Returns and Benefits from Public Space Investments 2021

Public Report for the UK SPACE AGENCY

know.space

March 2022

Contents

About us

know.space[1] is a specialist space economics consultancy, based in London and Dublin. Founded by the leading sector experts, Greg Sadlier and Will Lecky, it is motivated by a single mission: to be the source of **authoritative economic knowledge for the space sector**.

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know. */nəʊ/v.*

to understand clearly and with certainty

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Executive summary

Introduction

The ability to **accurately estimate the impact of space investments**, understand what returns result from what types of investment and what influences how much impact an investment has, is critical for justifying, managing, and targeting public investment to maximise social returns from limited public funds. However, such estimation **requires a suite of the latest differentiated up-to-date space-specific evidence** (evidence base).

Objective

The objective of this research exercise is to widen, strengthen and refine the UK Space Agency's (UKSA) **evidence base on the impacts of public space investments**, focused on two requirements:

1. Identification, characterisation, and quantification of the wide-ranging types of **benefits of public space investments**, including spillover benefits.
2. A comprehensive assessment of the latest evidence on key quantitative and qualitative appraisal parameters, assumptions, and calibrated values of **returns to of public space investments.**

Approach

The research approach comprised of secondary research (an **updated literature review** of all the available evidence on public space investments) supplemented by primary research (**interviews**) and **case studies**.

The scope of this study covers any **complete or partial** (lifetime, to-date, annual, ex post, ex ante) **economic evaluations of public investments in any space or space-related terrestrial application domain** from **2015-21**.

> Definition: 'Public space investments' include any expenditures (operations, grants, contracts, contributions) of public funds by any level of government (local, regional, national, supranational) into the space industry (all commercial and non-commercial organisations engaged in any space-related activity), usually for good and/or services (including R&D).

The 2015 review included **57 papers** calculating a rate of return on public space investments published in the years 1971-2015.

The **updated scan of literature** published in the years 2015-2021 identified 93 potential papers, which were then filtered for quality and relevance. To be included, a paper must not suffer from strong methodological limitations and include either a rate of return calculation or an assessment of the benefits of a public space investment. In total we identified **52 papers** (2015-21) which either calculate a rate of return or assess the benefits arising from investments without critical methodological weaknesses.

In addition to this **increased frequency** of relevant papers published (almost as many in the last 7 years as the previous 45 years), the **quality of studies has notably improved** in these recent years. That said, the evaluation literature continues to be marred by many of the same common limitations (heterogeneity of definitions, coverage and analytical methodologies; lack of methodological detail; limited quantification/monetisation).

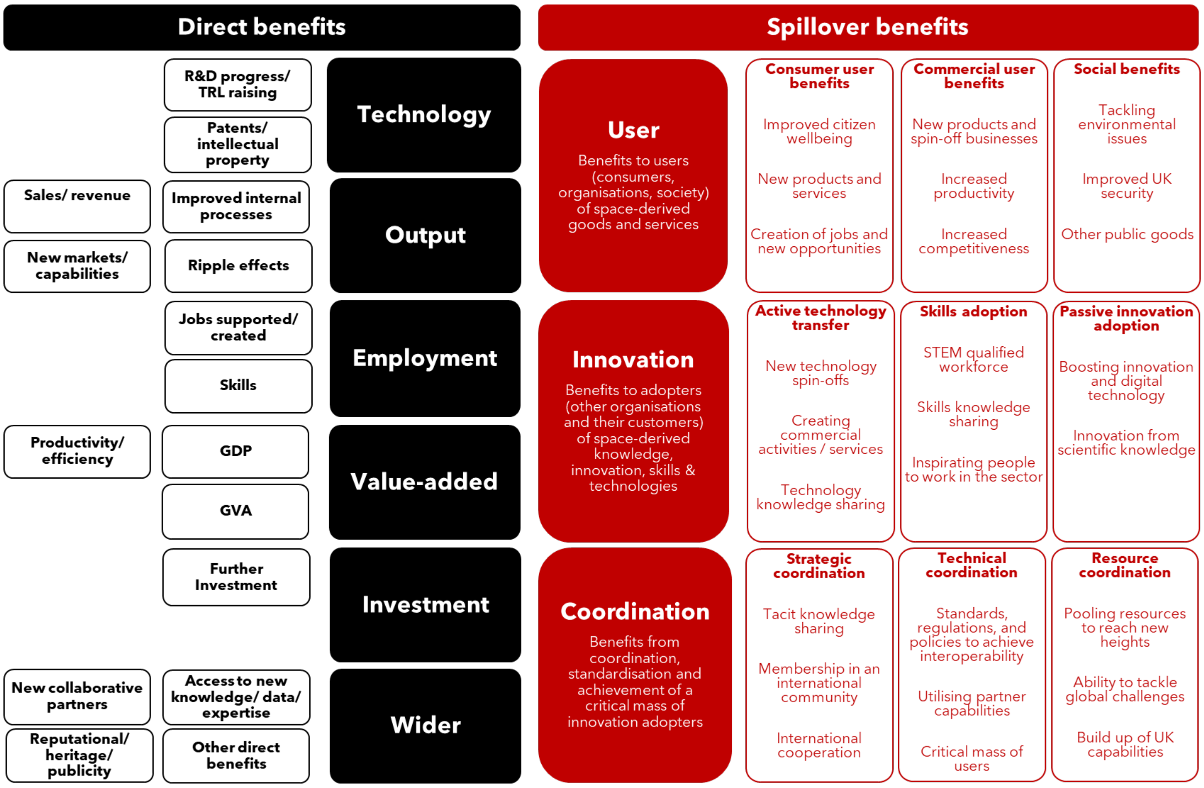
Benefits from public space investments

Nearly every paper contained some breakdown of the **types of benefits** considered, though there was **substantial variation** in the coverage of benefits across studies and methodologies used. Around **two-thirds of papers attempted to quantify benefits** and many papers presented a mix of quantified and unquantified benefits.

The evidence base is notable in its **heterogeneity**, across a range of aspects. Papers covered a broad geographical base – 20 countries' space investments were assessed individually, with a number of papers also considering ESA investments and public space investment globally. This **heterogeneity in approaches** presents a challenge to our analysis, as results are often not readily comparable.

The vast majority of studies are in some sense **partial**, only considering a subset of potential impacts. The literature also presents a mixture of analyses conducted ex-post, ex-ante and those somewhere in-between (conducted during ongoing investments), with most studies conducted during on ongoing investment.

Typology of benefits from space investments



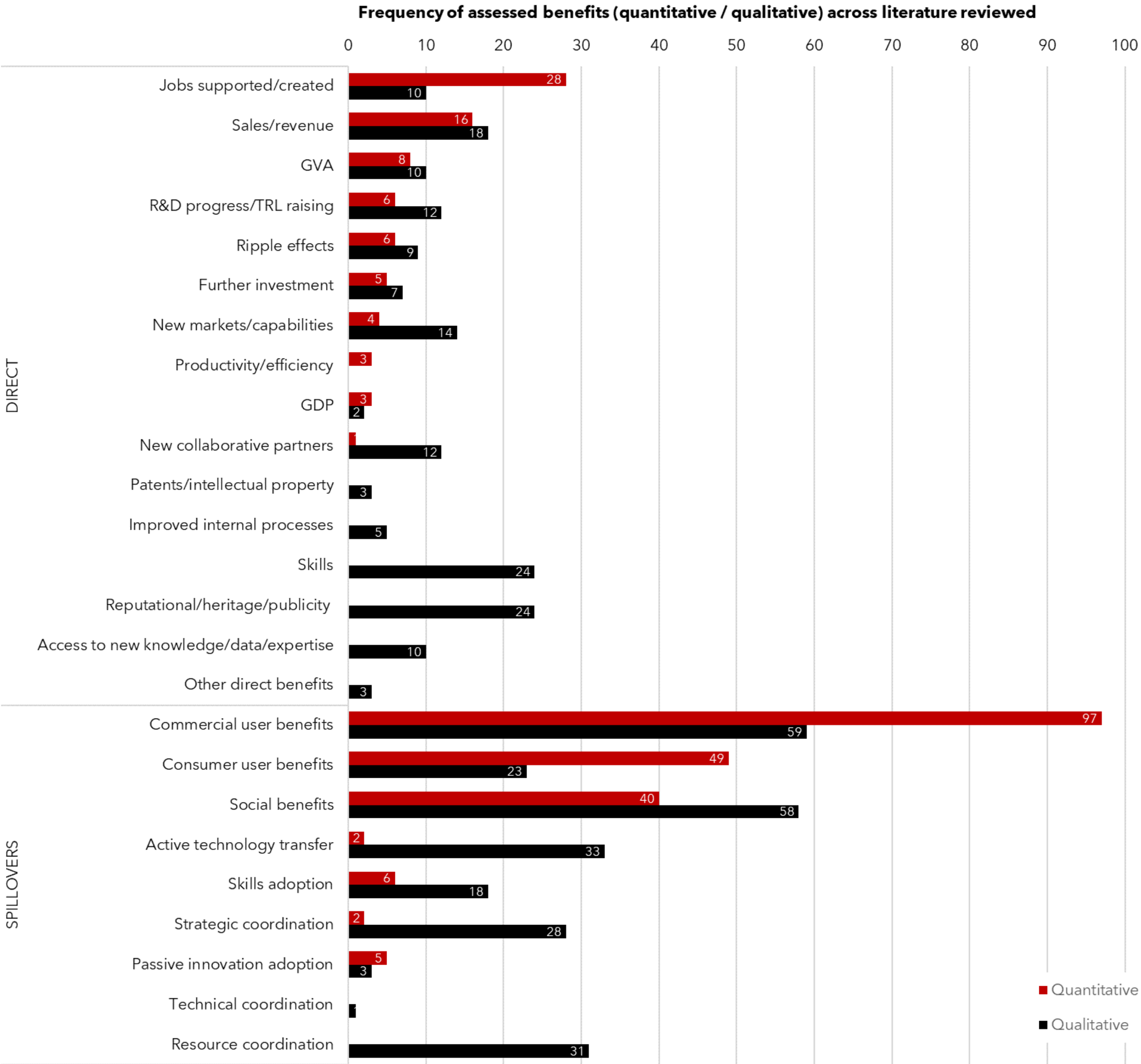
Source: know.space

Direct effects include **outputs that are produced** by the investment funding (e.g. technology/capability developed) and **benefits enjoyed (or costs borne) privately** by the recipient of the public space investment (e.g. funded activity plus follow-on sales or research of the technology/capability developed, known as 'ripple effects').

Spillover effects include the wide range of impacts that arise on **other parties outside** of the investment transaction (between the public investor and public investment recipient).

The following chart, summarising the frequency of analysed benefits, demonstrates the **wide, complex and varied range of benefits** which accrue from investments in space. The variation in quantitative versus qualitative reflects the wide-ranging nature of benefits and the difficulties inherent in quantifying certain benefit types.

Frequency of assessed benefits (quantitative and qualitative) across literature reviewed



Source: know.space

The heterogeneity of the wide range of benefits of public space investments defies quantitative summary, so the reader is encouraged to consult the detailed summary in the main report body. However, a high-level summary of key benefits is possible:

Direct benefits:

- **R&D progress:** TRL-raising from TRL 1-3 (basic research to feasibility) towards commercialisation.
- **Sales / revenue:** Revenues relating to the activity funded by the investment.


Image: UK Space Agency

- **New markets / capabilities:** De-risked capability development for entry into new markets (e.g. space science).
- **Ripple effects:** Additional revenues from follow-on sales leveraging the capability, product or service developed with the investment.
- **Jobs created / supported:** Count (FTEs) and value (labour compensation and taxes) of employment created or protected in the funding recipient organisation and its supply chain.
- **Productivity / efficiency:** Cost reduction and/or increased output (e.g. crop yield) benefits to funding recipients and sub-contractors.
- **Gross Value Added (GVA)** and **Gross Domestic Product (GDP):** Increases in labour compensation, tax revenues and/or retained earnings from the activity funded (and related to) the investment, directly (and indirectly) boosting the GDP of the country.
- **Further investment:** Further investment (public, private, or intramural) following initial public investment due to the enhanced reputation or visibility of the company.
- **New collaborative partners:** New collaborations generated as a consequence of network created by the public investment.

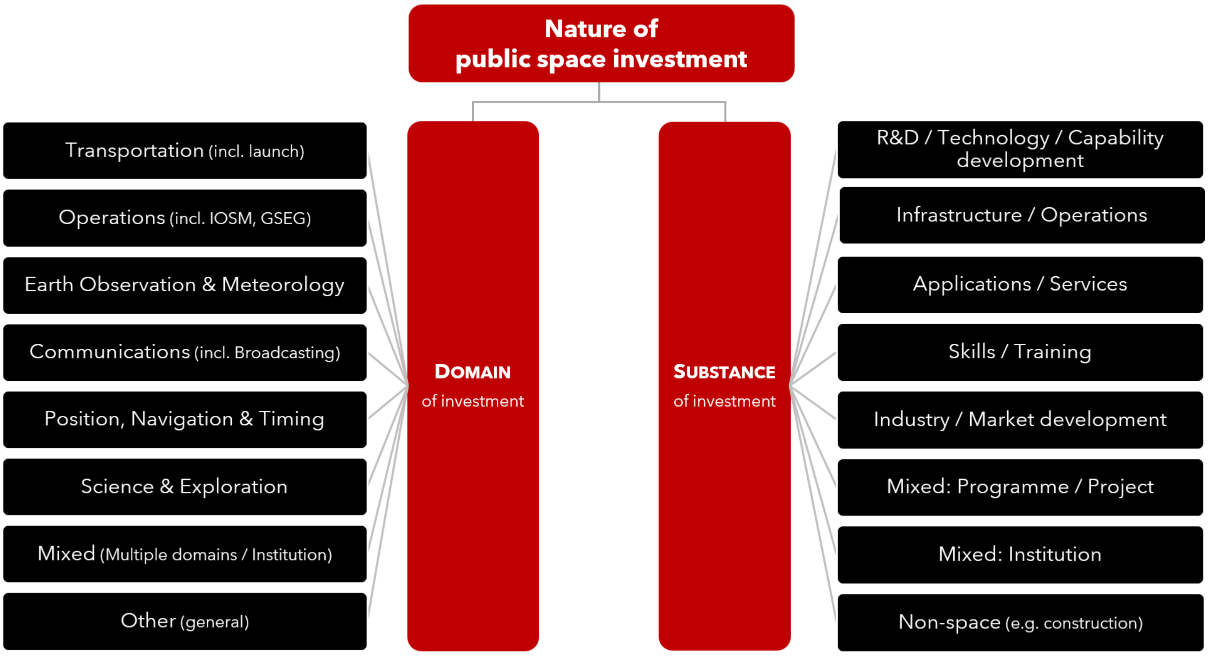
Spillover benefits:

- **Consumer user benefits:** Common benefits of this type include:
  - Transport time and cost savings (from satellite navigation).
  - Lives saved and injuries avoided or reduced (through better disaster response, enhanced safety from navigation, etc.).
  - Connecting rural communities (using satellite broadband).
  - Entertainment applications (live TV, broadband, fitness tracking, etc.).
  - Improved weather services.
  - Greater reliability of services or product availability.
- **Commercial user benefits:** Common benefits of this type include:
  - Commercial activities (e.g. new products and services, spin-off companies) enabled by funded space technology and satellite services.
  - Increased productivity and/or competitiveness of organisations in other sectors supported by funded space technology and satellite services.
  - Beneficiary industries include: Agriculture, Shipping, Environmental monitoring, Transport, Forestry, Oil and gas, Mining, Fishing, Surveying, Construction, and a wide range of other industrial sectors.
- **Social benefits:** Common benefits of this type include:
  - Monitor environmental changes and the contribution of anthropogenic CO_2 emissions, allowing cost savings in monitoring and better policy formation.
  - Support law enforcement (e.g. illegal shipping, illegal logging, pollution events, unauthorised construction, border control, etc.).
  - More efficient and effective delivery of public services (e.g. flood mapping and response management, agriculture land use validation, forest management, coastal erosion protection, air quality monitoring, etc.).
  - Avoided property damages and private costs from mitigated disasters.
- **Active technology transfer benefits:** Novel applications of technology developed for space to advance terrestrial activities and improve public welfare.
- **Passive innovation adoption benefits:** Applications of the scientific discoveries as a result of dissemination activities (e.g. scientific publications).
- **Other spillover benefits:**
  - Inspiration effect to boost skills development for STEM careers.
  - Closer international cooperation, knowledge transfer and strategic coordination between countries.

Returns from public space investments

Of the 52 papers reviewed in 2021, 19 calculated a rate of return, with several papers calculating the rates of returns for multiple investments, giving **24 estimates since 2015**. We combine our own research with the 44 rates of return on investments reported in the 2015 study to give **68 rates of return (RoR) estimates**. We classify investments according to the following framework, allowing for differentiated rates of return across different types and areas of investment.

Typology of public space investments[2]



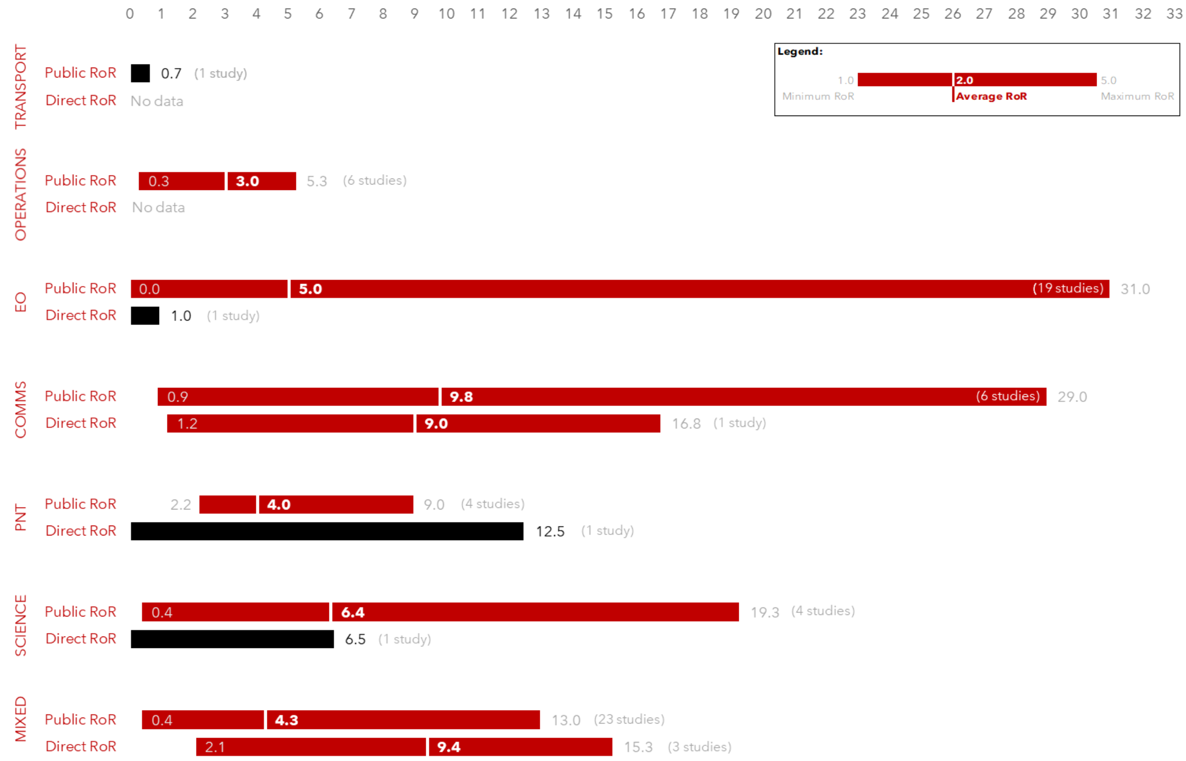
Source: know.space

The reviewed studies covered investments across a wide range of domains and substances. The coverage of individual domains and substances of investment vary, but most commonly, studies considered more than one domain and substance. The following charts summarise these findings and provide **recommend ranges for *ex ante* estimation of potential rates of return**. A number of informed subjective filters have been applied, both in the review methodology and in the analysis of collected estimates (note: outliers – defined as an estimated RoR of 50:1 or greater – have been filtered out from all ranges and averages[3]).

[2] A brief description of each category is provided in the annex.
[3] We have used the interquartile range approach (multiplying the interquartile range by a factor of 3) to find the outlier threshold, as a cross-check on our chosen threshold (50), giving a threshold of 20.3. However, given the very small sample involved we maintain 50 as a threshold to include as many valid RoR estimates as possible.

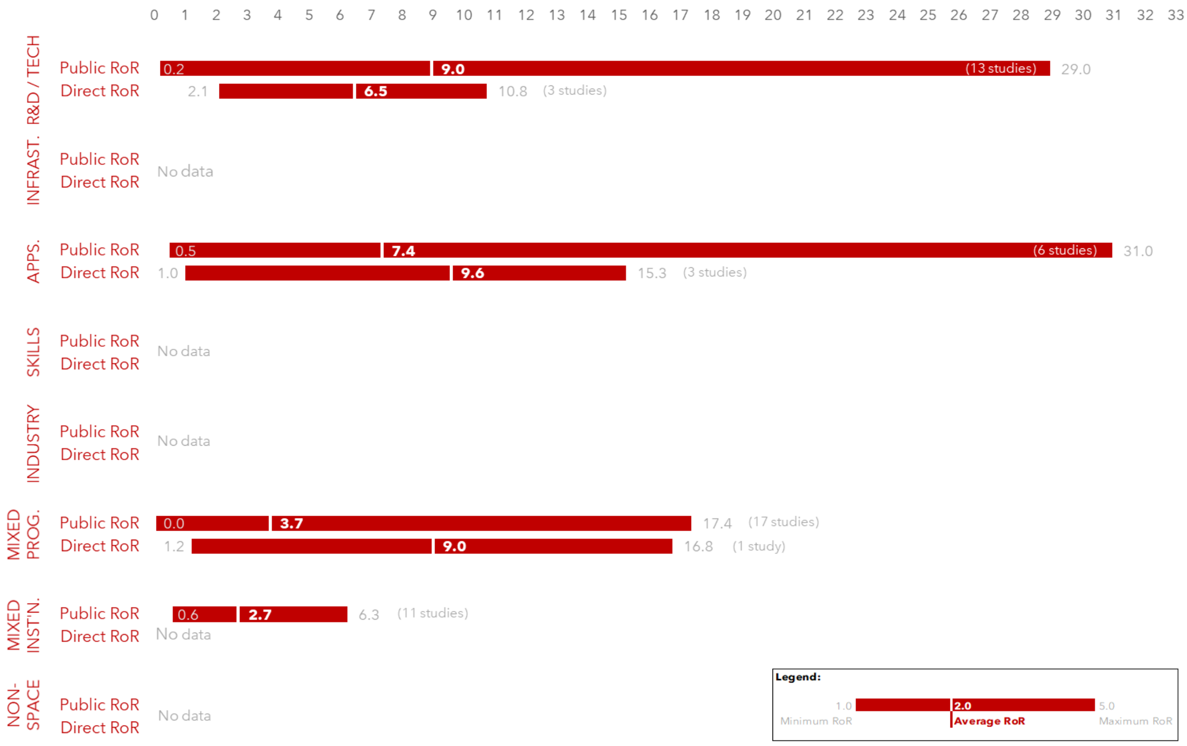
Image: UK Space Agency

Rates of return, by domain



Notes: A black bar indicates there is only one data point in a category. Outliers (defined as an estimated RoR of 50:1 or greater) have been filtered out from all presented ranges and averages.
Source: know.space

Rates of return, by substance



Note: A black bar indicates there is only one data point in a category. Outliers (defined as an estimated RoR of 50:1 or greater) have been filtered out from all presented ranges and averages.
Source: know.space

Image: UK Space Agency

Other parameters

We also investigate a range of factors relevant to assessing the returns on public space investments. These results are summarised below:

- **Lag** At a high-level our results support the conclusions of the 2015 study; we find a median lag of 6 years and recommend the following parameters:
    - **Science and exploration:** 2 years (construction), 10 years (exploitation)
    - **Infrastructure:** 5 years
    - **Technology development:** 2 years
- **Deadweight** The deadweight associated with most space investments appears to be low. Though the evidence base has improved significantly since 2015, we are still unable to provide quantitative estimates.
- **Benefit duration** Estimates range from 4-52 years, with a median duration of 17 years. We recommend using this median, with flexibility to adapt to the specifics of an investment.
- **Leveraging** Leveraged investment ranges from 0-100% of the public space investment, consistent with differing levels of matched investment.
- **Displacement** Analysis of displacement is extremely limited (one weak reference), so on conclusions are drawn.
- **Leakage** A number of studies mention leakages, yet these tend to be highly context-specific, not allowing us to draw generalised conclusions.

Acronyms

ADR	Active Debris Removal
ARTES	Advanced Research in Telecommunications Systems
BCR	Benefit-Cost-Ratio
BEIS	Department for Business, Energy and Industrial Strategy
CEOI	Centre for Earth Observation Instrumentation
CompAQS	Compact Air Quality Spectrometer
COSMIC	Cleaning Outer Space Mission through Innovative Capture
CSA	Canadian Space Agency
DEL	Departmental Expenditure Limit
EGNSS	European Global Navigation Satellite System
ELSA-d	End-of-Life Services by Astroscale-demonstration
EO	Earth Observation
ESA	European Space Agency
EU	European Union
FDI	Foreign Direct Investment
FTE	Full Time Equivalents
GBP	British Pound Sterling
GDP	Gross Domestic Product
GEO	Geosynchronous Equatorial Orbit / GEostationary Orbit
GMES	Global Monitoring for Environment and Security
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSEG	Ground Segment
GVA	Gross Value Added
HAPI	High-resolution Anthropogenic Pollution Imager
HIE	Highlands and Islands Enterprise
IOM	In-Orbit Manufacturing
IOS	In-Orbit Servicing
IOSM	In-Orbit Servicing and Manufacturing
IPP	International Partnership Programme
ISS	International Space Station
MAVEN	Mars Atmosphere and Volatile EvolutioN
NASA	National Aeronautics and Space Administration
NPV	Net Present Value
NSTP	National Space Technology Programme
OMV	Orbital Manoeuvring Vehicle
PNT	Positioning, Navigation, and Timing
R&D	Research and Development
RoI	Return on Investment
RoR	Rate of Return
SPIN	Space Placements in INdustry
SSGP	Space for Smarter Government Programme
SST	Space Surveillance and Tracking
STEM	Science, Technology, Engineering and Mathematics
TGO	Trace Gas Orbiter
TRL	Technology Readiness Level
UKRI	UK Research and Innovation
UKSA	UK Space Agency
WTP	Willingness To Pay


Image: UK Space Agency

1 Introduction

1.1 Background and context

To deliver its new National Space Strategy, the UK government has recently announced that it will increase UK Space Agency funding to over £600m by 2024-25[4]. The ability to **accurately estimate the impact of space investments** (*ex-ante* and *ex post*), understand what returns result from what types of investment and what influences how much impact an investment has, is critical for justifying, managing, and targeting public investment to maximise social returns from limited public funds. However, such estimation **requires a suite of the latest differentiated up-to-date space-specific evidence** (evidence base).

UKSA often estimate the economic returns to space investments using programme-specific information and findings from the *Returns from Public Space Investment 2015* and *Spillovers in the Space Sector 2018* studies. This space-specific evidence is then used to adapt the Department for Business, Energy & Industrial Strategy's (BEIS) Science & Innovation Net Present Value (NPV) model to estimate returns and quantitative benefits.

To date, UKSA have relied on using these studies to fill gaps where there is no specific investment information. The 2015 report analysed impact parameters and assigned space-specific defaults based on evaluations of space science and innovation investments, and found that per £1 of public investment, the return on investment (RoI) for three space industry subsectors was:[5]

- Earth Observation: £2-£4 (direct) plus £4-£12 (spillover);
- Telecoms: £6-£7 (direct) plus £6-£14 (spillover, lower as commercial); *and*
- Navigation: £4-£5 (direct plus partial spillover) plus £4-£10 (spillover).

The *Spillovers in the Space Sector 2018* study provided additional characterisation of spillovers based on a targeted review of the evidence on spillovers.

However, the **current evidence base is limited and dated**.

1.2 Objective

The objective of this research exercise is to widen, strengthen and refine the UK Space Agency's (UKSA) **evidence base on the impacts of public space investments**.

Definition: 'Public space investments' include any expenditures (operations, grants, contracts, contributions) of public funds by any level of government (local, regional, national, supranational) into the space industry (all commercial and non-commercial organisations engaged in any space-related activity), usually for good and/or services (including R&D).

[4] Department for Business, Energy and Industrial Strategy and UK Space Agency. https://www.gov.uk/government/news/government-announces-plans-for-largest-ever-rd-budget
[5] London Economics (2015). *Return from Public Space Investments*. Available at: https://londoneconomics.co.uk/wp-content/uploads/2015/11/LE-UKSA-Return-from-Public-Space-Investments-FINAL-PUBLIC.pdf


Image: UK Space Agency

The core component of the work is to provide an **updated literature review** of all the available evidence on space investments, supplemented by **interviews and case studies**, with a focus on the evaluation of best practice.

This revamp of the space-specific evidence based will focus on two requirements:

1. Identification, characterisation, and quantification of the wide-ranging types of **benefits of public space investments**, including spillover benefits.
    - The **range of benefits** are captured and categorised separately (not aggregated to a RoR), with any quantitative estimates (with calculated proportions to allow generalisation of estimates) and indication(s) of quantification/valuation methodology(ies). Where possible, benefits are mapped onto UKSA results indicators.
2. A comprehensive assessment of the latest evidence on key quantitative and qualitative appraisal parameters, assumptions, and calibrated values of **returns to of public space investments.**

The impact of public space investment is assessed across a range of factors:

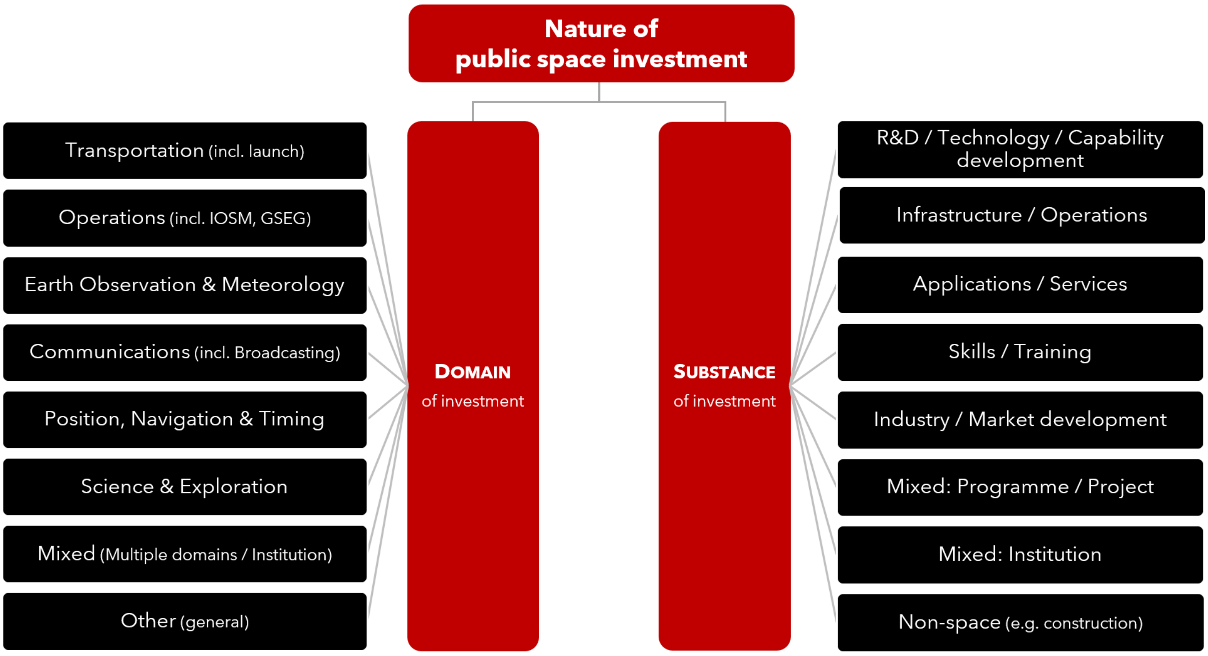
- **Rates of Return** to public investment in space, split into **direct benefits** (to the investing organisation) and **spillover benefits** (to other organisations and wider social benefits);
- Public investment and **leveraged investment** from private and third sector;
- **Ripple (or second order) effects** which capture the follow-on effects stemming from an investment, within the investing organisation/innovator;
- **Lag**: time (in years) before the impact begins to be realised;
- **Depreciation**: rate at which the benefits diminish over time;
- **Duration**: time (in years, from the end of the lag) that the impact endures;
- **Deadweight**: impact that would have occurred in the counterfactual, i.e. in the absence of the examined investment;
- **Displacement**/'crowding out': the decrease in third party investment (e.g. from private, foreign etc. actors.) resulting from the examined investment; and
- **Leakage**: effects that occur outside the domestic economy.

These enhancements will further support the UKSA's evidence-based assessment of expected **benefits** and robustness of estimated economic **rates of return** to inform UKSA's decisions on the future **public space investments**. This should ensure that UKSA business cases and benefits modelling are based on the best available evidence to deliver actionable insights (e.g. target funding to maximise impact).

1.3 Framework of investments and benefits

Investments are classified according to **substance of investment** and **domain of investment**. This overcomes a key limitation of the 2015 study, allowing for differentiated rates of return across different types and areas of investment and providing a more nuanced picture of returns. Rates of return in reviewed studies are classified according to this framework.

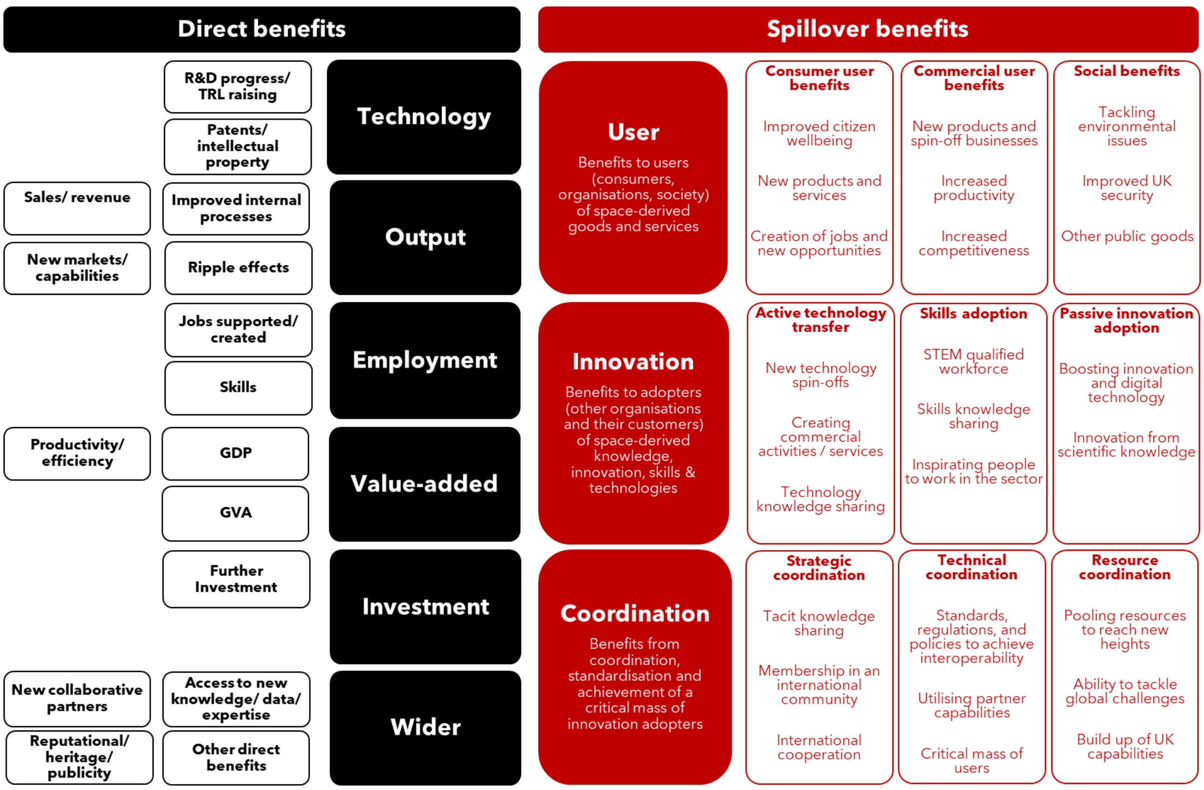
Chart 1 Typology of public space investments[6]



Source: know.space

Benefits are separated into two categories: **direct benefits** and **spillover benefits**. This typology was developed iteratively, with our own initial framework of shaped by the emerging evidence, allowing the evaluation literature to mould the framework.

Chart 2 Typology of benefits from public space investments



Source: know.space

[6] A brief description of each category is provided in the Annex.

1.4 Report structure

The remainder of the report body is structured in three blocks:

- **2. Evidence from evaluations**, presenting a summary of findings from 111 studies of the benefits and returns from public space investments.
- **3. Evidence from Case Studies**, outlines evidence on the benefits of 5 Case Studies of UKSA investments – collected through a combination of desk-based research and consultations with UKSA programme leads, analysts and industry stakeholders.
- **4. Summary and conclusion**, summarises the evidence found, proposes an updated set of evidence-based parameters and a tiered appraisal approach for future appraisals of proposed public space investments.

A full **Bibliography** is provided of all papers included in our review and further information on the **Methodology** is provided as an Annex.

2 Evidence from evaluations

2.1 Introduction

This review builds on the foundation of two previous reviews: *Return from Public Space Investments* (2015), and *Spillovers in the space sector* (2018).[7]

The 2015 review identified **57 papers** calculating a rate of return on public space investments published in the years up to 2015. In total we identified **52 papers** (2015-21) which either calculate a rate of return or assess the benefits arising from investments. Alongside this **increase in the volume** of relevant papers published, the **quality of studies has notably improved** since the 2015 review.

In this updated review, to deepen understanding of the drivers of return, we broaden the scope of our analysis to include papers which assess the **types of benefits** arising from public investments in space (i.e. calculation of a return is not a requirement), as well as the **methodologies used to assess benefits** and any **quantified breakdown of benefits**.

Our approach builds on the same definition and parameters as the 2015 study (for consistency with the BEIS NPV model approach) but **adds refinement – including a new typology and framework** developed to fit the evidence and UKSA requests – to allow for variation within parameters (where supported by the evidence) to increase the sophistication and robustness of estimated economic rates of return to inform UKSA's decisions on future public space investments.

2.2 Summary of methodological approach[8]

The scope of this study covers any **complete or partial** (lifetime, to-date, annual, ex post, ex ante) **economic evaluations of public investments in any space or space-related terrestrial application domain** from **2015-21**.

Our process started with an **initial scan of the literature**. This included checking the citations of the 2015 paper, as well as any publications citing seminal studies identified in 2015. A web-based search was then conducted, using both a bottom-up approach (checking space agency and consultancy websites etc.), as well as a top-down approach for a wider scan. Finally, we conducted a bibliometric cross check, examining the bibliographies of papers already identified. In total, **93 potential papers** were identified.

Papers were then filtered for **quality and relevance**. To be included, a paper must not suffer from strong methodological limitations, bias etc. and include either a rate of return calculation or an assessment of the benefits of a space investment. This reduced our initial pool of 93 papers to the final 52 included in this study.

[7] Both previous reviews were led by know.space Co-founder (and study lead) Greg Sadlier whilst at London Economics.
[8] Details of the methodological approach are provided in an Annex.

These 52 papers were then reviewed in detail. Relevant information on returns and benefits, as well as influencing factors, was collected and logged in a database (alongside the pre-2015 papers).

Caveats and limitations

Our report is subject to a number of important caveats, reflecting limitations in the available evaluation literature (though improving). These are summarised below:

- **Limited coverage of benefits.** Most studies only make reference to a subset of benefits, with a number of studies being deliberately partial analyses; for example, focusing on a specific use-case.
- **Lack of quantification of benefits.** The evidence base demonstrates an extremely broad set of potential benefits qualitatively, yet certain benefit types are rarely quantified. This is particularly true for less tangible benefits, such as improved firm reputation.
- **Lack of monetisation.** Even where benefits are quantified, they are often not monetised, for example, job creation is often framed in terms of the number of full-time equivalents (FTEs) created. This makes comparing the magnitude of benefits across different papers challenging, where different metrics are used.
- **Heterogeneity of analytical methodologies** (discussed below).
- **Lack of methodological transparency.** A significant minority of studies give virtually no detail on the methodological approach taken and few studies provide a detailed explanation.
- **Publication bias.** There is a possibility that studies finding unfavourable rates of return (particularly negative RoRs) may not be published, leading to a risk of an upwards bias in our findings on rates of return.

2.3 Benefits from public space investments

Overview

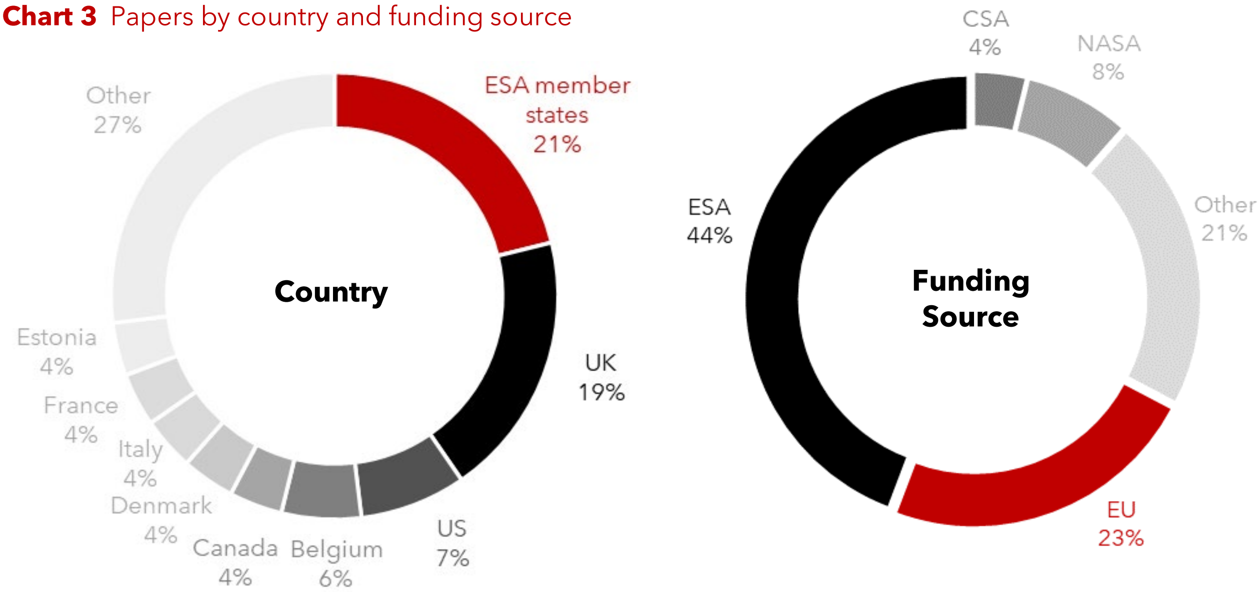
In addition to the high-level **Rate of Return (RoR) estimates**, the **range of benefits** that arise both for and outside of the public funding recipients and (sub-)contractor(s) have been extracted, categorised, qualitatively characterised, and (where a breakdown quantification is provided) quantitative estimates have been given.

Of the **52 papers** reviewed in 2021, nearly every paper contained some breakdown of the **types of benefits** considered, though there was **substantial variation** in the coverage of benefits across studies and methodologies used. Around **two-thirds of papers attempted to quantify benefits** and where benefits were quantified this was usually in monetary terms. Many papers presented a mix of quantified and unquantified benefits.

The body of literature reviewed covers a **wide geographic base**[9]. Many studies reviewed were, at least in part, evaluations of ESA investments, evaluating ESA investments either at the country level or across all ESA member states.

[9] Papers included cover 20 countries. Those not included in the graph for which there is one relevant study includes: Switzerland, Sweden, South Korea, Finland, Netherlands, Latvia, Germany, Spain, Norway, Poland Greenland, Ireland.

Chart 3 Papers by country and funding source



Source: know.space

There is substantial heterogeneity in the approaches used to assess benefits across studies. Most papers take a **bottom-up approach**, assessing individual benefits and aggregating these to the level of a programme or country, whilst a minority of studies use a **top-down approach**, for example assigning a proportion of the overall benefits of tackling a macro-level problem to a given space investment. Several studies take an **econometric approach**.

The vast majority of studies are **partial** in at least one respect – e.g. only considering a subset of potential impacts and/or timeline. A minority of studies deliberately restrict their scope of analysis to provide a detailed micro-level analysis of benefits; for example, the Sentinel benefits studies consider only the benefits from highly specific use cases of Copernicus. Most studies consider a broader range of benefits, but methodological limitations lead to an incomplete assessment of benefits; for example, spillovers are often excluded from analysis, given the difficulties in identifying and quantifying this type of benefit.

The literature also presents a mixture of analyses conducted **ex-post**, **ex-ante** or **ongoing** (evaluation during ongoing investments, will have ex ante and ex post elements). The majority of studies fall into the third category. For many studies, there is no clear ex-post, ex-ante distinction to be made, as the study considers a regular, ongoing investment (e.g., annual ESA contributions or a country's public investment in space as a whole), rather than a clearly defined programme. Even when a study considers a specific programme, these programmes are often ongoing at the time of evaluation.

Quantitative estimation of benefits generally relies on a combination of **desk-based research** and **consultation interviews**, whilst qualitative benefits are often assessed using **survey data**.

This **heterogeneity in approaches** presents a challenge to our analysis, as results are often not readily comparable. To deliver robust conclusions, making best use of the evidence available, we develop a framework of types of benefits and methodologies, which is outlined below.

Still, despite our best efforts to make use of the available data, it is important to note that most studies provide only a partial coverage of benefits and, as in 2015, our analysis is heavily constrained by the quality and quantity of available data.

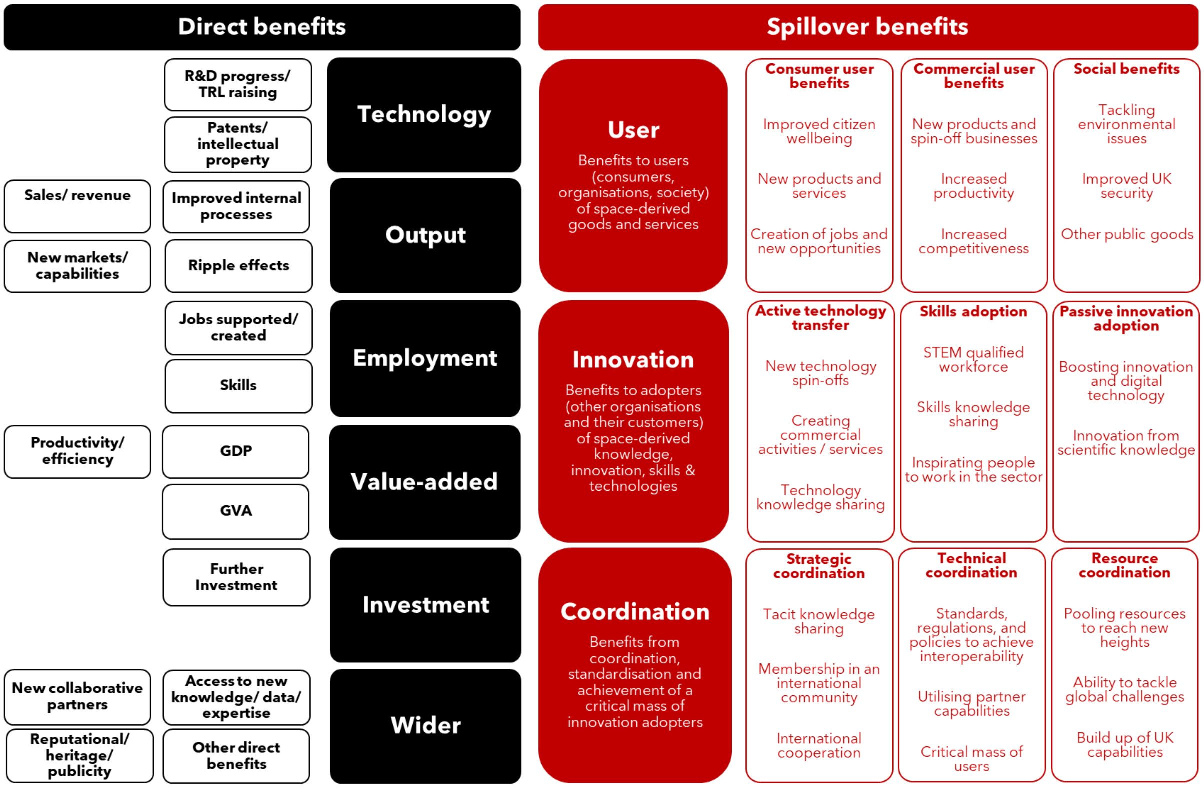
"Even the strongest studies including a quantification and/or monetisation of only a very limited range of benefits, making reference qualitatively to a further limited range of unquantified benefits." (London Economics, 2015).

The depth, breadth and quality of evidence has improved since 2015, but our results remain subject to a lot of the same **caveats**.

Types of benefits

Benefits are broadly separated into two categories: **direct** and **spillovers** (including wider effects). Based on our combined decades of experience, we have prepared the following thought-leading framework of direct and spillover benefits. This framework has been developed as part of the review, using a responsive approach to the evidence base found and allowing the benefits discussed in the literature to mould the framework.

Chart 4 Framework of direct and spillover benefits from space investments



Source: know.space

Direct effects

Direct effects include **outputs that are produced** by the investment funding (e.g. technology/capability developed) and **benefits enjoyed (or costs borne) privately** by the recipient of the public space investment (e.g. funded activity plus follow-on sales or research of the technology/capability developed, known as 'ripple effects'). We group direct benefits into the following categories:

- **Technology development**
    - R&D progress/TRL raising
    - Patents/intellectual property
- **Output**
    - Sales/revenue
    - New markets/capabilities
    - Improved internal processes
    - Ripple effects
- **Employment**
    - Jobs supported/created
    - Skills
- **Value-added**
    - Productivity/efficiency
    - GVA
    - GDP
- **Investment**
    - Further investment
- **Wider benefits**
    - New collaborative partners
    - Reputational/heritage/publicity
    - Access to new knowledge/data/expertise
    - Other direct benefits

A mapping of benefits is provided to **UKSA results indicators** (e.g., 'Sector size', 'Employment', 'Labour productivity').

Spillover effects

Spillover effects include the wide range of impacts that arise on **other parties outside** of the private funder and recipient relationship.

"(T)he term 'spillover' is used to describe any effect arising from an activity that is not reflected in the cost paid (or payoff received) by the parties directly involved in the activity, particularly on external third parties" (London Economics, 2018).

Our three-way classification system covers the wider societal effects and unintended consequences associated with government space investment. Following this framework, spillovers will be grouped into the following categories:

- **User benefits:** Benefits to users (consumers, organisations, society) of space-derived goods and services.
    - Consumer user benefits (including: Improved citizen wellbeing, New products and services, Creation of jobs and new opportunities)
    - Commercial user benefits (including: New products and spin-off businesses; Increased productivity; Increased competitiveness)
    - Social benefits (including: Tackling environmental issues; Improved UK security; Other public goods)

- **Innovation benefits:** Benefits to adopters (other organisations and their customers) of space-derived knowledge, innovation, skills & technologies.
    - Active technology transfer (including: New technology spin-offs; Creating commercial activities/services; Technology knowledge sharing)

- o Skills adoption (including: STEM qualified workforce; Skills knowledge sharing; Inspirating people to work in the sector)
- o Passive innovation adoption (including: Boosting innovation and digital technology; Innovation from scientific knowledge)

- **Coordination benefits:** Benefits from coordination, standardisation and achievement of a critical mass of innovation adopters.
    - o Strategic coordination (including: Tacit knowledge sharing; Membership in an international community; International cooperation)
    - o Technical coordination (including: Standards, regulations, and policies to achieve interoperability; Utilising partner capabilities; Critical mass of users)
    - o Resource coordination (including: Pooling resources to reach new heights; Ability to tackle global challenges; Build-up of UK capabilities)

A mapping of know.space benefit categories to **UKSA results indicators** is provided (e.g. 'Contribution to Climate & Environment Policy').

Types of assessment methodologies

Approaches used in the reviewed literature to assess benefits can be broadly classified into a dichotomy of **qualitative** and **quantitative** methodologies.

Qualitative methods

There is **wide variation** in the methods used to qualitatively assess benefits and the categories by which benefits are assessed, but assessments broadly fall into two categories:

1. Studies which make no attempt to measure the importance of identified benefits, but rather simply state the benefits.
2. Studies which attempt to assess the perceived relative importance of each identified benefit (e.g. Likert scale).

Simple statement of benefits (Type 1)

Benefits tend to be identified using a combination of desk-based research and open-ended surveys or interviews.

Studies falling into this category tend to mention qualitative benefits as an addition to quantitative benefits. These benefits may be deemed impossible to calculate given the paucity of relevant studies available or the complexity of the issue, for example reputational benefits are rarely quantified. Other studies choose to use qualitative analysis to avoid misleading quantitative results; for example, PwC's analysis of the Space Situational Awareness programme (PwC, 2016b) assesses benefits qualitatively since the strategic benefits of the programme are deemed to far outweigh any quantifiable economic benefits. In these studies, benefits are usually highly context specific, e.g. improved performance of flood forecasting models (London Economics, 2018b).

Relative importance of benefits (Type 2)

Categories of benefits tend to be identified using desk-based research before experts/stakeholders are interviewed or surveyed using a pre-set questionnaire. Some studies make use of the Likert scale, whilst another common approach is to ask yes/no

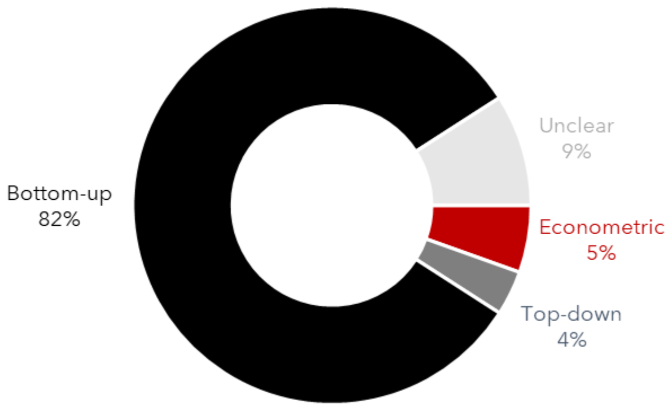
questions and report the percentage agreement; for example, Barjak et al. (2015) assess the percentage of companies and academics reporting 'new knowledge and understanding' etc. An exception is the OECD (2019) literature review, which reports the number of occurrences of pre-defined benefits in the literature. In these studies, benefits generally fall in clear pre-defined categories, which align more closely with our own benefits framework.

Quantitative methods

Quantitative methods are broadly separated into three categories: **bottom-up**, **top-down** and **econometric approaches**.

The vast majority of studies use a **bottom-up approach**, with considerable methodological variation within this category. Some studies provided very little methodological detail, with benefits simply stated.

Chart 5 Quantitative approaches



Source: know.space

Bottom-up approaches

Bottom-up approaches quantify individual benefits before grossing these up to give an overall benefit estimation. A bottom-up approach moves from the specific to the general.

A bottom-up approach has the advantage of specificity – better identifying and quantifying the individual benefits stemming from an investment than a top-down approach. However, the key disadvantage of this approach is that benefits may be difficult to aggregate, with the potential for double-counting, and liberal use of assumptions often necessary.

These studies typically use a combination of desk-based research and interviews with stakeholders, with a minority of studies relying purely on desk-based research and the occasional study using survey data. Often desk-based research is used to identify benefit categories, which are filled in using interviews or survey data.

There is considerable variety in the extent to which benefits are disaggregated. A minority of studies group benefits in a similar manner to our own framework, whilst some studies group benefits according to gross value added (GVA) by sector, others merely by beneficiary and finally, particularly those based on case studies, give highly specific, narrow benefit categories.

Top-down approaches

Top-down approaches start with the overall macro level (e.g. economy, industry, or aggregate benefits) then attempt to isolate relevant changes and attribute a portion of the change to the impact of the space investment. These approaches move from the general to the specific.

A top-down approach can offer a reliable high-level analysis of the overall impacts of a large-scale investment. However, any breakdown of the benefits based on a top-down

analysis is likely to be heavily assumptions-based. Only one study published after 2015 made use of a top-down approach (Rambøll Management Consulting and London Economics, 2016).

Econometric approaches

Econometric approaches use mathematics to model systems and assess the benefits of an investment in terms of the changes to the output of the econometric model.

Only three papers made use of econometric models and each study used econometric analysis in a different way. Notably, Graziola et al. (2015) derived a regression equation for the marginal product of the stock of knowledge, which can be interpreted as the marginal RoR of R&D capital, and estimated elasticities are interpreted as a lower bound for the RoR on space investments. In an entirely different use of econometrics, Loomis et al. (2015) used a logit model to estimate willingness to pay and from this estimated the consumer user benefits of Landsat.

Unclear approaches

Some studies provided benefit estimations with little to no methodological detail or explanation. The approach of these studies is therefore categorised as unclear.

Evidence of assessed benefits

In agreement with the findings of the 2015 study, our evidence demonstrates the **wide, complex and varied range of benefits** which accrue from investments in space, but furthermore gives an indication of the relative frequency and magnitude of each benefit and tabulates the evidence to give approximate estimates of the potential magnitude of benefits.

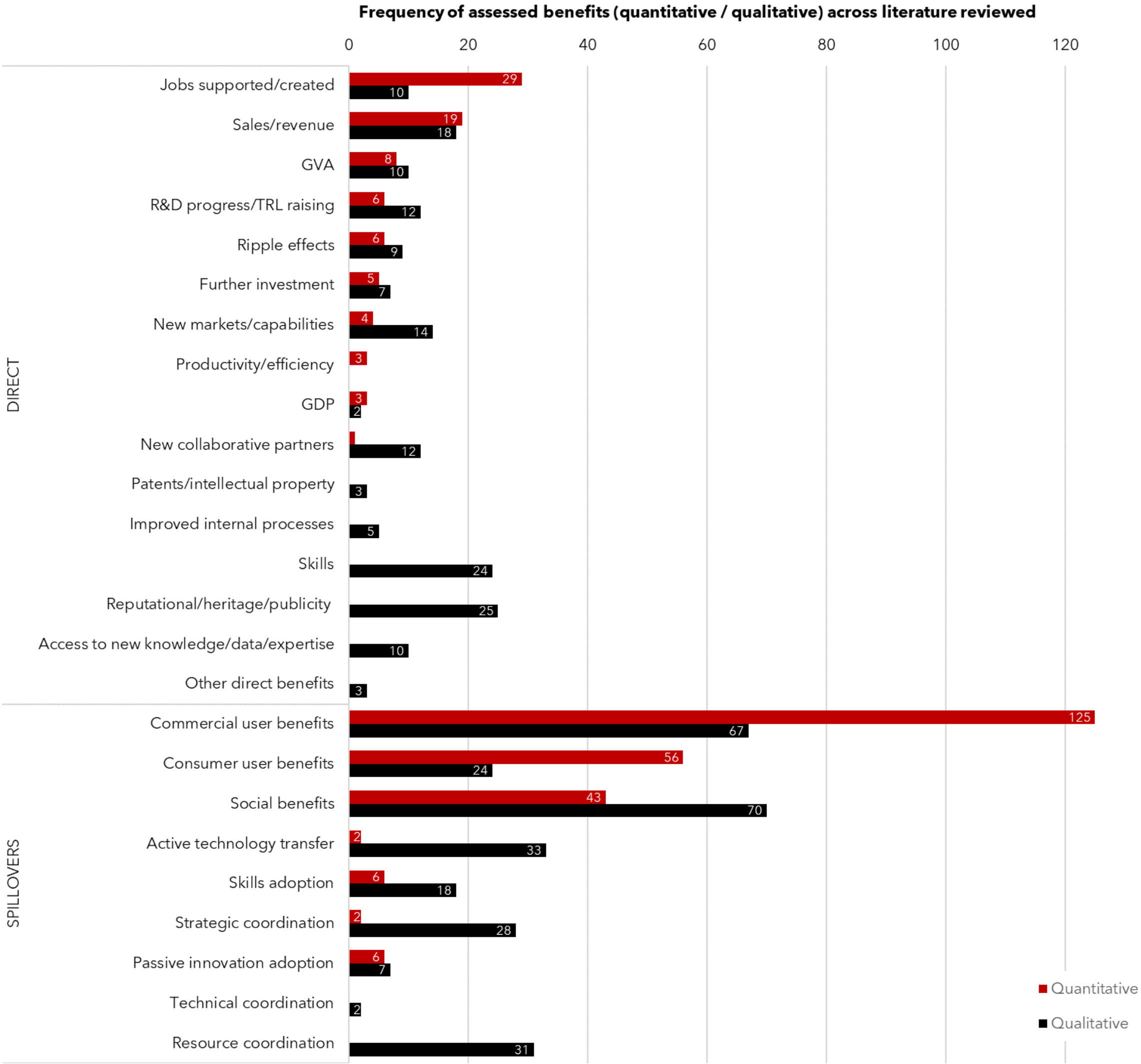
Chart 6 below summarises the evidence on qualitative and quantitative benefits, according to how frequently each category of benefit is mentioned across all papers. This is intended to give an overview of the relative importance of each type of benefit. It is important to note that this data reflects not just the importance of each benefit, but also the ease with which benefits can be recognised and/or quantified.

All of the most frequently mentioned benefits are spillovers. The **most commonly quantified benefits** are commercial user benefits, consumer user benefits and social benefits. The **qualitative benefits mentioned most** are commercial user benefits, social benefits and active technology transfer. This difference may arise because consumer user and social benefits are difficult to quantify, relative to other benefit types; for example, providing a monetisation of the value increased safety or tackling environmental issues is more complex than assessing the increased productivity of commercial users.

The **most commonly quantified direct benefits** are jobs supported/created sales/revenues and GVA, whilst the most frequently mentioned qualitative direct benefits are skills, reputational/heritage/publicity effects and sales/revenue. Again, this likely reflects the difficulties inherent in quantifying certain benefit types.

There is substantial variation in the frequency with which different benefit types are mentioned. Whilst there are 125 quantitative and 67 qualitative commercial user benefits noted across studies, there are no quantified estimates of technical coordination benefits and only two qualitative mentions.

Chart 6 Frequency of assessed benefits (quantitative and qualitative) across literature



Source: know.space

Direct effects

Benefits are grouped into the categories outlined. In this section, the specific quantified benefits are considered individually and tabulated in full.

A key limitation of our analysis is that studies generally do not follow the principles of the Green Book and are often opaque about their methodologies, making additionality difficult to infer; for example, most studies state the total number of employees sustained by an investment and do not provide a counterfactual in the absence of the investment. As such, the values given do not necessarily represent additionality.

Note that grey-filled cells indicate that information is missing or unavailable and does not imply that public or leveraged investment is zero.

R&D progress

The evidence suggests the potential for significant increases in the Technology Readiness Level (TRL) of space projects with government funding. Most projects start around TRL 1-

3, with government funding increasing their TRL considerably, though most projects do not progress to the stage where they are commercially viable.

Table 1 R&D progress

Author(s) and year	Programme	Public investment	Leveraged investment	Type of R&D progress	Value of R&D progress	Methodology type
Technopolis Group (2018)	National Space Technology Programme (NSTP)	£3.1M	£4.8M	Increased TRL of grant-funded projects	67% of respondents on TRL 1-2 (75% overall) reported moving to TRL 3 or above by end of project	Bottom-up
Barjak et al. (2015)	Swiss R&D funding			Increased TRL of grant-funded projects	84% of projects started at TRL 1-4, 15% TRL 5-7 and 1% TRL 8-9. After funding: 46% TRL 1-4, 27% TRL 5-7, 27% TRL 8-9	Bottom-up
Eparvier et al. (2020)	Investments for the Future Programme (France)	€755m		Increased TRL of grant-funded projects	Average TRL gain: 3.2, reaching an average of TRL 6.9 & median 7, from 3.6 average, 3 median	Bottom-up
Technopolis Group (2019)	ARTES			Increased TRL of grant-funded projects	Most projects started at TRL 1-2 and had moved to TRL 3 or above by the end of funding	Bottom-up
Eerme and Lillestik (2019)	Latvia's participation in ESA			Increased TRL of grant-funded projects	The majority of the completed projects reached TRL 3 and TRL 4	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

Sales/revenues

Increased consumer spending, sales or company revenues are often reported, but it is rare that studies provide enough information to compare increased revenues to an initial investment. The picture is further complicated as some studies report gross revenue figures, which risks double counting the benefits to consumers and firms, whilst other studies calculate GVA figures. Euroconsult (2019b) estimate that the value of additional sales generated through ARTES partnership projects will far outstrip the initial volume of investment, whilst Park et al. (2020) estimate that revenue will constitute only a fraction of initial investment in KOMPSAT-1/2/3/3A/5 and COMS. The evidence on the magnitude of increased revenue is limited.

Table 2 Sales/revenues

Author(s) and year	Programme	Public investment	Leveraged investment	Type of sales/ revenues effect	Value of sales/ revenues	Methodology type
NASA (2010)	NASA activities in Florida			Commodity purchases	$1,523m	Bottom-up
				Spending at the Visitor Center	$46m	
				Visitor Center purchases	$25m	
				Business visitor spending	$2.9m	

London Economics (2018a)	Space for Smarter Government Programme (SSGP)	£3.9m		Supply chain effects (direct, indirect and induced spending)	£3.0m	Bottom-up
Park et al. (2020)	KOMPSAT-1/2/3/3A/5 and COMS	4,445bn KRW		Increased revenue of participants	1,631bn KRW	Bottom-up
				Secondary industry utilization	2,248bn KRW	
Sawyer and Dubost (2016a)	Copernicus Sentinel	€ 500,000		Benefit of 1st pre-commercial thinning of trees	€1.67-3.34m	Bottom-up
				Benefit of 2nd pre-commercial thinning of tress	€0.76-1.53m	
Sawyer and Dubost (2016b)	Copernicus Sentinel			Revenue to primary service provider	€ 200,000	Bottom-up
Euroconsult (2019b)	ARTES Partnership Projects	€4bn		Additional sales expected and forecasted (industrial primes and selected subcontractors)	€13bn GVA	Bottom-up
				Additional sales expected and forecasted (operators)	€5bn	
Euroconsult (2019a)	ARTES 4S activities			Commercial revenues	€181M (by 2025) €3.2M (by 2040)	Unclear
Montanari et al. (2020)	ESA BASS	€286.3m		Commercial revenues	€1040m	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

New markets/capabilities

New markets/capabilities were only quantified twice and both times represented a relatively small benefit (1.5-2% of the total investment value). This suggests that this benefit class was relatively unimportant, though it is possible that this specific benefit class was overlooked or subsumed under other categories.

Table 3 New markets/ capabilities

Author(s) and year	Programme	Public investment	Leveraged investment	Type of new markets/ capabilities	Value of new markets/ capabilities	Methodology type
Park et al. (2020)	KOMPSAT-1/2/3/3A/5 and COMS	4,445bn KRW		Satellite data commercialization	76.7bn KRW	Bottom-up
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck and Solar Orbiter)	£554.2m	£4.6m (fully attributed) + £0.2m (partially attributed)	New facilities	£8m (fully attributed)	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

Ripple effects

The quantitative evidence on ripple effects is limited, but suggests they are potentially substantial; for example, London Economics (2019b) forecasts that leveraged sales from investments in the International Partnership Programme (IPP) will alone exceed the initial volume of investment in the programme.

Table 4 Ripple effects

Author(s) and year	Programme	Public investment	Leveraged investment	Type of ripple effect	Value of ripple effect	Methodology type
London Economics (2018b)	Rosetta	€1.4bn		New contracts	The OU and its subcontractors and suppliers will win contracts of ~€13M for PROSPECT	Bottom-up
UKSA (2017)	Herschel SPIRE	£16.5m		Contracts awarded to UK industry	£1.25m	Bottom-up
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck and Solar Orbiter)	£554.2m	£4.6m (fully attributed) + £0.2m (partially attributed)	Additional income from public funds (non-ESA/UKSA)	£47.3m (fully attributed) £15.0m (partially attributed)	Bottom-up
				Additional income from academic grants (non-ESA/UKSA)	£3m (forecast, partially attributed)	
				Additional income from sales (non-ESA/UKSA)	£3.3m (fully attributed) £9.5m (partially attributed)	
London Economics (2019b)	International Partnership Programme (IPP)	£78.1m	£17.1m	Leveraged sales	£147.7m forecasted	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

Jobs created/supported

Employment benefits are usually assessed in terms of full-time equivalents (FTEs) created or sustained by an investment, with a minority of studies assessing employment benefits in monetary terms. The full range of employment growth benefits logged from the literature review are summarised in **Table 5**.

There is huge variation in the numbers of employees supported by each investment, with just 29 FTEs employed directly and indirectly by the Space for Smarter Government Programme (public investment of £3.9m) and nearly 69,000 FTEs employed directly and indirectly by the much larger Moon to Mars programme (a multi-billion-dollar programme). As expected, larger investments are associated with greater employment.

Most programmes are associated with job creation of between 1,000-20,000 FTEs, directly and indirectly. The two studies reporting the greatest employment numbers consider a number of programmes together: Nathalie P. Voorhees Center for Neighborhood and Community Improvement (2020) assess the combined employment impact of all NASA investments (294,978 FTEs) and PwC (2016b) considers the total

employment impact of ESA's participation in the ISS (209,518 person years). These employment numbers reflect a number of distinct programmes. At the other end of the scale, the studies reporting the lowest employment numbers generally assess a small public investment, with the exception of Sawyer et al. (2018), which is a partial assessment of the benefits of Copernicus Sentinel.

Jobs creation is often divided into direct (employees whose wages are directly paid via the public investment) and wider supply chain (employees whose wages are indirectly paid via the public investment). In every study, wider supply chain employment is far larger than direct employment, with the ratio of direct to wider supply chain employment varying from 1.9 for the Space for Smarter Government Programme (London Economics, 2019a) to 20.9 for the Moon to Mars Programme (Nathalie P. Voorhees Center for Neighborhood and Community Improvement, 2020).

Where studies specify that jobs were created from an investment this is noted, but often studies are ambiguous about whether employment figures represent additionality.

Table 5 Jobs created/supported

Author(s) and year	Programme	Public investment	Leveraged investment	Type of employment effect	Value of jobs created/ supported	Methodology type
NASA (2010)	NASA activities in Florida			Direct employment	$984m	Bottom-up
				Employment at Visitor Center	$21m	
Euroconsult (2018)	Transport & Logistics			Job creation	GPS-supported Uber will generate up to 24,500 part-time equivalent jobs in Canada in 2027	Bottom-up
London Economics (2019b)	International Partnership Programme (IPP)	£78.1m	£17.1m	Direct employment	900 FTEs	Bottom-up
				Wider supply chain employment	2,400 FTEs	
London Economics (2018a)	Space for Smarter Government Programme (SSGP)	£3.9m		Direct employment	10 FTEs	Bottom-up
				Wider supply chain employment	19 FTEs	
Nathalie P. Voorhees Center for Neighborhood and Community Improvement (2020)	NASA Investments			Direct employment	17,022 FTEs/ $2.9bn in wages and benefits	Bottom-up
				Wider supply chain employment	294,978 jobs/ $20.8bn in wages and benefits	
	Moon to Mars Program (M2M)			Direct employment	3,155 FTEs/ >$520m in wages and benefits	Bottom-up
				Wider supply chain employment	>65,800 jobs/ $4,680m in wages and benefits	
Euroconsult (2015)	The Canadian Space Sector			Direct employment	9,784 FTEs	Bottom-up
				Wider supply chain employment	14,570 FTEs	
London Economics (2018b)	Synergistic Air-Breathing Rocket Engine (SABRE)	£60m	£49.5m	Direct job creation	130 employees	Bottom-up
BELSPO (2018)	ESA	€250m/year		Job creation & support	3,153 FTE (2015)	Bottom-up
Sawyer et al. (2018)	Copernicus Sentinel			Job creation	14 FTEs/ €1m	Bottom-up

Sawyer and Dubost (2016b)	Copernicus Sentinel			Job creation	€ 250,000	Bottom-up
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck and Solar Orbiter)	£554.2m	£4.6m (fully attributed) + £0.2m (partially attributed)	Direct job creation	£48.2m (fully attributed) £38.4m (partially attributed)	Bottom-up
				Wider supply chain job creation	£56.8m (fully attributed)	
				Direct safeguarding of jobs	£608.4m (fully attributed) £12.8m (partially attributed) £2.2m (forecast, partially attributed)	
				Wider supply chain safeguarding of jobs	£611.7m (fully attributed)	
PwC (2016b)	ESA participation in ISS	€8bn		Job creation	209,518 person years	Unclear
PwC (2016a)	Space Situational Awareness programme: Space Surveillance and Tracking	€1.7bn		Job creation	145 highly qualified jobs	Bottom-up
PwC (2019c)	ESA Future EO			Job support	54,510 FTEs	Econometric
PwC (2019a)	ESA's Ground Systems Engineering and Operations activities	€2.82bn		Job creation	23,340 person years	Unclear
PwC (2016c)	Copernicus	€7.4bn		Job creation	3,050-12,450 person years (2015-2020)	Bottom-up
Van Hoed, et al. (2019)	ESA	€559m		Direct & wider supply chain job creation	6,473 FTEs	Bottom-up
Montanari et al. (2020)	ESA BASS	€286.3m		Job creation	3,436 FTEs	Bottom-up
Boyle et al. (2021)	Copernicus Sentinel			Job creation	€53,000-106,000	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

Productivity/efficiency

Evidence on assessed direct productivity/efficiency effects was limited and not easily comparable. However, note that this category only includes direct productivity/efficiency savings (benefits to funding recipients and sub-contractors) and there are substantial spillover efficiency effects to commercial users, outlined in the commercial user benefits section.

Table 6 Productivity/efficiency

Author(s) and year	Programme	Public investment	Leveraged investment	Type of productivity effect	Value of productivity effect	Methodology type
Sawyer et al. (2018)	Copernicus Sentinel			Crop yield increases	€1/ha (potential)	Bottom-up

Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck, and Solar Orbiter)	£554.2m	£4.6m (fully attributed) + £0.2m (partially attributed)	Productivity gains	£9m (fully attributed)	Bottom-up
Montanari et al. (2020)	ESA BASS	€286.3m		High labour productivity in ESA BASS companies	€223,000 per employee	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

Gross Value Added (GVA)

Only one study specifically notes GVA as a benefit (Van Hoed, et al., 2019). However, a number of other studies mention increased tax revenues, a component of GVA:

GVA = Labour compensation + Tax revenues + Retained earnings

The evidence on tax revenues is limited, though the data suggests potential for governments to recoup a significant proportion of an initial public investment in tax revenue; PwC (2016b) concludes that for ESA's €8bn investment in the ISS, €7bn in tax revenues was collected.

Table 7 GVA

Author(s) and year	Programme	Public investment	Leveraged investment	Type of GVA effect	Value of GVA effect	Methodology type
Euroconsult (2018)	Air Traffic Management			Tax from growth in air traffic	CA$19m in 2027	Bottom-up
London Economics (2019a)	International Partnership Programme (IPP)			Tax revenue	£44.3m	Bottom-up
Nathalie P. Voorhees Center for Neighborhood and Community Improvement (2020)	NASA Investments			Tax revenue	$6.9bn	Bottom-up
	Moon to Mars Program (M2M)			Tax revenue	$1.5bn	
Euroconsult (2015)	The Canadian Space Sector			Tax revenue	CA$750m	Bottom-up
Van Hoed, et al. (2019)	ESA	€559m		GVA (direct, indirect & derived)	€642m	Bottom-up
Euroconsult (2019b)	ARTES Partnership Projects	€4bn		Tax revenue	€8bn	Bottom-up
PwC (2016b)	ESA participation in ISS	€8bn		Tax revenue	€7bn	Unclear

Note: Grey cells indicate missing data.
Source: know.space

GDP

GDP benefits are rarely reported, with most studies focusing firm or industry-level analysis. Despite these benefits rarely being reported, they are clearly substantial; the Size

and Health 2020 report (know.space, 2021), estimates that the space industry directly contributed 0.30% of UK GDP. Clearly, this value-added is not solely due to public investment, but gives us a sense of the scale of GDP impacts, if we were to attribute a proportion of this impact to public investment.

Table 8 GDP

Author(s) and year	Programme	Public investment	Leveraged investment	Type of GDP effect	Value of GDP effect	Methodology type
Euroconsult (2018)	Air Traffic Management			Enabling air travel	GDP impact of at least CA$25m	Bottom-up
	Benefits to remote/rural communities			Support for Canadian economy	CA$2.2bn addition to Canada's GDP over 2008 to 2017 through satellite enabled broadband households	
Park et al. (2020)	KOMPSAT-1/2/3/3A/5 and COMS	4,445bn KRW		Satellite components import substitution	305bn KRW	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

Further investment

Several studies report grantees receiving significant further investment following an initial government investment due to the enhanced reputation or visibility of the firm. In all cases, this further investment significantly outstripped the initial investment amount, suggesting this could be an important benefit class. It is possible that this benefit was overlooked by other studies, especially those conducting analysis before, or shortly after, the end of a project.

Table 9 Further investment

Author(s) and year	Programme	Public investment	Leveraged investment	Type of investment	Value of investment	Methodology type
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck, and Solar Orbiter)	£554.2m	£4.6m (fully attributed) + £0.2m (partially attributed)	Investment by grantee	£4.6m (fully attributed) £0.2m (partially attributed)	Bottom-up
Euroconsult (2019b)	ARTES Partnership Projects	€4bn		Investment from ESA, member states and industry	€7bn GVA	Bottom-up
PwC (2016a)	Space Situational Awareness programme: Space Weather	€503m		Investment benefits	€904m	Bottom-up
Montanari et al. (2020)	ESA BASS	€286.3m		Third party investments	€808m	Bottom-up
Eerme and Lillestik (2019) and Invent Baltics OÜ (2015)	Estonia's participation in ESA	€2.7m/year		Equity funding attracted due to enhanced reputation	Equity investments directly attributable to the ESA projects worth €12.1m	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

New collaborative partners

Only one paper gave a quantitative estimate of the number of new collaborative partners generated by an investment (Technopolis Group, 2019), but given that twelve papers qualitatively mentioned new collaborative partners, we should not rule out the importance of this benefit. Technopolis (2019) estimated over 73 new collaborations were generated between UK organisations as a consequence of the ARTES programme, suggesting this benefit could be large.

Table 10 New collaborative partners

Author(s) and year	Programme	Public investment	Leveraged investment	Type of collaborative partner effect	Value of collaborative partner effect	Methodology type
Technopolis Group (2019)	ARTES	£765m	£553m	New and strengthened partnerships	Estimate >73 new collaborations between UK organisations across the full portfolio of ARTES projects.	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

Spillover benefits

Consumer user benefits

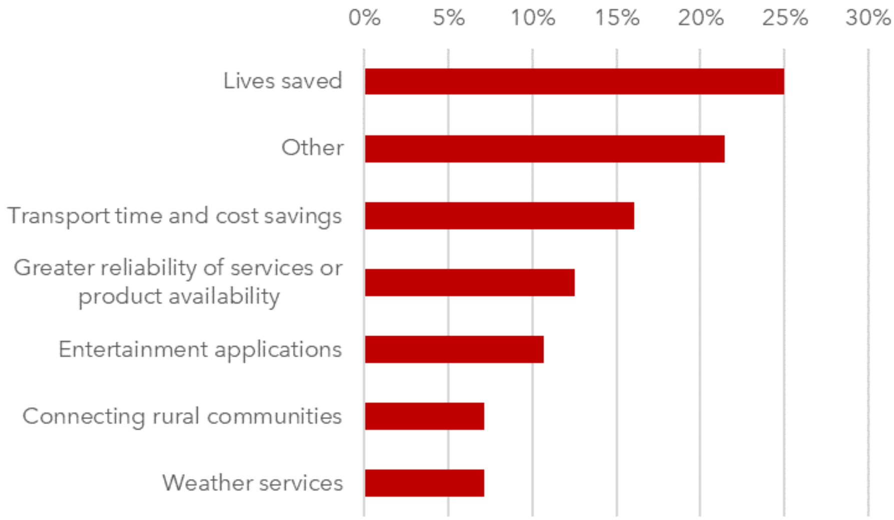
Consumer user benefits were the second most quantified of any benefit class and appear to be substantial and varied. Common types of consumer user benefits include:

- Transport time and cost savings (from satellite navigation)
- Lives saved (through better disaster response, enhanced safety from navigation etc.)
- Connecting rural communities (using satellite broadband)
- Entertainment applications (satellite TV and broadband, fitness tracking etc.)
- Weather services
- Greater reliability of services or product availability

Chart 7 notes the frequency with which consumer user benefits are mentioned by sub-category. Lives saved is by far the most-frequently mentioned consumer user benefit category, with benefits arising from better search and rescue, increased passenger safety, emergency response times, better air quality information etc.

Chart 7 Consumer user benefits by sub-category

Category of Consumer User Effect	Frequency
Lives saved	14
Other	12
Transport time and cost savings	9
Greater reliability of services or product availability	7
Entertainment applications	6
Connecting rural communities	4
Weather services	4



Source: know.space

Even within a specific consumer user benefit class, there is substantial variation. London Economics (2018c) estimate that the weather and climate services derived from satellites are worth £0.96bn/ year to the UK (~£14m per capita per year) from 2020. Euroconsult (2015) provide a far higher figure, estimating that weather services are worth CA$5.4bn/year to Canadian consumers (~£140m per capita per year). Canada's more extreme weather could account for some of the difference, but this highlights how context-specific quantitative estimates are.

Table 11 Consumer user benefits

Author(s) and year	Programme	Public investment	Leveraged investment	Type of consumer user effect	Value of consumer user effect	Methodology type
Technopolis Group (2010)	"Common R&D" policy			Healthcare	€1.5bn (10-20 years)	Top-down
				Secure access to high quality water resources	€60m (6-7 years)	
				Secure access to energy resources (oil and gas)	€100m (<5 years), €2bn (5-20 years)	
Leveson (2015)	GPS			Timing (serves as a standard)	$.025-.063bn	Bottom-up
				Transport benefits (time saved etc.)	$7.3bn-18.9bn	
Euroconsult (2018)	Air Traffic Management			Passenger safety enhancement	76% improvement towards complying to official safety targets	Bottom-up
	Disaster Management			Lives saved through disaster management	COSPAS-SARSAT has helped save the lives of >1,500 Canadians, and >32,000 lives globally	
				Support to search and rescue	CA$10m/year	
	Benefits to remote/rural communities			Connecting households & communities (satellite internet)	>200,000 households in remote areas of Canada	
				Provision of telemedicine	9 Northern communities saved $600,000/year (2017)	


Image: UK Space Agency

	Transport & Logistics			Health/ fitness downloads	>300,000 health and fitness apps downloaded by Canadians in May 2018	
London Economics (2019a)	International Partnership Programme (IPP)			Connecting isolated communities with emergency communications at onset of disaster	59 communities within 24 hours of the onset of a disaster	Bottom-up
				Internet connectivity for schoolchildren	437,000 schoolchildren	
				Avoidance of people killed, missing, or injured	688 persons	
London Economics (2018a)	Space for Smarter Government Programme (SSGP)	£3.9m		Better air quality information	£4.1m/year	Bottom-up
London Economics (2018c)	UK Satellite-derived Earth Observation impacts	£175m/year		Weather and climate services	£861.7m/year (current), £962.1m/year (by 2020)	Bottom-up
Euroconsult (2015)	The Canadian Space Sector			Weather services	$5.4 bn/year	Bottom-up
				Travel (time and fuel saved on commutes etc.)	5-15% /year in fuel savings	
				Entertainment (satellite TV)	7m subscribers	
				Satellite broadband	200,000 subscribers	
				Search and rescue	At least 1500 Canadians	
Rambøll Management Consulting (2016)	The Danish Space Sector			Copernicus earth observation benefits	DKK 7558m	Top-down
				Meteorology (accuracy of weather forecasts)	DKK 706m	
				Navigation	DKK 6.1bn	
London Economics (2018b)	Space for Smarter Government Programme (SSGP)	£1.3-1.5m/year		BBC's free-to-use 'MappAir' service	2m users within the first 48 hours of launching	Bottom-up
O'Connor et al. (2019)	GPS	$1.3bn/year 2010-2017		Electricity (Electrical system reliability and efficiency)	$15,730m	Bottom-up
				Location-based services	$215,702m	
				Telecommunications (Improved reliability and bandwidth utilization for wireless networks)	$685,990m	
Sawyer and Dubost (2015)	Copernicus Sentinel			General public benefits from reliable shipping (goods in shops, lower prices as firms hold less stock and reliable fuel supplies)	€3.5 – 17.5m	Bottom-up
Sawyer and Dubost (2016a)	Copernicus Sentinel	€ 500,000		Citizens' benefits (walks through forest etc.)	€1m	Bottom-up
Sawyer and Dubost (2016b)	Copernicus Sentinel			Benefits to citizens and local economy from satellite pipe monitoring (reduced risk of gas leakages,	€1.5-2.8m	Bottom-up

Image: UK Space Agency

				more reliable supply of gas and water etc.)		
PwC (2016a)	Space Situational Awareness programme: Space Weather	€503m		User benefits	€2,233m	Bottom-up
PwC (2016c)	Copernicus	€7.4bn		End user benefits (urban monitoring)	€1.1-1.4m	Bottom-up
				End user benefits (insurance)	€3 – 186m	
				End user benefits (oil and gas)	€101.3m	
London Economics (2017)	GNSS			Public safety answering point (emergency services)	£1,921m	Bottom-up
				Weather forecasting	£25m	
				Lone worker tracking	£247.6m	
				Road navigation/ Advanced Driver Advisory Systems	£1,921.3m	
				Search and rescue applications	£8.8m	
				ELTs (Emergency Locator Transmitters-aviation) and PLBs (Personal Locator Beacons-maritime)	£2m	
				Location-based services	£57.4m	
				Pedestrian navigation	£137.4m	
				Fitness tracking	£10m	
				Navigation/ Advanced driver advisory systems	£1,217.4m	
				Emergency and breakdown calls	£15m	
PwC (2017)	Copernicus programme			Search & Rescue	€1,195.1m	Bottom-up
Helios (2017)	Satcom enabled Air Traffic Control (ATC)			Passenger benefits (time savings, greater availability of flights etc.)	$570m	Unclear
Daraio et al. (2016)	COSMO-SkyMed Mission			New products	>900,000 CSK products	Bottom-up
Sawyer et al. (2021)	Copernicus Sentinel			Enabling leisure activities (e.g. swimming)	€3.1-6.2m	Bottom-up
Mamais et al. (2020)	Copernicus Sentinel			Cost savings to citizens from avoided damage to property	€29,372,552-58,745,104	Bottom-up
Sawyer and Boyle (2020)	Copernicus Sentinel			Reduced road closures	€1,350,000-€3,780,000	Bottom-up
Mamais et al. (2018)	Copernicus Sentinel			Avoided welfare costs from road disruption	€0.1-7.7m	Bottom-up
				Avoided flooding damage	€2.07-17.08m	
				People feel safer with flood monitoring systems in place (WTP)	€0.1-1.3m	

Sawyer and Oligschläger (2019)	Copernicus Sentinel			Benefits to citizens of security of having food in shops etc. (WTP)	€200,000-1.0m	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

Commercial user benefits

Across all studies, we found 125 quantitative estimates of commercial user benefits, suggesting this is a key benefit class for space investments.

Commercial user benefits were generally categorised by industry and tend to fall in two broad groups:

- Firms made more productive/ competitive as a result of space investments.
- Firms whose revenues are enabled by space investments via new products or spin-off businesses.

Productivity/ efficiency savings generally arise for commercial users because satellite data allows firms to make better, more informed decisions. This often means that problems can be detected early and can therefore be rectified more quickly; for example, Sawyer et al. (2018) find that where farmers in Denmark use Fieldsense, a service providing farmers with satellite images of their crops, they detect crop diseases and pests quickly. This allows them to treat a small area of crops before the problem spreads, generating time and cost savings, as fewer pesticides etc. are used.

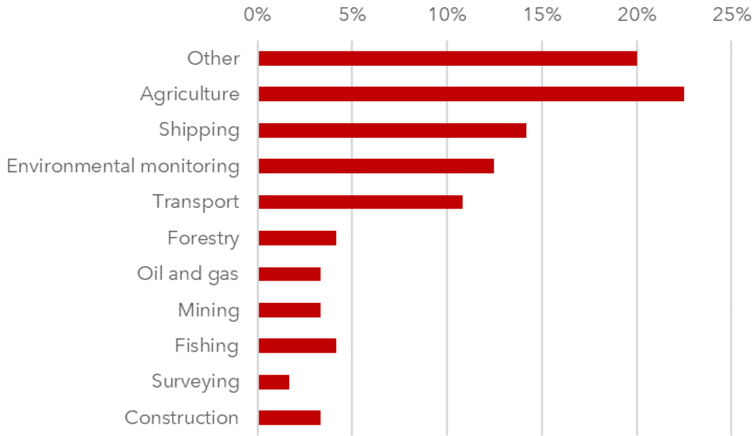
Commercial users also benefit from new products and spin-offs enabled by space investments; for example, Sawyer and Dubost (2016a) estimate EO service provider benefits of €50,000 from the use of Copernicus data for forest management in Sweden alone. These revenues are contingent on public space investments.

Despite finding 125 different quantitative estimates across studies, it is difficult to produce generalised conclusions, as only 25 papers produced estimates and investment amounts were only sometimes stated. Moreover, some papers provided estimates of gross enabled revenues, whilst others framed commercial benefits in terms of GVA or cost savings. Finally, no paper provided a truly comprehensive assessment of commercial user benefits, with most papers focusing on key commercial uses and number of papers providing a deliberately partial assessment of benefits, for example, the Copernicus Sentinels' Products Economic Value case studies. Still, the potential for extremely large commercial user benefits is clear; O'Connor et al. (2019) estimate commercial revenues of $437bn from GPS from 1984-2017 for US firms alone.

The industries that were most often reported to benefit from space investments are reported in **Chart 8**. Agricultural benefits are most frequently noted, with several studies (e.g., Sawyer et al., 2018) focusing exclusively on agricultural applications and many more studies mentioning commercial benefits in agriculture as part of a more comprehensive analysis. Benefits to the shipping industry, environmental monitoring and transport are also frequently cited.

Chart 8 Industries most frequently reported to benefit from space investments

Industry	Frequency
Other	24
Agriculture	27
Shipping	17
Environmental monitoring	15
Transport	13
Forestry	5
Oil and gas	4
Mining	4
Fishing	5
Surveying	2
Construction	4



Source: know.space

Table 12 Commercial user benefits

Author(s) and year	Programme	Public investment	Leveraged investment	Type of commercial user effect	Value of commercial user effect	Methodology type
Leveson (2015)	GPS			Precision Agriculture	$10.0-17.7bn	Bottom-up
				Construction (earthmoving with machine guidance)	$2.2-7.7bn	
				Surveying	$9.8-13.4bn	
				Air Transportation	$.119 -.168bn	
				Rail Transportation	$.010-.100bn	
				Maritime Transportation (private sector use of nautical charts etc.)	$.106-.263bn	
				Fleet Vehicle Connected Telematics	$7.6-16.3bn	
Euroconsult (2018)	Agriculture			Enabling precision agriculture (cost savings to farmers)	CA$500-550 m/year	Bottom-up
				Opening new agricultural markets	CA$100-200m /year canola export market for Canadian farmers	
	Environment Monitoring			Increased shipping efficiency	CA$5-10m	
	Transport & Logistics			Improving maritime container utilisation	CA$170m cost savings to the Canadian maritime industry (by 2025)	
				Fuel savings	CA$50m/year	
				Reduced damaged goods	CA$130m (from 2025)	
London Economics (2019a)	International Partnership Programme (IPP)			Additional crop yields	£372.9m	Bottom-up
				Saving of heavy fuel oil	5.3m litres	
London Economics (2018c)	UK Satellite-derived Earth Observation impacts	£175m/year		Better data on forests	£2.8m/year (current), £38m/year (by 2020)	Bottom-up
				Better monitoring of fisheries	£3.8m/year (by 2020)	
				More efficient traffic monitoring	£0.1m/year (by 2020)	
Euroconsult (2015)	The Canadian Space Sector			Improved maritime domain awareness	60% reduction in CP140 flights (maritime control plane)	Bottom-up

O'Connor et al. (2019)	GPS	$1.3bn/year 2010-2017		Precision agriculture technologies and practices	$5,830m (1984-2017)	Bottom-up
				Mining benefits (Efficiency gains, cost reductions, and increased accuracy)	$12,350m (1984-2017)	
				Maritime benefits (Navigation, port operations, fishing, and recreational boating)	Negligible	
				Oil and gas (Positioning for offshore drilling and exploration)	$45,922m (1984-2017)	
				Surveying (Productivity gains, cost reductions, and increased accuracy)	$48,124m (1984-2017)	
				Telematics (Efficiency gains, cost reductions, and environmental benefits)	$325,182m (1984-2017)	
Sawyer and Dubost (2016a)	Copernicus Sentinel	€ 500,000		Benefits to county boards using EO	€ 80,000	Bottom-up
				EO service provider benefits	€ 50,000	
				Benefit from earlier tree replanting to tree owners	€3.07-6.14m	
				Avoided costs of monitoring forests using planes or inspections	€10m (€9.5m net of costs)	
Sawyer and Dubost (2016b)	Copernicus Sentinel			Lower maintenance costs to gas suppliers	€ 4,750,000	Bottom-up
				Lower maintenance costs to water suppliers	€ 274,000	
Sawyer and Dubost (2015)	Copernicus Sentinel			Business benefits (the local economy is reliant on ships for imports and exports)	€6.3 - 63m	Bottom-up
				Fuel saving by icebreakers	€1m	
				Removing helicopters from icebreakers (needed without satellites)	€1.29m	
				Fuel saving by ships	€2.08 –3.33m	
				Reduced operational costs due to lower journey time	€5.84-9.42m	
				More accurate ship arrival times	€4.2 - 21m	
Sawyer et al. (2018)	Copernicus Sentinel			Reduced use of chemicals in farming (cost saving to farmers)	€2.6-5.2/ha (actual), €13-30/ha (potential)	Bottom-up
				Time savings for farmers	€0.6-1.5/ha (actual), €6-15/ha (potential)	
Park et al. (2020)	KOMPSAT-1/2/3/3A/5 and COMS	4,445bn KRW		Satellite data distribution	2,580bn KRW	Bottom-up
PwC (2017)	Copernicus programme			Revenues for intermediate users	€9,091m	Bottom-up
				Solar energy monitoring and forecasting	€125.7m	


Image: UK Space Agency

					Crops monitoring	€23,025.8m	
					Forestry management and protection	€8,603.5m	
					Water resources management	€3,447.7m	
					Wetlands monitoring	€7,658.2m	
					Ground elevation and ground motion monitoring	€867.9m	
					Urban area monitoring	€1,156.6m	
					Offshore wind infrastructure management	€6,923.4m	
					Oil and gas infrastructure management/ development and exploration activities	€9,771.4m	
					Minerals and raw materials extraction	€82.3m	
					Coastal monitoring	€2,182.m	
					Marine resources management	€36,409m	
					Water quality monitoring	€65.4m	
					Ice monitoring (ship routing)	€1,031m	
					Maritime navigation	€181.3m	
					Fire detection and monitoring	€8,946.2m	
					Flood monitoring and forecasting	€25,978.6m	
					Control of Illegal, Unreported and Unregulated (IUU) fishing	€11.5m	
PwC (2016c)	Copernicus	€7.4bn			Enabled revenues (agriculture)	€9.2-13.7m/year	Bottom-up
					Enabled revenues (forestry)	€4.2-6.2m	
					Enabled revenues (urban monitoring)	€4.6 – 6.7m	
					Enabled revenues (insurance)	€0 – 2.3m	
					Enabled revenues (Ocean Monitoring)	€5.8 – 8.6m	
					Enabled revenues (oil and gas)	€13.6m	
					Enabled revenues (renewable energies)	€1.8 – 2.7m	
					Enabled revenues (air quality)	€0.01 – 0.27m	
London Economics (2017)	GNSS				GVA (Fixed-line telecommunications)	£31.9m	Bottom-up
					GVA (Cellular telecommunications)	£5m	
					GVA (TETRA (terrestrial trunked radio))	£4.3m	
					GVA (Emergency vehicles)	£96.5m	
					GVA (Energy infrastructure costs)	£4.4m	
					GVA (Banking and stock exchanges)	£0.6m	
					GVA (Weather forecasting)	£75m	


Image: UK Space Agency

				GVA (Offender tracking)	£30.8m	
				GVA (CAP and CFP compliance monitoring)	£0.8m	
				GVA (Satcoms)	£31.7m	
				GVA (Logistics and fleet management)	£154.2m	
				GVA (Navigation and shipping)	£350m	
				GVA (Fishing)	£70m	
				GVA (Reduction in diversions and cancellations and CFIT (Controlled Flight Into Terrain))	£0.5m	
				GVA (Cultivation)	£284.4m	
				GVA (Cadastral surveying)	£4m	
				GVA (Mapping)	£0.96m	
				GVA (Mining)	£0.04m	
				GVA (Construction)	£7.5m	
				GVA (Marine surveying)	£1.4m	
				GVA (Asset management)	£0.1m	
				GVA (Driver advisory systems)	£10.8m	
				GVA (Insurance telematics)	£16.1m	
Helios (2017)	Satcom enabled Air Traffic Control (ATC)			Airline benefits (fewer holding penalties, fuel savings etc.)	$420m	Unclear
Daraio et al. (2016)	COSMO-SkyMed Mission			Institutional user benefits	>240 projects using COSMO SkyMed products	Bottom-up
Oligschläger (2019)	Copernicus Sentinel: WatchITgrow application			Savings on agricultural chemicals	€1.19-2.38m	Bottom-up
				Increased potato yields	€27-59.4m	
				Optimal harvesting	€2.7m-€3.95m (potential)	
				Fewer journeys for agronomists (fuel savings)	€144,000-180,000	
				Benefits for the potato processing industry from increased crops	€425k -850k (today) €16.5m –22m (full market and technology)	
Sawyer and Oligschlaeger (2021)	Copernicus Sentinel			Primary commercial user revenues	€7,000-12,000 (today), €225,000-450,000 (potential)	Bottom-up
				Cost savings to commercial users from reduced fertiliser use	€56,000-140k,000 (today), €1.2-3.6m (potential)	
				Better harvesting efficiency	€35,000-70,000 (today), €600,000-1.2m (potential)	
				Increased value of product (wine)	€735,000-1.1m (today), €14-24m (potential)	
				Better irrigation as it is easier to get regulatory approval with Sentinel data	€500,000 (potential)	
				Reduced inspection of vines	€300,000 (potential)	

Boyle et al. (2021)	Copernicus Sentinel			Time savings from reduced field inspections	€50,000-1,000,000	Bottom-up
Sawyer et al. (2021)	Copernicus Sentinel			Water treatment savings due to early warnings of algal blooms	€1.5-3m	Bottom-up
Mamais et al. (2020)	Copernicus Sentinel			Increased intermediate user revenues	€546,601-1,093,201	Bottom-up
				Cost savings to local authorities	€2,323,982-13,014,300	
Sawyer and Boyle (2020)	Copernicus Sentinel			Cost savings from better design enabled by satellite data	€2.43-4.9m	Bottom-up
				More efficient building construction using satellite data	€10,000-40,000	
Mamais et al. (2018)	Copernicus Sentinel			Cost savings in monitoring	€3.61m	Bottom-up
Sawyer and Oligschläger (2019)	Copernicus Sentinel			Reduction in costs associated with accidents and incidents navigating ice	€ 800,000	Bottom-up
				Greater catches for fisheries	€ 840,000	
				Cost savings for ferries and charter boats	€ 540,000	
				More passenger cruises made possible	€400,000-600,000	
				More efficient fuel delivery	€150,000-250,000	
				Avoided lost sailing days for Arctic Command	€600,000-1,000,000	
				Ice pilot services	€ 220,000	
				More efficient export of fish	€200,000-400,000	
				Increased efficiency in mining evaluations	€ 100,000	
				Logistical benefits to supermarkets	€260,000-520,000	
Sawyer et al. (2019)	Copernicus Sentinel			Costs saving from reduced use of chemicals in farming	€125,000 (today), €2.38m (full market and technology)	Bottom-up
				Increased crop yield	€800,000–1.2m (today), €40m–59m (full market and technology)	
				Better timing of harvest	€270,000 (today), €3.95m (full market and technology)	
				Reduced agronomist kilometrage	€150,000–180,000	
				Improved process management	€425,000-850,000 (today), €16.5m–22m (full market and technology)	

Note: Grey cells indicate missing data.
Source: know.space

Social benefits

Social benefits tend to derive from the monitoring capacity of satellites. Governments can better track environmental changes, as well as using satellite data to assist in law

enforcement, for example illegal shipping. This allows cost savings in monitoring and better policy formation.

Most social benefits are monetised, with the exception of several environmental benefits. Social benefits are difficult to compare, with some studies assessing benefits on the level of a programme, whilst others assess the benefits accruing to a country or group of countries. Moreover, most studies are partial assessments.

Despite the limited evidence, we can infer that social benefits are potentially very large. PwC (2017) estimates that the anthropogenic CO_2 emissions monitoring benefit of Copernicus is worth €29.2 billion and enhanced security services are worth €21.9 billion.

Even the lower social benefit estimates are large relative to initial public investment. London Economics (2018c) assesses satellite-derived benefits to the UK associated with public investment of £175m/year. The greatest benefits accrue from the monitoring of rail and road networks (transport benefits), worth £86.4m/year by 2020 to the UK government. This alone allows government to recoup nearly half of public investment. In total, the social benefits of satellites to the UK are estimated to be worth £224.3m/year by 2020, far outstripping public investment.

Table 13 Social benefits

Author(s) and year	Programme	Public investment	Leveraged investment	Type of social effect	Value of social effect	Methodology type
Technopolis Group (2010)	"Common R&D" policy			Renewable energy sources	€25m (<5 years), €6bn (>20 years)	Top-down
Euroconsult (2018)	Air Traffic Management			Reduction of CO2 emission per flight	Reduction of 27.6m tons of CO2 equivalent emission (across Canadian controlled airspace) by 2027	Bottom-up
	Environment Monitoring			Reporting on illegal shipping	>200 oil anomalies (2013-2017), 39 of which validated as discharge from ocean-going vessels.	
	Agriculture			Improved agricultural practices (government cost savings)	CA$75m (5 years)	
London Economics (2019a)	International Partnership Programme (IPP)			Avoidance of deforestation	4.3m hectares	Bottom-up
London Economics (2018a)	Space for Smarter Government Programme (SSGP)	£3.9m		Flood mapping (Operational cost saving)	£2.8m/year	Bottom-up
				Sea Level Space Watch (Operational cost saving)	£1m/year	
				Efficient detection and detainment of tree pests and pathogens	£9.2m/year	
				Peatland assessment (Operational cost saving)	£24m/year	
London Economics (2018b)	Space for Smarter Government Programme (SSGP)	£1.3-1.5m/year		Potential for more effective air quality interventions (leading to fewer hospital admissions)	£4.1m/year	Bottom-up


Image: UK Space Agency

London Economics (2018c)	UK Satellite-derived Earth Observation impacts	£175m/year		Wider agricultural benefits (reduced pollution)	£12.3m/year (by 2020)	Bottom-up
				Atmosphere benefits (fewer hospital emissions due to poor air quality etc.)	£4.3m/year (by 2020)	
				Avoided loss of land and assets due to coastal erosion	£5.9m/year (by 2020)	
				Avoided losses due to improved flood response	£14.4m/year (current), £21.5m/year (by 2020)	
				Agricultural benefits to government	£45.1m/year (current), £63.1m/year (by 2020)	
				Mapping benefits (easier mapping of natural resources and early detection of illegal planning)	£8.3m/ year (by 2020)	
				Better understanding of coastal erosion and coastal change	£1m/year (by 2020)	
				More efficient flood responses	£2.8m/year	
				Forestry management cost savings	£0.3m/year (current), £22.7m/year (by 2020)	
				Better monitoring of maritime environment (oil spill management, environmental, offshore energy etc.)	£12.1m/year, £11.8m/year (by 2020)	
				Cost savings to government from meteorological services	£3.9m/year, £4.2m/year (by 2020)	
				Transport benefits (monitoring of road and rail networks)	£86.4m/year (by 2020)	
PwC (2017)	Copernicus programme			Air quality and reduced pollution	€15,559.7m	Bottom-up
				Climate modelling	€3,070m	
				Oil pollution monitoring	€582m	
				Law enforcement and international crime	€8,983.6m	
				EU borders surveillance	€21.6m	
				Anthropogenic CO2 emissions monitoring	€29,171.3m	
				Arctic environment and snow evolution monitoring	€990.7m	
				Thermal infrared capability to monitor water and agriculture	€1,204.2m	

				Hyper spectral capability to monitor biodiversity, forestry, land, agriculture and mining	€1,237.8m	
				Enhanced security services	€21,919.2m	
Helios (2017)	Satcom enabled Air Traffic Control (ATC)			Reduced CO2 emissions (from efficient plane routing)	$110m	Unclear
Daraio et al. (2016)	COSMO-SkyMed Mission			Avoided property damages (landslides and floods)	€30.0m	Bottom-up
				Avoided fatalities (landslides and floods)	€3.4m	
				Avoided property damages (earthquakes)	€36.7m	
				Avoided fatalities (earthquakes)	€1.2m	
				Avoided property damages (volcanic eruptions)	€0.1m	
				Avoided deforestation from fires	€1.6m	
				Avoided clean-up costs from oil spills	€2.2m	
Sawyer and Oligschlaeger (2021)	Copernicus Sentinel			Benefits to the local community	€6,000-10,000 (today), €730,000-1.3m (potential)	Bottom-up
Mamais et al. (2018)	Copernicus Sentinel			Avoided future costs due to better public decision making	€0.61m	Bottom-up
Sawyer and Oligschläger (2019)	Copernicus Sentinel			Supports strategic value of Greenland to Denmark	€4,310,000-6,270,000	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

Active technology transfer benefits

Just two studies quantity active technology transfer benefits, making it difficult to draw any firm conclusions or their importance or magnitude, though the number of qualitative references to active technology transfer suggests this class of benefits may be difficult to quantify, yet commonly occurring and potentially important.

Table 14 Active technology transfer

Author(s) and year	Programme	Public investment	Leveraged investment	Type of active technology transfer	Value of active technology transfer	Methodology type
London Economics (2018b)	Rosetta	€1.4bn		Technology transfer (mass spectrometry technology used in PROSPECT mission)	Contracts worth ~€13m	Bottom-up
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder,	£554.2m	£4.6m (fully attributed) + £0.2m (partially attributed)	Spin out	£1,125m (partially attributed) £110m (forecast, partially attributed)	Bottom-up

	Planck and Solar Orbiter)					

Note: Grey cells indicate missing data.
Source: know.space

Passive innovation adoption benefits

The only quantified passive innovation adoption benefits are scientific discoveries, generally proxied by the number of academic publications citing project data. Clearly, space investments generate a huge volume of academic research, though interestingly ESA's participation in the ISS, with associated public investment of €8bn led to >1,000 relevant publications (PwC, 2016b), yet Herschel Spire, a far smaller project with public investment of just £16.5m, led to 1,691 academic papers (UKSA, 2017). Reasons for this difference may be methodological or simply reflect the broader access to data or time on Herschel Spire than experiment flight on ISS.

Table 15 Passive innovation adoption

Author(s) and year	Programme	Public investment	Leveraged investment	Type of passive innovation adoption	Value of passive innovation adoption	Methodology type
PwC (2016b)	ESA participation in ISS	€8bn		Scientific discovery	>1,000 relevant publications on European experiments on the ISS	Unclear
Technopolis Group (2019)	ARTES	£765m	£553m	Scientific discovery	Every 100 ARTES projects with UK involvement might create around 90 refereed papers, ~25 other publications, ~40 dissemination activities and 5-10 patents	Bottom-up
PwC (2019c)	ESA Future EO			Scientific discovery	10,273 publications citing ESA EO missions	Econometric
UKSA (2017)	Herschel SPIRE	£16.5m		Scientific discovery	1,691 refereed papers using Herschel data	Bottom-up
Eerme and Lillestik (2019)	Latvia's participation in ESA			Scientific discovery	3 academic publications as a direct result	Bottom-up
Boyle et al. (2021)	Copernicus Sentinel			Scientific publications	4 papers	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

Other spillover benefits

Skills adoption was not monetised by any papers, but our research suggests that space investments/programmes engage large numbers of people, inspiring them to work in the space sector and STEM careers more generally.

Strategic coordination benefits were rarely quantified, which is to be expected given their intangible nature.

Our qualitative evidence suggests that space investments can lead to closer cooperation between countries and knowledge transfer, as well as helping countries to keep

international commitments (e.g., aid assistance). This is true of both investments in ESA and unilateral investments.

Table 16 Other spillover benefits

Author(s) and year	Programme	Public investment	Leveraged investment	Type of benefit	Value of benefit	Methodology type
Euroconsult (2015)	The Canadian Space Sector			Skills adoption	Canadarm was voted the fifth most popular icon defining Canada (2008)	Bottom-up
				Skills adoption	>563,000 visitors to CSA multimedia exhibit (2011-14)	
				Skills adoption	~150,000 CSA Twitter followers (2014)	
UKSA (2017)	Herschel SPIRE	£16.5m		Skills adoption	>20,000 pupils/year in schools programme	Bottom-up
				Skills adoption	11 major public events	
Euroconsult (2018)	Disaster Management			Strategic coordination (supporting international relief efforts)	The International Charter activated 576 times (as of June 2018)	Bottom-up
PwC (2019c)	ESA Future EO			Strategic coordination (engaging international community)	53 workshops in 16 countries	Econometric
Eerme and Lillestik (2019)	Latvia's participation in ESA			Skills adoption (Education and awareness activities)	Budget of €221,222	Bottom-up

Note: Grey cells indicate missing data.
Source: know.space

2.4 Returns from public space investments

Overview

In this section, we consider the evidence on returns to investments in space. Of the 52 papers reviewed by know.space, 19 calculated some rate of return, with several papers calculating the rates of returns for multiple investments, giving **24 estimates since 2015**. We combine our own research with the 44 rates of return on investments reported in the 2015 study (London Economics, 2015) to give **68 rates of return (RoR) estimates**.

It is worth highlighting that all 68 rate of return estimates reviewed are positive. It is possible that this reflects a degree of publication bias, given that a negative RoR estimate may reflect poorly on the organisation publishing such a study.

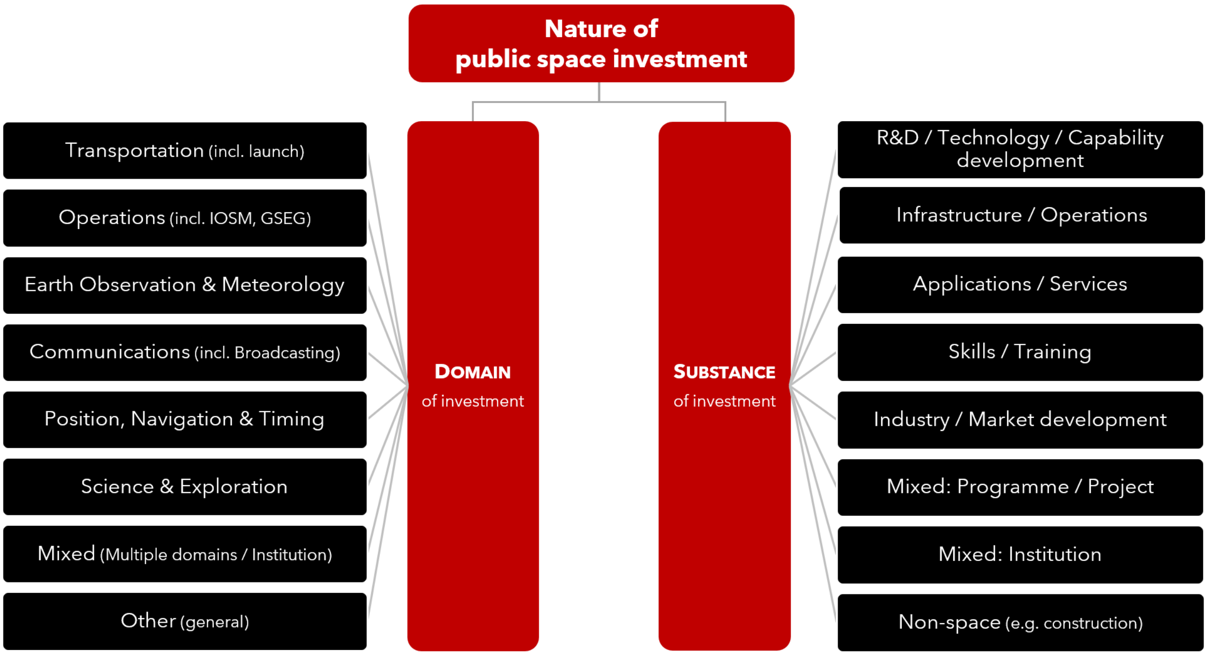
The majority of studies did not provide a rate of return figure directly. Excluding studies in the ESA group in 2015 (for which no information is available), 47 rates of return were inferred by know.space or London Economics, and only 13 rates of return were directly taken from studies. Returns were often inferred from cost-benefit ratios and in some cases from the magnitude of total benefits and investments[10].

[10] See Annex for details on how rates of return were inferred.

Nearly all of these studies calculate an overall social public rate of return but estimates of direct and spillover rates of return were rare. Only 3 studies allow us to infer a spillover rate of return and 4 a direct rate of return. This is generally due to a lack of information on leveraged investment. Accordingly, we focus on public rates of return.

The 2015 study divided papers into 'Evaluations of ESA membership' and 'Evaluations of space science and innovation investments'. With our larger pool of evidence and more detailed framework, we further classify studies according to **substance of space investments** and **domain of space investments**. This overcomes a key limitation of the 2015 study, allowing for differentiated rates of return across different types and areas of investment and providing a more nuanced picture of returns. Studies are classified according to this framework.

Chart 9 Typology and framework of public space investments[11]



Source: know.space

Note the inclusion of a **'non-space' category** for investment substance – though no studies included this split, based on consultations with practitioners it is important to acknowledge that some of the investment funds may pay for non-space activities. For example, funding for a new R&D centre might include some non-space (facility construction and equipage) and space (skills/training, technology development and operations) activities.

Definitions

Our approach adopts the same definitions as the 2015 study (for consistency with the BEIS NPV model approach). There is a conceptual 'Spillovers Rate of Return', but this is not widely cited. **Table 17** defines the three types of rates of return used in this study.

[11] A brief description of each category is provided in the Annex.

Table 17 Rates of return definition

Parameter	Definition
Public Rate of Return	*"The social net benefit/cost from the investment of public funds, measured as the impact on aggregate domestic economic output (GVA, producer surplus) and wider benefits (knowledge spillovers, consumer surplus, environment, health, safety, etc.) net of deadweight and displacement effects relative to the quantum of public investment"* (London Economics 2015).
	$Public\ Rate\ of\ Return = \frac{NPV}{DEL} = \frac{(TotalBenefits)\ -\ (TotalInvestment)}{(PublicInvestment)}$ $= \frac{(DirectBenefits\ +\ SpilloverBenefits)\ -\ (PublicInvestment\ +\ LeveragedInvestment)}{(PublicInvestment)}$
Direct Rate of Return	*"The direct net benefit/cost from the investment of leveraged private funds, measured as the impact on the output (producer surplus) or productivity (TFP) of the investing organisation net of deadweight and displacement effects relative to the quantum of leveraged private investment"* (London Economics 2015).
	$Direct\ Rate\ of\ Return = \frac{(DirectBenefits) - (LeveragedInvestment)}{(LeveragedInvestment)}$
Spillover Rate of Return	*"The wider net benefit/cost from the investment of leveraged private funds, measured as the impact on the output (producer surplus) or productivity (TFP) of other organisations and wider benefits (knowledge spillovers, consumer surplus, environment, health, safety, etc.) net of deadweight and displacement effects relative to the quantum of [public] investment."* (London Economics 2015, [adjusted]).
	$Spillover\ Rate\ of\ Return = \frac{(SpilloverBenefits) - (PublicInvestment)}{(PublicInvestment)}$

Note: NPV = net present value, DEL = departmental expenditure limit, i.e., public investment
Source: know.space

Quality

Rate of return estimates are given quality ratings consistent with those used in the 2015 review. A low-quality rating implies that a rate of return estimate is not particularly useful to our analysis, not that a study is of poor quality in itself. Studies are written for a range of purposes and a paper may be highly useful to other readers, yet receive a poor quality rating because its intended purpose differs from our own.

Table 18 Quality ratings

Quality rating	Symbol
Very weak	●○○○○
Weak	●●○○○
Moderate	●●●○○
Strong	●●●●○
Very strong	●●●●●

Note: No study has been rated as 'Very strong'.
Source: know.space

A 'very weak' estimate will be of extremely limited use in determining a true rate of return. Estimates are generally assigned 'very weak' status because the returns figure is stated with no methodological explanation, though sometimes these estimates are heavily caveated by the authors themselves. 17 estimates were assigned this status, the vast majority of these being from pre-2015 studies.

A 'very strong' estimate would follow from a sound and transparent methodology, with authors stating (or allowing us to infer) a rate of return in line with our own rate of return definitions. Such an estimate would provide strong guidance on the actual or true rate of return. No estimates were assigned this status in our analysis, though a number of papers

Image: UK Space Agency

provided 'strong' estimates. This category is still included to allow for the possibility of exceptional studies.

Discounting

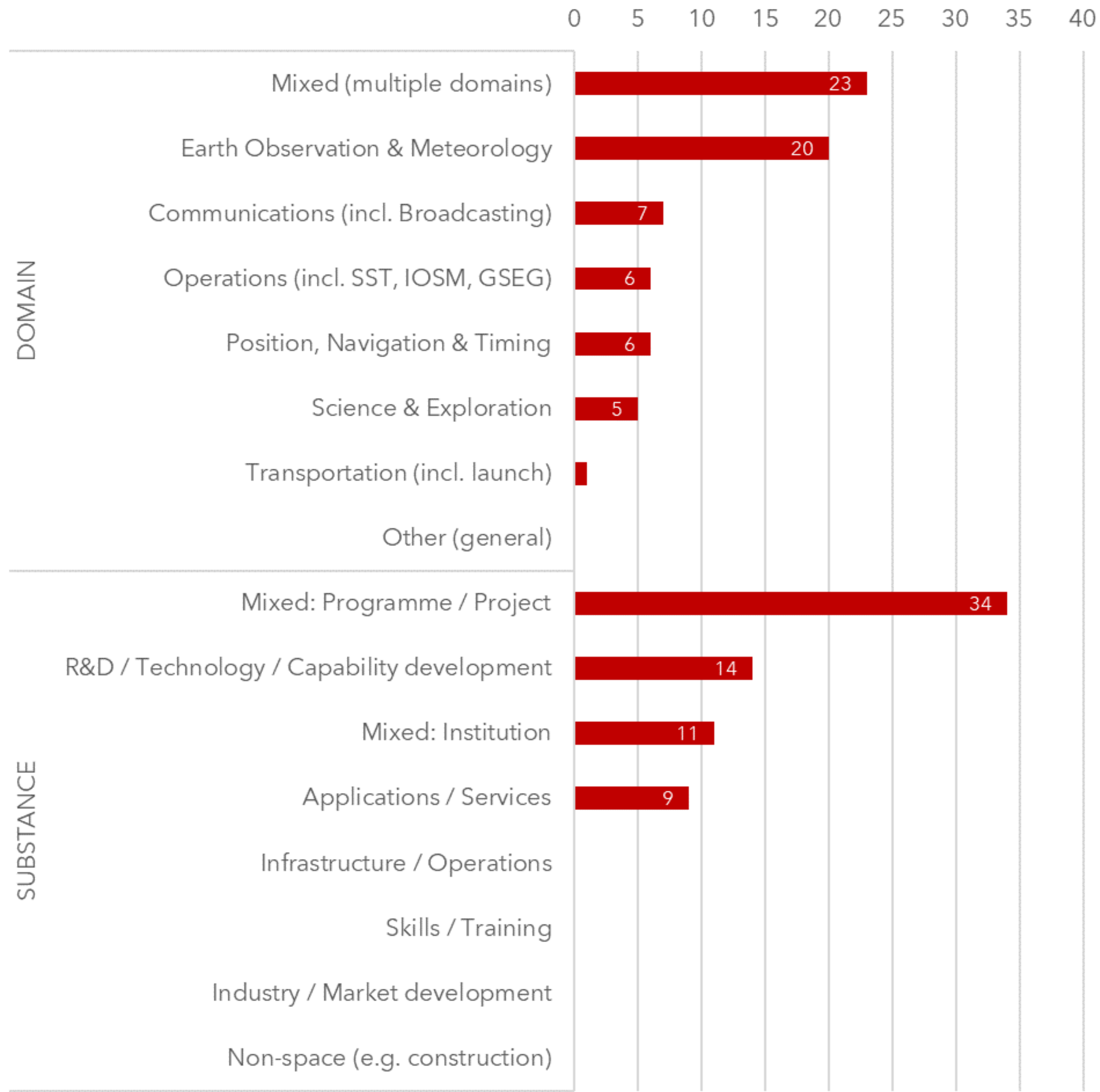
Although the discount rate should be a key parameter in evaluating a public investment, the evidence base is muted in this regard. Studies typically made no mention of discounting, suggesting that the practice is fairly uncommon (though there is a possibility that some studies used discounting, but did not make this known to the reader). Even when papers implied that a NPV figure was used, the discount rate used was rarely specified. As such, we cannot draw any conclusions on the extent to which the choice of discount rate drives RoR estimates, but we note that this is a generalised weakness in the literature.

Rates of return

The reviewed studies covered investments across a wide range of domains and substances. The coverage of individual domains and substances of investment vary, but most commonly, studies considered more than one domain and substance. The most common domain was the Mixed (multiple domains) category (23 studies) followed by Earth Observation & Meteorology (20 studies), and by far the most common substance of investment was Mixed: Programme/Project (34 studies).

Chart 10 provides a summary of the frequency of rate of return estimates across the literature reviewed, categorised by domain and substance of investment; for example, 23 papers estimated the rate of return across Mixed (multiple domains). Papers are grouped into domain and substance groups by type of investment, rather than the resulting benefits. As such, though we list non-space benefits (e.g. construction) in the preceding chapter, no papers are classed as evaluating a non-space investment, since the primary focus of the investment is better described by other categories.

Chart 10 Frequency of rates of return across literature reviewed



Source: know.space

Rates of return, by domain

In the following tables, grey-filled cells indicate missing data. Where a study did not specify the amount of public investment, we may still have a rate of return figure, because the authors stated a rate of return or cost-benefit ratio, without providing their calculations.

Transportation

Only one study calculated a public rate of return on transportation investments. As such, we cannot draw any firm conclusions on this domain of investment, except to note the need for more research.

Table 19 Transportation

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
Robinson and Westgaver (2000)	Ariane early launch vehicles			0.7	●●○○○	Authors adopt a conservative approach, underestimating uncertain values.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space

Operations

Six studies estimated the public rate of return for operations investments. Estimates for the public rate of return on operations investments range from 0.3-5.3, with a mean rate of return of 3.0.[12]

Table 20 Operations

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
Hickling Corporation (1994)	Canada's long term space plan: Mobile Servicing System (MSS)			3.3	●●○○○	Lack of methodological detail.
British National Space Centre (2009)	Canadarm			5.0	●○○○○	Lack of methodological detail -no reference to estimate provided.
BELSPO (2018)	ESA SSA programme	€6.79M (2017-2020)		1.3	●●●○○	Authors explain low RoR as result of low contribution to programme.
PwC (2016a)	Space Situational Awareness programme: Space Weather	€503m		5.3	●●●●○	Lack of methodological detail. Authors consider results to be conservative estimates.
	Space Situational Awareness programme: Near Earth Objects	€160m (Survey & Follow up scenario) €225m (Deflection mission scenario)		0.3 (Survey & Follow up scenario) 0.4 (Deflection mission scenario)		
PwC (2019a)	ESA's Ground Systems Engineering and Operations activities	€2.82bn		3.0	●●●○○	Lack of methodological detail.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space

Earth observation & meteorology

Across all studies, there were 19 estimates of the public rate of return on investments in earth observation & meteorology, with estimates ranging from 0.0-31.0. However, it is likely that the public return on investments lies between 0.0-9.5, given Sawyer and Dubost's (2016a) figure is derived from a partial assessment of the costs and benefits of Copernicus, only considering the localised costs associated with a specific use case, and not the cost of Copernicus itself.

[12] Where one study gives multiple rates of return on one programme/investment, the mean estimate is taken.

The mean public rate of return on investments in earth observation & meteorology is 5.0 (3.6, excluding Sawyer and Dubost (2016a)). Only one study calculated a direct rate of return on earth observation & meteorology investments, giving an estimate of 1.0.

Table 21 Earth observation & meteorology

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
McCallum et al. (2010) and Bouma et al. (2009)	Global Earth Observation System of Systems (GEOSS)			0.5	●●○○○	Limited coverage of benefits.
SpaceTec Partners (2012a) and Knight et al. (2012)	EO and Copernicus Downstream Services for the Agriculture Sector			1.0 (Direct RoR)	●○○○○	Limited coverage of benefits; no consideration of public investment costs.
Booz & Co. (2011)	GMES (Option A: Baseline, Option B: Baseline extended, Option C: Partial continuity, Option D: Full continuity)			0.0 (Option A) 1.3 (Option B) 2.2 (Option C) 2.7 (Option D)	●●●○○	RoR low for options with a lower future investment commitment, e.g. Option A: no ongoing commitment to replace infrastructure
Robinson and Westgaver (2000)	Meteosat			1.5	●●○○○	Authors adopt a conservative approach, underestimating uncertain values.
SpaceTec Partners (2013)	Copernicus (Option A: Service Delivery Pull; Option B: Intermediate; Option C: Technology Driven)			2.3 (Service Delivery Pull) 2.2 (Intermediate) 2.0 (Technology Driven)	●●●○○	Follow on analysis from Booz & Co. (2011).
UK Space Agency (2014a)	National Space Technology Programme (MetOp-SG)			3.0	●○○○○	Lack of methodological detail - no reference to estimate provided. R&D in a commercially maturing segment (telecommunications).
Sridhara Murthi et al. (2007)	Indian Remote Sensing Programme			3.3	●●○○○	Methodological inconsistencies and limits.
Hickling Corporation (1994)	Canada's Long Term Space Plan: Earth Observation (EO)			3.9	●●○○○	Lack of methodological detail.
EADS Astrium (2006)	UK investment in Disaster Monitoring Constellation (DMC)			8.0	●○○○○	No methodological detail or reference to estimates provided.
EUMETSAT (2013)	EPS/Metop-Second Generation satellite programme			3.6 (Minimum) 17.4 (Likely)	●●●○○	Meteorological satellites in use in weather forecasting applications.
European Space Policy Institute (2011) using data from Booz & Co. (2011)	GMES			9.5	●●●○○	RoR is described as being an upper bound due to cost underestimates.
Booz Allen Hamilton (2005)	NASA Geospatial Interoperability			0.2	●○○○○	Study only considers current benefits from R&D in progress.
London Economics (2018c)	UK Satellite-derived Earth Observation impacts	£175m/year		4.4 6.1 by 2020	●●●○○	Considers social and user benefits from EO only.
Park et al. (2020)	KOMPSAT-1/2/3/3A/5 and COMS	4445bn KRW		0.2	●●●○○	Limited coverage of benefits. Authors attribute lower RoR than European studies to difficulty in technology diffusion in South Korea.

Sawyer and Dubost (2016a)	Copernicus Sentinel	€500,000		31	●●●●○	Partial consideration of costs and benefits. Not comparable to other RoRs.
BELSPO (2018)	PLEIADES (bilateral with France)	€893k (2004-)		1	●●○○○	Belgium contributes an amount equal to the value of Belgian contracts giving a RoR of 1.
	SAOCOM (bilateral with Argentina)	€1.92M (2001-2016)		1		
	MUSIS	€20.361 (2011-2022)		1		
PwC (2019c)	ESA Future EO			3.8	●●●○○	Considers pioneering scientific research, where many benefits are qualitative.
PwC (2016c)	Copernicus	€7.4bn		0.6	●○○○○	Considers only user benefits. Lack of methodological clarity.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space

Communications (incl. broadcasting)

Seven studies estimated a public rate of return on communications investments, with a range from 0.9 to over 100. The mean public rate of return is 31, though given the extremely wide range of estimates, this should not be taken as an expected rate of return.

Two studies calculated a direct rate of return on communications investments, ranging from 1.2 to 55.

Table 22 Communications (incl. broadcasting)

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
Robinson and Westgaver (2000)	ESA programmes: ESA Telecommunications			5.7	●●○○○	Methodological inconsistencies.
EADS Astrium (2006)	UK investment in ARTES			6.0	●○○○○	No methodological detail or reference to estimates provided.
Hickling Corporation (1994)	Canada's Long Term Space Plan: Advanced Satellite Communication (ADvSatCom)			8.6	●●○○○	Lack of methodological detail.
UK Space Agency (2014a)	E3000 spacecraft (telecommunications satellite)			29.0	●○○○○	Lack of methodological detail - no reference to estimate provided. R&D in a commercially maturing segment (telecoms).
Oxera (2015) (Confidential)	[REDACTED]					
Euroconsult (2019b)	ARTES Partnership Projects	€4bn		5.3	●●○○○	Lack of methodological detail. Covers period from R&D to commercialisation.
Technopolis Group (2019)	ARTES	£765m	£553m	7.5 (Public RoR, based on net income) 0.9 (Public RoR, based on net profit) 16.8 (Direct RoR, based on net income) 1.2 (Direct RoR, based on net profit)	●●●●○	RoR only includes direct benefits. Low TRL projects.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space

Position, navigation & timing

Five studies estimated the public rate of return on position, navigation and timing investments and one study estimated the direct and spillover rates of return.

Estimates of the public rate of return range from 2.2-399.0, with a mean of 37.0, although the 399.0 estimate (O'Connor et al., 2019) rests on strong assumptions and is designed to be an indicative estimate. Excluding O'Connor et al. (2019), the mean public rate of return on position, navigation and timing investments is 4.0 and the range is 2.2-9.0.

Again, there is not enough evidence to make any strong conclusions on the direct and spillover returns to investments, with only one study providing estimates.

Table 23 Position, navigation & timing

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
Micus Management Consulting (2010)	Introduction of GNSS technology applications in German public sector			2.2 (Base case) 4.5 (Best case)	●●●●○	Considers only the operational benefits of GNSS to German public sector.
European Commission (2011)	European Global Navigation Satellite System (EGNSS)			4.6 (Baseline Option) 5.0 (Revised Services) 5.0 (Revised Services) 4.0 (Degraded Services) 4.0 (Termination of Galileo)	●●●○○	Not a complete assessment of benefits (the report focuses on benefits of policy options).
PwC (2001)	Galileo Global Navigation Satellite System			3.6 (Lower estimate) 6.0 (Upper estimate)	●○○○○	Limited coverage of benefits.
GSA (2009)	Use of EGNOS in aviation			12.5 (Direct RoR) 7.3 (Spillover RoR)	●●●○○	Partial consideration of costs and benefits.
O'Connor et al. (2019)	GPS	$1.3bn/year 2010-2017		99.0 (2010-2017) 399.0 (2010-2017 if it is assumed 25% of GPS expenditure related to civilian use 9.0 (1984-2017) if it is assumed that spending on GPS has been approximately the same since it was first permitted for civilian use)	●●●○○	Higher estimates do not account for historic R&D costs of GPS.
London Economics (2017)	UK public funding for GNSS	€1,478m since 2000		3.0-4.0	●●○○○	Counterfactual is difficult to assess as GNSS is decades old.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space


Image: UK Space Agency

Science & exploration

Five studies provided a public rate of return on science and exploration investments, with estimates ranging from 0.4-99.0 and a mean public rate of return of 24.9. If EADS Astrium (2006) is excluded as an outlier, the range is 0.4-19.3 and the mean is 6.4.

Only two studies provided estimates of the direct rate of return with a range of 6.5-302.8. One study estimated the spillover rate of return as 256.3.

Table 24 Science & exploration

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
Technopolis Group (2010)	Historic space exploration spin-offs NASA and ESA;			5.0 (NASA spin-offs) 0.4 (ESA spin-offs)	●○○○○	Lack of methodological detail. Only considers spillover benefits from R&D.
Hertzfeld (1998)	NASA Life Sciences R&D			19.3 6.5 (Direct RoR)	●●●○○	Limited coverage of benefits; considers only economic benefits to firms developing spin-offs from R&D.
EADS Astrium (2006)	UK Space-based research			99.0	●○○○○	Estimates benefits from commercialisation of scientific research. No methodological detail given.
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck and Solar Orbiter)	£554.2m	£4.6m (fully attributed) + £0.2m (partially attributed)	1.5 (Public RoR, fully attributed) 3.8 (Public RoR, partially attributed and forecast) 302.8 (Direct RoR, fully attributed) 298.7 (Direct RoR, partially attributed and forecast) 256.3 (Spillover RoR, partially attributed and forecast)	●●●●○	Considers frontier scientific research at an early stage.
PwC (2016b)	ESA participation in ISS	€8bn		0.8	●●●●○	Considers fundamental research, where most benefits are not quantified.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space

Mixed (multiple domains)

More studies considered rates of return across multiple domains than for any single domain. Estimates for the public rate of return across multiple domains ranged from 0.4-13.0, with a mean of 4.3.

Several of the higher rates of return estimates were associated with older studies of NASA investments, whilst evaluations of ESA membership tend to give lower rates of return figures (which could reflect duration, data, and/or methodological differences).

Three studies provided direct rate of return estimates, with a range of 2.1-15.3 and a mean of 9.4.

One study also estimated the spillover rate of return to be 2.0.

Table 25 Mixed (multiple domains)

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
NASA and Bay Area Economics (2010)	NASA Ames Research Centre			0.4 – 0.5 (Public RoR) 10.8 (Direct RoR)	●●○○○	Limited coverage of benefits and lack of methodological detail.
NASA (2010)	NASA activities in Florida			2.4	●●○○○	Limited coverage of benefits- does not consider spillovers from research.
Midwest Research Institute (1971)	Stimulated Technological Activity (NASA R&D)			6.1	●●●○○	Dated. Considers spillover benefits from NASA R&D.
Midwest Research Institute (1988)	Stimulated Technological Activity (NASA R&D)			8.0	●●●○○	Dated. Considers spillover benefits from NASA R&D.
Douglas Johnson et al. (1977)	NASA Tech Brief Programme			9.0	●●●○○	Dated. Considers spillover benefits from NASA R&D.
MathTec (1977)	NASA's Technology Utilization Office (TUO)			9.0	●●●●○	Dated. Considers spillover benefits from NASA R&D.
Chase Econometric Associates (1976)	NASA R&D			13.0	●●●○○	Dated. Considers spillover benefits from NASA R&D.
Oxford Economics Forecasting (2006)	R&D in Aerospace (Europe, US and Canada)			0.7	●○○○○	R&D focus. No methodological detail given.
Technopolis Group (2010)	Common R&D policy			11.9	●●●●○	Benefits framed as how existing space technologies can help to solve key global challenges.
Technopolis Group (2018)	National Space Technology Programme (NSTP)	£3.1M	£4.8M	7.0 (Public RoR) 2.1 (Direct RoR) 2.0 (Spillover RoR)	●●●●○	Low-mid TRL. RoR likely an underestimate, as not all recipients surveyed, and study conducted soon after investments.
London Economics (2019b)	International Partnership Programme (IPP)	£78.1m	£17.1m (additional)	2.4 (Public RoR) 15.3 (Direct RoR)	●●●●○	Focuses on grantee benefits. Projects still ongoing at time. Direct benefits only.
London Economics (2018a)	Space for Smarter Government Programme (SSGP)	£3.9m		0.8	●●●○○	Potential government benefits excluded. Key benefit types not quantified, e.g. R&D progress.
Van Hoed, et al. (2019)	Belgium's participation in ESA	€559m (worth of georeturned contracts)		0.6 (3 first years)	●●●○○	Limited range of benefits. Analysis conducted early in investment.
BELSPO (2018)	Belgium's participation in ESA	€250M/year		1.0 (general) 2.2 (for €1 invested by Belgium into ESA in private organisations, additional €2.2 revenue in the space sector)	●●●○○	Limited range of benefits. RoR of 1.0 due to equal value of ESA investments and contracts.
Graziola et al. (2015)	Italian space investments			0.4	●●●○○	Only considers technology spillovers. Uses data on

						private sector R&D to estimate returns on public space investments.
Belgian Federal Science Policy Office (2012)	ESA membership			2.3	●○○○○	No description of methodological approach.
Ramboll Management (2008)	ESA membership			3.5	●●●○○	Limited coverage of influencing factors
Clama Consulting (2011)	ESA membership			1	●●●○○	RoR of 1.0 due to equal value of ESA investments and contracts.
Rosemberg et al. (2015) (Confidential)	[REDACTED]					
London Economics and PwC (2012)	ESA membership			2.5	●●●●○	Partial estimate of benefits
Triarii (2005)	ESA membership			2.4 (2004) 3.3 (2011)	●●○○○	Limited coverage of influencing factors, simplification of benefit appraisal
High Tech Systems and Materials top team (2012)	ESA membership			4.3	●●●○○	Simplification of benefit calculation, lack of methodological detail
BETA/CETAI (1989) and CETAI/BETA (1994)	ESA membership			2.5 (1979-1988)	●●○○○	Limited coverage of benefits, methodological explanation and influencing factors. Relatively dated.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space

Rates of return, by substance

R&D / technology / capability development

14 studies estimated the public rate of return for R&D / Technology / Capability development investments, with a range of 0.2 to over 100 and a mean of 19.8. This category is dominated by NASA investments, in contrast to the evidence base as a whole.

Four studies provide estimates of the direct rate of return, ranging from 2.1 to 55. Excluding outliers, the range is 2.1- 10.8, and the mean is 6.5. One study provides an estimate of the spillover rate of return of 2.0.

Table 26 R&D / technology / capability development

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
UK Space Agency (2014a)	E3000 spacecraft (telecommunications satellite)			29.0	●○○○○	Lack of methodological detail - no reference to estimate provided. R&D in a commercially maturing segment (telecoms).
Oxera (2015) (Confidential)	[REDACTED]					
Booz Allen Hamilton (2005)	NASA Geospatial Interoperability			0.2	●○○○○	Study only considers current benefits from R&D in progress.
NASA and Bay Area Economics (2010)	NASA Ames Research Centre			0.4 – 0.5 (Public RoR) 10.8 (Direct RoR)	●●○○○	Limited coverage of benefits and lack of methodological detail.

Technopolis Group (2010)	Historic space exploration spin-offs NASA and ESA;			5.0 (NASA spin-offs) 0.4 (ESA spin-offs)	●○○○○	Lack of methodological detail. Only considers spillover benefits from R&D.
Midwest Research Institute (1971)	Stimulated Technological Activity (NASA R&D)			6.1	●●●○○	Dated. Considers spillover benefits from NASA R&D.
Midwest Research Institute (1988)	Stimulated Technological Activity (NASA R&D)			8.0	●●●○○	Dated. Considers spillover benefits from NASA R&D.
Douglas Johnson et al. (1977)	NASA Tech Brief Programme			9.0	●●●○○	Dated. Considers spillover benefits from NASA R&D.
MathTec (1977)	NASA's Technology Utilization Office (TUO)			9.0	●●●●○	Dated. Considers spillover benefits from NASA R&D.
Chase Econometric Associates (1976)	NASA R&D			13.0	●●●○○	Dated. Considers spillover benefits from NASA R&D.
Hertzfeld (1998)	NASA Life Sciences R&D			19.3 (Public RoR) 6.5 (Direct RoR)	●●●○○	Limited coverage of benefits; considers only economic benefits to firms developing spin-offs from R&D.
Oxford Economics Forecasting (2006)	R&D in Aerospace (Europe, US and Canada)			0.7	●○○○○	R&D focus. No methodological detail given.
Technopolis Group (2010)	"Common R&D" policy			11.9	●●●●○	Benefits framed as how existing space technologies can help to solve key global challenges.
Technopolis Group (2018)	National Space Technology Programme (NSTP)	£3.1M	£4.8M	7.0 (Public RoR) 2.1 (Direct RoR) 2.0 (Spillover RoR)	●●●●○	Low-mid TRL. RoR likely an underestimate, as not all recipients surveyed, and study conducted soon after investments.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space

Applications / services

Seven studies provide estimates of the public rate of return on applications/services investments, with a range of 0.5-399.0. Excluding outliers, the range is 0.5-31.0 and the mean public rate of return is 7.4.

Three studies also calculate a direct rate of return, with estimates ranging from 1.0-15.3 and a mean of 9.6. There is also one estimate of the spillover rate of return of 7.3.

Table 27 Applications / services

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
McCallum et al. (2010) and Bouma et al. (2009)	Global Earth Observation System of Systems (GEOSS)			0.5	●●○○○	Limited coverage of benefits.
SpaceTec Partners (2012a) and Knight et al. (2012)	EO and Copernicus Downstream Services for the Agriculture Sector			1.0 (Direct RoR)	●○○○○	Limited coverage of benefits; no consideration of public investment costs.

Micus Management Consulting (2010)	Introduction of GNSS technology applications in German public sector			2.2 (Base case) 4.5 (Best case)	●●●●○	Considers only the operational benefits of GNSS to German public sector.
GSA (2009)	Use of EGNOS in aviation			12.5 (Direct RoR) 7.3 (Spillover RoR)	●●●○○	Partial consideration of costs and benefits.
London Economics (2019b)	International Partnership Programme (IPP)	£78.1m	£17.1m (additional)	2.4 (Public RoR) 15.3 (Direct RoR)	●●●●○	Focuses on grantee benefits. Projects still ongoing at time. Direct benefits only.
London Economics (2018a)	Space for Smarter Government Programme (SSGP)	£3.9m		0.8	●●●○○	Potential government benefits excluded. Key benefit types not quantified, e.g. R&D progress.
London Economics (2018c)	UK Satellite-derived Earth Observation impacts	£175m/year		4.4 6.1 by 2020	●●●○○	Considers social and user benefits from EO only.
O'Connor et al. (2019)	GPS	$1.3bn/year 2010-2017		99.0 (2010-2017) 399.0 (2010-2017 if it is assumed 25% of GPS expenditure related to civilian use 9.0 (1984-2017) if it is assumed that spending on GPS has been approximately the same since it was first permitted for civilian use)	●●●○○	Higher estimates do not account for historic R&D costs of GPS.
Sawyer and Dubost (2016a)	Copernicus Sentinel	€500,000		31.0	●●●●○	Partial consideration of costs and benefits. Not comparable to other RoRs.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space

Mixed: programme / project

Half of all rate of return estimates were based on mixed programmes/ projects. Estimates of the public rate of return range from 0.0-99.0, with a mean of 6.5. All but one of the rates of return estimates lie in the range of 0.0-17.4. If we exclude EADS Astrium's (2006) estimate of 99.0, the mean rate of return for mixed programmes/projects is 3.7.

Even assessments of the same programme produce varying rates of return, due to methodological differences and differing focus; for example, the European Space Policy Institute (2011), using data from Booz & Co. (2011), find the public rate of return on GMES is 9.5. Booz & Co. (2011) themselves find the rates of return on future GMES scenarios lie between 0.0-2.7 and SpaceTec Partners (2013) find the rate of return on Copernicus lies between 2.0-2.3. This highlights the difficulty in pinning down a specific value for the rate of return on public investments, even within a specific area.

Two studies also provided direct rate of return estimates with a range of 1.2-302.8.

Table 28 Mixed: programme / project

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
Booz & Co. (2011)	GMES (Option A: Baseline, Option B: Baseline extended, Option C: Partial continuity, Option D: Full continuity)			0.0 (Option A) 1.3 (Option B) 2.2 (Option C) 2.7 (Option D)	●●●○○	RoR low for options with a lower future investment commitment, e.g. Option A: no ongoing commitment to replace infrastructure
Robinson and Westgaver (2000)	Meteosat			1.5	●●○○○	Authors adopt a conservative approach, underestimating uncertain values.
SpaceTec Partners (2013)	Copernicus (Option A: Service Delivery Pull; Option B: Intermediate; Option C: Technology Driven)			2.3 (Service Delivery Pull) 2.2 (Intermediate) 2.0 (Technology Driven)	●●●○○	Follow on analysis from Booz & Co. (2011).
UK Space Agency (2014a)	National Space Technology Programme (MetOp-SG)			3.0	●○○○○	Lack of methodological detail - no reference to estimate provided. R&D in a commercially maturing segment (telecoms).
Sridhara Murthi et al. (2007)	Indian Remote Sensing Programme			3.3	●●○○○	Methodological inconsistencies and limits.
Hickling Corporation (1994)	Canada's Long Term Space Plan: Earth Observation (EO)			3.9	●●○○○	Lack of methodological detail.
EADS Astrium (2006)	UK investment in Disaster Monitoring Constellation (DMC)			8.0	●○○○○	No methodological detail or reference to estimates provided.
EUMETSAT (2013)	EPS/Metop-Second Generation satellite programme			3.6 (Minimum) 17.4 (Likely)	●●●○○	Meteorological satellites in use in weather forecasting applications.
European Space Policy Institute (2011) using data from Booz & Co. (2011)	GMES			9.5	●●●○○	RoR is described as being an upper bound due to cost underestimates.
Robinson and Westgaver (2000)	ESA programmes: ESA Telecommunications			5.7	●●○○○	Authors adopt a conservative approach, underestimating uncertain values.
EADS Astrium (2006)	UK investment in ARTES			6.0	●○○○○	Commercially maturing market segment. No methodological detail or reference to estimates provided.
Hickling Corporation (1994)	Canada's Long Term Space Plan: Advanced Satellite Communication (ADvSatCom)			8.6	●●○○○	Commercially maturing market segment. Lack of methodological detail.
European Commission (2011)	European Global Navigation Satellite System (EGNSS)			4.6 (Baseline Option) 5.0 (Revised Services) 5.0 (Revised Services) 4.0 (Degraded Services) 4.0 (Termination of Galileo)	●●●○○	Not a complete assessment of benefits (the report focuses on benefits of policy options).

PwC (2001)	Galileo Global Navigation Satellite System			3.6 (Lower estimate) 6.0 (Upper estimate)	●○○○○	Limited coverage of benefits.
Robinson and Westgaver (2000)	Ariane early launch vehicles			0.7	●●○○○	Authors adopt a conservative approach, underestimating uncertain values.
Hickling Corporation (1994)	Canada's long term space plan: Mobile Servicing System (MSS)			3.3	●●○○○	Lack of methodological detail.
British National Space Centre (2009)	Canadarm			5.0	●○○○○	Lack of methodological detail -no reference to estimate provided.
EADS Astrium (2006)	UK Space-based research			99.0	●○○○○	Estimates benefits from commercialisation of scientific research. No methodological detail given.
Park et al. (2020)	KOMPSAT-1/2/3/3A/5 and COMS	4445bn KRW		0.2	●●●○○	Limited coverage of benefits. Authors attribute lower RoR than European studies to difficulty in technology diffusion in South Korea.
BELSPO (2018)	ESA SSA programme	€6.79m (2017-2020)		1.3	●●●○○	Authors explain low RoR as result of low contribution to programme.
	PLEIADES (bilateral with France)	€893k (2004-)		1	●●○○○	Belgium contributes an amount equal to the value of Belgian contracts giving a RoR of 1.
	SAOCOM (bilateral with Argentina)	€1.92m (2001-2016)		1	●●○○○	
	MUSIS	€20.361m (2011-2022)		1	●●○○○	
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck and Solar Orbiter)	£554.2m	£4.6m (fully attributed) + £0.2m (partially attributed)	1.5 (Public RoR, fully attributed) 3.8 (Public RoR, partially attributed and forecast) 302.8 (Direct RoR, fully attributed) 298.7 (Direct RoR, partially attributed and forecast) 256.3 (Spillover RoR, partially attributed and forecast)	●●●●○	Considers frontier scientific research at an early stage.
Euroconsult (2019b)	ARTES Partnership Projects	€4bn		5.3	●●○○○	Covers period from R&D to commercialisation in commercially mature segment.
Technopolis Group (2019)	ARTES	£765m	£553m	7.5 (Public RoR, based on net income) 0.9 (Public RoR, based on net profit) 16.8 (Direct RoR, based on net income) 1.2 (Direct RoR, based on net profit)	●●●●○	RoR only includes direct benefits. Low TRL projects.
Graziola et al. (2015)	Italian space investments			0.4	●●●○○	

PwC (2016b)	ESA participation in ISS	€8bn		0.8	●●●●○	Considers fundamental research, where most benefits are not quantified.
PwC (2016a)	Space Situational Awareness programme: Space Weather	€503m		5.3	●●●●○	Lack of methodological detail. Authors consider results to be conservative estimates.
	Space Situational Awareness programme: Near Earth Objects	€160m (Survey & Follow up scenario) €225m (Deflection mission scenario)		0.3 (Survey & Follow up scenario) 0.4 (Deflection mission scenario)		
PwC (2019c)	ESA Future EO			3.8	●●●○○	Considers pioneering scientific research, where many benefits are qualitative.
PwC (2019a)	ESA's Ground Systems Engineering and Operations activities	€2.82bn		3.0	●●●○○	Lack of methodological detail.
PwC (2016c)	Copernicus	€7.4bn		0.6	●○○○○	Considers only user benefits. Lack of methodological clarity.
London Economics (2017)	UK public funding for GNSS	€1,478m since 2000		3.0-4.0	●●○○○	Counterfactual is difficult to assess as GNSS is decades old.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space

Mixed: institution

11 studies provided estimates of the public rate of return on investments in mixed institutions. Estimates of the public rate of return ranged from 0.6 to more than 5, with a mean of 2.7. Estimates in this category were closely grouped, with no outliers.

Table 29 Mixed: institution

Author(s) and year	Programme	Public investment	Leveraged investment	Rate of return	Quality	Notes
NASA (2010)	NASA activities in Florida			2.4	●●○○○	Limited coverage of benefits- does not consider spillovers from research.
Van Hoed, et al. (2019)	Belgium's participation in ESA	€559m (worth of georeturned contracts)		0.6 (3 first years)	●●●○○	Limited range of benefits. Analysis conducted early in investment.
BELSPO (2018)	Belgium's participation in ESA	€250M/year		1.0 (general) 2.2 (for €1 invested by Belgium into ESA in private organisations, additional €2.2 revenue in the space sector)	●●●○○	Limited range of benefits. RoR of 1.0 due to equal value of ESA investments and contracts.
Belgian Federal Science Policy Office (2012)	ESA membership			2.3	●○○○○	No description of methodological approach.
Ramboll Management (2008)	ESA membership			3.5	●●●○○	Limited coverage of influencing factors

Clama Consulting (2011)	ESA membership			1	●●●○○	RoR of 1.0 due to equal value of ESA investments and contracts.
Rosemberg et al. (2015) (Confidential)	[REDACTED]					
London Economics and PwC (2012)	ESA membership			2.5	●●●●○	Partial estimate of benefits
Triarii (2005)	ESA membership			2.4 (2004) 3.3 (2011)	●●○○○	Limited coverage of influencing factors, simplification of benefit appraisal
High Tech Systems and Materials top team (2012)	ESA membership			4.3	●●●○○	Simplification of benefit calculation, lack of methodological detail
BETA/CETAI (1989) and CETAI/BETA (1994)	ESA membership			2.5 (1979-1988)	●●○○○	Limited coverage of benefits, methodological explanation and influencing factors. Relatively dated.

Note: Grey cells indicate missing data. Rates of return are public, unless otherwise stated.
Source: know.space

Lag

Lag is defined as the time before the impact of an investment starts. Our research broadly supports the conclusion of the 2015 study: by distinguishing phasing of investments, the construction phase lag is around 2 years, and the exploitation phase lag is around 10 years (London Economics, 2015).

As in 2015, few studies report lags and reporting is poorly standardised. Just 6 studies (2015-2021) quantify the lag on returns, with estimates ranging from zero for the direct GDP impact of ESA Future EO investments (PwC, 2019c) to 15 years for the development of EarthSense (London Economics, 2018b).

Table 30 Lag

Author(s) and year	Programme	Lag
Booz & Co. (2011)	GMES (Option A: Baseline, Option B: Baseline extended, Option C: Partial continuity, Option D: Full continuity)	0-2 years
Oxera (2015) (Confidential)	[REDACTED]	
Micus Management Consulting (2010)	Introduction of GNSS technology applications in German public sector	After a time lag, long-term market returns will be 5 times larger than short term market returns.
Chase Econometric Associates (1976)	NASA R&D	4 years (for GNP increases to occur), 2 years (for productivity increases to occur)
Robinson and Westgaver (2000)	Ariane early launch vehicles	10 years
Technopolis Group (2010)	"Common R&D" policy	5 years ("Common R&D")
Åström et al. (2010)	Swedish National Space Technology Research Programme	2-10 years (under RUAG Space and Swedish Space Corporation), 17-20 years (under Volvo Aero Corporation)
House of Commons Science and Technology Committee (2013)	Research commercialisation in the UK	20-40 years (to realise a return). Up to 15 years (to progress from basic science to product application)
Li (2012)	General R&D investment programmes	2 years (gestation lag)
Schmidt et al. (2005)	Galileo	6 years
European Commission (2010b)	EGNOS/SBAS use in Africa	5 years
The Tauri Group (2013)	All NASA investment programmes	A commercialisation lag mentioned, but not quantified

PwC (2006)	GMES/Copernicus	3 years (Efficiency benefits), 6 years (European policy formulation benefits), 20 years (Global action benefits)
London Economics (2018a)	Space for Smarter Government Programme (SSGP)	Benefits to grantees assumed to be immediate. 4 years after the first funding round no benefits to government had been realised
London Economics (2018b)	Space for Smarter Government Programme (SSGP)	15 years of academic research led to development of EarthSense
PwC (2016a)	Space Situational Awareness programme: Space Weather	8 years
	Space Situational Awareness programme: Space Surveillance and Tracking	6-9 years
PwC (2019c)	ESA Future EO	GDP impact immediate, whilst spillovers take more time to realise
Eerme and Lillestik (2019)	Latvia's participation in ESA	3-4 years for the 'real effects' to appear
Eerme and Lillestik (2019) and Invent Baltics OÜ (2015)	Estonia's participation in ESA	4-5 years for indirect industrial effects. Longer for early stage applied research.

Source: know.space

Deadweight

Consistent with the 2015 study, deadweight is defined as the impact that would have occurred in the counterfactual, i.e. in the absence of the examined investment.

The deadweight associated with most space investments appears to be low. Direct benefits would rarely have materialised or have been far lower in the absence of public investment, although there is potential for larger deadweight where end user benefits are significant and UK users could free ride off investments made by other countries.

The number of studies considering the deadweight associated with an investment has significantly increased since 2015. London Economics (2015) found just 4 studies making qualitative mention of deadweight, from which they could deduce one deadweight percentage. From 2015-21, 25 programme assessments consider deadweight, with several studies providing quantitative estimates.

Many studies use stakeholder surveys or interviews to construct a counterfactual, asking grantees whether their projects would have gone ahead in the absence the public investment. Other studies research technologies which could have been developed in the absence of public space investments and how these technologies could have been used.

Table 31 Deadweight

Author(s) and year	Programme	Deadweight
Robinson and Westgaver (2000)	Meteosat	A scenario where Meteosat would not exist would be "catastrophic" or have a "significant negative impact".
Midwest Research Institute (1971)	Stimulated Technological Activity (NASA R&D)	80%
PwC (2006)	GMES/Copernicus	-
London Economics (2013)	Seventh Framework Programme (FP7) for GNSS	Vast majority of Project Coordinators say funding is vital for the future development of their project.
Leveson (2015)	GPS	eLoran or a system of GEOs provide a counterfactual in terms of timing benefits. $43.8m saving per year from GPS relative to these systems
Technopolis Group (2018)	National Space Technology Programme (NSTP)	15%
London Economics (2019b)	International Partnership Programme (IPP)	80% indicated that their project would not have proceeded at all without grant funding. 20% indicated that their project would still have proceeded in some form, albeit not on the same scale and in different form. £30.7m of industrial activity would have occurred without the IPP (out of £162.7m)

London Economics (2019a)	International Partnership Programme (IPP)	Non-space alternatives exist, but cannot substitute for space entirely
London Economics (2018a)	Space for Smarter Government Programme (SSGP)	Almost all industry consultees indicated that their project would either not have taken place or not as quickly without SSGP funding. No comparable exists that raises awareness of satellite services within government
Barjak et al. (2015)	Swiss R&D funding	70% of projects would not have been realised without public funding.
London Economics (2018b)	Space for Smarter Government Programme (SSGP)	Would not have been possible without SSGP funding
	Synergistic Air-Breathing Rocket Engine (SABRE)	Only viable source of funding in 2016
O'Connor et al. (2019)	GPS	Assumed that pre-existing positioning, navigation, and timing (PNT) systems continued to be available in the absence of GPS. Analyses what each sector of interest used before GPS became available and what technologies would have evolved to provide the same services as GPS in its absence; for most sectors, the counterfactual assumption is that in the absence of GPS a Loran-based network (similar to Loran-C) likely would have received more investment to fully cover the U.S.
Sawyer and Dubost (2016a)	Copernicus Sentinel	In the absence of satellite imagery, it is likely that either ground-based inspections or aerial footage from planes would have been used. The cost of these two options is averaged to calculate the cost saving benefit to the Swedish Forest Agency
Sawyer and Dubost (2015)	Copernicus Sentinel	Helicopters were used pre-2003 to assess ice in the area immediately surrounding a ship. Helicopters would be an imperfect replacement (limited by weather etc.)
Sawyer et al. (2018)	Copernicus Sentinel	Without this technology, farmers have to physically inspect their fields
UKSA (2017)	Herschel SPIRE	Other projects were not funded as a consequence of funding SPIRE, but by definition these projects had a lower scientific priority
Sawyer and Dubost (2016b)	Copernicus Sentinel	In the counterfactual, utility companies can only respond to gas/water leakages when they happen and replace all pipes purely according to their age
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck and Solar Orbiter)	Minimal- Nearly all respondents reported that the technology and services developed would not have been undertaken without SSP funding
Technopolis Group (2019)	ARTES	77% reported that their organisations would not have gone ahead with the project in the absence of the ARTES funding. Projects which stated they would have gone ahead with the project in the absence of funding are excluded
PwC (2016a)	Space Situational Awareness programme: Space Weather	Compares to a 'do nothing' scenario: reliance on US NOAA systems
	Space Situational Awareness programme: Near Earth Objects	Compares to 'do nothing', do “Survey and Follow-up” & 'do deflection' scenarios
	Space Situational Awareness programme: Space Surveillance and Tracking	Compares to 'do nothing', 'do nationally' & 'do ESA CRD scenarios
PwC (2017)	Copernicus programme	Shutdown option: €33,492.6m loss of benefits (2025-2030 cumulative, undiscounted), €58,215.7m additional benefits which could have been realised (2031-2035)
Papadakis, 2019	ESA Copernicus Sentinel	Company would still exist without Sentinel data: 77% Sentinel data increases profitability, but the company would survive without it: 24% Sentinel data increases efficiency, but the company would survive without it: 39%
London Economics (2017)	GNSS	GNSS had not been developed or chosen as a source of PNT
	UK public funding for GNSS	UK never contributed to the development of EGNSS. UK would free ride on Galileo, so most of the quantified benefits remain, though Galileo could not have been developed in exactly the same form. The qualitative benefits mentioned would be lost e.g., UK prestige
Helios (2017)	Satcom enabled Air Traffic Control (ATC)	Benefits could not be provided in oceanic regions with satellite communications
	Satcom enabled Airline Operational Communications (AOC)	

Oligschläger (2019)	Copernicus Sentinel: WatchITgrow application	Drones or ground-based sources could be used, but satellite data enables a higher, faster and cheaper coverage of a whole area, and data collections may be more effective

Source: know.space

Benefit duration

For consistency with the 2015 study, benefit duration is defined as the time (in years) that the impact endures.

Estimates for benefit duration range from zero to infinity, with some studies using zero as a lower bound, whilst some econometric papers assume that the benefits from scientific discovery are of infinite duration, as this knowledge cannot be lost (e.g., Graziola et al., 2015). Most estimates are in the range of 5-20 years.

Table 32 Benefit duration

Author(s) and year	Programme	Benefit duration
McCallum et al. (2010) and Bouma et al. (2009)	Global Earth Observation System of Systems (GEOSS)	Benefits can only be accrued for 10 weeks in each year but are assumed to exist for as long as the satellite systems focus on algal blooms.
Booz & Co. (2011)	GMES (Option A: Baseline, Option B: Baseline extended, Option C: Partial continuity, Option D: Full continuity)	17 years (2016 – 2033)
Oxera (2015) (Confidential)	[REDACTED]	
Midwest Research Institute (1971)	Stimulated Technological Activity (NASA R&D)	18 years
Midwest Research Institute (1988)	Stimulated Technological Activity (NASA R&D)	18 years
London Economics (2013)	Seventh Framework Programme (FP7) for GNSS	58% of project coordinators believe that benefits would last between one and three years.
Douglas Johnson et al. (1977)	NASA Tech Brief Program (TSP)	Mostly 5 years, although "some net benefit streams [will] continue."
UK Space Agency (2014a)	MetOp-SG	At least 20 years
Chase Econometric Associates (1976)	NASA R&D	Productivity benefits not explicitly assumed to end.
Technopolis Group (2018)	National Space Technology Programme (NSTP)	5 years
Euroconsult (2018)	Disaster Management Agriculture Air Traffic Management Environment Monitoring Benefits to remote/rural communities Transport & Logistics	0-10 years
London Economics (2019b)	International Partnership Programme (IPP)	up to 8 years
London Economics (2019a)	International Partnership Programme (IPP)	up to 8 years
London Economics (2018a)	Space for Smarter Government Programme (SSGP)	4 years for realised benefits
Park et al. (2020)	KOMPSAT-1/2/3/3A/5 and COMS	12-30 years
O'Connor et al. (2019)	GPS	33 years
UKSA (2017)	Herschel SPIRE	18 years
Sawyer and Dubost (2016b)	Copernicus Sentinel	9 years
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck and Solar Orbiter)	18 years
Euroconsult (2019b)	ARTES Partnership Projects	25 years
Technopolis Group (2019)	ARTES	10 years
Graziola et al. (2015)	Italian space investments	Infinite
PwC (2016b)	ESA participation in ISS	21 years

Image: UK Space Agency

PwC (2016a)	Space Situational Awareness programme: Space Weather	16 years
PwC (2017)	Copernicus programme	18 years (Baseline, Enhanced environmental services & Enhanced security Service) 13 years (Shutdown)
PwC (2019b)	ESA Science Programme	52 years
PwC (2019c)	ESA Future EO	17 years
PwC (2019a)	ESA's Ground Systems Engineering and Operations activities	18 years
PwC (2016c)	Copernicus	12 years
Helios (2017)	Satcom enabled Air Traffic Control (ATC)	15 years
	Satcom enabled Airline Operational Communications (AOC)	

Source: know.space

Leveraging

In line with the 2015, we define leveraging/ crowding in as, "*(t)he increase in private, third sector and foreign public investment in the project as a proportion of the domestic public investment*" (London Economics, 2015).

18 studies considered the amount of private investment that the public investment attracted, or 'leveraged'. In most cases, the range of leveraged investment is in the 0%-100% range consistent with matched investment, and some studies consider whether the origin of the investment is domestic or foreign (representing an injection into the domestic economy).

Table 33 Leveraging

Author(s) and year	Programme	Leveraged investment
Hertzfeld (1998)	NASA Life Sciences R&D	Domestic private crowding in: 312%
Åström et al. (2010)	Swedish National Space Technology Research Programme	Domestic private crowding in: 100% (1:1 ratio of public funding to leveraged funding)
Oxera (2015) (Confidential)	[REDACTED]	
Faugert & Co Utvärding AB (2012)	Swedish National Space Board's National Earth Observation Programme	Domestic private crowding in: 15.5%
NASA and Bay Area Economics (2010)	NASA Ames Research Centre and NASA Research Park	Domestic public and private: 12%
London Economics (2013)	Seventh Framework Programme (FP7) for GNSS	Private crowding in: 56%
European Commission (2010b)	EGNOS/SBAS use in Africa	Private crowding in: 14.5%
Warwick Economics and Development (2013)	Feasibility Studies Programme of the Technology Strategy Board	Domestic private crowding in: 39%
SpaceTec Partners (2012a) and Knight et al. (2012)	EO and Copernicus Downstream Services for the Agriculture Sector	Some amount
PwC (2001)	Galileo GNSS	Some amount
Technopolis Group (2018)	National Space Technology Programme (NSTP)	Domestic private crowding in: 54%
London Economics (2019b)	International Partnership Programme (IPP)	53% (gross) 23% (additional)
London Economics (2018b)	Synergistic Air-Breathing Rocket Engine (SABRE)	Some amount
BELSPO (2018)	Belgium's participation in ESA	€1.7 (for €1 invested by Belgium into ESA in private organisations, €1.7 in additional R&D investment from private enterprises in the space sector)
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck and Solar Orbiter)	Some amount
Technopolis Group (2019)	ARTES	85%
London Economics (2018c)	UK Satellite-derived Earth Observation impacts	UK government's use of EO is estimated to support approximately £10m in commercial

		revenue and £3m in grant-funded projects per annum for UK industry
Montanari et al. (2020)	ESA BASS	Industry leverage: 105% Private leverage: 295%

Source: know.space

Displacement

Displacement (also known as 'crowding out') refers to the decrease in investment from private, third and foreign sources which as a result of domestic public investment, as a proportion of the domestic public investment.

Analysis of, and therefore evidence on, displacement is extremely limited – with one study reporting anecdotal evidence of displaced activity.

Table 34 Displacement

Author(s) and year	Programme	Displacement/ crowding out
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck and Solar Orbiter)	Occasional evidence, but effects do not appear to be large. One second level beneficiary reported restructuring their business to focus more heavily on supplying technology for space missions and away from commercial work

Source: know.space

Leakage

Leakages are benefits arising outside of the domestic economy.

Though most studies focus only on the domestic economy of the funder and recipient, some studies expand consideration to analyse the extent to which funding and/or benefits leak out of the funding economy (e.g., foreign contractor divisions or subcontractors). These instances are highly specific – e.g., by design, the UKSA's own International Partnership Programme benefits overseas developing economies – in addition to building capability, proven experience and client contacts/referrals for UK industry.

Table 35 Leakage

Author(s) and year	Programme	Leakage
PwC (2006)	GMES/Copernicus	41.50%
Leveson (2015)	GPS	GPS used globally- acknowledgement that benefits accrue outside the US, but leaves quantification for further studies
London Economics (2019b)	International Partnership Programme (IPP)	The primary purpose of the IPP is to aid overseas development
London Economics (2018c)	UK Satellite-derived Earth Observation impacts	£22m/year supply of EO solutions to foreign governments. Ambitions to grow to £250m
Loomis et al. (2015)	Landsat	$399m/year in benefits to users outside US
Nathalie P. Voorhees Center for Neighborhood and Community Improvement (2020)	NASA Investments Moon to Mars Program (M2M)	Leakages assumed to occur between US states, but not outside US
Sawyer and Dubost (2015)	Copernicus Sentinel	Services shared with Estonia
UKSA (2017)	Herschel SPIRE	Of 1031 SPIRE papers, 682 (66%) had UK authors and 260 (21%) were UK-led
Winning Moves (2020)	Space Science Programme (SSP) (Bepi-Colombo, Gaia, Herschel, James Webb Space Telescope, Lisa Pathfinder, Planck and Solar Orbiter)	Occasional evidence, but effects do not appear to be large- one company based in the UK employed some of its staff in Spain


Image: UK Space Agency

PwC (2016a)	Space Situational Awareness programme: Space Surveillance and Tracking	20%
PwC (2017)	Copernicus programme	Significant e.g. 94% of climate modelling benefits accrue outside the EU
PwC (2019c)	ESA Future EO	Use of freely available data outside of Europe is seen as a benefit (by boosting Europe's reputation), not a leakage

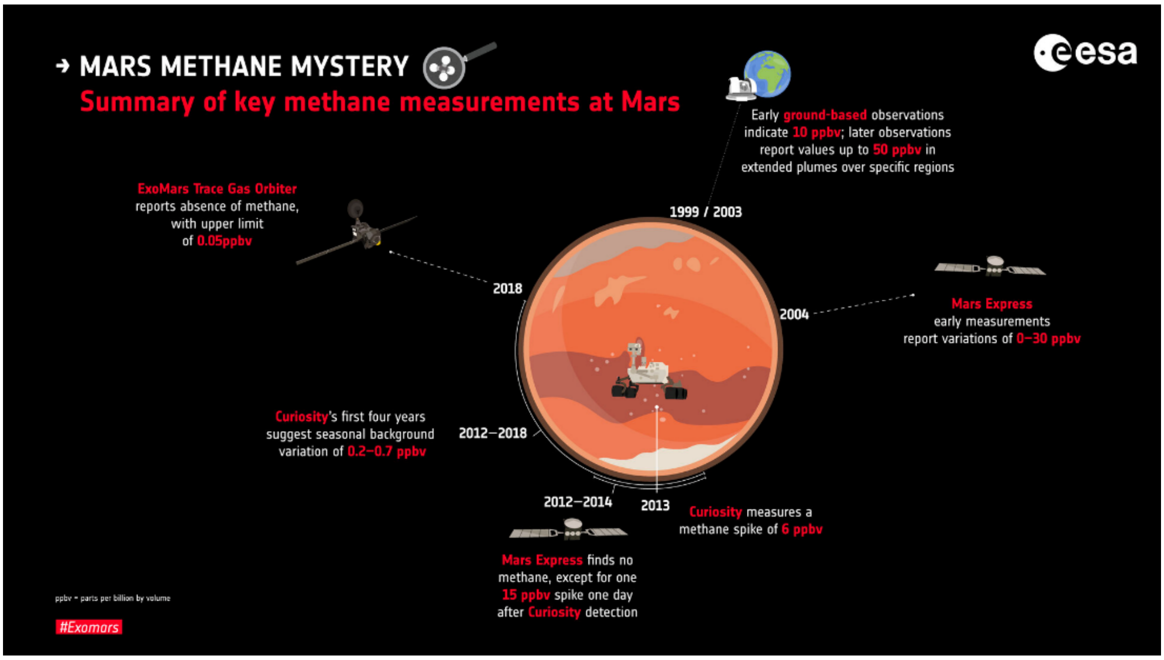
Source: know.space

3 Evidence from Case Studies

Case Study: ExoMars

ExoMars: Trace Gas Orbiter and the Rosalind Franklin Rover

Has there ever been life on Mars? The evidence of past life on Mars would be the greatest scientific discovery in the history of space exploration to date: it could profoundly change our expectation of the amount of life in the universe, and help biologists to better understand how life emerged here on Earth.



Source: ESA[13]

The UK is participating in both missions of the ExoMars programme:

The first mission, which launched in 2016, brought the Trace Gas Orbiter (TGO) to Mars' orbit. The TGO has two functions: it relays important scientific data from Mars rovers and is measuring methane and other gases to determine the likelihood of present or past life.[14]

[13] ESA. *The Methane Mystery.* https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/ExoMars/The_methane_mystery

[14] ESA. *ExoMars Trace Gas Orbiter (TGO).* https://exploration.esa.int/web/mars/-/46475-trace-gas-orbiter


Image: UK Space Agency

The second mission aims to deploy the ExoMars rover (named *Rosalind Franklin*) on the surface of Mars. The Rosalind Franklin rover includes a drill to access the sub-surface of Mars as well as a miniature life-search laboratory kept within an ultra-clean zone. Through a multitude of instruments, the rover will examine Mars for evidence of past life. This is the first rover that will be able to drill down two metres to access rocks unaffected by the harsh Martian radiation environment. It will help us to understand the past Martian environment and how it has evolved, importantly when and for how long were there conditions that could have supported life.[15]

ESA are studying all options on how to take ExoMars forward, but the earliest an independent ESA mission could be launched is likely to be 2028, following the suspension of ESA's cooperation with Roscosmos.[16] The impact of rescheduling the launch will be to delay the science benefits generated by the ExoMars rover's discoveries (likely by 6 years), though the technology benefits of the mission development will still hold.

UK investment and outputs to date

The UK Space Agency has invested €287 million to the overall ExoMars mission and €14 million to the instruments over 13 years, mostly through funding to ESA. This makes the UK the second largest European contributor to ExoMars. A further £0.4 million has been committed nationally on the spacecraft's instrument operations and over £2.5 million on data analysis.[17]

From ESA funding, ~€220m worth of contracts on Mars exploration have been awarded to UK industry and academics since 2013, with contracts still being awarded into 2021. Many more contracts are expected in 2022 and beyond, both in development and design and in data analysis and science.[18]

More than 15 UK companies and academic institutions have been involved in the mission so far, mainly in the development of the rover vehicle, software, and the design of the parachute sub-system. UK scientists have also been involved in two scientific instruments on the rover and one on the TGO.[19]

Science outputs from TGO are still on-going. At the Open University, several researchers have been given grants to study data from the TGO to determine the climate on Mars, water vapour, and find evidence of primitive life.[20] The UKSA, through its on-going Aurora research grants, have allowed researchers to exploitation data from InSight and TGO Work that underpins the analysis of ExoMars data, including modelling/theory.[21]

Although launch of the rover is delayed, Airbus, as prime contractor, has designed, developed, and tested the rover in Stevenage, UK.

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[15] ESA. *Robot Exploration of Mars.* https://exploration.esa.int/web/mars/-/45084-exomars-rover
[16] ESA (2022). *Rover ready – next steps for ExoMars.* 28/03/2022.
https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/ExoMars/Rover_ready_next_steps_for_ExoMars
[17] UK Space Agency. https://www.gov.uk/government/case-studies/exomars
[18] Based on ESA geo-return data Q2 2021.
[19] UK Space Agency. https://www.gov.uk/government/case-studies/exomars
[20] Open University. https://www.open.ac.uk
[21] UK Space Agency. https://www.gov.uk/government/publications/announcement-of-opportunity-aurora-science-2020


Image: UK Space Agency

Benefits and returns

The primary benefit of the ExoMars mission will, of course, be the scientific knowledge. Nonetheless, multi-decade science and exploration missions like ExoMars have important socio-economic benefits too:

- Benefits to the contractors, allowing them to grow, expand through R&D, establish new partnerships, upskill their employees, grow exports, and more.
- Benefits to the UK space industry, through job creation, bolstering of our national supply chain, up-skilling, research-industry partnerships, and increased coordination
- Wider benefits to society, through the inspirational value of grand-scale Mars exploration science and the growth in STEM fields as a result, and the spillover of technology to future missions, e.g. human spaceflight missions to Mars and beyond.

There are considerable difficulties involved in attaching monetary valuations to these benefits and estimating a rate of return on public investment. This is in part because the rover has not been launched yet, so many benefits have yet to be realised and remain uncertain. We simply do not know the value of potential follow-on sales to contractors, for example. Benefits to contractors and the UK space industry as a whole should become easier to monetise with time (e.g., using firm-level data on employment numbers, R&D investment etc.).

However, wider benefits to society remain inherently very difficult to quantify. This is in part due to difficulties in attribution: to what extent can we ascribe a growth in STEM fields to the inspiration effect generated by missions like ExoMars? Furthermore, it is challenging to assign monetary values to intangible benefits, such as the value of scientific knowledge. These difficulties mean that our estimates are generally qualitative, demonstrating the challenges in estimating rates of return on public space investments.

Direct benefits

Scientific progress The TGO is already both delivering important scientific results obtained by its own instruments and through relaying data from the existing Mars rovers. Recently, researchers from the Open University revealed that TGO had found traces of water vapour, one of the key ingredients of life. In May 2020, Dr Matt Balme reported the discovery of ancient rivers on Mars. More recently, Dr Manish Patel reported new findings from the ExoMars Trace Gas Orbiter mission, which observed the transport of water vapour and 'semi-heavy water' high up into the atmosphere of Mars, providing another clue in answering the mystery of when there could have been life on Mars in its history.[22]

New capabilities and skills Through the development of the rover, the UK has made significant technical progress on autonomy, robotics, and sensitive instruments, which will position the UK strongly for future contracts on exploration and science missions. This bolsters the national supply chain, opening more commercial opportunities both nationally and internationally. Going to Mars is different because of the atmosphere, and Airbus had to develop new skills in the thermal engineering teams, which has enabled new roles for mechanisms engineers. It has allowed them to formally established robotics

[22] Open University. http://www.open.ac.uk

team –- an inter-disciplinary team -– bringing lots of internal staff together and recruiting several new people.

Follow-on sales Test facilities at Airbus developed for ExoMars are also sold on day rate to other organisations, like University of Leicester, which uses the mechanical test facilities as to test their radio isotope telescope.

Future contracts The demonstrated capabilities specifically in robotic autonomy by Airbus UK on ExoMars has meant the UK is in pole position to lead the development of the Sample Fetch Rover in the brand-new mission, Mars Sample Return. Sustained UK leadership not only has inspirational value, it also helps industry plan for future growth and demonstrates the attractiveness of the UK space industry.

Spillover benefits

Scientific knowledge One of the most significant unique features of the ExoMars rover is that it has the ability to drill down 2 metres beneath the surface (for context: NASA's Perseverance rover can drill to 6cm). The samples extracted from this distance below the surface are deep enough to be protected from the intense radiation of the Martian environment, and so any evidence of pre-existing life forms on Mars would be preserved for detection and further study. Any such evidence would be a monumentally significant discovery – the very first proof of life beyond Earth – and foster a whole new field of research study (with future missions) for decades to come.

Impact on future missions Findings from UK scientists analysing the ExoMars mission showed how a global dust storm on Mars had affected the location of water vapour in the atmosphere.[23] The collected data will help to evaluate risks for future crewed missions as well as assist in broader studies of Martian geochemistry and environmental science. Understanding Martian dust storms are crucial to assessing the viability of any future landing sites and even potential Mars colony sites. [24]

Technology transfer The new technical capabilities in the development of the ExoMars rover will spillover into satellite manufacturing, Active Debris Removal (ADR), In-Orbit Servicing (IOS) and In-Orbit Manufacturing (IOM). Specifically, the progress made on robotic autonomy and Airbus' robotic arm is crucial to enabling in-orbit services and rendezvous and proximity operations in orbit, opening a whole new world of capabilities for the satellites industry. Robotics and autonomous space exploration capabilities can also eventually be used on the moon for commercial rovers. Here on Earth, the sterile environment achieved for the rover could be used for environments on Earth that need hyper-sterility, and welding techniques have already led to 12% cost savings on raw materials in aluminium manufacturing.[25] There is significant potential for future spillovers resulting from the terrestrial application of ExoMars technologies – including using stereo cameras to monitor carbon emissions, detection of minerology for mining, advanced insulation for energy efficient heating and refrigeration, advanced autonomous robotics for mining, sub-marine exploration and other dangerous or inaccessible environments.

Coordination The ExoMars mission was originally planned as a joint mission between ESA and Roscosmos, but following ESA's suspension of cooperation with Roscosmos,

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[23] ESA. https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Exploration/ExoMars/ExoMars_discovers_new_gas_and_traces_water_loss_on_Mars
[24] Airbus. https://www.airbus.com/en/products-services/space/exploration/mars
[25] London Economics (2015) *Return from Public Space Investments.*

enhanced coordination between ESA Member States and international partners will be essential to achieve success. Coordination with NASA has also allowed UK researchers access to other spacecraft including NASA's MAVEN and the other NASA rovers.

Inspiring the future generation Answering the biggest scientific questions is not only very valuable in itself, missions like ExoMars inspire future scientists to ask big questions and help build the technology needed to answer them. Through their ExoMars work, Airbus has a STEM centre attached to their Mars Yard, aiming to attract more than 5,000 students a year[26]. Students that have previously visited have since applied for internships and apprenticeships.

Lag and duration of benefits

When discussing the benefits of large space missions, it is important to appreciate the timescales at play. ExoMars has been planned and funded for more than a decade now, with some of the UK camera technology having its roots in the Beagle-2 mission, and will still produce science a decade (and potentially decades) in the future. It may yet be 10-15 years before we have a definite answer on the question to whether there has ever been life on Mars. Once we do have an answer, there is the potential for the benefits of this mission to have decades-long, if not permanent benefits -- not least to the UK, but the world as a whole. Discovering life on Mars would change the way we approach the universe around us.

From the point at which funding is provided, several years can pass before we see the creation of jobs in industry and longer still for the access to data for researchers. Once the contracts have been awarded, which can take a few years, the benefits to industry can last anywhere from a few months for shorter contracts to 5+ years for bigger contracts. The benefits from gains in skills, technical capabilities, and R&D will last much longer than that, and can benefit both the recipient, the supply chain, and the wider economy for 10+ years after the contract.

Case Study: Air Quality remote sensing

National Space Technology Programme: Air Quality remote sensing

The third pillar of the newly released *National Space Strategy* sets out steps to transform the UK into a science and technology superpower. The UK government had already set targets for total R&D spending to constitute 2.4% of GDP by 2027, and will continue to invest heavily in national innovation and technology development initiatives.[27]

The National Space Technology Programme (NSTP) was designed to build UK capability by stimulating growth of the space sector, encourage knowledge exchange, and

[26] Airbus. https://www.airbus.com/en/newsroom/news/2016-05-airbus-defence-and-space-to-build-stem-centre-at-its-uk-exomars-rover-test
[27] UK Space Agency. *National Space Strategy*. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1034313/national-space-strategy.pdf

welcoming new entrants while striving to secure a strong foundation for growth and resilience across the UK.[28]

As part of funding through the NSTP's second round, industry-academic partnerships between University of Leicester, University of Oxford, AAC Clyde Space, RAL, Satellite Applications Catapult Thales Alenia Space and STFC have resulted in novel Air Quality sensing instruments and data processing techniques.

NSTP funding has allowed the development of space technology and the subsequent spilling over to other sectors which is using the technology to better the lives of citizens. Increasing technological capabilities in air quality sensing is critical for the health of UK citizens, and is a fundamental to both national and local air quality policymaking. The UK and the rest of the world face an ever-growing air quality problem: it is estimated that the cost of poor air quality in the United Kingdom alone could lie between £9-20bn p.a.[29]

UK investment and outputs to date

In the second round of NSTP funding, funding related to Earth Observation was delivered through CEOI until 2018, after which it was brought in-house to the UKSA. During the time CEOI were delivering projects for NSTP, four Air Quality projects received grant money:

- *Compact Air Quality Spectrometer or CompAQS* by University of Leicester [On-going]
    - In 2018, an aircraft carrying the pioneering CompAQS NO2 scanner demonstrated CompAQS ability measure nitrogen dioxide levels in environment below it.
- *Hyperspectral Imaging for Air Quality: Application of a Hyperspectral Imaging Suite for 3D Retrieval*s by the University of Leicester [Study published]
- *High-resolution Anthropogenic Pollution Imager (HAPI) payload on an OmniSat platform* by Thales Alenia Space UK [Study published]
- *A miniaturised multi-spectral Thermal Infrared (TIR) space imaging system for improving volcanic ash monitoring* by University of Bristol [Study published][30]

Benefits and returns

The primary benefits of NSTP funding are the increased technological readiness of key air quality sensing technologies, the subsequent (expected) use of the technology, and the follow-on activity it will generate. These will be:

- Benefits to the researchers and industry grant-receivers, allowing them to conduct R&D, establish new partnerships, upskill, and more.
- Benefits to the UK space industry, through job creation, increased knowledge of key technologies, and research-industry partnerships.
- Wider benefits to society, through the application of Air Quality sensing to improve health outcome, and through the heightened capacity to understand our own planet and the environmental result of our behaviours.

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[28] UK Space Agency. *National Space Technology Programme.* https://www.gov.uk/guidance/apply-for-funding-through-the-national-space-technology-programme
[29] UKRI. https://gtr.ukri.org/projects?ref=NE/L002930/1
[30] CEOI, Annual Report 2015-2016. https://ceoi.ac.uk/about-2/ceoi-st-annual-reports/

Given the ex-ante nature of our assessment (the technology is not currently in use), there is considerable uncertainty surrounding the benefits which will eventually be realised, years into the future. This makes the quantification of benefits challenging, so they are rarely monetised, except to note the magnitude of potential savings.

Direct benefits

Increasing technological readiness Sensing NO_2 is both a great proxy for understanding air quality and is also itself harmful to human health, being associated, for example, with respiratory damage and premature death.[31] There are two main methods for sensing NO2 in our atmosphere: in situ measurements (on ground and in our atmosphere) and remote sensing techniques (both ground-based and space-based observations). To understand air quality nationally, or even in urban environments, it is not feasible to install a large number of in situ measurement points, and until recently, space-based observation had been infeasible due to low spatial resolutions.[32] However, thanks to an industry-academic partnership between University of Leicester and SSTL and Airbus, we now have a demonstrated way to achieve ground sampling distances (GSD) of around 1-2 km: with the CompAQS (Compact Air Quality Spectromete), using a concentric optical design based on an Offner relay spectrometer with superior spectral and spatial performance.[33],[34]

Further applications Remote sensing is not limited to NO2 sensing, and technological developments in this area will help measure a host of other relevant markers in our atmosphere. Additionally, after the progress made on the Trace Gas Orbiter of the ExoMars programme, it is likely we will see technological progress in remote sensing play a key role in understanding atmospheric make-up of other bodies in our solar system in the future.

Opening commercial opportunities University of Leicester researchers partnered with Thales Alenia Space and STFC to develop a novel instrument for the remote sensing of NO2 with high spatial and temporal resolution, while being small enough to be deployed on constellations of small satellites. Called the HAPI-OmniSat, this technology has the potential to allow the monitoring of air quality at a global scale with unprecedented spatial and temporal resolution, opening up for hundreds of millions of GBP through a globally exploitable commercial data service.[35]

Spillover benefits

Spinoff commercialisation EarthSense is a spinoff company from the University of Leicester. Their Air Quality Hotspot Mapper uses Copernicus MACC II and other data sources to deliver near real time pollution monitoring over urban areas, producing a heatmap of pollution hotspots. This provides local authorities with a valuable commercial service: near real time map of the air quality and support in pollution mitigation. EarthSense was recently selected as a supplier for Transport Technology and Associated Services Framework (TTAS). After achieving 60% year-on-year growth and a recruitment

[31] WHO Regional Office for Europe (2013).
[32] Villena *et al.* (2020) *Discrete-wavelength DOAS NO2 slant column retrievals from OMI and TROPOMI.*
[33] CEOI. https://ceoi.ac.uk/technologies/optical-spectroscopy/compaqs/uv-visible-compact-spectrometers/
[34] CEOI, Annual Report 2015-2016. https://ceoi.ac.uk/about-2/ceoi-st-annual-reports/
[35] NSTP Programme Brochure, (2018).


Image: UK Space Agency

drive which has seen the team grow to 26, EarthSense announced in 2021 that it will occupy a whole floor at Space Park Leicester.[36]

Environmental and health benefits The potential benefits of more effective air quality interventions in UK have been estimated at £4.1 million per annum.[37] With better remote sensing and better air quality data, local authorities will be equipped to take decisions in the interest of citizen health. Ultimately, effective interventions can reduce adverse health effects associated with poor air quality, and thus reduce emergency hospital admissions for air quality-related emergencies and the associated cost.

Technical coordination Research institutions like University of Leicester and the University of Oxford have worked with AAC Clyde Space, RAL, Satellite Applications Catapult, Thales Alenia Space (TAS), Airbus and STFC. The HAPI project, for example, was developed by a uniquely qualified industrial and academic partnership of satellite constellation specialists at Thales Alenia Space (TAS), the Earth Observation Science group (EOS) at the University of Leicester optical design experts at the Astronomy Technology Centre and mechanical/thermal test facilities provided by Rutherford Appleton Laboratory.[38]

Lag and duration of benefits

The funding rounds from NSTP runs over several calls, and the time from funding to benefit can therefore vary greatly. Some grants are for preliminary studies and can be relatively quick, others are building out technology in risk-free environments, which can take several years. We are still 5+ years away from having an air quality remote sensing constellations that can provide air quality measurements down to a spatial resolution that is useful to local governments and therefore many years from realising any benefit to public health.

The coordination benefits are likely to persist for more than the duration of the program, as for example with the HAPI project. Strong industry-academic partnerships can have benefits long after the project is due, through relationship building, knowledge exchange, likelihood to work together on future projects, etc.

As evidenced by EarthSense, several years can pass before a project is funded until we see commercial spin-off activity and the associated economic benefits. Since spin-out, EarthSense has grown year-on-year for 5 years now, signalling a probably decade-long duration of the benefit.

The nature of NSTP funding targets technologies that specifically need a higher readiness, so there are inherently very high levels of skill-up happening in the research and industry teams. The benefits of relevant skilling-up can potentially last for several years.

[36] EarthSense. https://www.earthsense.co.uk/
[37] London Economics (2019) *Economic Evaluation of SSGP.* https://www.ukspace.org/wp-content/uploads/2019/04/Economic-evaluation-of-SSGP_March2019.pdf
[38] Villena *et al.* (2018) *The High-resolution Anthropogenic Pollution Imager (HAPI): a closer look into air pollution*.

Case Study: Space safety

Space safety: Active debris removal

Orbital congestion with space debris remains a global challenge. Both the UK's critical national infrastructure and a multitude of both commercial and public services rely on a functioning satellite-based infrastructure. The Active Debris Removal (ADR) and In-Orbit Servicing (IOS) markets have only just begun maturing, but estimates put the total market size the UK could capture at $1bn by 2030, with the potential to create value to the UK economy worth tens of billions in the medium to long-term.[39] Being among the first movers in this new market would develop national skills, expertise and robotics capability needed to conduct ADR and IOS has long term strategic benefits, and will pave the way for future capabilities, such as orbital assembly or space-based power generation.

The ADR and IOS market are likely to grow rapidly in the future, and it is vital for the UK to differentiate itself to capture a significant part of the growing market. Without clear leadership in the ADR field, the UK cannot play a substantial role in the efforts to ensure the protection of critical national infrastructure and the preservation of the satellite services used by civilians in the UK and around the world.

UK investment and outputs to date

In line with its ambitions, UKSA has funded three ADR Phase 0-A mission feasibility studies through its Space Surveillance and Tracking (SST) programme: Astroscale; ClearSpace; and SSTL. The three groups share a total funding pot of approximately £1 million.

For the purposes of brevity, the current Case Study focuses one of the three studies – Astroscale UK's Cleaning Outer Space Mission through Innovative Capture (COSMIC) study,[40] which received approximately £0.5 million of funding.

In August 2021, Astroscale UK successfully demonstrated its ability to magnetically capture a replica satellite during with its End-of-Life Services by Astroscale-demonstration (ELSA-d) satellite.[41] Over the coming months, the company will have to demonstrate more complex non-tumbling and tumbling captures before de-orbiting the target.

Benefits and returns

The primary purpose of the COSMIC ADR study was primarily to demonstrate that the UK had the capability to perform debris removal. However, the UK also wants to nurture national ADR and IOS industries to ensure a large capture of the global market in the future. The benefits to funding into these activities are:

- Benefits for the recipients (e.g. Astroscale) allowing them to grow, expand through R&D, establish new partnerships, upskill their employees, grow exports, and more.

[39] Satellite Applications Catapult. *In-Orbit Servicing Capabilities.* https://sa.catapult.org.uk/news/in-orbit-servicing-capability/
[40] Astroscale. https://astroscale.com/astroscale-awarded-uk-space-agency-bid-to-study-removal-of-two-defunct-satellites-from-space/
[41] Astroscale. https://astroscale.com/astroscales-elsa-d-successfully-demonstrates-repeated-magnetic-capture/

- Benefits to the space industry, through job creation, bolstering of our national supply chain, up-skilling, research-industry partnerships, new export markets, increased UK reputation and influence in the field, and increased coordination.
- Wider benefits to society, as we can ensure the continued operation of satellites providing key services to UK citizens, and technology that will spill over into other key areas, such as in-orbit manufacturing, refuelling, and repair, which will increase our satellite capabilities greatly.

At this early stage, most benefits remain speculative and uncertain. In-orbit servicing and debris removal are predicted to become large markets in the medium-to-long term, but the technology is currently still in demonstration. This makes quantification very challenging. As such, some benefits are described qualitatively, and it is not possible to estimate the return on public investment to-date.

Direct benefits

Growth Astroscale's UK team has grown from 3 to ~80 employees. Astroscale has also bolstered the local supply chain: they currently work in partnership with MDA, TAS, SSTL, Catapult, Willis, and a host of SMEs; levelling up areas of the UK outside the South-East and creating the potential for 100s of new jobs. The skilling-up of UK workers at Astroscale and in the wider supply chain are happening in crucial fields: orbital mechanics and optimization, docking, rendezvousing, robotics, satellite manufacturing, and more.

New capabilities and facilities A National In-Orbit Control Centre was built at Harwell, which was 50% co-funded by Astroscale. This state-of-the-art facility will serve as the base for future In-Orbit service operations and demonstrates UK leadership in the field. It will attract future commercial activity and is a prime example of technical and strategic coordination enabling win-win benefits.[42]

Spillover benefits

Reputational gains The Astroscale demonstrations has already had reputational gains for the UK in the field of sustainable space and the clearing of orbital congestion. Conducting national missions is always a clear signal to international partners that the field is taken seriously, and the stamp of approval for the industry involved can have great commercial ripple effects.

Technology transfer The part-UK-owned OneWeb will launch 650 of satellites into constellation in the next few years. In June 2019, OneWeb announced its initiative Responsible Space, outlining specific approaches on sustainability and safe operations in space. As part of this initiative, OneWeb plans to include a grapple fixture on its satellites so third-party satellite can de-orbit it, should the satellite prove non-responsive.[43] ADR and IOS technological capability will be crucial to the success of OneWeb.

Reduced costs for users Astroscale is demonstrating that ADR can be done for much lower costs than anticipated. Once a single ADR satellite can perform multiple debris removals in one life cycle, this would represent potentially huge cost savings for future satellites

[42] UKRI. https://gtr.ukri.org/projects?ref=104193
[43] SpaceNews. https://spacenews.com/can-satellite-megaconstellations-be-responsible-users-of-space/


Image: UK Space Agency

operators. If the UK can demonstrate much cheaper decommissioning, it can differentiate itself in the ADR and IOS market on price.

Access to space and continued satellite services Humanity increasingly relies on satellite services every day. The loss of satellite services even for just five days could amount to £5 billion, equivalent to £1billion a day.[44] The worst case, labelled the *Kessler Syndrome*, would be that there is a domino effect of space debris crashing into itself around the planet, trapping us under a sheet of debris. ADR missions and demonstrations like ELSA-d have enormous social benefits in ensuring we are ahead of the curve on debris, so that we can all continue using satellite services in our daily lives.

Improved coordination There have been a clear direction from top with the COSMIC study and the ambition to fly a UK-based ADR mission by 2025. Because of this, both industry and academic partners are working together on ADR and IOS capabilities across several industries. A coordinated effort is crucial to establish the UK as a leader in ADR and IOS operations and licensing.

Lag and duration of benefits

As with any mission, there is expected lag between funding and benefit. In the case of COSMIC, the UK benefitted from Astroscale UK's previous ADR expertise from their Japanese parent company, which allowed Astroscale UK to demonstrate ADR capability the same year as the study grant. Once activity on the mission is underway, we see the benefits ripple out from Astroscale and into the supply chain.

The benefits around skill-up and new capabilities are likely to last at least 10 years, and potentially longer depending on the UK's ability to capture large parts of the ADR market in the future. The coordination benefits and the learnings from undertaking a national space mission are likely to impact the UK space sector for decades to come.

The more immediate benefits from the Harwell Control Centre comes just a few years after funding, and will see benefits throughout this decade, potentially further.

If the UK is successful at establishing a differentiating position in the ADR/IOS market, the commercial benefits would last well into the middle of the century. However, it will be at least another 7 years before we will know just how strongly the UK stands in the field.

Case Study: SPIN

SPIN: 'Space Placements in Industry' scheme

The 'Space Placements in Industry' (SPIN) funding scheme has supported the aims of the UK Space Agency by encouraging and supporting the provision of internships within the space sector for university students. In doing so, it has helped address the skills needs of the UK space sector, improving awareness of the UK's space programme and the skills in most need across the sector.

[44] GOV.UK. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/619544/17.3254_Economic_impact_to_UK_of_a_disruption_to_GNSS_-_Full_Report.pdf

The scheme has been managed by the UK Space Agency and supported by the Satellite Applications Catapult. It has been running since 2013 and continues to grow in popularity.

UK investment and outputs to date

Each year, the UKSA has typically funded 25 placements (£75k), the Spaceflight programme a further 17 placements (£42k), and companies self-funded 20 placements (£60k). This equates to around £3,000 per student placement. In 2021, the programme saw 3,500 applicants, and ~60 placements were awarded, a big increase on previous years (~900 applicants and 20-60 placements).

In general, companies have been keen for more SPINterns than the UKSA could fund. 53% of space industry businesses report offering a vacation work placement (including a SPINtern).[45] Companies across the industry have taken SPINterns in, including Orbex, Astroscale, Deimos, SpaceForge, Skyrora, and many more.[46]

Benefits and returns

The primary benefit of the SPIN scheme has been to address the skills gap in the industry. This means that both the interns, the companies, and the wider industry have benefitted from the scheme:

- Benefits to the interns, allowing them to upskill, get exposure in the industry, establish partnerships, and understand the nature of skills required.
- Benefits to the company, through savings in recruitment cost, access to talent, outreach, and value-add for the duration of the placement.
- Wider benefits to society, as the skill-gap narrows, the UK space industry grows, and the UK attracts more commercial business and more ESA contracts in the future, and as more students from more backgrounds get the opportunity to work in a fast-growing sector.

The benefits of the SPIN scheme are challenging to monetise, so many benefits are described qualitatively. Where possible, we have given quantitative estimates, but some key benefits are intrinsically difficult to value monetarily – this is particularly true for intangible benefits, such as aiding mindset change in the industry. Even where quantification is possible, monetisation may be challenging; for example, placing a monetary value on increased diversity in the sector.

Direct benefits (interns and companies)

Increased job prospects and upskilling After a SPIN placement, ~60% of placements have gone on to receive a job offer. This is higher than the industry standard for placements and internships. Companies have reported being very happy with the programme, and that it has given them more breathing room to upskill talent earlier in their career. SPIN also helped students understand what skills to acquire to be competitive candidates. For example, after a few years of SPIN and placements, physics students started increasingly electing for coding courses.

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[45] UK Space Agency. *Space Sector Skills Survey 2020*.
[46] Satellite Applications Catapult. https://sa.catapult.org.uk/work-with-us/space-placements-industry-spin/


Image: UK Space Agency

Making SMEs competitive Through SPIN, smaller companies have gained access to talent earlier in their careers. Traditionally, larger companies like Airbus would attract the majority of early-stage talent in form of internships and placements. SPIN gives smaller organisations the chance to attract talent to them early in their career. In the beginning of SPIN, a small SME would get a couple of applications for summer internships, but by last summer, every company got at least 40 applicants.

Levelling-up Through SPIN, there has been a positive shift in the representation of universities at internship placements in the industry. Not traditionally 'space-focused' universities in the North-East, Cornwall, and Wales have had their students win placements.

Spillover benefits

Diversity and access to opportunity The scheme provides opportunities to young people from diverse backgrounds, with students placed through SPIN coming from a wide range of regions and universities, e.g., up to a fifth of placements are European students. This causes ripple effects in the industry, as diversity breeds more diversity, ultimately making sure any talented young student can have equal access to opportunity in the space industry.

Solving the skills gap takes a mindset change The space industry finds it difficult to provide entry level jobs and enable time for new hires to upskill. SPIN helps inspire a mindset change in the space industry to allow talent earlier in their career the opportunity and space to skill-up. SPIN itself will not bridge the gap but is an important part of the puzzle: it causes both small and larger businesses to shift their recruitment efforts to people earlier in their career, and thus helps them acquire the skills they need. After participation in the scheme, companies increasingly launch their own internship programmes following the successful placements of student interns.

Placing talent where talent does not normally go A key benefit to the SPIN scheme is the ability to distribute talent outside the South-East. For example, the Cornwall spaceport had two 'SPINterns' last summer, despite the council having a hiring freeze, and there are similar stories of the programme bringing talent to underrepresented regions that were unlikely to come otherwise.

Lag and duration of benefits

The timelines (lag and duration) of these benefits to skill-up varies. In simple terms, there is only a few months of lag between funding and first benefit, when interns are placed in the industry to provide value on projects and begin skilling up. Initially, this value is short-term for the interns and companies – only lasting for the duration of the placements.

Then, there is a 6-months to 1 year lag from funding to students being introduced to new needed skills and making educational changes to skill-up following their placements. This benefit can last for very long; educational changes made by students may impact them for the rest of their lives.

There is a 1-2 years' lag from the point of funding to students entering full-time employment (60% of students will enter a FTE position), and a further 2-4 years from funding until these new FTEs can be estimated to have a more fundamental impact in the sector for their employers. At this point the duration of benefit can be a few years to a lifetime: for the intern, the opportunity and the skill-up will likely impact their career


Image: UK Space Agency

permanently; for the company, the added value can make a profound impact to operations in both the short-term and medium-term.

The industry-wide mindset change to focus on talent earlier in the career has happened a few years into the SPIN programme, and is expected to continue to happen in the future. The benefit this has to solving the skills gap will be felt for many years to come. Equally the more equitable distribution of talent, both in terms of regional placements, regional origin, and background, will have long-term ripple effects in the industry and wider society.

4 Summary and conclusion

4.1 Introduction

Having reviewed the evidence on returns and benefits from public space investments – from new evaluation literature (2015-21), combined with that of the 2015 study and with 4 Case Studies of real investments, we now present a summary of our results.

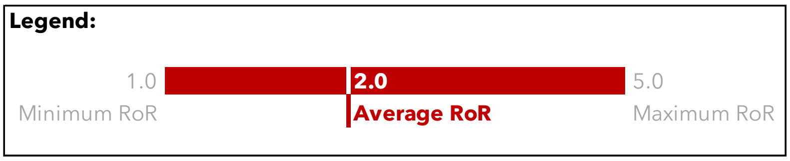
4.2 Rates of return

By domain

The recommended ranges of Rate-of-Return (RoR) for each **domain** are presented below – based on the reviewed evidence. A number of informed subjective filters have been applied – both in the review methodology (outlined in the Annex) and in the analysis of collected estimates (note: outliers (defined as an estimated RoR of 50:1 or greater) have been filtered out from all ranges and averages[47]).

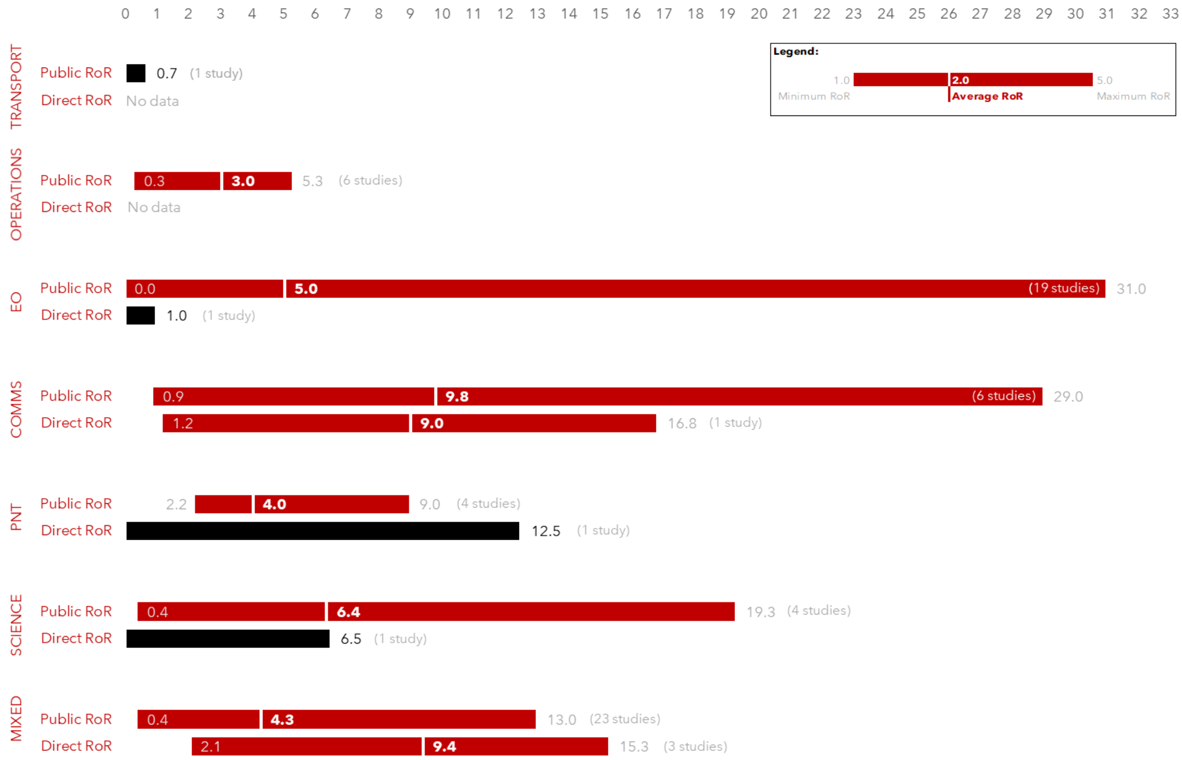
Note that the following charts are based on the limited evidence base available and as such are subject to a number of **caveats**. Therefore, though we have tried to ensure that the evidence presented is as reliable as possible, the averages given may not represent the true average return on investment in each category. Furthermore, it should be noted that the **true return on an investment will always be context-specific and an average or median value cannot capture this heterogeneity**.

Note: Charting convention
Graphical summaries of the proposed parameter ranges are used as a presentational aid in the subsequent sections. Each graphical summary is presented using a common chart format, explained in the legend below. The red bars displayed in the charts represent the judgement-adjusted range[48] of observed evaluation evidence – from the minimum Rate of Return (RoR), the average RoR and the maximum RoR, as shown in the indicative Legend below:



[47] We note that we have cross-checked our chosen threshold (50) using the interquartile range approach (multiplied by a factor of 3), giving a threshold of 20.3. However, given the very small sample involved we maintain 50 as a threshold to include as many valid RoR estimates as possible.
[48] A quality threshold was applied, and outliers were removed.

Chart 11 Rates of return, by domain

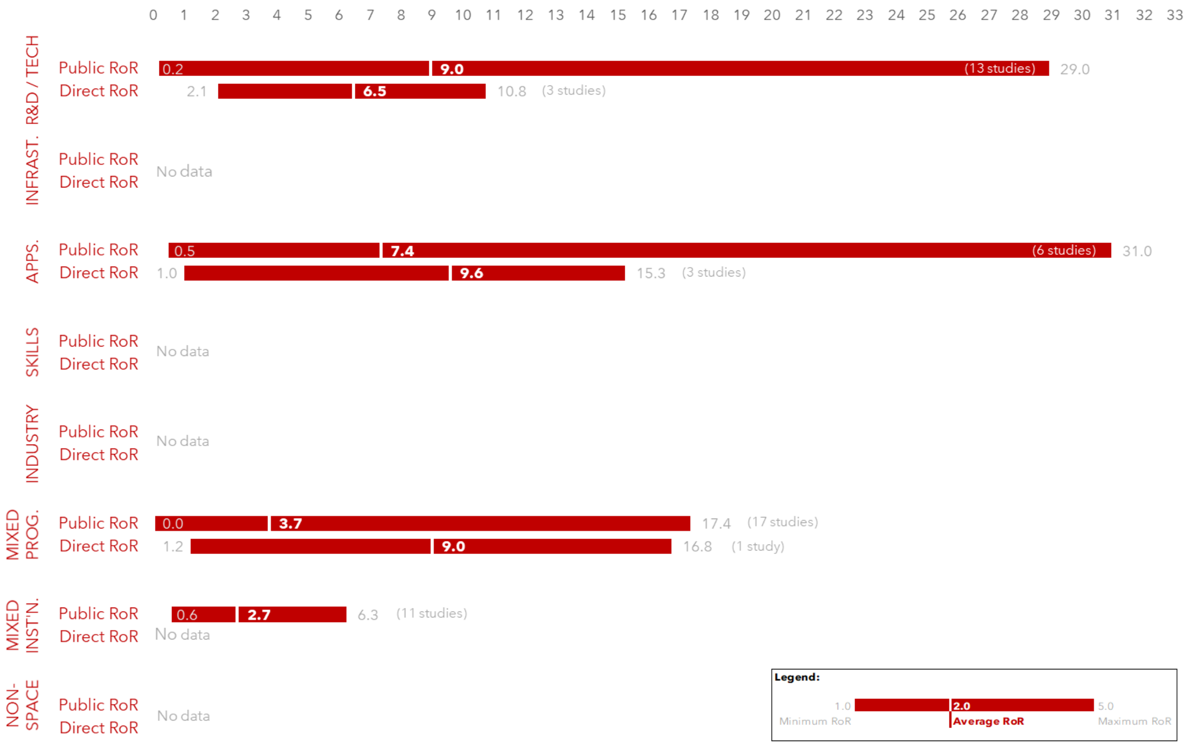


Notes: A black bar indicates there is only one data point in a category. Outliers (defined as an estimated RoR of 50:1 or greater) have been filtered out from all presented ranges and averages. Outliers have been removed from COMMS (REDACTED), PNT (RoR of 399.0) and SCIENCE (RoR of 99.0).
Source: know.space

By substance

The recommended ranges of Rate-of-Return (RoR) for each **substance** are presented below. Note that no estimates were available for some substance categories from the space-specific literature reviewed, meaning that such estimates would need to be drawn from the more general science and innovation literature – but that this is still a very important and worthwhile exercise as it enables a more nuanced consideration of investments.

Chart 12 Rates of return, by substance



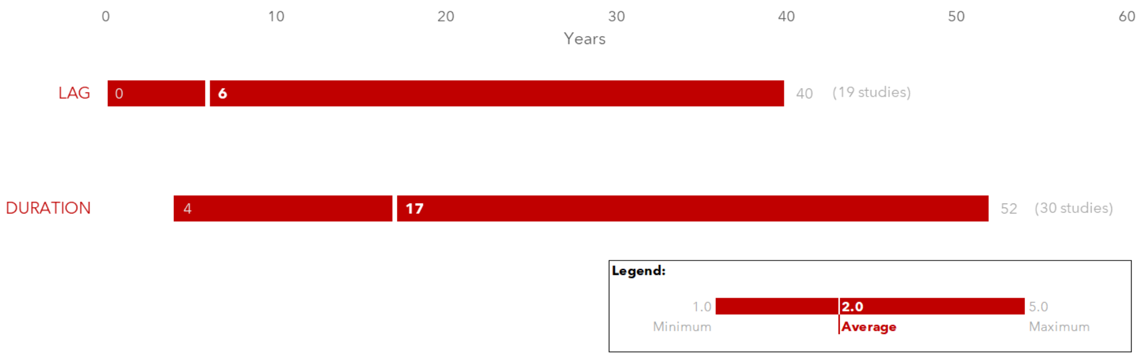
Note: A black bar indicates there is only one data point in a category. Outliers (defined as an estimated RoR of 50:1 or greater) have been filtered out from all presented ranges and averages. Outliers have been removed from R&D/ TECH (REDACTED), APPS. (RoR of 399:1) and MIXED PROG. (RoR of 99:1).
Source: know.space

4.3 Lag and benefit duration

Due to the limited evidence base available, we are unable to provide quantitative estimates for all parameters considered. In this section, we therefore present a summary of the evidence on lag and duration of benefits only.

The chart below gives an overview of the evidence from the literature review on lags and duration of benefits. We find a median lag of 6 years and a median duration of 17 years.

Chart 13 Lags and duration of benefits



Note: Averages given are medians to prevent upwards bias.
Source: know.space

Image: UK Space Agency

Our case studies support this evidence and provide greater nuance. The case studies suggest that shorter lags tend to be associated with the direct benefits arising from an investment, which accrue as soon as public funds are used (e.g. job creation), whilst longer lags are associated with the achievement of the final goal of public funding (e.g. answering the question of whether life has ever existed on Mars), which imply large spillover benefits, e.g. an inspiration effect.

With regard to lags, our results support the conclusions of the 2015 study at a high-level. We recommend the following parameters, as a baseline, with potential to augment these estimates to the specifics of an investment, using our case studies and referring to individual studies cited in the literature review:

Table 36 Recommend lags

Type of investment	Recommended lag
Science and exploration	2 years (construction), 10 years (exploitation)
Infrastructure e.g., antennas etc.	5 years
Technology development	2 years

Source: know.space

Since 2015, the evidence on benefit duration has improved significantly. For top-down estimation, we recommend an average duration figure of 17 years, with flexibility to use an estimate at the higher end of the range (e.g. closer to 50 years) for science programmes whose main output is greater scientific knowledge and to use estimates at the lower end of the range for projects for which the main benefits are direct and cease when public funding ends.

4.4 Conclusion

The heterogeneity of space investments, and of the evidence from their evaluation, underscores the analytical superiority of a bottom-up approach to appraisal of new public space investments populated with investment-specific inputs to the furthest extent possible. Nonetheless, due to input, timing and/or resource limitations, such detailed appraisal may not be possible.

Bibliography

Papers included in the 2015 review (1971-2015)

ACIL Tasman (2010) The economic value of earth observation from space: A review of the value to Australia of Earth observation from space, Prepared for the Cooperative Research Centre for Spatial Information (CRC-SI) and Geoscience Australia.

Amesse, F., Cohendet, P., Poirer, A., and Chouinard, J. (2002) Economic effects and spin-offs in a small space economy: The case of Canada.

Applied Sciences Program NASA Earth Science (2012) Measuring Socioeconomic Impacts of Earth Observations – A Primer.

Åström, T., Jansson, T., & Mattsson, P. (2010) Mid-term Evaluation of the Swedish National Space Technology Research Programme (NRFP), Report by Technopolis Group.

Bach, L., Cohendet, P., & Schenk, E. (2002) Technological transfers from the European Space Programmes: A dynamic view and comparison with other R&D projects.

Belgian Federal Science Policy Office (2012) Politique scientifique fédérale, Annuaire 2012, pp 35-36.

BETA/CETAI (1989) Indirect economic effects of ESA contracts on the Canadian economy.

Booz & Co. (2011) Cost-Benefit Analysis for GMES for the European Commission: Directorate-General for Enterprise & Industry.

Booz & Co. (2014) Evaluation of socio-economic impacts from space activities in the EU, prepared for the European Commission Enterprise and Industry Directorate-General.

Booz Allen Hamilton (2005) Geospatial Interoperability Return on Investment Study, National Aeronautics and Space Administration, Geospatial Interoperability Office.

Bouma, J., van der Woerd, H., Kuik, O. (2009) Assessing the value of information for water quality management in the North Sea.

British National Space Centre/London Economics (2009) Space Exploration Review, pp.82-83.

Bureau d'Economie Théorique et Appliquée (1980) Economic benefits from ESA contracts, Final Reports for the European Space Agency.

Bureau d'Economie Théorique et Appliquée (1988) Study of the economic effects of European space expenditure, Results Vol 1., and Report on investigation theory and methodology, Vol. 2 , Reports for the European Space Agency.

Bureau d'Economie Théorique et Appliquée (1989) Analyse des mécanismes de transfert de technologies spatiales: le role de l'Agence Spatiale Européenne, Final Report for the European Space Agency.

CETAI/BETA (1994) Les effets economiques indirects des contrats de l'ASE sur l'economie canadienne (deuxieme etude, 1988-1997).

Chase Econometric Associates (1976) The Economic Impact of NASA R&D Spending.

Clama Consulting (2011) Survey of the Economic Impact of Portugal's Participation in ESA from 2000 to 2009.

EADS Astrium (2006) Case4Space 2006.


Image: UK Space Agency

EUMETSTAT (2013) The case for EPS/Metop Second Generation: Cost benefit analysis.

European Commission (2010a) Proposal for a Regulation of the European Parliament and of the Council establishing the Copernicus Programme and repealing Regulation (EU) No 911/201, European Commission Staff Working Document, Impact Assessment.

European Commission (2010b) Provision of Satellite Navigation Augmentation Services (SBAS) over Africa, Detailed Concept Paper.

European Commission (2011) Impact Assessment, Proposal for a Regulation of the European Parliament and of the Council on further implementation of the European satellite navigation programmes (2014-2020), SEC(2011) 1447 final.

European Space Policy Institute (2011) The Socio-Economic Benefits of GMES: A synthesis derived from a comprehensive analysis of previous results and focusing on disaster management.

F. Douglas Johnson, Panayes Gastseos, and Emily Miller, with assistance from Charles F. Mourning, Thomas Basinger, Nancy Gundersen, and Martin Kokus (1977) NASA Tech Brief Program: A Cost Benefit Evaluation, Executive Summary, University of Denver Research Institute, Contract NASW-2892, pp. i–iii.

Faugert & Co Utvärding AB (2012) Impact evaluation of the Swedish National Space Board's National Earth Observation Programme.

Federal Aviation Authority (2010) The Economic Impact of Commercial Space Transportation on the U.S. Economy in 2009.

Frontier Economics (2014) Rates of return to investment in science and innovation, Report prepared for the Department for Business, Innovation and Skills.

GSA – GNSS Supervisory Authority (2009) EGNOS Cost Benefit Analysis in Aviation.

Hertzfeld, H. (1998) Measuring the Returns to NASA Life Sciences Research and Development, Space Policy Institute, George Washington University.

Hickling Corporation (1994) The Canadian Space Program 1994: A review of the strategies and economics of Long-Term Space Plan II.

High Tech Systems and Materials top team (2012) ESTEC White Paper - Spinning in and spinning off: Ways to strengthen the ties between ESTEC and the Dutch knowledge infrastructure.

HM Treasury (2003a) The Green Book: Appraisal and evaluation in Central Government, Treasury Guidance.

HM Treasury (2003b) Public sector business cases using the five-case model, Green Book supplementary guidance on delivering public value from spending proposals.

House of Commons Science and Technology Committee (2013) Bridging the valley of death: improving the commercialisation of research, Eighth Report of Session 2012–13.

Knight, Miller and Orson (2009) An up-to-date cost/benefit analysis of precision farming techniques to guide growers of cereals and oilseeds, Home-Grown Cereals Authority (HGCA) Project No 3484.

Li, W. C. Y. (2012) Depreciation of Business R&D Capital - Bureau of Economic Analysis/National Science Foundation, R&D Satellite Account Paper, U.S. Bureau of Economic Analysis.

London Economics and PwC (2012) Evaluation of Norwegian Space Programs.

London Economics (2013) Impact analysis of the FP7 GNSS R&D programme.

MathTec (1977) A Cost-Benefit Analysis of Selected Technology Utilization Office Programs.

McCallum, I., Fritz, S., Khabarov, N., Fuss, S., Szolgayoba, J., Rydzak, F., Havlik, P., Kraxner, F., Obersteiner, M., Aoki, K., Schill, C., Quinten, M., Heumesser, C., Bouma, J., Reyers, B., Schneider, U., Pignatelli, F., Pavanello, L., Borzacchiello, M.T, & Craglia, M. (2010) Identifying and Quantifying the Benefits of GEOSS.


Image: UK Space Agency

Micus Management Consulting (2010) Einsatzpotenziale eines globalen Navigationssatellitensystems – GNSS – im Öffentlichen Sektor, Im Auftrag des Bundesministeriums für Verkehr, Bau und Stadtentwicklung.

Midwest Research Institute (1971) Economic Impact of Stimulated Technological Activity, Final Report, Contract NASW-2030.

Midwest Research Institute (1988) Economic Impact and Technological Progress of NASA Research and Development Expenditures

NASA (2010) Economic impact of NASA in Florida, FY 2010.

NASA and Bay Area Economics (2010) Economic benefits study - NASA Ames Research Center and NASA Research Park in Silicon Valley.

OECD (2014) The space economy at a glance.

Oxera (2015) What is the economic impact of the UK's ARTES funding?, Assessment of Inmarsat's ICE programme phase 1 R&D.

Oxford Economic Forecasting (2006) Assessing the Economic Impact of Aerospace Research & Development (unpublished).

Oxford Economics (2009) The Case for Space: The Impact of Space Derived Impact and Data.

PwC (2001) Inception study to support the development of a Business Plan for the GALILEO programme.

PwC (2006) Socio-economic benefits analysis of GMES.

Ramboll Management (2008) An Evaluation of Danish Industrial Activities in the European Space Agency (ESA): Assessment of the economic impacts of the Danish ESA membership.

Robinson, P., Morel de Westgaver, E. (2000) Economic Benefits from ESA Programmes, Report by Bramshill Consultancy and ESA.

Rosemberg, C., Simmonds, P., Cassagneau-Francis, O., and Jansson, T. (2015) Evaluation of Ireland's involvement in the European Space Agency, Report by Technopolis Group.

Schmidt, M., Giorgi, L., Chevreuil, M., Paulin, S., Turvey, S., & Hartmann, M. (2005) GALILEO Impacts on road transport, European Commission Joint Research Centre (JRC), Institute for Prospective Technological Studies.

SpaceTec Partners (2012a) Assessing the Economic Value of Copernicus: "The potential of Earth Observation and Copernicus Downstream Services for the Agriculture Sector".

SpaceTec Partners (2012b) Assessing the economic value of Copernicus: European Earth Observation and Copernicus Downstream Services Market Study, Publishable Executive Summary.

SpaceTec Partners (2013) Injection paper: Preliminary Note in Preparation for Copernicus Impact Assessment.

Sridhara Murthi, K., Sankar, U., Madhushudhan, H. (2007) Organizational systems, commercialization and cost-benefit analysis of Indian space programme, pp. 1817 – 1822.

Technopolis Group (2010) Summary Report – Space Exploration and Innovation, Space Policy and Coordination Unit.

Technopolis Group (2013) Big science and innovation.

The Tauri Group (2013) NASA Socio-Economic Impacts.

Triarii (2005) ESTEC's Value to the Netherlands Final Report and High Tech Systems and Materials top team (2012) ESTEC White Paper - Spinning in and spinning off: Ways to strengthen the ties between ESTEC and the Dutch knowledge infrastructure.

UK Space Agency (2014a) Review and Evaluation of the National Space Technology Programme.

UK Space Agency (2014b) Executive Summary: The Size and Health of the UK Space Industry.

Warwick Economics and Development (2013) Evaluation of the Technology Strategy Board's Feasibility Studies Programme.

Williamson,R. A., Hertzfeld H. R., Cordes, J., Logsdon, J.M. (2002) The socioeconomic benefits of Earth science and applications research: reducing the risks and costs of natural disasters in the USA, Space Policy, Volume 18, Issue 1, Pages 57-65.

Papers added in this review (2015-2021)

Barjak, F., Bill, M. and Samuel, O. (2015) *Evaluation of the existing Swiss institutional R&D funding in-struments for the implementation of the space-related measures*.

belspo (2018) *RAPPORT D'ACTIVITÉS: ACTIVITÉS SPATIALES depuis le Conseil ministériel de l'ESA de décembre 2014 à Luxembourg et de décembre 2016 à Lucerne*.

Boyle, D., Mamais, L. and Khabarov, N. (2021) *Copernicus Sentinels' Products Economic Value: A Case Study Grassland Monitoring in Estonia*.

Daraio, M.G., Battagliere, M.L. and Coletta, A. (2016) "COSMO-SkyMed Mission: Social and Economic Benefits,".

Eerme, T. and Lillestik, O. (2019) *Study on Latvia's Participation in European Space Agency Since 2015*. Available at: https://www.izm.gov.lv/lv/media/4642/download (Accessed: November 24, 2021).

Eparvier, P. *et al.* (2020) *Évaluation des projets relevant du secteur spatial financés dans le cadre du PIA Rapport final-Version publique*. Available at: www.technopolis-group.com (Accessed: October 14, 2021).

Euroconsult (2015) *Comprehensive Socio-Economic Impact Assessment of the Canadian Space Sector*.

Euroconsult (2018) *Socio-Economic Benefits of Space Utilization: Final Report*.

Euroconsult (2019a) *Socio-Economic Impact Assessment of ESA's Activities on Secure Satcom for Safety and Security*.

Euroconsult (2019b) *Socio-Economic Impact Assessment of Selected ESA Telecommunication Partnership Projects*.

Graziola, G., Cristini, A. and di Ciaccio, S. (2015) "The Importance of the Technological Spillovers for the Returns to Space Investments, with an Empirical Application to the Italian High-Tech and Space Sectors," *https://home.liebertpub.com/space*, 3(3), pp. 180–190. doi:10.1089/SPACE.2015.0010.

Helios (2017) *The Benefits of Satcom to Airlines*.

van Hoed, M. *et al.* (2019) "Impact des investissements belges dans les programmes de recherche dans le domaine du Spatial."

Invent Baltics OÜ (2015) *Ex ante assessment of multiplier effects induced by space investments from very small ESA candidate countries' perspective*.

know.space (2020) "Size & Health of the UK Space Industry 2020." Available at: www.know.space

Leveson, I. (2015) *GPS Civilian Economic Value to the U.S., Interim Report*.

London Economics (2015) *Return from Public Space Investments. A report for the UK Space Agency*.

London Economics (2017) *The economic impact on the UK of a disruption to GNSS*.

London Economics (2018a) *Economic evaluation of the Space for Smarter Government Programme (SSGP). A report for the UK Space Agency*.

London Economics (2018b) *Spillovers in the space sector: A research report for the UK Space Agency*.


Image: UK Space Agency

London Economics (2018c) *Value of satellite-derived Earth Observation capabilities to the UK Government today and by 2020: Evidence from nine domestic civil use cases*.

London Economics (2019a) *Economic evaluation of the International Partnership Programme (IPP): Cost-Effectiveness Analysis*.

London Economics (2019b) *Economic evaluation of the International Partnership Programme (IPP): Economic return to the UK*.

Loomis, J. *et al*. (2015) "Valuing geospatial information: Using the contingent valuation method to estimate the economic benefits of landsat satellite imagery," *Photogrammetric Engineering and Remote Sensing*, 81(8), pp. 647–656. doi:10.14358/PERS.81.8.647.

Mamais, L., Milosavljevic, I. and Khabarov, N. (2019) *Copernicus Sentinels' Products Economic Value: A Case Study Farm Management Support in Poland*.

Mamais, L., Oligschläger, C. and Khabarov, N. (2020) *Copernicus Sentinels' Products Economic Value: A Case Study Aquifer Management in Spain*.

Mamais, L., de Vries, M. and Khabarov, N. (2018) *Copernicus Sentinels' Products Economic Value: A Case Study Flood Management in Ireland*.

Maury, T. *et al*. (2020) "Application of environmental life cycle assessment (LCA) within the space sector: A state of the art," *Acta Astronautica*, 170, pp. 122–135. doi:10.1016/J.ACTAASTRO.2020.01.035.

Montanari, E., de Mercado, G.M. and Jamieson, E.F. (2020) "ESA Space Solutions: Socio-Economic Impact Analysis of NEWSPACE," in, pp. 12–14.

Nathalie P. Voorhees Center for Neighborhood and Community Improvement (2020) *National Aeronautics and Space Administration & Moon to Mars Program: Economic Impact Study*. Available at: https://www.nasa.gov/sites/default/files/atoms/files/nasa_economic_impact_study.pdf (Accessed: October 11, 2021).

O'Connor, A., *et al*. (2019) *Economic Benefits of the Global Positioning System (GPS)*.

OECD (2019) *The Space Economy in Figures: HOW SPACE CONTRIBUTES TO THE GLOBAL ECONOMY*.

Oligschläger, C. (2019) "Assessing the social, economic and environmental benefits derived from Earth Observation-based services along a value chain: a use-case driven approach".

Papadakis (2019) *Copernicus Sentinel Benefits Assessment*.

Park, J.H. *et al*. (2020) "The economic impact analysis of satellite development and its application in Korea," *Acta Astronautica*, 177, pp. 9–14. doi:10.1016/J.ACTAASTRO.2020.06.031.

PwC (2016a) *An ex-ante cost benefit analysis of the ESA SSA programme*. Available at: www.pwc.com/structure (Accessed: November 4, 2021).

PwC (2016b) *Assessment of the socio-economic impact of the ESA participation to the ISS Programme*.

PwC (2016c) *Study to examine the socio-economic impact of Copernicus in the EU: Report on the Copernicus downstream sector and user benefits*. Publications Office.

PwC (2017) *Copernicus ex-ante benefits assessment: Final report*. Available at: www.pwc.fr/space.

PwC (2019a) *Socio Economic Impact Assessment of ESA's Ground Systems Engineering and Operations Activities & Related Foresight Study*.

PwC (2019b) *Socio-economic impact assessment of ESA's Science Programme*. Available at: www.pwc.fr/space.

PwC (2019c) *Socio-economic impact assessments and accompanying foresight study of selected ESA Earth Observation activities*. Available at: www.pwc.fr/space.


Image: UK Space Agency

Rambøll Management Consulting and London Economics (2016) *The Danish Space Economy 2016 Summary Report of Analyse-og Evidensgrundlag for Rumområdet i Danmark*. Available at: www.londoneconomics.co.uk (Accessed: October 13, 2021).

Sawyer, G. and Boyle, D. (2020) *Copernicus Sentinels' Products Economic Value: A Case Study: Ground Motion Monitoring in Norway*.

Sawyer, G. and Dubost, A. (2015) *Copernicus Sentinels' Products Economic Value: A Case Study of Winter Navigation in the Baltic*.

Sawyer, G. and Dubost, A. (2016a) *Copernicus Sentinels' Products Economic Value: A Case Study of Forest Management in Sweden*.

Sawyer, G. and Dubost, A. (2016b) *Copernicus Sentinels' Products Economic Value: A Case Study Pipeline Infrastructure Monitoring in the Netherlands*.

Sawyer, G. and Oligschlager, C. (2021) *Copernicus Sentinels' Products Economic Value: A Case Study Making Wine in France*.

Sawyer, G. and Oligschläger, C. (2019) *Copernicus Sentinels' Products Economic Value: A Case Study Navigation through sea-ice in Greenland*. Available at: www.ocean.dmi.dk (Accessed: March 4, 2022).

Sawyer, G., Oligschläger, C. and Khabarov, N. (2021) *Copernicus Sentinels' Products Economic Value: A Case Study Lake Water Quality Management in Germany*.

Sawyer, G., de Vries, M. and Khabarov, N. (2018) *Sentinels Benefits Study: A Case Study Farm Management Support in Denmark*.

Technopolis Group (2018) *National Space Technology Programme 2 Evaluation: Final Report*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/723550/NSTP_Evaluation_2018.pdf

Technopolis Group (2019) *An evaluation of UKSA funding through the ARTES programme: Final Report*. Available at: www.technopolis-group.com.

UKSA (2017) *Impact Evaluation Report: Herschel SPIRE Instrument*.

Winning Moves (2020) *An assessment of the industrial impacts of UK funding through the ESA Space Science Programme*.

Annex: Methodology

Scope

Any complete or partial (lifetime, to-date, annual, ex post, ex ante) economic evaluations of public investments in any space or space-related terrestrial application domain.

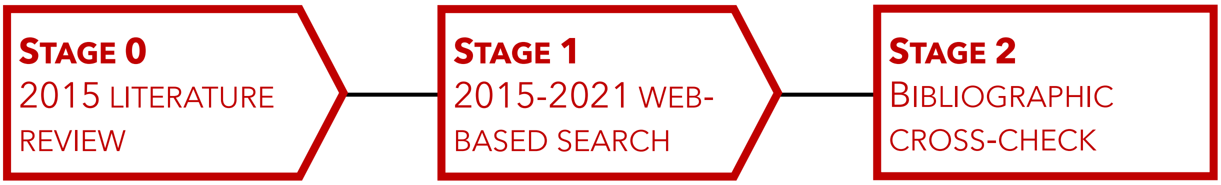
Sources: Agencies, consultancies, academic journals and publications, UKSA internal evaluations.

Date range: 2015-2021 (with some flexibility).

Geography: UK, Europe (and nations), USA, Australia, New Zealand, Canada, others in listed languages.

Languages: English, French, German, Italian, Spanish.

Literature scan



Stage 0: 2015 literature review

We reviewed publications citing the 2015 report, as well as publications citing the seminal studies identified in the 2015 report.

Stage 1: 2015-2021 web-based search

The majority of studies were identified in this stage of the process. To ensure full coverage, we checked a range of both bottom-up and top-down sources.

Bottom-up sources:

- Consultancy websites (commissioned research)
- 11 national space agencies and 5 national strategy documents (citing evidence)
- ESA Global Space Economic Forum repository
- International Space University (ISU) Library knowledge portal
- International Astronautical Congress (IAC) papers

Top-down sources for a wider sweep:

- Google
- Google Scholar

Results considered: The first 10 pages of any search.

The following search terms were used:

["public" OR "national" OR "state"]
AND
["space" OR "space sector" OR "space agency"]
AND
["investment" OR "program" OR "programme" OR "funding" OR "support"]
AND
["evaluation" OR "assessment" OR "appraisal" OR "analysis" OR "impact" OR "effects" OR "return" OR "benefits" OR "spillovers"]

Publication date: We imposed a filter on the new literature scan from 2015-2021.

Stage 2: Bibliographic cross-check

We checked the bibliographies and citations of papers yielded in the initial search, using Google Scholar.

We then removed any duplicates from the initial search.

This process was repeated for all articles identified in this stage.

Many papers already in our pool were identified at this stage, whilst very few new papers were found, suggesting that stage 1 of the search had been successful in identifying relevant papers.

In total **93 potential papers** were identified.

Filter and critical evaluation

This initial pool of papers was then rapidly reviewed (at the level of Executive Summary or Abstract) for relevance. Relevant papers were critically evaluated for the analytical quality (approach, data, methodology, potential bias). Each study had to meet the minimum **quality** threshold (scope and method) to be included, covering:

- Methodological limitations (e.g. poor data, no counterfactual, cherry-picking)
- Subjectivity and potential bias
- Assumptions
- Lack of quantitative rigour
- Interpretation of data

Then the quality-assessed papers were filtered to include either:

- Papers qualitatively and/or quantitatively analysing **benefits** of space investments; and/or
- Papers that calculate some **rate of return metric** (e.g. NPV, Return on Investment, Internal Rate of Return, £ benefit for £1 invested, multiplier, etc.).

We filtered our initial pool of 93 potential studies identified in stages 1 and 2, to give the additional 52 studies included in the literature review.

Review and evidence collation

The full text of each of the filtered studies was reviewed and information extracted and logged (in a database) on the following key parameters of interest:

- **Rates of Return** to public investment in space, split into **direct benefits** (to the investing organisation) and **spillover benefits** (to other organisations and wider social benefits);
- **Range of benefits** are captured and categorised separately (not aggregated to a RoR), with any quantitative estimates (with calculated proportions to allow generalisation of estimates) and indication(s) of quantification/valuation methodology(ies).
    - Where possible, benefits are mapped onto UKSA results indicators.
- Public investment and **leveraged investment** from private and third sector;
- **Ripple (or second order) effects** which capture the follow-on effects stemming from an investment, within the investing organisation/innovator;
- **Lag**: time (in years) before the impact begins to be realised;
- **Depreciation**: rate at which the benefits diminish over time;
- **Duration**: time (in years, from the end of the lag) that the impact endures;
- **Deadweight**: impact that would have occurred in the counterfactual, i.e. in the absence of the examined investment;
- **Displacement**/'crowding out': the decrease in third party investment (e.g. from private, foreign etc. actors.) resulting from the examined investment; and
- **Leakage**: effects that occur outside the domestic economy.

Inferring rates of return

For consistency across studies, many rate of return estimates were inferred, either by know.space or London Economics (2015), from information given in the studies.

Some rates of return were inferred using a benefit-cost ratio (BCR) provided. A BCR is just the ratio of total benefits to total costs, where the total cost is the total value of investment (public and leveraged investment). As such, where there is zero leveraged investment, the rate of return multiplier is simply estimated as the BCR minus one, as can be seen in the following formulas:

$$Public\ Rate\ of\ Return = \frac{(Total\ Benefits) - (Total\ Investment)}{(Public\ Investment)} = \frac{NPV}{DEL}$$

$$BCR = \frac{(Total\ Benefits)}{(Total\ Investment)}$$

Therefore:

$$Public\ Rate\ of\ Return = BCR - 1$$

Where a study did not provide a BCR, but investment and benefit values were known, a multiplier was calculated using the public rate of return formula.

… now you **know**.