboratories; the number of publications, studies and other resources commissioned; etc.

3.2. Measuring the benefits of space technology transfer and commercialisation

Beyond tracking the actual instances of space technology transfers, assessing their qualitative and quantitative benefits is more challenging. This section discusses how space technology transfers have been assessed in larger evaluation programmes and how assessment of the commercialisation of government intellectual property has been conducted.

Space technology transfers assessed in larger evaluation programmes

Space technology transfers are often assessed within the framework of a much larger evaluation and performance studies by space agencies or other public administrations.

Interesting data and information can be found in a number recent assessment studies. The evaluation of Norway's participation in the ESA's science programmes documented a number of technology transfers in the private sector from firms that received initial industrial contracts associated with these science programmes (Hoegh Berdal, 2018[61]). In a 2015 Swiss qualitative evaluation of R&D funding instruments for space activities, more than 60% of private sector respondents reported that participation in ESA programmes had led to product innovations for non-space markets, while more than half saw a diversification of clients (58%) and target markets (56%) (Barjak, Bill and Samuel, 2015[62]). The most recent evaluation survey of the United Kingdom's funding of space activities through the ESA Advanced Research in Telecommunications Systems programme (Technopolis, 2019[63]) found that British private sector's participation in the programme led to new and strengthened partnerships, improved skills, knowledge and capabilities and increased visibility. Several projects had also already generated additional revenues outside of the space sector. In a similar vein, Sadlier, Farooq and Esteve (2018[64]) looked at the spillovers from government space programmes among academic and private organisations in the United Kingdom. The analysis included space technology transfers and commercialisation of IP. The outcomes from three case studies are presented in Table 3.2.

Table 3.2. Selected outcomes associated with space programme participation in the United Kingdom

Case study	Description	Outcomes
National Space Technology Programme (NSTP)	The NSTP is the UK Space Agency's national capability programme. It provides grant funding to organisations looking to develop space technology and capabilities.	98% of surveyed organisations reported that their attractiveness as an R&D partner has increased. 93% report an increase in visibility and reputation.
Herschel SPIRE	The Herschel Space Observatory was an ESA-funded astronomical satellite that launched in 2009 and operated until 2013. SPIRE was one of its three scientific instruments. Cardiff University was the lead institute in an 18-institution consortium.	Three recorded spin-off firms. Enhanced scientific reputation of Cardiff University, enabling participation in other projects. New relationship developed between University of Cardiff and Airbus, resulting in GBP 4 million in follow-on contracts for the university.
Rosetta	Rosetta was an ESA funded space probe launched in 2004. This involved an in-depth analysis of comet 67P/Churyumov-Gerasimenko using instruments on-board both the Rosetta Orbiter and its lander Philae.	Instrument technology was developed during the mission to be used on the lunar Prospect mission. Ptolemy sensor technology has been transferred to develop an air monitoring system for military submarines. Other technologies are receiving further funding for commercialisation.

Source: Sadlier, Farooq and Esteve (2018[64]), *Spillovers in the Space Sector*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/788725/LE-UKSA-Spillovers_in_the_space_sector-FINAL_FOR_PUBLICATION_050319.pdf.

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[65]). In order to complement the information, other ad-hoc studies are regularly conducted. For instance the evaluation of the 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[26]). 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, and to reserve another 0.3% for Small Business Technology Transfer programmes 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[26]).

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 mapping of technological transfer activities, their outputs and outcomes covering all of KARI's aerospace programmes (Figure 3.2 below). The analysis shows that since 2001, there have been a total 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 annual sales improvement of recipient firms was KRW 390 million (USD 0.33 million), with technology transfers contributing directly 20.3% in additional sales (Park, 2020[69]). Figure 3.2 further shows the utilisation by "internal" and "third party" actors of KARI's facilities, indicating a significant growth in external usage over the years.

Box 3.1. Embedding technology transfer requirements in the space programme itself: An example from Canada

Canada has a long history of monitoring the outcomes and impacts of its space programme with a series of fit-for-purpose industry surveys, indicators and dedicated studies. The following is an example of an interesting monitoring exercise focussed on space technology transfers.

Canada chose space robotics early on as one of its key niche areas, in order to develop dedicated expertise within its industry and link up with other economic domains (Sallaberger, 1997[66]). The Strategic Technologies in Automation and Robotics (STEAR) was an eleven-year long Canadian R&D programme intended to create a new generation of SMEs for space robotics and encourage spin-in and technology transfers of technologies (1990-2000). The programme had two specific goals:

- Promote the participation of Canadian SMEs in the development of innovative automation and robotics technologies for possible incorporation into the Mobile Servicing System, a robotic system on board the International Space Station (e.g. different generations of the "Canadarm" have contributed to the assembly of the station's modules) and later, into other human space flight related infrastructure programmes.
- Trigger the commercialisation of newly developed technologies to non-space industrial sectors with the possibility for SMEs to propose projects and become strategic players, nationally and internationally, building on both their expertise and the support received by the Canadian Space Agency.

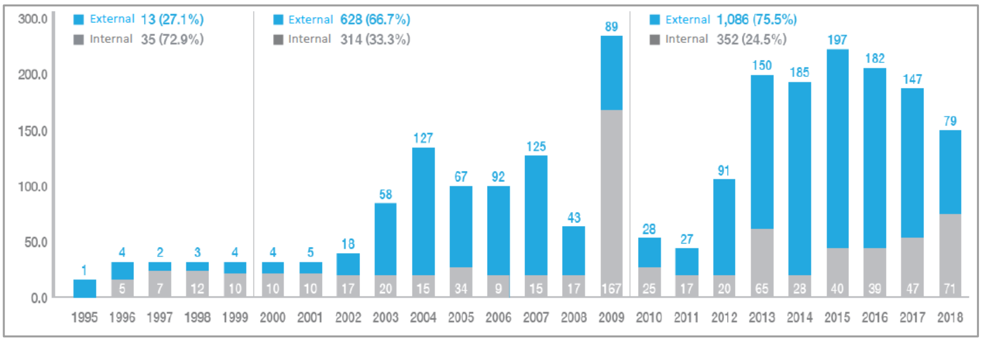
The selection criteria for SMEs to take part in the programme focused on the commercial viability of proposed projects and the financial commitment of the selected firms. The tendering process facilitated the selection of the best ideas for innovative automation and robotics technologies with the highest potential for future commercialisation, in other words, the commercialisation process was a mandatory element within the STEAR Program, a rather novel approach in the space sector at that time (OECD, 1997[67]). From the initial request-for-proposal stage, the commercialisation plan and the technology development plan had almost equal weight in the evaluation process.

The full evaluation of the programme, conducted in the early 2000s, identified 28 filed patents, more than 45 licences for technology exploitation, as well as a number of scientific publications, research partnerships and spin-off firms (Amesse, Cohendet and Poirier, 2002[16]). The programme generated 600 new highly-skilled jobs and at least CAD 10 million in additional revenues from sales of new products over 7-8 years (after the first early evaluation in the early 2000s) and led to improved organisational and commercialisation skills in firms, particularly in the area of medicine (tele-medicine, surgical simulation techniques, and laboratory automation).

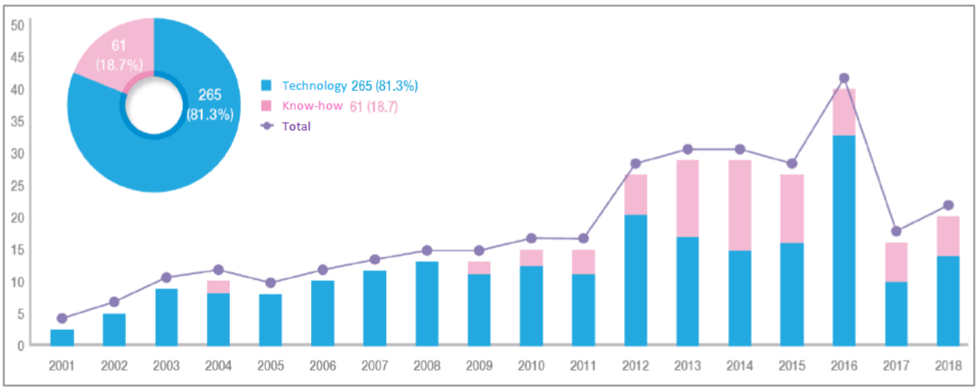
This type of long-term programme provided both incentives and the framework to keep space robotics as a niche area for Canadian firms. This provided a solid foundation for further innovation in both the Canadian space sector and beyond for continued technology transfers. The Canadarm2 has now been operating on the International Space Station for close to 20 years, and the Canadarm3 will be designed as Canada's contribution to the United States-led Lunar Gateway, a space station to be placed in orbit around the moon (CSA, 2020[68]).

Figure 3.2. Technological transfers at KARI

a) Internal and third party utilisation of KARI facilities



b) The number of transfers of technologies and know-how to firms



Note: In the report, technology transfer refers to technology licensing, while know-how transfers refers to transfers via direct collaboration.
Source: Park, J.-H. (2020[69]),"The Socio-Economic Impacts of KARI's R&D Activities over the Last Three Decades".

Quantitative assessment of the commercialisation of government intellectual property

Intellectual property is a key element of any technology transfer, and over the years a number of administrations and agencies have attempted to assess the benefits derived from the commercialisation of space-related patents through licensing.

The benefits generated by the commercialisation of government intellectual property at NASA have been analysed by Comstock and Lockney (2011[70]). The authors analysed 187 transfers recorded in NASA's annual *Spinoff* publication between 2007 and 2011 resulting from commercialisation of NASA intellectual property. They identify benefits as reported by recipient firms, according to a consistent set of indicators, although only a minority of case studies (or "stories") report quantifiable data. These benefits range from new or additional jobs in the firms, to revenues and environmental benefits (Table 3.3). Focussing on the economic benefits of technology transfers from NASA's life sciences programme, Herztfeld found a rather large return to the fifteen firms that were surveyed based on their commercialisation of new products under NASA licenses (Hertzfeld, 2002[71]). All firms reported profitable product-lines and provided evidence of benefits extending to the commercial users of their products.

Table 3.3. Selected benefits of NASA technological transfers

Indicators	Quantifiable benefits	Share of case studies with quantifiable data
New or additional jobs	1 665 new jobs collected from 8 transfer stories (e.g. composite manufacturing)	4%
New or additional revenues	USD 532 million (mainly single year of sales) from 9 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 2 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.

Note: Based on 187 tech transfer stories collected between 2006 and 2010.
Source: Comstock and Lockney (2011[70]), "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 is also supporting the commercialisation of its intellectual property via a network of 22 business incubation centres (BIC) in its member states, resulting in the creation of more than 700 firms since the launch of the first centres in 2003 (ESA, 2020[72]). The initiative supports on average some 180 start-ups per year (ESA, 2020[72]). Reporting practices from each BIC centre vary quite significantly though. 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[73]). The Bavarian ESA BIC, established in 2009, had in 2018 incubated a total of 130 start-ups, generating 1 800 job creations and EUR 150 million in annual turnover (ESA BIC Bavaria, 2018[74]). Since its start in 2016, ESA BIC Switzerland (CH) has supported 40 start-ups nationwide, investing a total of more than EUR 6 million non-dilutive funding from ESA. Since then, ESA BIC CH start-ups have raised more than EUR 170 million in third-party funding and created more than 300 domestic jobs. At least five ESA BIC CH supported start-ups have CHF 1 million annual revenues, and some of these new firms attract well-known organisations like IBM to support their ambition. The best-known alumni of ESA BIC CH is ClearSpace, which received a contract of EUR 86 million from ESA to demonstrate the first space debris clearance mission (Startupticker ch, 2020[75]).

Methodological challenges

The review of different types of benefits generated by technological transfers shows that there is significant 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 3.3, 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[76]):

- **Lags**: There is sometimes a significant 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 it they date back several years. This is perhaps particularly the case for small- and medium-sized enterprises (SME), 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, 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 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, introducing follow-on surveys, etc. (National Academies of Sciences, Engineering, and Medicine, 2016[26]).

4. The way forward

This section proposes a possible way forward to improve evidence on collection and international comparability of the benefits of transfer and commercialisation of space technologies, building on experiences from both space agencies and other sectors in developing replicable metrics.

4.1. Steps in developing comparable metrics across countries

Expanded data collection often requires considerable resources, and skillsets. In order to leverage these efforts, the use of internationally recognised definitions and standard indicators would make it possible to compare findings and outcomes across agencies, sectors and countries. This paper is taking a first step in this direction by proposing a definition for space technology transfers originating from initial public investments and suggesting different types of standard indicators.

> *Within the specific context of this paper, space technological transfers and commercialisation (TTCs) are defined as the movement of know-how, skills, technical knowledge, procedures, methods, expertise or technologies from one public research organisation (e.g. space agency, space research centre) to another organisation (e.g. a firm), generating value and economic development outside the space sector. This narrow definition involves the adoption of a specific knowledge or space technologies, initially developed thanks to public investments, enabling the recipient to eventually develop new or improved processes, products or services.*

A reliable quantitative results framework is based on meaningful and replicable indicators that are similar to those applied in other innovation domains and sectors, and generally relevant across countries and space agencies. The two tables below provide information on the types of metrics used in closely related domains. Some space and non-space organisations already propose a number of metrics for their own uses (e.g. licensing revenues), but improved international comparability would increase the evidence base and benefit all stakeholders. Within institutions, it could be useful to compare outcomes by mission directorates, centres and projects (National Academies of Sciences, Engineering, and Medicine, 2016[26]). This may help agencies improve the design of their policies and processes and identify the projects more likely to yield space TTCs.

There are already ongoing efforts to harmonise knowledge transfer metrics across countries in Europe. Table 4.1 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 these metrics.

Table 4.1. Selected general metrics used by technology transfer offices (TTOs)

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

Source: Adapted from ASTP (ASTP, 2021[77]) "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

Finally, Table 4.2 suggests some of the most commonly used indicators for tracking the wider socio-economic benefits of technological transfers, as outlined in Comstock and Lockney (2011[70]). The forthcoming *OECD Handbook on Measuring the Space Economy* discusses the methodological aspects of measuring impacts in greater detail.

Table 4.2. Selected socio-economic benefits of technology transfers

Indicator	Description
Jobs created	Number of people hired to produce or use a space-derived product or service
Revenues generated	Monetary estimations of revenues generated by a firm producing or offering a product or service that is a direct application or a transfer of space technology
Productivity and efficiency gains	Monetary quantification of saved and/or avoided costs thanks to the use of space-derived products or services, either by the firm or by its customers
Lives saved	Number of lives not lost as a result of a product or service that is a direct application of space technology. Can also be monetised
Lives improved	Number of people whose lives have been extended and/or improved by a product or service that is a direct application of the transfer of space technology. Can be quantified through quality-adjusted life years, avoided health costs, etc.
Environmental impacts	Reduced levels of pollution

Source: Adapted from Comstock and Lockney (2011[70]), "A sustainable method for quantifying the benefits of NASA technology transfer", https://spinoff.nasa.gov/pdf/AIAA 2011 Quantifying Spinoff Benefits.pdf

4.2. Recommendations on improving data collection and the analysis of impacts

There is still much to learn about technological transfers and several issues need to be resolved in order to design the most appropriate framework to capture the full benefits of TTCs in the context of publicly funded space programmes.

- ***Improve data collection and management at agency level:*** The amount and type of data that space agencies collect on their internal technology transfer activities and outputs (e.g. number of publications, patents) is variable, and would benefit in some cases from improved comparable indicators at the international level. As an illustration, KARI provides indicators on domestic and production of technical papers, patents and licenses, internal and third-party facility utilisation, etc. The German Aerospace Centre equally keeps track of similar activities, including visiting scholars and spin-off firms, but data are not specific to space and include also other agency missions (e.g. security, aeronautics, defence). However, not all agencies have these data readily available. Any new efforts in setting up an evaluation framework to inform decision-makers will come with a need for adequate resources to develop relevant indicators, perform the evaluations, with staff having the right skillsets. Finding the right frequency of reporting and evaluation is also important when setting up such an evaluation framework.
- ***Improve the long-term tracking of the outcomes of technological transfers:*** As discussed earlier, reporting outcomes and longer-term benefits of specific public R&D programmes can be very challenging for both smaller and larger organisations, but few space agencies request data from their contractors in the first place and some organisations may have little obligation or incentives to provide data. Reporting requirements to project participants may be considerable in some cases, but do not necessarily include outcomes. Reviewing NASA's management of outcomes from the SBIR programme, the National Academies of Sciences, Engineering and Medicine pointed to other agencies that require organisations to report on outcomes when applying for new funding, such as the US Department of Defense's Company Commercialization Record (CCR) database (National Academies of Sciences, Engineering, and Medicine, 2016[26]). Thorough programme evaluations are a good start, but this only provides a snapshot and does not capture future outcomes. To systematically capture longer-term effects of its R&D funding, the Canadian Space Agency intends for example to launch an annual survey including former public and private participants of R&D programmes.
- ***Improve comparability of data:*** Expanded data collection requires considerable 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. This paper is taking a first step in this direction by proposing a comprehensive definition for space technology transfers and suggesting different types of standard indicators. The determinants and channels of the technological transfer may affect the chances of success. It could be useful to compare outcomes by mission directorates, centres, firms and projects, etc., and look at causal factors such as firm size and age, and location (National Academies of Sciences, Engineering, and Medicine, 2016[26]). This may help agencies improve the design of their policies and processes and identify the organisations and projects more likely to succeed.
- ***Learn more about other technological transfer processes and their impacts:*** The channels that are most easily tracked (e.g. collaborative research, IPR commercialisation) are not necessarily the most significant. More work needs to be carried out to identify and measure the effects of scientific publications and more informal channels (e.g. impacts of workshops and other networking events). One promising avenue of research is patent citations of non-patent literature.

The OECD Space Forum will continue to work with space agencies and technology transfer offices to track developments in space technology transfers and commercialisation in order to measure better the impacts of space investments on societies and the economy.

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