Return from Public Space Investments

An initial analysis of evidence on the returns from public space investments

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About London Economics

London Economics (LE) is a leading independent economic consultancy, headquartered in London, with a dedicated team of professional economists specialised in the application of best practice economic and financial analysis to the space sector. As a firm, our reputation for independent analysis and client-driven, world-class and academically robust economic research has been built up over 25 years.

Drawing on our solid understanding of the economics of space, expertise in economic analysis and best practice industry knowledge, our space team has extensive experience of providing independent analysis and innovative solutions to advise clients in the public, private and third sectors on the economic fundamentals, commercial potential of existing, developing and speculative market opportunities to reduce uncertainty and guide decision-makers in this most challenging of operating environments.

All consultants of our space team are highly-qualified economists with extensive experience in applying a wide variety of analytical techniques to the space sector, including:

- Insightful and accurate market analysis and demand forecasting;
- Analysis of industrial structure, strategy and competitive forces;
- New technology adoption modelling;
- Estimation of public utility benefits;
- Opportunity prioritisation and targeting to maximise exploitation of investment;
- Sophisticated statistical analysis (econometrics, regression);
- Economic and financial modelling, including: Cost-Benefit Analysis (CBA), cost effectiveness analysis, Value for Money (VfM), impact assessment, policy evaluation, business case development, cash flow and sustainability modelling.

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Key Findings

- 'Space' is broad term, covering a range of diverse activities along the value chain across the public, private and third sectors: R&D, engineering, manufacturing, operation, application, commercialisation, innovation, technology and knowledge transfer, diffusion, education and promotion; across a variety of areas: science, exploration, earth observation, communication, navigation, and defence.
- Space is unique. Distinctive aspects of the space industry, wider space economy and space science and technology support a hypothesis that the profile of economic returns to public space investments may be substantively different from general science and innovation investments.
- However, the empirical literature on the returns to investments in space is limited (57 relevant studies have been identified and reviewed), and in general, suffers from a range of methodological weaknesses and limitations, including: a lack of consistency in terminology, definitions, typologies, methodologies, and only partial coverage of impacts – with significant unquantified benefits being a recurring theme.
- Owing to the ubiquity of applications of space technology and services, the socio-economic impacts derived from space investments are diverse, difficult to identify, and, with few exceptions, not quantifiable or monetisable with current knowledge – resulting in systematic underestimation of the true returns to public space investments.
- For these reasons, it is not possible to simply average over reported rates of return to give a fair generalised return to typical public space investment. Nonetheless, there is a decently large number of robust studies to justifiably conclude that the reported partial returns (typically private/direct only) do provide a conservative **lower bound.** With research on returns to public science and innovation investments suggesting that spillover returns are typically 2 to 3 times larger than private/direct returns, which studies often focus on, we may estimate typical returns as**:**
  - **ESA membership:** £3-£4 (direct) plus £6-£12 (spillover) per £1 of public investment
  - **Space science and innovation:**

    Earth Observation: £2-£4 (direct) plus £4-£12 (spillover) per £1 of public investment
    Telecoms: £6-£7 (direct) plus £6-£14 (spillover, lower as commercial) per £1 of public investment
    Navigation: £4-£5 (direct plus partial spillover) plus £4-£10 (spillover) per £1 of public investment
- After accounting for wider spillover effects, therefore, there is strong evidence that there are high returns from public space investments, and (if adjusted to account for known limitations) that public investments in space may on average produce higher returns than 'average' science and innovation investments. Within the overall story, though, there a number of sub-themes:
  - There is evidence that the returns to membership of ESA increases with the duration of continued membership, highlighting the importance of consistent funding to maintain momentum.
  - The lag between initial investment and the commencement of benefits varies by type of programme (e.g. pure science and exploration have, in general, a longer lag than infrastructure formation, which has a longer lag than near-market innovations of existing technologies). Different types of benefit (direct, spillover) tend come on-stream at different times, related to the phase of the programme (manufacturing, operational, legacy).
  - Support is provided for long-lasting benefits from space R&D, as the evidence shows that the legacy benefits for space R&D programmes (i.e. enduring spillover benefits through technology transfer, spinoffs, and innovation of existing technology) are much larger than average.
- Notwithstanding these findings, there is nothing to dispute the applicability of generic science and innovation estimates, or the above space-specific estimates, as a **conservative** default. Ultimately, we recommend that evaluators employ, in order of preference: programme-specific information; space-specific estimates on returns where supported by evidence; and generic science and innovation estimates on returns as a conservative fallback.
- In view of the identified limitations, further research is recommended to improve the breadth, depth and robustness of the evaluation evidence base.

Executive Summary

Appraisal of investment options is most robust when it is based on accurate information that is as specific to the investment as possible. Appraisal of public space investments is no different.

Where possible, the UK Space Agency estimates the economic returns to space investments using programme-specific information. However, in some cases the returns from investments can be highly uncertain, for example concerning the economic value of scientific data generated. To help illustrate the potential impact of funding, the Agency has previously used research on the impact of science and innovation funding to develop appropriate assumptions.[1]

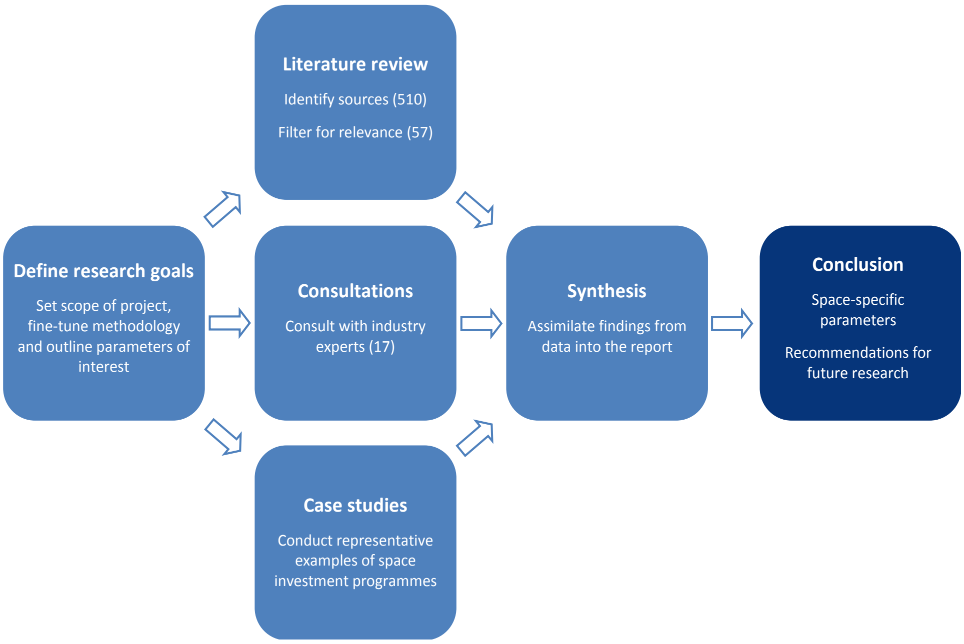
However, there is a variety of factors that could support a hypothesis that the profile of economic returns to public space investments is substantively and sufficiently different from general science and innovation investments so as to warrant space-specific assumptions on impact parameters.

To investigate whether such a hypothesis is supported by the empirical evidence, the UK Space Agency commissioned London Economics to conduct an initial and rapid assessment of the evidence on the returns to public investments in the space sector.

Objectives and methodology

The objective of the study is to provide an initial analysis to 'find space-specific evidence on the returns from public space investments', including quantitative estimates for Rates of Return. It aims to synthesise this evidence and to assess the strength and applicability of space-specific estimates of the rates of return to investment in view of estimates available for science and innovation generally, to produce, where possible, tailored space-specific assumptions to improve the robustness of the UK Space Agency's analysis.

This initial analysis was undertaken following a three-stage research approach:



[1] For example, Frontier Economics (2014), *Rates of Return to investment in Science and Innovation*, report prepared for the Department of Business, Innovation and Skills

Literature review: A review of UK, EU and international (including US) literature on the return to public investment in space. Using a standardised table approach for literature summaries more than 50 studies have been identified as relevant and reviewed in-depth, from an initially identified pool of over 500 sources. This guides the majority of the quantitative estimates for Rate of Return.

Case studies: A range of 8 Case Studies were selected to cover the breadth of UK space activities and serve to provide worked examples of quantified and monetised returns to these key UK public investments (to date in most cases).

Consultations: A programme of 17 consultations was undertaken to provide experienced opinion and insight into the 'softer' elements of the impact parameters. Information provided by consultees helped guide the general theme and conclusions of the report.

Synthesis, Conclusion: The assembled evidence was synthesised and assessed to conclude on the extent to which there is sufficient evidence to support the application of space-specific science and innovation assumptions (in the absence of programme-specific information), with a view for the UK Space Agency adopting more tailored parameters for assessing the potential impact of its interventions.

The impact parameters of interest include:

- **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) when leveraged investment is present;
- **Duration of benefit** profiles to investment in space;
- Assessed role of public investment in space, in the context of the other objectives of the project, in **leveraging** private and third sector investment ('crowding-in');
- **Influencing factors** for the returns estimates, such as programme characteristics;
- **Lag** time until benefits are realised for space investments;
- Quantitative measures of impact on key outputs and outcomes adjusted for **deadweight** and **displacement** effects;
- **Wider societal impacts and unintended consequences** (links to spillover benefits); and
- Identify **areas for future work** to improve our understanding of these issues.

It has been necessary to adopt a standardised measure of Rate of Return for consistency and comparison purposes. After consulting with government economists to ensure applicability, we decided to adopt an NPV/DEL (Net Present Value/Departmental Expenditure Limit) multiplier calculation to measure the Rate of Return, equivalent to the **return per £1 of public investment**.

Role and nature of public space investment

The underlying rationale for public space investments is founded in market failure[2] and may be summarised by the following arguments:

[2] "Market failure refers to where the market has not and cannot of itself be expected to deliver an efficient outcome; the intervention that is contemplated will seek to redress this" HM Treasury (2003a), The Green Book: Appraisal and evaluation in Central Government, Treasury Guidance, p. 11.

- Space is a largely externality-inducing industry, governments or regulatory authorities are therefore needed to manage these **externalities** to a socially optimum outcome.
- To enable provision of space services, which can be considered to be a **public good**.
- Manage the risk of **under-investment** in the infrastructure-forming, yet R&D-intensive, upstream segment of space economy value chain that enables the downstream applications.
- To facilitate socially desirable but often **long and costly development** programmes, and to manage high-risk programmes, for which finance and/or insurance might not be provided by the private market.
- To support **R&D** programmes, which can generate more spillover benefits than direct benefits, so often do not provide an appropriate incentive for private investors.

Why might space be a special case?

The factors supporting a hypothesis that space is a special case of science and innovation relate to the unique and distinctive aspects of the space industry, the wider space economy and space science and technology, and the knowledge created:

Space industry	■ The space industry is **highly research intensive**; ■ Space economy employees are **highly skilled** and **highly productive**; ■ The **cost of securing an R&D job** in space is the lowest of 8 high-tech sectors evaluated; ■ The UK space industry is **export-orientated** and has **increasing levels of inward investment** in the form of FDI; ■ The space industry is a **high-growth** sector, consistently outgrowing domestic output at both the global and UK level.
Wider space economy	■ Space acts a **ubiquitous and integral enabler** of necessary, everyday services; ■ The space value chain impacts **every region of the UK**; ■ Space can **capture the public's imagination** and **inspire** society to an unparalleled extent, as well as promoting the uptake of **STEM** education and careers.
Space science & technology	■ Space investments offer opportunities for testing infrastructure in the **harsh conditions**, e.g. microgravity testing on the ISS, component technology testing on a CubeSat. ■ Space investments place the industry at the forefront of **cutting edge** manufacturing and science, and when combined with the ubiquity of application, **maximises the exposure** for technology and knowledge transfer, boosting the potential for **spillover benefits**. ■ But investing in space holds significant **developmental and technical risk**. Space typically requires **large amounts of invested capital** to make an investment worthwhile, resulting in a **financing gap**. Additionally, UK companies are often competing against US and international competitors cross-subsidised through sizeable Defence expenditures. ■ However, the landscape is changing. What was once dominated by government investment, is becoming increasingly commercialised and private sector driven, so targeting of public investment is becoming increasingly important to ensure additionality.

Limitations of the space-specific evaluation literature

There are a number of important limitations of the evidence base on space-specific public investments that the reader should be aware of and bear in mind when reading the summary and conclusions:

- There are a **limited range of evaluation studies** (57 identified), representing a collection of specific examples, making it difficult to generalise findings to a range of broadly-applicable conclusions. Furthermore, though a divergence in parameter values for different types of investment programmes (e.g. commercial telecoms compared to a space exploration mission) may be intuitively supported and clearly relayed in consultations, the empirical evidence base is too thin to allow a cross-sectional analysis at this level without biasing the conclusion by individual studies;
- The majority of the available studies suffer from a range of weaknesses that strongly influence the reported Rates of Return:
  - **A lack of a standard evaluation framework** – Differences in terminology, definitions, estimation methodology, data sources/collection, typology of impact and metrics of return render it difficult to group and draw any like-for-like comparisons of Rate of Return estimates derived across different strands of the literature.
  - **Methodological transparency –** A lack of clear detail on data, treatments, methodology, workings and interim (e.g. per annum) results, with this ambiguity sometimes even extending to final results. In most cases, we have had to subjectively infer the terminology and impacts in order to be able map to our standard framework.
  - **Variation in completeness of analysis** – On the **cost side**, though **public investment costs** tend to be clearly and fully included (facilitated by the monetary and clear public-reporting of such information), only a few studies consider the **leveraged private** investment that might be necessary to deliver identified benefits (limiting the ability to estimate the direct and spillover return to leveraged investment). On the **benefit side**, there is wide variation in the coverage of the analysis: Ideally, both direct and spillover **types of benefits** should be considered, quantified and monetised in each of the three **phases** (construction/manufacturing, operational, and legacy) at the **level** of the firm, industry and economy and valued over the full lifetime **duration** of costs and benefits (in discounted terms, adjusted for deadweight and displacement). In reality, the reviewed studies have tended to address an incomplete selection of these dimensions, and address each selected dimension to only a partial extent.
    - Unsurprisingly, studies reporting both **direct and spillover benefits** have the highest returns, on average, followed by studies reporting only spillover benefits, whilst studies that just report direct benefits have the lowest returns.
    - However, though a similar increasing pattern would be expected with respect to **benefits by programme phase** (i.e. manufacturing, operation, legacy), no such relationship can be identified in the empirical evidence. One exception is that legacy benefits for space *R&D* programmes (i.e. enduring spillover benefits of space R&D through technology transfer opportunities, spinoffs, and continuous near market innovation on existing technology), which are much larger than average returns.
  - **Unquantifiable benefits** - One recurring finding from the literature review and Case Study exercise has been the theme that the full range of benefits of space is wide, complex and varied - making them extremely difficult to value. This is, at least in part, a direct result of the pervading profile of the space industry, which acts as a key enabler

in every-day life, with the extent and value of the impact in many areas not fully understood or explored. 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. In appreciating this fact, it seems certain that our estimates, and more particularly those estimates prevalent in existing literature, suffer from a potentially severe undervaluation.

- **Unforeseen benefits** – The esoteric nature of space science and technology results in a capability supply-led, rather than demand-driven process of application development and innovation. This means that future applications are near-impossible to foresee at the point of investment, causing forward-looking studies to understate the true value of an investment in space R&D.
- **Influence on calculated Rates of Return** – The lack of thorough reporting and analysis of costs and benefits has obvious implications for the Rates of Return. The interaction of the above limitations across studies prevents conclusions being drawn on either type of benefit, or phases of investment.

Nonetheless, there exists a decently large number of robust studies to justifiably draw a range of conclusions on the returns to public investment in space – as outlined below.

Summary of evidence and conclusions

Rates of Return

Rates of Return estimates are mostly derived from our literature review as consultees were, in general, unable to give figures for returns, and case studies were not numerous enough.

Space-specific evidence	**Evaluations of ESA membership** **Public:** In general, analysis in the reviewed studies has been limited to the direct (industrial) benefits, with little or no valuation of spillover benefits. Adjusted for methodological robustness of evaluations, our analysis suggests a (direct-only) rate of return of **3.0-4.0** per £1 of public investment. The period of analysis varies (either a single year or an aggregate of years) but, assuming constancy of annual Member State contributions, this rate can be used as either a lifetime or an annual rate of return. However, this return is an **underestimate** due to the exclusion of wider 'spillover' benefits, though it can be used as a starting point for further analysis examining the wider societal impact of ESA membership: Drawing on evidence (Frontier Economics, 2014),that spillover returns from public investment in science and innovation are typically 2 to 3 times larger than private/direct returns, which studies often focus on, we may estimate typical returns as **£3-£4 (direct) plus £6-£12 (spillover)** per £1 of public investment. **Spillover: N/A*** **Direct: N/A*** *Reviewed literature considers investment in this scenario to be in the form of Member State contributions to ESA, so there is no room for leveraged investment or findings on direct or spillover Rates of Return. **Evaluations of space science and innovation investments** It is important to recognise that all Rate of Return estimates indicated below constitute un-annualised, multi-year/aggregate Rates of Return. Also note that

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evidence (Frontier Economics, 2014) suggests that spillover returns from public investment in science and innovation are typically 2 to 3 times larger than private/direct returns, which reviewed studies typically focus on. This ratio is used to upgrade direct/private return estimates below.
Public: The public Rates of Return to space science and innovation types of public space investments display a high degree of variation. A key differentiating factor underlying this variation is different space applications:
■ EO: The empirical evidence provides conservative estimates of the returns to Earth Observation programmes ranging from approximately 2.0-4.0, covering direct/private returns almost exclusively. With complete benefit consideration, the true return from EO programmes is likely much larger than this range, which suffers from underestimates due to unquantifiable benefits and incomplete reporting. Based on the direct : spillover ratio, we may estimate typical returns as £2-£4 (direct) plus £4-£12 (spillover) per £1 of public investment in EO.
■ Telecoms: The literature reviewed displays a significant degree of variation in the public Rate of Return to investments in the telecommunications sector. Based on the few studies analysing benefits from telecoms investments, it appears sensible to estimate a return per £1 of public investment of between 6.0 – 7.0, covering direct/private returns. However, due to the inherently commercial nature of telecommunications, a highly leveraged investment programme in a near-market telecoms innovation will result in returns significantly larger. Furthermore, although providers are very good at extracting and commercialising the value of satellite communication, there will still be additional spillover benefits. Using a reduced (1-2 : 1) direct : spillover ratio, we may estimate typical returns as £6-£7 (direct) plus £6-£14 (spillover) per £1 of public investment.
■ Navigation: Literature-based sources generally expect that the social returns to investments in satellite navigation might range between 4.0 – 5.0 per £1 of public investment. As satellite navigation investments tend to include a heavy public contribution (owing to the public good characteristics of some services), evaluation studies tend to include some estimate of spillover benefits, but the coverage remains limited. Using a reduced (1-2 : 1) direct : spillover ratio, we may estimate typical returns as £4-£5 (direct plus partial spillover) plus £4-£10 (spillover) per £1 of public investment.
■ NASA programmes: While not forming a recommended parameter, NASA programmes provide useful information for Rates of Returns from public space investments. Literature suggests a return per pound of public investment of between 6.0 – 9.0 for NASA investment programmes.
Spillover: N/A*
Direct: N/A*
*A lack of transparency and narrow breadth of study in most existing literature prevent us from estimating direct and spillover Rates of Return.
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<td>Recommended space-specific default</td>
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<u>Evaluations of ESA membership</u>
■ £3-£4 (direct) plus £6-£12 (spillover) per £1 of public investment
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	public investment ■ **Navigation:** £4-£5 (direct plus partial spillover) plus £4-£10 (spillover) per £1 of public investment

Recurring evidence in the literature review (in particular, but not exclusively, in relation to membership of ESA), and interviews with several consultees, has highlighted the existence of a **cumulative duration effect** within space investment programmes. These information sources suggest quite consistently that the longer a membership of a space-specific organisation (e.g. ESA), or the longer a programme continues with consistent funding (e.g. NASA R&D, UK space science), the greater the Rate of Return. Put simply, there appears to be a positive relationship between project duration and the size of the returns from that project.

Further, a nation-wide investment programme in a small, undiversified, space industry will require the imports of technology and knowledge (i.e. leakages), reducing domestic benefit and the Rate of Return; as compared to investment by a larger nation where these leakages wouldn't occur. This can extend to differences in the Rate of Return between investments placed by ESA compared to NASA, with literature suggesting NASA investments lead to a higher Rate of Return. This can be explained by considering the age of NASA compared to ESA (the Duration Effect as above), NASA's larger budget leading to more capability in the US space-industry supply chain, or potential inefficiencies caused by ESA investments being required to obey a rule of geo-return.

Leverage

Owing to the fact that leveraged private investment is often a condition of the grant of public investment funding (e.g. matched funding under ARTES), it is likely that the most appropriate and robust information on leverage will be specific to the investment being evaluated – and available to the evaluator in the form of the proposal or business case.

Space-specific evidence	<u>**Evaluations of ESA membership**</u> N/A – no evidence to confirm or contradict the science and innovation assumptions. <u>**Evaluations of space science and innovation investments**</u> Evidence exists that public space investments did leverage private investment, boosting the public Rate of Return. However, there is not enough evidence to predict how much leveraged investment would be for certain programme types. In reality, it depends on the nature of the programme (e.g. the extent to which the outputs of the R&D/innovation can be commercialised will influence private companies' willingness to invest). Therefore, it seems sensible to use investment-specific information in the first instance and, where this is not available, to split 'near-market innovation' (using the generic estimate) and 'pure science' (using an assumption of no leverage) investment types. There is not enough information available concerning leveraged investment from a foreign source to support any conclusion on a space-specific parameter.
Recommended space-specific default	<u>**Evaluations of ESA membership**</u> ■ **Leverage:** N/A ■ **Foreign leverage:** N/A <u>**Evaluations of space science and innovation investments**</u> ■ **Space science, (non-prospecting) exploration and manned spaceflight:**

	Leverage: No space-specific, leveraged private investment found, an adoption of programme-specific knowledge is recommended. **Foreign leverage:** No space-specific, foreign leveraged private investment found, an adoption of programme-specific knowledge is recommended. ■ **Near-market innovation:** **Leverage:** No space specific evidence found.

Lag

If the investment being evaluated is a near-market innovation, with a clear commercialisation plan, it is likely that the most appropriate and robust information on the expected lag for direct benefits (to the investing and/or innovating organisation) will be investment-specific – and available to the evaluator in the form of the proposal or business case. In the absence of such information, or as a useful validation, the following assumptions should be adopted.

Space-specific evidence	<u>**Evaluations of ESA membership**</u> As discussed, studies tend to consider Member State contributions and the ESA contract sum to be constant, resulting in no lag. Just two studies track contributions and benefits over time (i.e. a 'follow-the-money' approach); the lag applied for benefits to commence in this instance is 3 years in both cases. <u>**Evaluations of space science and innovation investments**</u> The reporting of lags is generally inconsistent and poorly standardised in the literature, making a conclusion hard to draw. Of 53 summary tables, only 13 refer to a time lag from initial investment to commencement of benefits. We had expected the literature to support a hypothesis of longer lags for more heavily exploratory or deeper development infrastructure-based projects, and shorter lags for technologies that are more developed and closer to commercialisation. However, despite there not being enough empirical evidence to confirm or reject this, the intuition has been confirmed in the process of our consultations. Based on these consultations, it is recommended to split investments by objective: pure science and exploration (e.g. instrument development; space craft or rover design, build and launch); infrastructure formation (e.g. constellation of satellites); and innovations of existing technologies (e.g. application development). It is also proposed, based on consultation findings, to adopt an approach based on phases [construction (manufacturing), exploitation (operational and legacy)] for pure science and exploration, as benefits may be expected during the construction phase (e.g. novel materials or techniques applicable to other industries) as well as the exploitation phase (e.g. value-added applications of data and knowledge).
Recommended space-specific default	<u>**Evaluations of ESA membership**</u> ■ **Lag:** 3 years, if adopting a 'follow-the-money' approach (space-specific = generic). <u>**Evaluations of space science and innovation investments**</u> ■ **Pure science and exploration:** **Construction (manufacturing) phase:** 2 years (space-specific). **Exploitation (operational and legacy) phase:** 10 years (space-specific). ■ **Infrastructure formation:** 5 years (space-specific). ■ **Innovations of existing technologies:** 2 years (space-specific).

Benefit duration and depreciation

The space-specific empirical evidence typically adopts a simple 'window of benefits' approach, which certainly has its limitations and flaws, but this mismatch makes inferring assumptions from the empirical evidence more difficult.

If the investment being evaluated is a near-market innovation, with a clear commercialisation plan, it is likely that the most appropriate and robust information on the expected **duration of direct return** (to the investing and/or innovating organisation) will be investment-specific – and available to the evaluator in the form of the proposal or business case. The **duration of spillover return** is much more difficult to estimate *ex ante*, so it is recommended to use the following default assumptions.

Space-specific evidence	<u>**Evaluations of ESA membership**</u> **Benefit duration:** Studies typically only calculate benefits for a certain time window (in some cases, a single year), if at all, rather than the full duration of one or more benefits from a particular starting point – but again, this is an artefact of the methodology rather than a reflection of reality. **Depreciation:** No study considered depreciation of the ESA membership effect – in fact, a number of studies repeated in a later time period suggest that the return tends to increase over time with a Member State's continued membership of ESA. However, the appreciation of the returns to ESA membership will only continue as long as ESA membership contributions continue. If ESA membership were to cease, it is likely that there would be depreciation in returns over time. Unfortunately from an empirical evidence perspective, there has not been a study of such a case to date so it is not possible to estimate the rate of depreciation. As ESA membership combines elements of science and innovation investment, it is recommended to use a combination of the generic science/innovation estimates. <u>**Evaluations of space science and innovation investments**</u> **Benefit duration:** Duration of benefits was one of the most poorly and inconsistently reported parameters throughout our review - the majority of studies simply analyse a particular window or timeframe. Of studies which consider full benefits, a duration of at least 15 years is often seen, with some of the studies which report a shorter duration than this not considering all benefits or not considering benefit duration of relevant infrastructure systems. However, the number of times this parameter is reported is not sufficient to conclude a duration of 15 years is likely with any degree of certainty. For this reason, it is recommended to use the below assumptions based on the generic science and innovation evidence. **Depreciation:** It is recommended to use the below assumptions based on the generic science and innovation evidence.
Recommended space-specific default	<u>**Evaluations of ESA membership**</u> ■ **Benefit duration:** Duration of ESA membership plus the lag of 3 years. ■ **Depreciation:** **Period of ESA membership plus lag:** 0% per annum (space-specific). ***after which:*** **Period of depreciation:** No space specific evidence found. <u>**Evaluations of space science and innovation investments**</u> ■ No space specific evidence found.

Wider benefits

Wider benefits are inherently varied in nature, and can be sub-categorised as benefits that impact on the environment, society, or a third, loosely-defined category if they do not fall into these two (e.g. impact on tax receipts, employment multipliers). Environmental benefits accrue mostly from satellite (especially Earth Observation & Remote Sensing) programmes, either indicative of the fact that these sorts of programmes do, in fact, create more environmental benefits, or instead that they enjoy more comprehensive literature. Further, in studying the social benefits sub-category, it is apparent that spinoffs from investment programmes mostly affect the **healthcare** industry, which can be explained by the large amounts of R&D necessary to support manned spaceflight.

Displacement (crowding out)

Displacement is not explicitly reported once in any of the studies reviewed, and many consulted stakeholders believed that public investment has the opposite effect (to leverage private investment, or crowding-in). Nonetheless, the absence of references to displacement is suggestive that public space investments do not crowd out private businesses.

Recommendations for future research

Our review of existing literature on the returns from public space investments highlighted a number of key limitations, caveats and gaps across the available literature. Based on these overall shortcomings of analyses to date, we have derived a number of key recommendations for future research, to ensure that forthcoming analyses complement the existing literature and facilitate a deeper understanding of the Rate of Return to public space investments (and other key impact parameters outlined). Our recommendations are broadly categorised into three overall themes:

- Recommendations to improve and standardise the methodological approach used for future analyses:
  - A set of internationally agreed and accepted standards for estimating the returns to public space investments;
  - A dedicated UK Standard Industrial Classification of Economic Activities (UK SIC) Code for the space industry;
  - Consistent and transparent reporting of research outputs; and
  - Causal link between the investment and the estimated net benefits.
- Suggestions to widen the scope of future analyses to ensure comprehensive coverage of all relevant costs and benefits:
  - A long-term evaluation strategy for public investments in space programmes (as has been recently announced by the UK Space Agency);
  - Quantify the ‘unquantified benefits’ using dedicated research;
  - Additional research into the factors driving the returns to space investments;
  - Research to better understand the time profile and dynamics of benefits.
- Propositions on how to maximise the use of the evidence base on the returns to public space investments and facilitate continuous learning from future analyses:
  - Establish a comprehensive and regularly updated database of evaluation evidence;
  - Increased use of benchmarking of returns against alternative investments;
  - A series of new evaluation studies for individual public space investments, to subsequently be collated into a meta-analysis.

1 Introduction

The President of the United States, George Bush (Snr.) once remarked that *"… the Apollo Program was 'the best return on investment since Leonardo da Vinci bought himself a sketchpad'"*.[3] Whilst somewhat facetious, such sentiments and claims are common, though the empirical evidence to support them is unclear.

To support the ongoing development of an evidence-based framework for evaluation of their funding and activities, the UK Space Agency has commissioned London Economics to conduct an initial and rapid assessment of the evidence on the returns to public investments in the space sector. This report presents the findings of this exercise.

Note: Information from confidential studies provided under a non-disclosure agreement has been redacted from this published report.

1.1 Background and context

The UK government has set ambitious growth targets for the UK space sector, which continues to grow at a rate consistently well above that of the general economy. To sustain this path and foster further growth, the government (in collaboration with the space industry) has founded a number of important initiatives to position the UK strategically to exploit emerging trends in the global space economy. However, the continued success of the UK space industry cannot be taken for granted. Recent research[4] has warned that without further public investment and regulatory support, these future growth opportunities will not materialise.

The case for such public investment must be properly argued and justified. In times of austerity and increased competition for a limited general government budget, it is essential that space be assessed using standard public policy evaluation procedures based on space-specific evidence to yield robust estimation of the returns to investment.

There is much anecdotal evidence on the impact of space and the important catalysing role for public investment, which in conjunction with assumptions based on wider science and technology estimates, suggest a large return on public space investment. However, robust quantitative evidence is lacking and anecdotal and qualitative evidence on the impact of public space investments is not sufficient to build a convincing case.

Where possible, the UK Space Agency estimates the economic returns to space investments using programme-specific information. In the absence of such specific information, generic assumptions are used based on 'Science' and 'Innovation' estimates that have been assessed as broadly appropriate to the wide range of science and innovation research and development activities undertaken using public (and leveraged) investment.[5]

This research aims to fill this gap by collecting and synthesising the existing evidence on the returns to public space investment from a wide range of published literature, confidential studies, case studies and consultations with practitioners and formulate with conclusions for how to

[3] Chandler, D.L. (1989) "Taking the Next Step: Analysts Weary of President's Go-It-Alone Space Push," *Boston Globe*, July 31, p. 21.
[4] London Economics (2015) *The Case for Space 2015.*
[5] For example, Frontier Economics (2014) report on 'Rates of return to investment in science and innovation'

approach the overarching modelling of UK Space Agency funding. Such evidence can also be used to support business case development, target investment, inform policymaking and shape the strategic direction of the UK Space Agency.

Whilst the review focuses on quantified estimates, this is not its sole objective. In recognition of the many varied impacts that are intangible, unquantifiable and non-monetisable, the review also considers evidence (where available) on wider benefits such as environmental benefits and social benefits, which are often qualitative in nature. However, although such benefits are an important part of the story, assessing the *quantified* economic impact as much as possible can be helpful to make the case for space funding, and to help inform choices around prioritisation of limited resources.

It is also important to recognise that the findings of this review do not infer which investment area is 'better': it is likely that more of the benefits are unquantifiable in some areas, such as Earth Observation, than when comparing to, say, Telecoms, where benefits can be easier to measure. Rather, it is about *quantifying where possible*, to provide evidence to support investment decision and policy making.

1.2 Aim and objectives of the research

Aim: An initial analysis (albeit one that includes quantitative estimates) to '*find space-specific evidence on the returns from public space investments*'.

Method: Build off the existing science and innovation appraisal evidence, methodology and model, supplemented by a review of UK, EU and international (including US) literature on the return to public investment in space (specifically), evaluation evidence for Agency programmes, case study evidence, and the inherent knowledge and experience within the Agency and other organisations to assess the strength and applicability of space-specific estimates of the rates of return to investment in view of estimates available for science and innovation generally, to produce, where possible, tailored space-specific assumptions to improve the robustness of the UK Space Agency's analysis.

Objectives: The findings will be used as generic assumptions of returns in the absence of more specific evidence on impacts from a particular intervention, particularly on:

- Up-to-date, high-level estimates of **Rates of Return** to public investment in space, split into **direct** and **spillover** benefits;
- **Duration of benefit** profiles to investment in space;
- Assessment of the role of public investment in space, in the context of the other objectives of the project, in **leveraging** private and third sector investment (so-called 'crowding-in');
- Influencing factors for the returns estimates, such as programme characteristics (e.g. 'pure science' vs. 'innovation/near-market' programmes; infrastructure vs. applications);
- **Lag** time until benefits are realised for space investments;
- Quantitative measures of impact on key outputs and outcomes adjusted for **deadweight** and **displacement** effects;
- **Wider societal impacts and unintended consequences** (links to spillover benefits); and
- Identify **areas for future work** to improve our understanding of these issues.

1.3 Structure of the report

The remainder of this report is structured as follows:

- **Section 2** details the methodological approach, terminology and definitions employed;
- **Section 3** investigates the theoretical case for investment in space being a special case;
- **Section 4** presents a synthesised summary of the available space-specific evidence on public investments in space;
- **Section 5** provides a range of Case Studies tracking the return to specific individual public space investments; and
- **Section 6** rounds up with concluding judgements on the merits for space-specific assumptions across the range of impact parameters and offers recommendations for future research based on the lessons learned in the review of the existing evidence.

2 Methodological statement

In this section, we outline the terminology and definitions employed throughout the analysis, before explaining our methodological approach to address the research objectives. Some more technical explanations are provided to explain the calculation of public, private and spillover rates of return undertaken to maximise consistency and comparability of the various studies reviewed and ensure clarity and transparency. Finally, we discuss scope, limitations and caveats, and outline the methodology adopted to assess the strength of the space-specific evidence gathered.

2.1 Terminology and definitions

2.1.1 Action

- **Public space investment:** A direct investment of public capital and/or resources to a space-related programme, project, infrastructure, facility or organisation (e.g. R&D).

2.1.2 Impact parameters

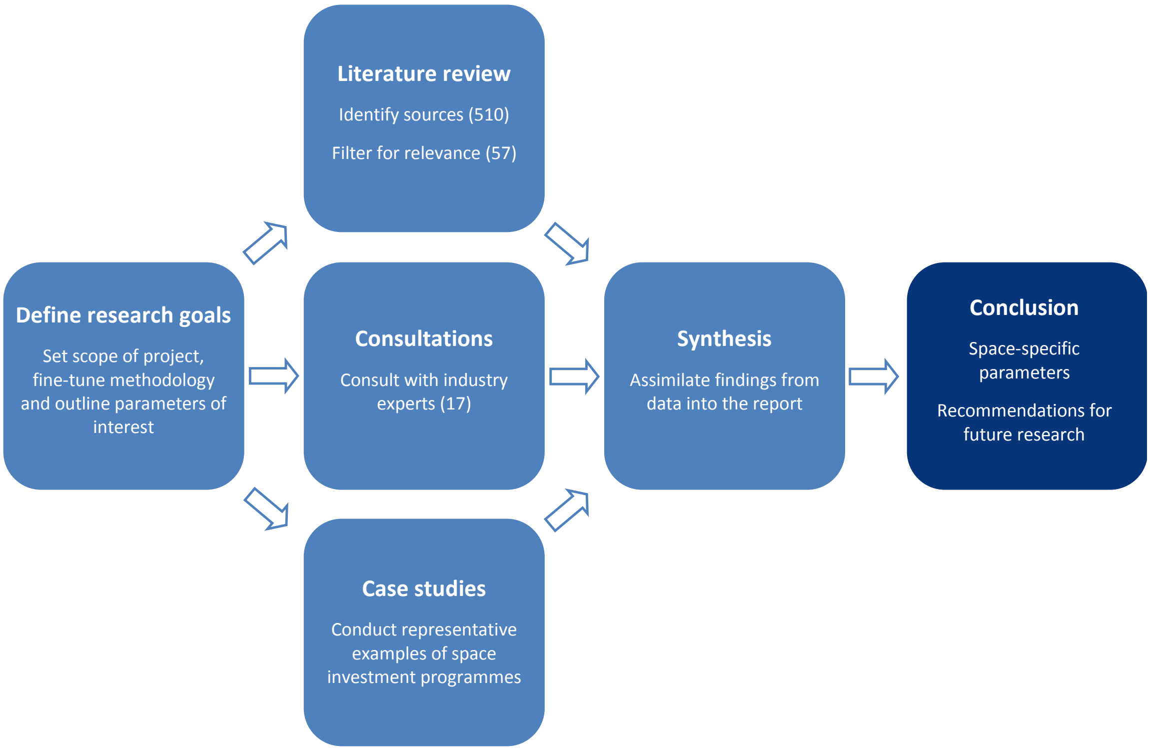
The impact of a public space investment can be measured (or modelled) with reference to a range of factors, or 'impact parameters', as defined below:

- **Rate of Return**:
  - **Public (Social) 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 (to avoid double-counting with direct and spillover effects of leveraged investment, below).
  - **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.
  - **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 leveraged private investment.
- **Lag:** Time in years before the impact starts.
- **Benefit duration:** Time in years (from the end of the lag) that the impact endures.
- **Deadweight:** The returns that would have occurred without the public investment, as measured by the 'Do Minimum' case.
- **Leveraging or 'Crowding in':** The *increase* in private, third sector and foreign public investment in the project as a proportion of the domestic public investment.
  - **Domestic private crowding in:** The increase in *private/third* investment in the project as a proportion of the domestic public investment.
  - **Foreign private crowding in:** The increase in *foreign private/third* investment in the project as a proportion of the domestic public investment.

  - **Foreign public crowding in:** The increase in *foreign public* investment in the project as a proportion of the domestic public investment.
- **Displacement or 'Crowding out':** The *decrease* in private, third sector and foreign public investment in the project as a proportion of the domestic public investment.
- **Leakage:** Benefits arising outside of the domestic economy.
- **Other quantitative outputs**: Quantitative measures of impact on key outputs and outcomes adjusted for deadweight and displacement effects (e.g. employment, spin-offs, prototypes, commercialised products, academic papers).
- **Wider benefits:** The wider societal impacts and unintended consequences associated with the public space investment, linking to spillover benefits (e.g., employment, economic multiplier, consumer surplus, producer surplus, environmental impacts, and social impacts).
- **Benefit phase:**
  - **Manufacturing phase**: The phase during which benefits from the construction of necessary infrastructure and or equipment occurs (e.g. novel techniques or materials).
  - **Operational phase**: The phase during which benefits from the day-to-day operations of the programme occurs (e.g. satellite communications and broadcasting).
  - **Legacy phase**: The phase during which benefits still occur after the termination of the particular programme (e.g. technical and scientific knowledge, archived Earth Observation and exploration data).

2.2 Approach to evidence gathering

The research has been conducted following a staged approach, as summarised in the schematic below. Each stage is described separately in the subsequent pages.



2.2.1 Literature review

The literature review was conducted in a range of iterative steps to ensure that studies were recorded, categorised by relevance, reviewed and condensed in a consistent and targeted manner:

- We identified several extensive reports containing potentially useful studies, and extracted their references into a database (in Excel).
- For each of the studies recorded in this manner, we then reviewed the study's abstract and undertook a preliminary scan of the paper to identify whether the analysis was space-specific, and whether it conducted an evaluation of public investments or programmes.
- In conjunction with this initial review and classification of studies, we generated a (Word based) standardised framework to extract relevant information on the above-mentioned key parameters of interest.
- The standardised review framework was piloted to ensure effectiveness and relevance. We then conducted an in-depth review of a small number of key papers, adjusting the framework's cell content and structure as necessary.
- Once we achieved a final agreed review framework, we then conducted a full review of the relevant sources to populate the review tables for each relevant paper.
- Throughout the review, we added further relevant studies to the Excel database based on references in the papers already reviewed and studies suggested and provided in consultations, with iterative rounds of additions to the database to ensure that the identification process was comprehensive and thorough.
- Finally, a separate cross-check (a keyword search of economic journals, Google Scholar and the internet) was undertaken to ensure comprehensive identification of all relevant sources.

Using bibliographies and references from several extensive reports (Frontier Economics (2014), Technopolis Group (2013), Booz & Co. (2014)), supplemented with additional LE research as well as papers provided by the UK Space Agency, a total of **510 sources** were filtered (abstract read, or report skimmed) in order to ascertain usefulness (erring on the side of inclusion). **57 sources** were determined to be relevant, or 'useful' in pursuit of a literature review into the returns to public space investment.

Table 1 Sources identified, filtered and unobtainable

Identification	Total sources	Filtered (deemed relevant)	Unobtainable*
Frontier [1]	103	1	0
Technopolis [2]	126	5	32
Booz & Co. [3]	218	14	24
Additional LE research	51	32	1
UK Space Agency	12	5	2
Total	**510**	**57**	**59**

Note: * We exclude from this category any relevant studies which were unobtainable but which were summarised in other studies in sufficient detail as to allow calculation of the relevant parameters of interest. Sources may be classified as unobtainable due to confidentiality, pay-walls (e.g. paid research), broken links or incomplete referencing in the original reports preventing identification.
[1] Frontier Economics (2014); [2] Technopolis Group (2013); [3] Booz & Co. (2014). Please see 'References' for full citations.
Source: London Economics' analysis

Using a **standardised table approach** for literature summaries the total of **57 relevant studies** has been condensed into a total of **53 tables**[6].

2.2.2 Consultations

We completed 17 consultations with experienced researchers and practitioners from organisations including: UK Space Agency, European Space Agency, OECD, Dept. for Business, Innovation and Skills, InnovateUK, Satellite Applications Catapult, Knowledge Transfer Network, Cardiff University, Airbus Defence & Space and Clyde Space. The findings of these consultations are integrated into the evidence synthesis.

2.2.3 Case studies

In conjunction with the UK Space Agency, we selected a range of Case Studies covering the breadth of space activities supported by UK public investment – the selection was made so as to offer a **representative** view across the various areas of UK public investment in space, rather than cherry-picking strong or positive examples. Although the selection is influenced by the degree to which enough information is available to construct a Case Study.

Using a combination of desk-based secondary research supplemented by consultations with Programme Leads, industry representatives and academic researchers, we have attempted to provide applied examples of quantified and monetised returns to these key UK public investments.

2.3 Methodology to synthesise findings

2.3.1 *Aggregate* versus *Annual* Rates of Return

One particularly common and obstructive issue experienced in our review has been the lack of any standardised method or metric in the reporting of Rate of Return, with an overriding theme throughout this report being the inconsistencies between reported annual Rates of Return and reported aggregate Rates of Return.

Aggregate (e.g. lifetime) Rates of Return are most often quoted and much more easily inferred, but the best comparison to the generic rates of return to investment in science and innovation, as estimated in the recent comprehensive review prepared for the Department for Business, Innovation and Skills, would warrant annualised figures. Many times this is not possible, as it relies on the completeness of the source material, which would need to either report the annualised figure itself, or duration of benefits, duration of costs and a time lag.

Box 1 illustrates this issue by using findings from the seminal Midwest Research Institute (1971) study on returns from NASA R&D investments. This is one of the few studies which reports annualised benefits, thus making both an annualised and aggregate Rate of Return possible.

[6] For presentational purposes, in some instances, several studies were condensed into an individual table, as appropriate and relevant.

Box 1 *Aggregate* vs. *Annual* Rates of Return – an example

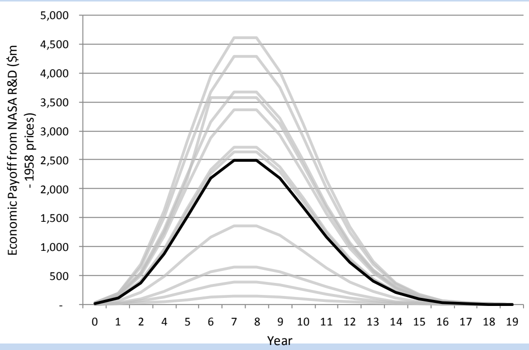
The Midwest Research Institute (1971) study assumes NASA starts a new R&D investment programme each year for 11 years from 1959-1969 inclusive, with total costs and annual benefits reported by the authors. This creates a scenario where one particular year experiences benefits from several R&D programmes at once, as spin-offs and other benefits accrue concurrently to each other. In separating each study to consider the changes in benefits from their base year (with Year 0 being year of project inception/initial investment), we can compare them alongside each other.

These payoffs from investment in all 11 programmes can be seen in Figure 1, along with an average benefit curve. Figure 2 shows the annualised Rate of Return from these programmes, and provides us with a much more realistic picture of how benefits and Rates of Return on investment change through time, compared with simply assuming a lag, linear Rate of Return, and duration of benefit.

The form of both graphs is the same, and is Gaussian in shape (bell-shaped) with a slightly extended back-tail. This implies that the time it takes a Rate of Return to ebb away from its highest point is longer than the time it takes the Rate of Return to reach its highest point from R&D project inception.

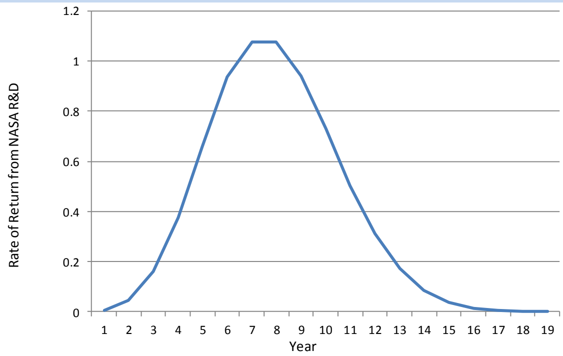
No time lag as such is seen, although peak benefits (highest value of US$4.6bn/year, lowest value of US$138m/year, average of US$2.5bn/year – all figures 1958 prices) is reached within 7 years, the same time it takes the Rate of Return to reach its peak return multiplier of 1.08/year.

Figure 1 Average economic payoff



Note: Grey curves represent economic payoff from the 11 NASA R&D projects, the black curve is the arithmetic mean of these.

Figure 2 Average annualised return



Note: Assuming all costs are incurred in an up-front, lump sum investment.

The average annualised Rate of Return for each investment programme is relatively low, at just 0.39. This can be explained by the tails of the curve, but it should be noted that at a time when these space investment programmes are running concurrently, the Rate of Return across all programmes per year would be much higher. This can be compared to the aggregate return we report of 6.16.

This example, therefore, highlights both the difference in values for reporting an annualised or aggregate Rate of Return, as well as providing a useful assessment of the benefit profile for a specific, annualised space investment programme.

Source: Midwest Research Institute (1971), Economic Impact of Stimulated Technological Activity, Final Report, Contract NASW-2030 & London Economics' Analysis

Typology of Rates of Return

To resolve some of the issues discussed regarding annualised Rates of Return, each study that reports a Rate of Return is described in our summary tables as being either:

1) **A single-year, annualised Rate of Return**, if the Rate of Return is annualised as an artefact of the assumptions of the study, with the study comparing 1 year's costs to a year's benefits (with or without a lag), e.g. most of the ESA membership studies fall under this category.

1) **A multi-year, annualised Rate of Return,** if the study compares whole life cycle costs and benefits but then provides calculated annual net benefits , or LE have managed to infer an annualised Rate of Return.
2) **An un-annualised, multi-year/aggregate Rate of Return,** if the study presents a Benefit-Cost Ratio for a time period of programme operations, whole life-cycle costs and benefits or LE cannot infer an annualised Rate of Return.

2.3.2 Calculating the public Rate of Return

It is necessary to develop a method to calculate the Rate of Return from public space investments that can make use of all approaches found in literature, from listed total costs and benefits, to aggregated Benefit-Cost Ratios (which is the most commonly used approach in literature), in order to obtain a standardised figure. The quality of many of the studies is too poor to report an annualised, percentage of costs and benefits as can be found in the generic science and innovation estimates, so instead we have used a **multiplier approach.**

After consulting with government economists, we have decided to adopt an NPV/DEL multiplier calculation, which translates into a **return per £1 of public investment.**

The division of NPV (Net Present Value, defined as the total discounted benefits less total discounted costs – both public and private) by DEL (Departmental Expenditure Limit, the name given to the total discounted domestic public investment) results in a multiplier which can be interpreted as the average *additional* economic benefit to the economy after an initial public investment of £1, or the return per pound of public investment.

Though the definition is fairly simple, the calculation of this multiplier is not always as straightforward; often being complicated by the information and return metric used in published studies. For clarity, we present below a worked example, which serves to illustrate the methodology used to calculate the multiplier in the presence of complete information, and the ways it can differ depending on the completeness of information available.

Calculating the NPV/DEL multiplier with varying levels of information: A worked example

For illustration, we assume an example programme investment with lifetime aggregate parameters as follows:

- Public investment (Departmental Expenditure Limit, DEL) of £100m;
- Leveraged private investment of an additional £150m;
  (Total domestic investment of £250m; Leverage ratio of 150%)
- Direct benefits of £400m; and
- Spillover benefits of £500m.
  (Total social benefits of £900m)

All impacts are discounted totals to Present Value terms, and benefits are adjusted for deadweight and displacement effects (i.e. additional).

With complete information, the NPV/DEL multiplier would be calculated as:

$$\frac{NPV}{DEL} = \frac{(DirectBenefits + SpilloverBenefits) - (PublicInvestment + LeveragedInvestment)}{PublicInvestment}$$

$$\frac{NPV}{DEL} = \frac{(£400m + £500m) - (£100m + £150m)}{£100m} = 6.5$$

At this point, it is worth highlighting the difference between this multiplier and the Benefit-Cost Ratio (BCR), the latter being defined as a simple ratio of the Present Values of Total Benefits to Total Costs. Under complete information, the BCR would be calculated as 3.6 (i.e. £900m/£250m), whilst with no leverage the multiplier is just the BCR minus 1.

With incomplete information, however, there are at least six ways (see Table 2) of calculating an NPV/DEL multiplier for this hypothetical scenario, as shown in Table 2. Public investment (Departmental Expenditure Limit, DEL) is always known (£100m).

Table 2 NPV/DEL multipliers (public Rates of Return) calculated with differing levels of information

Benefits known?	Leverage?	
	Yes	No
Both Direct and Spillover Benefits	6.5	8
Only Spillover Benefits	2.5	4
Only Direct Benefits	1.5	3

Source: London Economics' analysis

The variation in multipliers in the table, calculated for the same hypothetical investment example, illustrates the importance that research studies consider the full range of factors, and the influence of considered factors on the calculated Rate of Return on investment. If a study only considered the public and private investments, and direct benefits, the calculated multiplier (return per pound of public investment) would be just **1.5**. If total direct and spillover benefits were compared to the public investment alone while ignoring the leveraged private investment, then the multiplier (return per pound of public investment) would be **8**. However, if all factors are taken into account, including leveraged investment and spillover benefits, the multiplier (return per pound of public investment) would be **6.5**.

For this reason, it is important to distinguish between the Rates of Return reported from each study, and what has been included in that multiplier (as is done in Table 5).

2.3.3 Calculating direct and spillover Rate of Return multipliers

As defined in Section 2.1, **direct benefits** capture the impact on the output or productivity of the private organisation making the investment (net of deadweight and displacement effects), whilst **spillover benefits** measure wider effects, and the impact on output or productivity of other, non-investing organisations as a consequence of the leveraged private investment (net of deadweight and displacement effects). The sum of direct and spillover benefits equals the total (social) benefit, which we can use to calculate the direct and spillover Rates of Return, as shown in Figure 3.

Figure 3 Definition of public, direct and spillover Rates of Return

$$\textbf{Public Rate of Return} = \frac{\text{(Total benefits) - (Total investment)}}{\text{(Public investment)}} = \frac{\text{NPV}}{\text{DEL}}$$

$$\textbf{Direct Rate of Return} = \frac{\text{(Direct benefits) - (Leveraged investment)}}{\text{(Leveraged investment)}}$$

$$\textbf{Spillover Rate of Return} = \frac{\text{(Spillover benefits) - (Leveraged investment)}}{\text{(Leveraged investment)}}$$

Note: Shown alongside public Rate of Return for comparison purposes.

Source: London Economics' analysis

Table 3 presents estimated direct and spillover Rates of Return based on the example programme outlined above. The table highlights the relatively detailed level of information on types of investment (initial public investment vs. private leveraged investment) as well as the types of benefits (direct vs. spillover) required to undertake an accurate calculation of direct and spillover Rates of Return.

Table 3 Direct and spillover benefits calculated with differing levels of information

Benefits known?	Direct Rate of Return		Spillover Rate of Return	
	Leverage?		Leverage?	
	Yes	No	Yes	No
Both Direct and Spillover Benefits	1.7	N/A	2.3	N/A
Only Spillover Benefits	N/A	N/A	2.3	N/A
Only Direct Benefits	1.7	N/A	N/A	N/A

Source: London Economics' analysis

2.4 Scope, limitations and caveats

As summarised by Bruston (2014)[7] there are some structural difficulties, inherent to the space sector, which make the measurement and evaluation of the socio-economic impacts of space activities difficult, such as:

- **Fragmented structure of recording and reporting economic data** – space is not recognised as a category in international standards of industrial classification (e.g. UK SIC 2007). For example: data on the space manufacturing sector are captured, and lost, within the much larger sectors of aerospace and electronic equipment. As a result, Official

[7] Bruston, J.* (2014) "Space: the Last Frontier for Socio-economic Impacts Evaluation?", *Yearbook on Space Policy 2011/2012 - Space in Times of Financial Crisis*, pp. 183-191. * DG's Office for EU Relations, European Space Agency.

Statistics data do not allow for space to be isolated as a distinct economic activity and the measurement of space within the overall economy must be approximated;

- **Wide and prolonged diffusion of impacts of space activities** – space infrastructure, downstream applications, value-added services, and knowledge and market spillovers are:
  a) cross-cutting, enabling and enhancing a huge number of diverse applications – some obvious, and others hidden (e.g. timing & synchronisation using GPS satellites) – with wide-ranging and widely disseminated economic and social benefits throughout many sectors; and
  b) diffused over a long period, owing to the advanced R&D nature of the technologies, complicating the task of linking the returns to the investment.
- **Late acceptance of the need, and planning, for evaluation by the space community** – As a result, the space sector is not yet set up to routinely collect and report data that could support the evaluation of socio-economic impacts.

There are further complicating factors:

- **Sensitive and classified information:** The extent and nature of government activity in the sector, comprising both civil and military applications, also poses difficulties in terms of data availability and granularity;
- **Seamless integration of space technology:** The success of space-enabled capabilities in becoming seamlessly and 'silently' integrated within value-added services, equipment and applications means that users, and often even vendors, are not aware of the enabling contribution of space technologies.
- **Small, but significant, fringe suppliers:** Space manufacturing supply chains often depend on inputs from suppliers for whom the space industry represents only a very small proportion of their overall output. Identifying, engaging and measuring the contribution of these suppliers is challenging.
- **Lack of international comparability:** National statistics vary in definition, coverage and methodology, limiting international comparison, though this is changing thanks to the thought leadership of the OECD.
- **Long lag between investment and reaping the benefits of exploitation.**

These difficulties have been evident in our review. In addition, and more specific to our objectives:

- Initial analysis of available existing research only, supplemented by consultations;
- Lack of standardised framework, definitions, terminology, etc. in evaluations;
- Paucity of studies implementing a robust methodological approach, with comprehensive consideration of economic impact parameters;
- Difficulties in terms of matching literature and findings to impact parameters, so time-consuming;
- Database approach dropped due to non-standardised approaches and findings of studies; and
- Unusual for studies to report 'Rate of Return' – much more common to report aggregate NPV and/or Benefit-Cost Ratios (more information below).

Nonetheless, there exists a decently large number of robust studies to justifiably draw a range of conclusions on the returns to public investment in space – as outlined in Section 6.

2.4.1 Exclusion of space industry assessment studies (e.g. Case for Space)

A relatively large, yet separate strand of the existing space-related literature assesses the size of, and economic conditions within, national space industries[8]. As outlined above, the overarching objective of this research is to undertake an initial analysis to '*find space-specific evidence on the returns from public space investments*'. While public investments in space programmes play a crucial role in shaping national space industries, these industries are also influenced by a vast array of other factors (such as a country's political and legal environment, the availability of necessary labour, capital and other inputs, the state of the aggregate national economy, etc). As such, existing analyses of the size of national space industries commonly do not provide estimates of the returns to particular public space investments, but instead estimate key performance indicators within the industry, and consider the direct, indirect and economic impacts of the space sectors themselves on the national economy in which they operate. Given this difference in scope and objectives, such space industry assessment studies are excluded from the in-depth review of relevant literature undertaken for this research.

2.5 Assessing strength of space-specific evidence

There are a range of problems inherent in aggregating values, and drawing the conclusions we wish to arrive at from a wide range of literature. These are summarised below.

Methodological limitations: A key developing theme across all categories is the severe limitation of the studies, and their lack of consistency in terminology, methodology and scope. Many are not comprehensive enough to be able to report findings on key aspects such as leveraged investment, leakages, displacement and deadweight scenarios. This creates difficulties in attempting to compare and/or aggregate separate sources and highlights the need for improved literature in this field.

Subjectivity and potential bias: Some of the studies are survey-based or rely on interviews with industry experts and pose hypothetical questions. Subjectivity and optimism biases may result, so it is difficult to estimate how precise any figures are.

Assumptions: Many impact parameters are simply assumptions within the studies (e.g. lag, duration), and as such are not strictly considered by the author.

Lack of quantitative rigour: There are few econometric and data based estimation methods used in relevant sources.

To overcome these issues, an assessment of the robustness and strength of the evidence parameters is made before any conclusions surrounding the parameter are drawn.

- **Strength of the evidence:**
  - ●○○○○: The parameter provides very little or no use in our assessment as to the true value. This could be the case if the figure is simply stated (without a reference or methodological justification), not quantified, or very heavily caveated. This does not mean that a study is 'bad', but merely that it is not useful for the purposes of this study.

[8] Space industry assessments are typically undertaken at national level (e.g. UK Space Agency, (2014b) for the UK) as well as at supra-national level (e.g. OECD, 2014).

- ●●○○○: The parameter is of some little use in our assessment of the true value. This could be the case if the figure is caveated, has poor methodological justification, or heavily inferred.
- ●●●○○: The parameter will be used to help us refine our estimate of the true value. This could be the case if the parameter has sound methodology but some ambiguity surrounding an inferred value.
- ●●●●○: The parameter will guide us to our estimate of the true value. The parameter is either stated by the author and consistent with our own definitions, or inferred but with strong methodology.
- ●●●●●: The parameter is the output of a comprehensive analysis of the return on investment using a fully robust methodology.

  Note: Given the number of important limitations, caveats and gaps highlighted across the evaluation literature on the returns to public investment in space, no studies are awarded the top strength assessment.

These assessments of strength are applied to the particular impact parameter in question, and, along with the number of times the parameter has been reported on, enable us to pass judgement on the suitability of an estimated range for the parameter. No mechanical weighting system is used in achieving this, with the above categories instead being used as subjective guidelines in our approach.

3 Role and nature of public investment in space

3.1 Role for government investment in space

The discussion that follows presupposes an appreciation of the rationale for government investment in space – argued with reference to the unique characteristics of space. A brief summary is provided below – please see *The Case for Space 2015* for a full explanation.

Classical economic theory provides a rationale for government intervention where there is an identified imperfection in the efficient allocation of resources, known as 'market failure' – that is, the market left to its own devices fails to deliver the most efficient outcome. Key identified market failures underpinning the need for government intervention to influence supply and demand for space-enabled applications include:

- The risk of under-investment in the infrastructure-forming, yet R&D-intensive, upstream segment of space economy value chain, as compared to the commercially lucrative downstream segment;
- High risk, large fixed costs and long and costly development phases associated with space investments, rendering the private market unable to provide the necessary financing;
- Positive externalities associated with R&D innovation (providing both benefits to the innovator as well as wider spillover benefits which the innovator does not take account of), resulting in underinvestment in R&D below the socially optimal level;
- Externalities associated with the use of space, of both negative (e.g. in terms of space debris) and positive (e.g. the use of space-enabled technologies contributes to cleaner environment and other social benefits) nature, requiring government to restrict negative externalities and promote activities yielding positive spillover effects;
- The public good nature of many space applications (individuals cannot be effectively excluded from consumption, and consumption by one individual does not reduce availability to others, nor increase costs of provision), impeding private incentives to invest in the systems.

3.2 Why might space be a special case?

Appraisal of investment options is most robust when it is based on accurate information that is as specific to the investment as possible. Appraisal of space investments is no different.

Where possible, the UK Space Agency estimates the economic returns to space investments using programme-specific information. In the absence of such specific information, generic assumptions are used based on generic 'Science' and 'Innovation' literature (e.g. Frontier Economics, 2014) that have been assessed as broadly appropriate to the wide range of science and innovation research and development activities undertaken using public (and leveraged) investment. To the extent that such generic science and innovation parameters are appropriate to investments in space, this is not an issue; but what if they are not?

There is a variety of factors that could support a hypothesis that the profile of economic returns to public space investments are substantively and sufficiently different from general science and innovation investments so as to warrant space-specific assumptions on impact parameters.

The points that follow are derived from the literature, our own knowledge of the industry and points made by stakeholders consulted in the process of our research.

3.2.1 Distinctive aspects of the space industry

The UK space industry is highly **research intensive** – the space manufacturing segment in particular, with R&D representing 26.1% of its total GVA[9], compared to total R&D expenditure across the UK in 2011, which represented just 1.1% of GDP.[10]

Space economy employees are **highly skilled** (3 in 4 hold a higher education qualification) and **highly productive** (labour productivity of £140,000 – *more than three times the national UK average* of £46,000.[11]

Furthermore, the **cost of securing R&D jobs** is also lower for businesses operating in the space sector. In an assessment of the impact of the Technology Strategy Board's (now InnovateUK) *Feasibility Studies Programme*, Warwick Economics and Development (2013) found that of all sectors in the study, space had the lowest grant cost necessary to produce an R&D job at £6,780, *less than half the average grant cost* of £16,405 and nearly one-fifth of the grant cost necessary to generate an R&D employment opportunity in the energy sector (£32,550).

The UK space industry is also **export-orientated** – evidenced by an export share of 62% (of the space industry's turnover when Direct-to-Home broadcasters are excluded) – *more than four times the export share of the UK economy* as a whole (15%).

With a 40% increase in Foreign Direct Investment (FDI) activity in 2006-2015 than the previous decade,[12] space is increasing its **inward investment** and global linkages. *The Space Economy at a Glance 2014* study by the OECD highlights this progression, by claiming that, "space systems are also increasingly evolving at the international level ... supply chains for space systems are internationalising at a rapid pace" (p.9). Such success in attracting foreign investment can translate into increased **foreign leveraged investment** for UK public space investments – increasing the returns to public space investments without additional investment cost to the UK economy.

The potential future impact of economic returns is boosted by the fact that the space economy (covering both the provision and the use of space services) is a **high-growth sector.** The space economy is growing strongly at both the global and the UK level. The global space economy consistently outgrows global economic output, with growth rates of 7% and 4% for 2012 and 2013 respectively,[13,14] compared to growth in global aggregate economic output of 3.1% and 3.0% respectively.[15] In the UK, aggregate space turnover has grown at an annual rate of 8.8% since 2000, compared to the growth rate of UK GDP of 1.6% over the same time period[16]. These high growth rates across the space sector are indicative of the increasing demand for technical knowledge and skills, which can be further created and fostered through spillover benefits accruing from successful investment programmes to sustain strong growth for the future.

[9] London Economics (2015) *The Case for Space 2015* - Executive Summary
[10] Office for National Statistics, Statistical Bulletin – Business Enterprise Research and Development, 2011
[11] London Economics (2015) *The Case for Space 2015* - Executive Summary
[12] As measured by incorporations, mergers and acquisitions. London Economics (2015) *The Case for Space 2015* - Executive Summary
[13] The Space Foundation – The Space Report 2014
[14] The Space Foundation – The Space Report 2013
[15] International Monetary Fund – World Economic Outlook (WEO) Update, January 2014
[16] London Economics (2015) *The Case for Space 2015* - Executive Summary

Further, reflecting a view of the space sector as an ecosystem with a clear value chain, consultees highlighted a **chain effect** that ties these factors together: in response to an identified technical need and as a result of public and private funding, research and development is undertaken, creating technologies and skills, establishing UK technical leadership in a particular area, boosting revenues, value-added and productivity of the workforce, attracting inward investment, and continuing to drive growth of the industry; with a feedback loop continuing the cycle.

3.2.2 Distinctive aspects of the wider space economy

More fundamentally, space technology and space-powered services are already a **ubiquitous and integral** part of the everyday lives of UK citizens and businesses, **enabling and enhancing** an increasingly wide and diverse range of applications for commercial, scientific research, public sector and consumer end-users throughout the UK economy. As a result, space has **expansive catalytic effects**: all nine national critical infrastructures rely on space, and almost all sectors would be disrupted in the absence of space services.

Not only is space ubiquitous in use, it provides an important **link** between academia, industry, and government which **operates in every region of the UK**, and around the world, with satellite launches attributable to **52 nations**[17].

Space science and **exploration** (both manned and robotic) boost knowledge, stimulate innovation and inspire future generations. At a qualitative, social level, space has the rare ability to capture imagination and **inspire and promote STEM education and careers**. A 2015 YouGov poll found that over 1 in 4 people said they would like to become an astronaut[18]; while a 2009 study by Nature magazine found that, of 800 scientists and researchers to have been published in the magazine, half said they had been motivated to become a scientist because of the Apollo programme and 89% thought that human spaceflight encourages younger generations to study science[19].

This ability of space to **capture the public's imagination** can be seen in interactions through social media, NASA's main account has around 12 million followers on Twitter[20], and through public engagement activities intrinsic to the success of many modern space missions (e.g. Crowdfunding – Planetary Resources, Lunar Mission One, "Reboot the Suit". Public Competitions – "Design a space meal for the Principia mission", "Name Rosetta's landing site", etc.). These same missions can generate huge amounts of media coverage, with successive consultees claiming that in doing so, these missions represent a **cost effective way to raise awareness of the space industry**.

3.2.3 Distinctive aspects of space science and technology, and space investments

Consultees highlighted the fact that spillover benefits are maximised when the relevant investment is **seeking to achieve something novel**, rather than incremental evolutions of existing knowledge – and this is typically the case with space-related R&D:

- Space offers **unique opportunities for scientific experiments in microgravity** – which, given the substantial cost, is only undertaken when there is no other available option – guaranteeing novelty. For example, one success quoted was a more fundamental

[17] The Space Foundation – 52 nations have "space interests" as of end-2010.
[18] The most desired jobs in Britain – Astronaut (27%) - https://yougov.co.uk/news/2015/02/15/bookish-britain-academic-jobs-are-most-desired/
[19] Shooting for the Moon - 15 July 2009 | Nature 460, 314-315 (2009)
[20] NASA also operates many other social media accounts for specific programmes or research centres.

understanding of alloys, allowing researchers to model alloys more naturally, and invent more alloys more quickly.

- Secondly, the unique characteristics of space as an operating environment (remote, extreme temperatures, energy independence, long-duration, high radiation, distant communication, programmed autonomy, microgravity, weight minimisation, technology miniaturisation, reliability, resilience to vibration, etc.) means that there is bespoke engineering and cutting edge technology in almost every dimension, requiring high reliability manufacturing, quality assurance, testing, technology demonstration and planning at every stage, whilst also **retaining conservative engineering designs** (there remains a trade-off between existing and untried).

These characteristics establish space at the forefront of **cutting edge manufacturing and science**, but when combined with the **ubiquity of applications of space technology and services**, space comes into its own in terms of **maximising the exposure** of this cutting edge technical knowledge, technological innovations and the potential knowledge transfer – and therefore **boosting** the potential for, and impact of, knowledge, market and network **spillover benefits**. There are even programmes (e.g. ESA's Technology Transfer Programme) and organisations (e.g. UK's Satellite Applications Catapult, ESA's Business Incubation Centres, and ECSAT, the European Centre for Space Applications and Telecommunications – all at Harwell) tasked with maximising the diffusion of space-derived applications and knowledge.

However, this cutting edge technology and knowledge comes at a cost: R&D, with both **developmental and technical risks**– attested by the fact that organisations seeking to expand vertically tend to acquire rather than develop expertise/technical ability. Space investments tend to have a distinct high-risk/high-reward profile. In spite of this attention, attracting sufficient levels of investment can be a problem for businesses in the space sector, especially when there is low public financial support for space activities, such as in the UK. Relative to organisation size and capitalisation, space typically requires **large amounts of invested capital** to make an investment worthwhile, resulting in a **financing gap**.

For this reason, government-orientated space investments have historically dominated, with the origins of Earth Observation and GPS being primarily military in nature. This is particularly notable in the United States – where the Department of Defence's space budget is 1.6-times that of NASA. Such levels of investment have given American companies a significant competitive edge over international competitors. As defence budgets in the UK and EU are fragmented along national lines, public sector funding is even more important to level the playing field to allow UK space companies to compete on anywhere near an equal footing internationally – an important driver for growth of the industry. However, though this remains true, things are beginning to change – with **increased private space investments** and commercial opportunities bringing the space sector more in line with the industrial norm. Public-private partnerships in the form of US Commercial Crew (CCDev), or allowing private operations on the ISS (e.g. NanoRacks, Space Adventures etc.) are starting to **shift the make-up of the space investments** into a private, profit-seeking arena alongside the majority of comparative industrial sectors. As a result, decisions on when and where to invest public money without displacing private investment (crowding-out) and maximising additionality will become increasingly important.

By extension, these features also characterise the upstream segment as having **higher barriers to entry** than other industries, with technical know-how, expensive resources, and a favourable legal framework often necessary for a productive investment environment for companies operating in the upstream space industry.

Finally, it is important to consider the **esoteric nature** of space science and technology. End-users don't know what is possible and what can provide value to them and others (spillovers), so progress in the sector is often technology and capability **supply-led rather than demand-driven**. Whilst the development of applications is always focussed closely on end-user benefit, the development risk means that without investment, socially beneficial technological progress may be hampered or precluded by a lack of initial financing.

On this final point, consultees sounded the warning of the **need for continued and sustained investment and benevolent regulatory support**, or growth opportunities would not materialise for the UK space industry. Public support, from regulatory reform to targeted financial support, has played a key role in collaboration with industry to position the UK space industry in a position of great strength and potential – a tactical high-ground from which to build a position of leadership. However, as highlighted in *The Case for Space 2015*, without continued public investment and regulatory support, these opportunities will not materialise and will pass the UK by, and it could take decades to re-establish leadership – similar to the case of the UK's lost leadership in launcher technologies following the decision not to develop new rocket launchers in the 1970s.

4 Space-specific evidence on impact parameters

4.1 Introduction

This section presents a synthesis of the existing space-specific evidence structured according to impact parameter.

Having initially attempted to categorise the studies into ‘Near-market innovation, infrastructure and derived services’ and ‘Space Science and Exploration’, this was deemed too difficult or arbitrary (e.g. ESA evaluations deal with the full range of innovation through space science/exploration; robotic innovations on the ISS, such as the Canadarm). Accordingly, we instead split the studies into two categories:

- Evaluations of ESA membership; and
- Evaluations of space science and innovation investments.

It was decided to group evaluations of ESA membership together separately, as these studies form a relatively homogenous group in terms of investment type, aim, scope, methodology and return metrics. These studies would also be particularly useful for an evaluation of the UK’s membership of ESA.

4.2 Evaluations of ESA membership

The identification of 9 studies which consider the impact of ESA membership presents us with an opportunity to assess the Rate of Return on investment, as well as a select few other parameters, specific to a nation’s involvement with the European Space Agency. The general theme of these studies was that the Member States’ contribution was treated as the investment cost, whilst the benefits were calculated from the effects of ESA placing contracts in that nation’s space industry.

4.2.1 Rate of Return

Table 4 presents information on the Rates of Return based on the 9 studies estimating the returns to ESA membership. All of these studies either explicitly quote a Rate of Return, or make it possible to implicitly infer one using stated Benefit-Cost Ratios (BCRs). Note that all of the Rates of Return indicated in Table 4 constitute **public Rates of Return**, as none of the studies consider private leveraged investment as part of their analysis.

The studies represent a range in aggregate Rate of Return multipliers between 1 and to 6.3, and an arithmetic mean of 3.2[21]. However, using an average is misleading as it provides equal weight to the findings of all studies. In reality, particular studies will be more relevant to our literature review, provide a more thorough calculation or a more transparent methodology, leading to more confidence in these figures. In an attempt to make it easier to factor this into account, Table 4 provides the Rates of Return by country the study considers, including a strength assessment of each study and a series of caveats and weaknesses of the study.

[21] Where a study gives more than one Rate of Return, we have considered the most recent figure only.

Table 4 Summary of Rates of Return for ESA Membership Studies and Strength Assessment

Author(s) and year	Country	Public Rate of Return	Caveats & Weaknesses	Strength Assessment *
Belgian Federal Science Policy Office (2012)	Belgium	2.3	Cursory report, severely limited in scope. No description of methodological approach.	●○○○○
Ramboll Management (2008)	Denmark	3.5	Limited coverage of influencing factors	●●●○○
Clama Consulting (2011)	Portugal	1	Limited coverage of influencing factors	●●●○○
Rosemberg et al. (2015)	[redacted]	[redacted]	[redacted]	[redacted]
London Economics and PwC (2012)	Norway	2.5	Partial estimate of benefits	●●●●○
Triarii (2005)	Netherlands (ESTEC)	2.4 (2004) 3.3 (2011)	Limited coverage of influencing factors, simplification of benefit appraisal	●●○○○
High Tech Systems and Materials top team (2012)	Netherlands	4.3	Simplification of benefit calculation, lack of methodological detail	●●●○○
BETA/CETAI (1989) and CETAI/BETA (1994)	Canada	2.5 (1979-1988) 3.2 (1989-1992)	Limited coverage of benefits, methodological explanation and influencing factors. Relatively dated.	●●○○○
BETA (1980, 1988, 1989)	All Member States	1.9 (1980) 2.2 (1988)	Limited coverage of benefits, methodological explanation and influencing factors. Relatively dated.	●●○○○

Note: All Rates of Return are public Rates of Return, as only public investment constitutes Member State contributions. Influencing factors refer to key parameters affecting the size of the Rate of Return estimated, such as lag, duration of benefits, deadweight etc.
* London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.
Source: London Economics' analysis of relevant literature

After taking the strength of the studies into account, a sensible estimate for the *aggregate* public Rate of Return on ESA membership for Member States is **around 3.0 - 4.0**. With the general lack of consideration of duration and/or lags in these studies (see Section 4.2.2), this broadly translates into an *annual* Rate of Return estimate (i.e. studies either only consider a single year, or an equal number of years, of costs and benefits, the aggregate estimate can be taken to represent an annual rate of return).

Figure 4 Rates of Return from ESA Membership

* London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.
Source: London Economics' analysis

It also seems to be the case that a country's Rate of Return on ESA membership is positively correlated with the length of time they have been a member. This can be observed with the studies on *Canada*, *Netherlands (ESTEC)* and *All Member States* all seeing an increase in return with an increase in duration of membership, and also in the concluding remarks of the *Portuguese* study, "similar studies with a higher number [Norway, Denmark] have been ESA Members for a very long time ... the lower value for Portugal is most likely due to the long period necessary for satellite development." Other factors brought up in literature that would result in an increased Rate of Return with a longer period of membership include:

- It takes time for the existing space sector to adapt to ESA's standards, delaying the placing of large ESA contracts in that country.
- A space industry's continued development will most likely result in a more diversified national supply chain, reducing the need for external products, reducing leakages and increasing the Rate of Return.
- It takes a period of time for ESA's geo-return policy, of returning as close to the Member State's contributions in contracts as possible, to become feasible due to ongoing contracts in other countries and prior funding commitments. The longer a country is within ESA, the more likely their geo-return would be close to 1.0.

4.2.2 Lag

While a lag is reported for indirect benefits within the *Norwegian* study, the other reports take the approach of assuming no lag, that is, they compare benefits in one year to costs (membership fees) in the same year. The rationale for doing this is that membership programmes represent an ongoing and constant payment of membership fees over an extended period of time. In line with ESA's geo-return policy, this would also result in the contract sum to space industries to be relatively constant, and thus a lag is not necessary.

However, this does somewhat over-simplify the relationship between membership fees and benefits from ESA contracts. Whilst small fluctuations in the value of contracts may not require a lag to be modelled correctly, large changes in member states' contributions, such as the UK increasing their contributions to ESA by 25% in 2012[22], will warrant a lag to more accurately track the economic impact.

4.2.3 Deadweight

Not one of the ESA Membership studies explicitly considered or quantified a deadweight or counterfactual scenario. This is indicative of the narrow scope of much of the literature dealing with returns from public space investment.

4.2.4 Benefit duration

Studies generally only calculate benefits for a certain time window relevant to their report, if at all, rather than the full duration of one or more benefits from a particular starting point. This, along with the fact that most studies consider a lag of zero, results in an underlying assumption that benefits will last only as long as costs, and thus ESA membership, lasts.

4.2.5 Leveraging/Crowding in

There is no quantitative calculation of leveraging, or crowding in (private investment taking place solely because of prior public investment), in any of the ESA Membership studies. The only mention of leveraging is in the *Portugal* study, where we are told that, "companies have taken advantage of Portugal's participation in ESA to leverage investment."

4.2.6 Displacement/Crowding out

No studies mention displacement or crowding out.

4.2.7 Leakage

Leakages are sparsely reported as well, with only 1 of the 9 studies mentioning it. The *Danish* study calculates leakages in the form of foreign subcontractors to use in their spinoff calculation, but doesn't state the actual leakage value. It was also possible to infer an upper bound for leakages of 25% within the *Norwegian* study by comparing economic activity determined to be within Norway against ESA contract values.

[22] Britain Pledges 25% Boost in ESA Spending – Space News (Accessed July 2015), http://spacenews.com/32288britain-pledges-25-boost-in-esa-spending/

4.2.8 Wider benefits

Wider benefits determined to accrue from ESA Membership to Member States include a wide variety of scientific, technological, environmental and social issues. These range from ESA centres within a country providing a strong educational stimulant, increased likelihood for the detection of illegal fishing and oil spills within a nation's maritime boundaries due to access to ESA satellite data, reputational effects from being associated with ESA for companies involved with ESA contracts, participation in scientific breakthroughs due to exploration-based projects run by ESA (e.g. Rosetta mission), and access to technological spinoffs and innovations from ESA research that could lead to new companies in a particular Member State.

4.3 Evaluations of space science and innovation investments

4.3.1 Rate of Return

Table 5 summarises Rates of Return to public space investments based on a total of 36 studies[23] which either explicitly estimated such rates or which allowed for an implicit inference of Rates of Return based on a comparison of the investment value to the resulting benefits. Note that the vast majority of studies typically only calculated Benefit-Cost Ratios (BCRs) or provided cost and benefit estimates separately, implying that it was necessary to infer the relevant Rate of Return for these studies. While the numbers presented should be interpreted with this caveat in mind, the inferred Rates of Return nevertheless provide a valuable overview of the net benefits to public space investments across the literature. Further, as with the returns to ESA membership presented above, we provide an indication of the perceived strength of each estimate based on the methodological caveats and other weaknesses in the literature.

Please note that, in the following, we focus on **public Rates of Return to space investments**. As outlined in Section 2.3, these are calculated as NPV/DEL multipliers, meaning they measure the **return per pound of public investment**. While the literature typically allows for an inference of these public Rates of Return, it is usually not feasible to calculate the direct or spillover Rates of Return associated with any leveraged private investment. This is linked to an overall lack of distinction of total benefits into direct and spillover benefits across the literature, as well as a typical absence of estimates of leveraged private sector investments (as further discussed in Section 4.4.3) which would be required for a calculation of direct or spillover returns.

In addition, and similarly, it is important to note that the calculation of the public Rates of Return has been undertaken based on varying degrees of complete or incomplete information in terms of the particular benefits included in studies' estimates, as well as the level of public investment as compared to leveraged private investment, providing one key underlying explanation for observed differences in Rates of Return (see Section 2.3). To ensure clarity and transparency, Table 5 includes a range of detailed information on the type of benefits considered in each study's estimates, the project phase during which these benefits are estimated, as well as key information on parameters influencing the size of each particular multiplier (as applicable and available).

[23] In some instances, for presentational purposes, several studies were combined to infer or extract a particular Rate of Return, e.g. where a particular study combines costs and benefits of a programme based on references to a different source (e.g. SpaceTec Partners (2012) and Knight et al. (2012)). Note further that some of the studies (e.g. the analysis undertaken by the Hickling Corporation (1994)) allow for an inference of Rates of Return for several particular public space investments in different application areas. Such distinct estimates are indicated separately throughout Table 5 as appropriate, i.e. some studies are included in the table in more than one row.

Further, it is important to recognise that all Rate of Return estimates indicated throughout the following constitute **un-annualised, multi-year/aggregate Rates of Return**, capturing the total net benefits associated with public space investments over the entirety of the period of observation considered by each study. The calculation of un-annualised returns has been undertaken to keep the resulting estimates across the literature as consistent as possible. As outlined in more detail below, the majority of studies do not provide sufficient information on duration of benefits, lags, or the timing of public investments, all of which constitute key factors necessary to undertake a consistent calculation of annualised Rates of Return across the literature.

Compared to the ESA membership estimates presented above, the public Rates of Return to other types of public space investments display a significantly higher degree of variation. As outlined in Table 5, one key differentiating factor underlying this variation in estimates relates to the different focus in the literature on public investments on different space applications. Common application areas considered in the literature include:

- Earth Observation programmes, with analyses of Copernicus (previously Global Monitoring for Environment and Security) being particularly prevalent, but also other programmes such as GEOSS, Meteosat, EPS/Metop Second Generation, or the Indian Remote Sensing Programme);
- Investments in Satellite Navigation (including Galileo, EGNOS and the wider EGNSS programme);
- Telecommunications, such as projects funded under ESA's Advanced Research in Telecommunications (ARTES) programme, the European telecommunications programme, or Canada's AdvSatCom;
- NASA investments, which cover a series of public investment programmes initiated by NASA, with a focus on NASA R&D projects.

Two studies undertaken by the Hickling Corporation (1994) and Robinson and Westgaver (2000) provide interesting contributions in comparing the relative size of public Rates of Return across these application areas. Both analyses evaluate the returns to public investments in space programmes in telecommunications as well as Earth Observation, thus allowing for a direct comparison. In particular, while Robinson and Westgaver (2000) focus on ESA's telecommunications programme and Meteosat, the analysis undertaken by the Hickling Corporation (1994) evaluates Canada's Advanced Satellite Communications and Earth Observation programmes. In both cases, the inferred public Rates of Return to public investments in telecommunications are considerably larger than the returns to such investments in Earth Observation programmes. However, the Earth Observation returns did not include unquantified benefits, which are more prevalent in the application of remote sensing using satellites.

Cautionary note on comparison

One of the most pervasive findings from the literature review and Case Study exercise has been the recurring theme that the full range of benefits of space is wide, complex and varied – making them extremely difficult to value. This is, at least in part, a direct result of the pervading profile of the space industry, which acts as a key enabler in every-day life, with the extent and value of the impact in many areas not fully understood or explored.

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.

Additionally, there are also unforeseen benefits. The esoteric nature of space science and technology results in a capability supply-led rather than demand-driven process of application development and innovation, meaning that future applications are near-impossible to foresee at the point of investment – causing forward-looking studies to understate the true value of an investment in space R&D.

In appreciating these factors, it seems certain that our estimates, and more particularly those estimates prevalent in existing literature, suffer from a potentially severe undervaluation. What's more: certain types of investment are more susceptible to this limitation than others: for example, benefits to a focused, mature and commercial market such as satellite communications are more easily quantified and valued than the more nebulous and unquantifiable benefits of a less developed and (currently) less commercialised market like that for Earth Observation services.

For this reason, comparison or ranking of the Rates of Return is not meaningful, nor advisable.

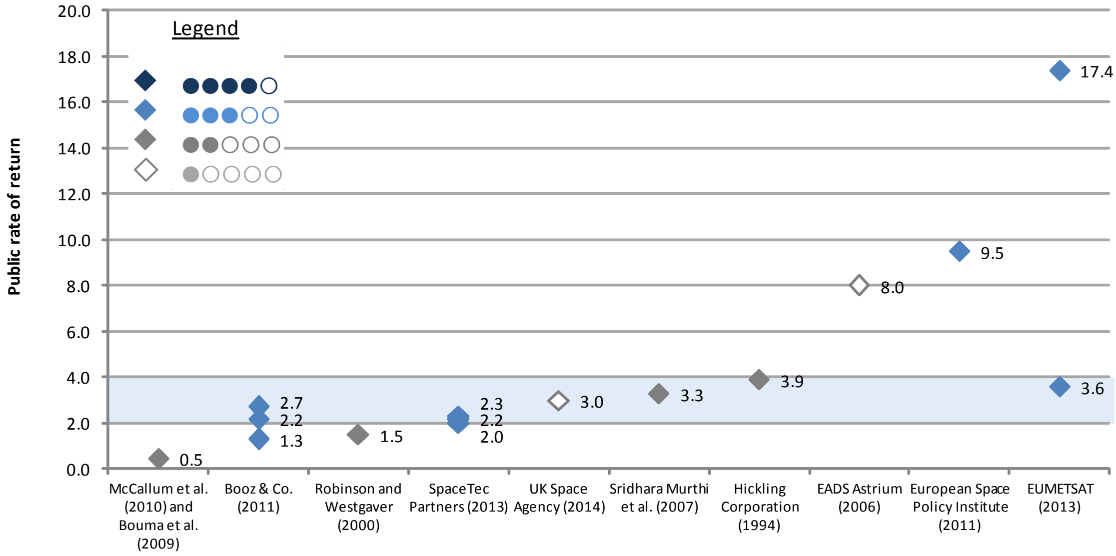
Earth Observation

Taking into account the relative strength of estimates across the literature, it appears that a sensible estimate for the lifetime public Rate of Return to public investments in Earth Observation programmes stands at approximately **2.0-4.0** (see Figure 5).

A key potential explanation behind the relatively low returns to Earth Observation programmes estimated across the literature is the fact that the benefits derived from such programmes, while intuitively obvious, are often difficult to quantify. For example, McCallum et al. (2010) highlight that while EO programmes are crucial for improved decision-making, they often involve significant sunk costs in the face of uncertain benefits. They refer to the prevention of damages through improved weather forecasts and early warning or better-informed rescue missions as a key example of benefits which are high, but also difficult to quantify. Similarly, a study on the EPS Second-Generation programme undertaken by Eumetsat (2013) discusses a range of benefit areas (e.g. contributions to safety of life, defence and security, or climate monitoring) for which a quantitative assessment cannot be provided, stressing that the quantitative omission of these impacts results in conservative benefit estimates overall.

It is of utmost importance, then, to stress that the majority of the benefits of Earth Observation are of a ***non-quantifiable*** and ***non-monetisable*** nature, and so the monetised Rate of Return statistic substantially understates the value of the benefits of Earth Observation and remote sensing. Some examples of quantified wider benefits provided by EO programmes can be found in section 4.4.7.

Figure 5 Public Rates of Return to space investments in Earth Observation



Note: Rate of Return multipliers are rounded to the nearest decimal. In instances where several estimates were calculated based on the same source, all estimates have been included in the figure. * London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Source: London Economics' analysis of relevant literature

Telecommunications

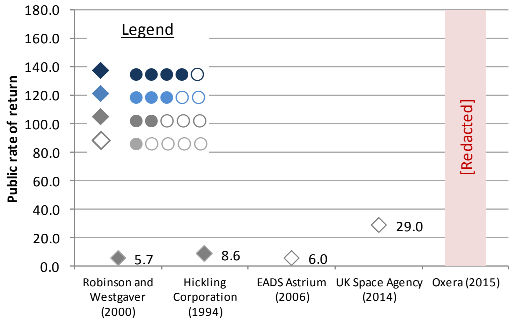
As outlined in Figure 6, the relevant literature reviewed displays a significant degree of variation in the public Rate of Return to investments in the telecommunications sector. A potential explanation behind this degree of variation relates to the particular objectives and types of programmes under evaluation in each of the studies. Robinson and Westgaver (2000) focus on ESA's early telecommunications programme, intended to develop and provide a satellite system capable of handling European telecommunications traffic, and of distributing two television channels as part of the European network. The study by the Hickling Corporation (1994) similarly focuses on public investment in the upstream part of the value chain, analysing the Canadian Advanced Satellite Communications (AdvSatCom) intended to test and develop the next generation telecommunications satellite and small satellite and mobile personal satellite communications systems.

Based on these (few) studies analysing the benefits associated with public investments in telecommunications, it thus appears sensible to provide two separate estimates of the expected public Rates of Return to such investments. For upstream investments into telecommunications satellite development, an estimated range of public returns of approximately **6.0-7.0** seems sensible. For public investments in near-market technologies with large commercial potential, the literature indicates that very high public Rates of Return might be achieved.

Satellite navigation

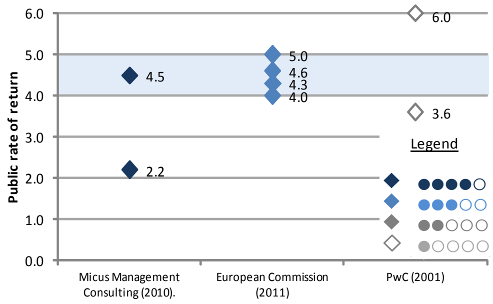
None of the studies reviewed draw a direct comparison between programmes in satellite navigation to public investments in other space sectors. However, from the (again relatively few) relevant studies on satellite navigation, it appears that public returns to satellite navigation programmes are slightly larger than the returns to public investments in Earth Observation, bearing in mind that many EO benefits are less quantifiable. Based on the relevant literature, it is expected that the public returns to investments in satellite navigation might range between **4.0 – 5.0** (see Figure 7).

Figure 6 Public Rates of Return to space investments in telecommunications



Note: Multiplier values are rounded to the nearest decimal. All Rates of Return constitute un-annualised, multi-year / aggregate Rates of Return. * London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.
Source: London Economics' analysis of relevant literature

Figure 7 Public Rates of Return to space investments in satellite navigation



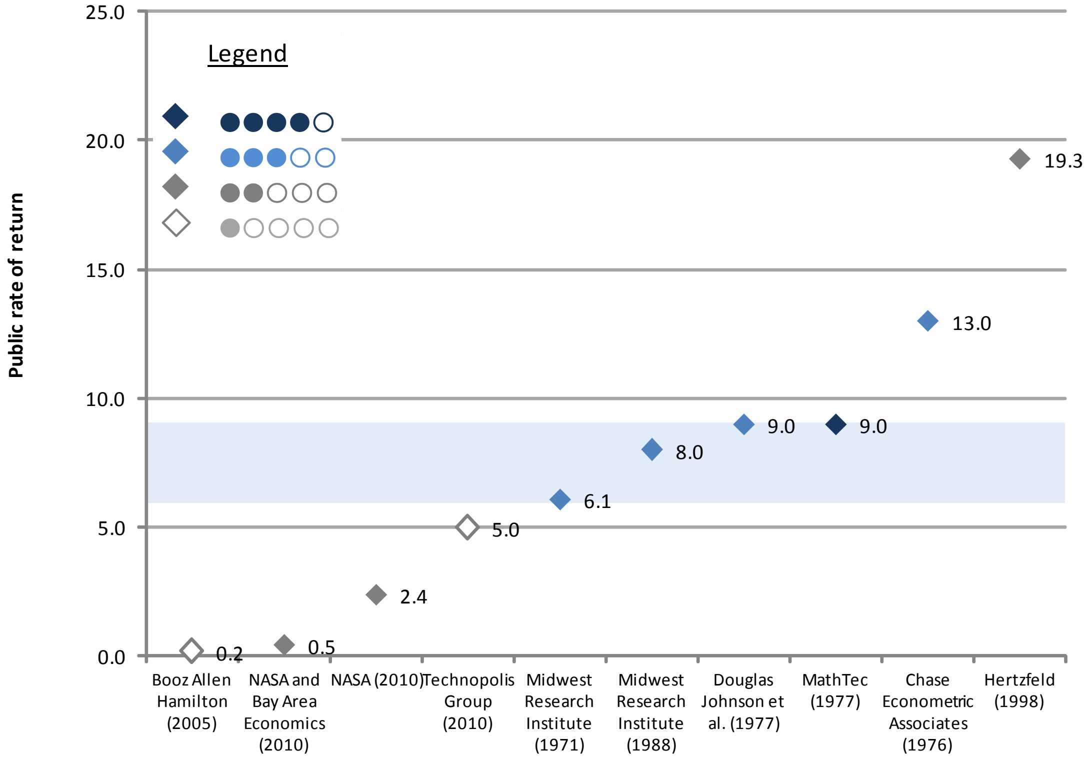
Note: Multiplier values are rounded to the nearest decimal. In instances where several estimates were calculated based on the same source, all estimates have been included in the figure. All Rates of Return constitute un-annualised, multi-year / aggregate Rates of Return.* London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.
Source: London Economics' analysis of relevant literature

Returns to NASA investments

In addition to applications, another differentiating factor in estimates of public returns to space investments appears to be the agency making the investment, with notable differences between the returns to ESA and NASA investments. For instance, the Technopolis Group (2010) estimates that the public Rate of Return to NASA space exploration (in terms of spin-offs) is more than 12 times larger than the return to such investments from ESA. This difference is likely to be because of the larger magnitude of space exploration activity undertaken by NASA, and due to NASA's higher global profile than ESA leading to a relatively higher potential for non-space use of its technologies. A "duration effect" similar to that found for ESA membership (see section 4.2.1) could also play a part in causing this disparity.

More generally, the studies reviewed analysing NASA investments focus on a range of programmes which differ markedly from the public investments in Earth Observation, telecommunications or satellite navigation discussed in the above. In particular, the NASA-related studies consider NASA R&D activities in a wider sense (e.g. NASA Life Sciences R&D, or NASA Stimulated Technological Activity) or targeted technology transfer programmes (e.g. NASA Tech Brief); in addition, one study (NASA, 2010) considers the economic impact of NASA's John F Kennedy Space Centre in Florida. Overall, across these studies, it appears that a sensible estimate for the return to NASA's investments in space stands at approximately **6.0-9.0** (see Figure 8).

Figure 8 Public Rates of Return to space investments undertaken by NASA



Note: Multiplier values are rounded to the nearest decimal. In instances where several estimates were calculated based on the same source, all estimates have been included in the figure. All Rates of Return constitute un-annualised, multi-year / aggregate Rates of Return. * London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Source: London Economics' analysis of relevant literature

Table 5 Summary of Rates of Return (RoR) for evaluations of space-related public investments

Author(s) and year	Programme	Public RoR	Direct RoR	Spillover RoR	LE Inferred?	Benefit Phase	Type of Benefit	Influencing factors	Caveats & weaknesses	Strength Assessment*
Earth Observation / Remote Sensing / Meteorological satellites:										
McCallum et al. (2010) and Bouma et al. (2009)	Global Earth Observation System of Systems (GEOSS)	0.5			X	Operational	Unclear	N/A	Limited coverage of benefits; large variation in estimates.	●●○○○
SpaceTec Partners (2012a) and Knight et al. (2012)	EO and Copernicus Downstream Services for the Agriculture Sector		1.0		✓	Operational	Direct	N/A	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)			✓	Manufacturing, Operational, & Legacy	Direct & Spillover	Adjusted for inflation	Inconsistent measure of benefit duration across options.	●●●○○
Robinson and Westgaver (2000)	Meteosat	1.5			✓	Manufacturing, Operational, & Legacy	Direct & Spillover	Value added not included in the benefit to cost ratio	Methodological inconsistencies.	●●○○○
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)			✓	Manufacturing, Operational, & Legacy	Direct & Spillover	N/A	Benefits and costs are not discounted to Net Present Values.	●●●○○
UK Space Agency (2014a)	National Space Technology Programme (MetOp-SG)	3.0			✓	Unclear	Unclear	N/A	Lack of methodological detail - no reference to estimate provided.	●○○○○
Sridhara Murthi et al. (2007)	Indian Remote Sensing Programme	3.3			✓	Operational	Direct & Spillover	N/A	Methodological inconsistencies and limits.	●●○○○
Hickling Corporation (1994)	Canada's Long Term Space Plan: Earth Observation (EO)	3.9			✓	Unclear	Direct & Spillover	N/A	Lack of methodological detail.	●●○○○
EADS Astrium (2006)	UK investment in Disaster Monitoring Constellation (DMC)	8.0			✓	Unclear	Unclear	N/A	No methodological detail or reference to estimates provided.	●○○○○
EUMETSAT (2013)	EPS/Metop-Second Generation satellite programme	'Minimum': 3.6 'Likely': 17.4			✓	Operational	Unclear	NPV, Duration >= 20 years	Large variation in estimates.	●●●○○
European Space Policy Institute (2011) using data from Booz & Co. (2011)	GMES	9.5			✓	Operational	Direct & Spillover	NPV	Rate of Return is described as being an upper bound due to cost underestimates.	●●●○○

Telecommunications:										
Robinson and Westgaver (2000)	ESA programmes: ESA Telecommunications	5.7			✓	Manufacturing, Operational, & Legacy	Direct & Spillover	Value added not included in the benefit to cost ratio	Methodological inconsistencies.	●●○○○
EADS Astrium (2006)	UK investment in ARTES	6.0			✓	Unclear	Unclear	N/A	No methodological detail or reference to estimates provided.	●○○○○
Hickling Corporation (1994)	Canada's Long Term Space Plan: Advanced Satellite Communication (ADvSatCom)	8.6			✓	Unclear	Direct & Spillover	N/A	Lack of methodological detail.	●●○○○
UK Space Agency (2014a)	E3000 spacecraft (telecommunications satellite)	29.0			✓	Unclear	Unclear	N/A	No methodological detail - no reference to estimate provided.	●○○○○
Oxera (2015) **(Confidential)**	[redacted]	[redacted]	**[redacted]**			[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Satellite navigation:										
Micus Management Consulting (2010)	Introduction of GNSS technology applications in German public sector	Base case: 2.2 Best case: 4.5			✓	Operational	Direct & Spillover	Lag (0 years), Duration >=10 years	No complete explanation of efficiency gains.	●●●●○
European Commission (2011)	European Global Navigation Satellite System (EGNSS)	4.6 (Baseline Option) 5.0 (Revised Services) 4.3 (Reduced Services) 4.0 (Degraded Services) 4.0 (Termination of Galileo)			✓	Manufacturing & Operational	Direct & Spillover	NPV (4% discount rate), Duration >= 20 years	Not a complete assessment of benefits (the report focuses on benefits of policy options)	●●●○○
PwC (2001)	Galileo Global Navigation Satellite System	Lower estimate: 3.6 Upper estimate: 6.0			✓	Operational	Spillover	NPV (5.67% discount rate), Duration >=12 year	Lack of methodological detail. Limited coverage of benefits. Not possible to distinguish type of RoR.	●○○○○
GSA (2009)	Use of EGNOS in aviation		12.5	7.3	✓	Operational	Direct & Spillover	NPV, Duration>=22 years	Does not consider public investment in EGNOS.	●●●○○
NASA investments:										
Booz Allen Hamilton (2005)	NASA Geospatial Interoperability	0.2			✓	Operational	Direct	NPV, "Risk-adjusted"	Future benefits are not taken account of – estimates inconsistent with other studies.	●○○○○
NASA and Bay Area Economics (2010)	NASA Ames Research Centre	0.4 – 0.5	10.8		✓	Operational	Spillover	Leverage	Assumes that all leverage mentioned is private. Limited coverage of benefits and lack of methodological detail.	●●○○○
NASA (2010)	NASA activities in Florida	2.4			✓	Operational	Direct & Spillover	N/A	Limited coverage of benefits; lack of methodological detail.	●●○○○

Technopolis Group (2010)	Historic space exploration spin-offs NASA and ESA;	NASA spin-offs: 5.0 ESA spin-offs: 0.4			✓	Unclear	Spillover	N/A	Lack of methodological detail. Benefit phase is unclear.	●○○○○
Midwest Research Institute (1971)	Stimulated Technological Activity (NASA R&D)	6.1			✓	Operational	Spillover	Duration >=18 years, Deadweight, discounted costs	Relatively dated, assumptions around general R&D being representative of space R&D.	●●●○○
Midwest Research Institute (1988)	Stimulated Technological Activity (NASA R&D)	8.0			✓	Operational	Spillover	Adjusted for inflation, Duration >=18 years	Relatively dated, assumptions around general R&D being representative of space R&D.	●●●○○
Douglas Johnson et al. (1977)	NASA Tech Brief Programme	9.0			✓	Operational & Legacy	Direct & Spillover	Adjusted for inflation	Relatively dated. Lack of methodological detail.	●●●○○
MathTec (1977)	NASA's Technology Utilization Office (TUO)	9.0			✓	Operational	Unclear	NPV	Relatively dated.	●●●●○
Chase Econometric Associates (1976)	NASA R&D	13.0			✓	Operational	Unclear	Lag	Relatively dated, struggled to replicate results.	●●●○○
Hertzfeld (1998)	NASA Life Sciences R&D	19.3	6.5		✓	Operational & Legacy	Spillover	Adjusted for inflation, Leverage	Limited coverage of benefits; relatively dated	●●●○○
Others:										
Oxford Economics Forecasting (2006)	R&D in Aerospace (Europe, US and Canada)	0.7			X	Unclear	Unclear	N/A	No methodological detail, no reference to estimate provided.	●○○○○
Robinson and Westgaver (2000)	Ariane early launch vehicles	0.7			✓	Manufacturing, some operations	Direct & Spillover	Value added not included in the benefit to cost ratio	Methodological inconsistencies.	●●○○○
Hickling Corporation (1994)	Canada's long term space plan: Mobile Servicing System (MSS)	3.3			✓	Unclear	Direct & Spillover	N/A	Lack of methodological detail, cursory report.	●●○○○
British National Space Centre (2009)	Canadarm	5.0			X	Unclear	Unclear	N/A	Lack of methodological detail - no reference to estimate provided.	●○○○○
Technopolis Group (2010)	"Common R&D" policy	11.9			✓	Operational & Legacy	Direct & Spillover	Duration >=17 years, Lag (5 years)	Profile of benefits not completely clear.	●●●●○
EADS Astrium (2006)	UK Space-based research	99.0			✓	Unclear	Unclear	N/A	No methodological detail or reference to estimates provided.	●○○○○

Note: Multipliers are rounded to the nearest decimal. All Rates of Return constitute un-annualised, multi-year / aggregate Rates of Return; in some instances, an annualised Rate of Return was reported by the original studies. In these instances, we assumed for simplicity that the annual rate equals the aggregate, multi-year returns. Note that there is often a level of uncertainty as to the categorisation of benefits, but we have used our informed judgement in grouping them where possible.

* London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Source: London Economics' analysis of relevant literature

Benefit phase

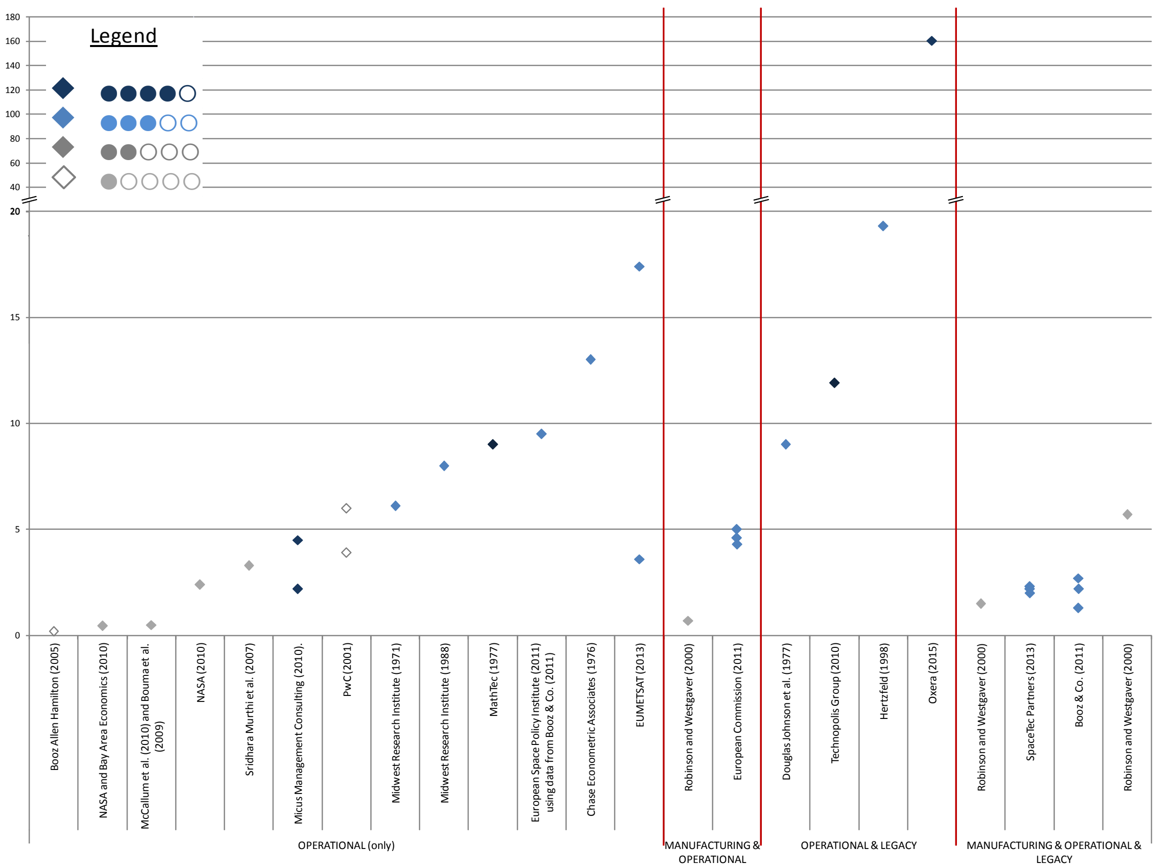
In order to facilitate a like-for-like comparison, Table 5 includes information on the particular benefit phase considered by each study, where available. Similar to the type of application, the phase during which an investment programme's benefits are measured constitutes another key factor contributing to the size of the public Rates of Return estimated throughout the literature.

The three benefit phases are not explicitly stated in literature and are based around subjective judgements. However, when inferable, these benefit phases represent distinct sections of a programme's lifetime, over which benefits can be generated:

- Manufacturing phase – the phase during which benefits from the manufacturing of necessary infrastructure occurs;
- Operational phase – the phase during which benefits from the day-to-day operation of the programme occurs;
- Legacy phase – the phase during which benefits still occur after the termination of the particular programme.

Note: Benefit Phase classification is subjective in nature, being based on our judgement following review of the study.

Figure 9 Public Rate of Return by Benefit Phase



Note: There exists a discontinuity in the graph to accommodate for Rates of Return above 20. * London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Source: London Economics' Analysis

The operational phase is included the most, with every study which implicitly allows for distinction between benefit phases reporting at least the operational phase. As manufacturing and legacy phases are only considered alongside operations, it is difficult to isolate them and come to a conclusion as to their effect on Rate of Return.

However, studies which quantify manufacturing benefits do not result in noticeably larger returns than studies which do not consider this manufacturing phase, as seen in Figure 9. This could be because:

- Benefits from the manufacturing phase compared to the operational phase across space investment programmes are relatively small;
- Other studies have included manufacturing benefits, just not explicitly stated so (in effect drowning out the manufacturing effect from those studies which have implied the inclusion of manufacturing benefits); or
- Manufacturing benefits are not sufficiently measured/stated for a relationship to be observed between inclusion of these benefits and Rate of Return.

When a legacy phase is considered for R&D projects, the return is high, with the three projects that include legacy benefits from space R&D investments having returns of 9.0 (Douglas Johnson et al. (1977)), 11.9 (Technopolis Group (2010)), and 19.3 (Hertzfeld (1998)). This is supportive of the widely-accepted view that R&D programmes can have an extended lifetime of valuable benefits, with (mostly) spillover benefits continuing to accrue in a legacy phase through technology transfer opportunities, spinoffs, and continuous near market innovation on existing technology.

However, when legacy benefits are considered for other projects there is no discernible difference in Rate of Return. This leads to a generalised conclusion that once a non-R&D programme is ended, with infrastructure no longer operational, only small, if any, benefits accrue.

Type of benefit

The type of benefit reported, whether direct, spillover, or both direct and spillover, does appear to affect the public Rate of Return, with studies that consider both direct and spillover benefits reporting a higher average public Rate of Return than studies which only consider spillover benefits, whilst just one study only consider direct benefits.

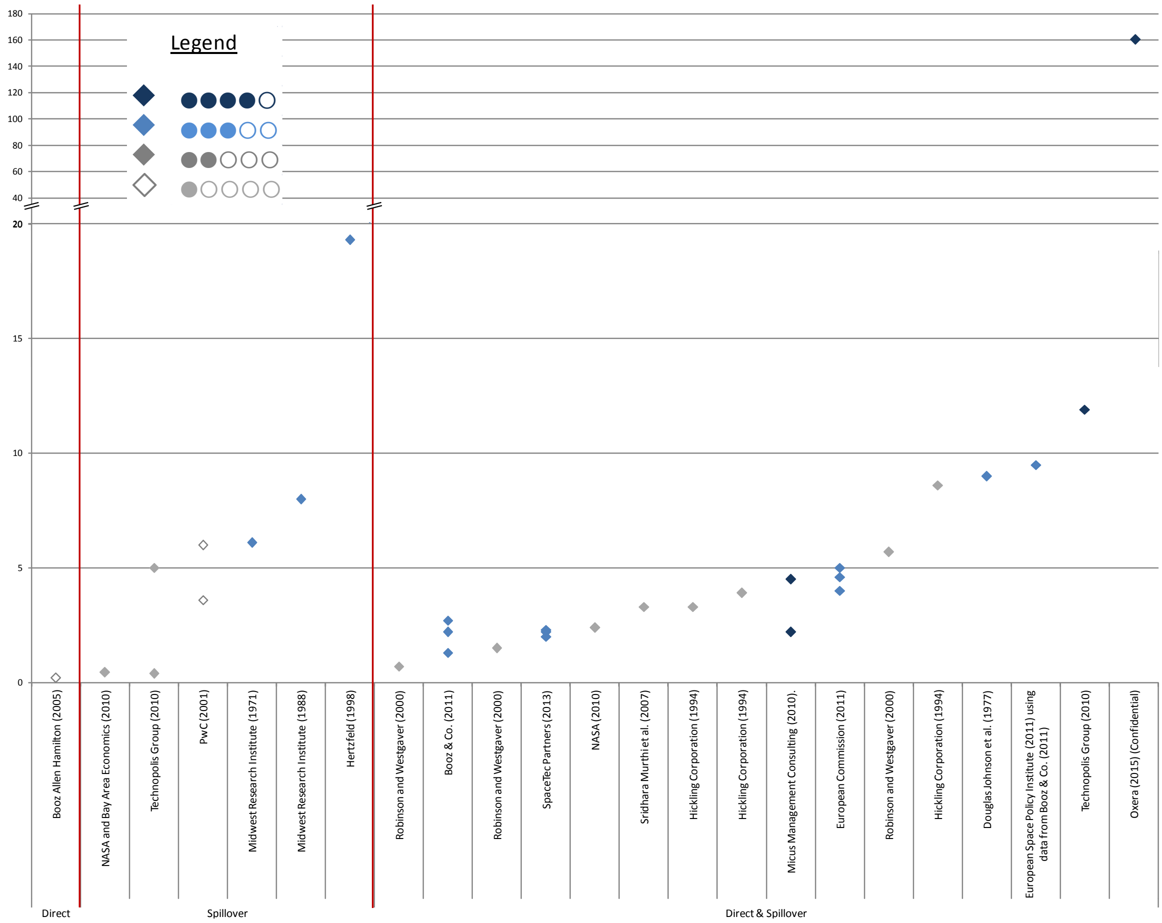
However, the lack of transparency in many of the studies has led to benefits being poorly defined, if at all, in existing literature. As with analysis on the benefit phase above, this section suffers from the need to subjectively infer the type of benefit, the fact that many benefits cannot be placed into a category due to the incomplete reporting of information within literature, and the consistent lack of complete quantification of benefits.

Having said this, assuming that studies which report both direct and spillover benefits would lead to a higher Rate of Return than studies which only report one of these makes intuitive sense. This relationship, which can be observed in Figure 10, also highlights the fact that the stronger studies, as assessed by the LE strength assessment, are unsurprisingly more likely to report the full range of direct and spillover benefits.

It is also the case that R&D investment programmes primarily consider spillover benefits, this is perhaps because the impacts of R&D programmes are often measured in terms of spinoff, or technology transfer opportunities, benefits from which do not necessarily accrue to the investing party. Removing R&D investment programmes from this type of benefit analysis would accentuate the extent to which studies reporting on direct and spillover benefits have a larger Rate of Return, compared to studies which just report spillover benefits.

Note: Benefit type classification is subjective in nature, being based on our judgement following review of the study.

Figure 10 Public Rate of Return by Type of Benefit



Note: There exists a discontinuity in the graph to accommodate for Rates of Return above 20. * London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Source: London Economics' Analysis

4.4.1 Lag

The reporting of lags is generally inconsistent and poorly standardised, making it hard to draw a conclusion from the literature analysed. Of 53 tables created from condensed studies, only 13 make use of, or mention, a time lag from the point of initial investment to the point at which benefits start to accrue. Of these 13, some lags are not even quantified and others are not for sole use within the space industry – hence the numerous "●○○○○" and "●●○○○" highlighted in our strength assessment.

A summary of these findings on lags is provided in Table 6, along with the programmes the studies are dealing with, caveats and weaknesses surrounding the study, and a strength assessment (of the parameter in question rather than the study as a whole).

Table 6 Summary of Lags for Space-Related Studies and Strength Assessment

Author(s) and year	Programme(s)	Lag	Methodological notes	LE Inferred?	Strength Assessment*
Robinson and Westgaver (2000)	Ariane early launch vehicles	10 years	Inferred lag, only applies to employment for the Ariane programme.	✓	●●○○○
Technopolis Group (2010)	Spinoffs and "Common R&D"	5 years ("Common R&D")	-	X	●●●●○
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)	No explicit lag used in study; however these lags are mentioned for a project to go from idea to commercialisation.	✓	●●○○○
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)	Aerospace lag, so not specific to the space industry.	X	●●○○○
Li (2012)	General R&D investment programmes	2 year (gestation lag)	A general lag, not specific to the space industry.	X	●○○○○
Schmidt et al. (2005)	Galileo	6 years	Galileo was expected to be implemented by 2008, and was under development since 2002.	✓	●●●○○
Oxera (2015) (Confidential)	[redacted]	[redacted]	[redacted]		[redacted]
Booz & Co. (2011)	GMES/Copernicus	0-2 years	0 year lag for immediate use benefits, 1 year lag for user uptake, 2 year lag for policy benefits.	X	●●●○○
European Commission (2010b)	EGNOS/SBAS use in Africa	5 years	-	✓	●●●●○
Chase Econometric Associates (1976)	NASA R&D	4 years (for GNP increases to occur) 2 years (for productivity increases to occur)		✓	●●●○○

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.	A time lag briefly mentioned, but not quantified.	X	●○○○○
The Tauri Group (2013)	All NASA investment programmes	A commercialisation lag mentioned, but not quantified	Lack of quantification makes use redundant.	X	●○○○○
PwC (2006)	GMES/Copernicus	3 years (Efficiency benefits) 6 years (European policy formulation benefits) 20 years (Global action benefits)	Assuming institutional and international cooperation.	X	●●●●○

Note: * London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Source: London Economics' analysis of relevant literature

The fact that less than one-quarter of studies use or mention a lag is very surprising, and could be explained by recognising that some studies model an immediate, but small, benefit return which increases as time progresses.

Using the information in Table 6, and particularly the "●●●●○" and "●●●○○" assessments, in conjunction with findings from consultations, it makes sense to consider two types of time lags. Firstly, a lag from initial investment to the point at which benefits from the construction of infrastructure for the project accrue, a construction or manufacturing lag; and secondly a lag from initial investment to the point at which benefits from exploitation, or the operations of the project, accrue. This construction phase lag is estimated to be 2 years, whilst the exploitation phase lag is estimated to be 10 years.

We had expected the literature to support a hypothesis of longer lags for more heavily infrastructure based projects, and shorter lags for projects that are more developed and closer to commercialisation. However, despite there not being enough empirical evidence to confirm or reject this, the intuition has been confirmed in the process of our consultations.

4.4.2 Deadweight

A quantitative figure for deadweight is not given in any of our studies that deal with returns to public space investment, but occasionally a qualitative assessment of a counterfactual scenario where the programme in question didn't exist is provided, and just once it has been possible to deduce a deadweight percentage.

Table 7 Summary of Deadweight for Space-Related Studies and Strength Assessment

Author(s) and year	Programme(s)	Deadweight	Methodological notes	LE Inferred?	Strength Assessment*
Robinson and Westgaver (2000)	Meteosat	A scenario where Meteosat would not exist would be "catastrophic" or have a "significant negative impact".	Not quantified	X	●●●○○
Midwest Research Institute (1971)	Stimulated Technological Activity (NASA R&D)	80%	It is assumed that this rate, originally from technological progress, can be applied to NASA R&D.	✓	●○○○○
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.	Not quantified	X	●●●○○
PwC (2006)	GMES/Copernicus	-	Deadweight indirectly mentioned, but not quantified.	X	●○○○○

Note: * London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Source: London Economics' analysis of relevant literature

Due to the very low number of studies that report deadweight, it would be inappropriate to attempt to aggregate them into one figure, or even draw a conclusion other than to say deadweight counterfactuals are rarely reported on in existing literature.

4.4.3 Benefit duration

Duration of benefits was one of the most poorly and inconsistently reported parameters throughout our review. The inherent value of benefit duration as a parameter, is in considering the time span for which benefits accrue (an important factor in determining the return from an investment programme) , which can then have uses in calculating annualised Rates of Return, or as an input itself into modelling Rates of Return.

However, the majority of studies forego the consideration of benefit duration, instead considering a particular window or timeframe that is conducive to their reporting. This creates inconsistencies in the literature between those sources which accurately report benefit duration and those which do not. Commenting on these timeframes would be misleading, and detract from the few instances where absolute benefit duration is considered, so Table 8 only shows those studies which have considered the actually duration of benefit lifetime.

Table 8 Summary of Benefit Duration for Space-Related Studies and Strength Assessment

Author(s) and year	Programme(s)	Benefit Duration	Methodological notes	LE Inferred?	Strength Assessment*
McCallum et al. (2010) and Bouma et al. (2009)	The 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.	Benefit duration is only considered on a yearly basis, with no mention of the actual duration in relation to the duration of the satellite system.	X	●●○○○
Douglas Johnson et al. (1977)	NASA Tech Brief Program (TSP)	Mostly 5 years, although "some net benefit streams [will] continue."	Doesn't consider duration of all of the benefits.	X	●●●○○
Oxera (2015) **(Confidential)**	[redacted]	[redacted]	[redacted]		[redacted]
Midwest Research Institute (1971)	Stimulated Technological Activity (NASA R&D)	18 years	-	X	●●●●○
Midwest Research Institute (1988)	Stimulated Technological Activity (NASA R&D)	18 years	-	X	●●●●○
Booz & Co. (2011)	GMES / Copernicus	17 years (2016 – 2033)	Full benefits are assumed to start in 2016, and under option B the programme will terminate in 2033.	✓	●●●○○
London Economics (2013)	Seventh Framework Programme (FP7) for GNSS	58% of project coordinators believe that benefits would last between one and three years.	Not a consensus opinion amongst the project coordinators.	X	●●●○○
UK Space Agency (2014a)	MetOP-SG	At least 20 years	Limited in detail	X	●●●○○
Chase Econometric Associates (1976)	NASA R&D	Productivity benefits not explicitly assumed to end.	Only considers productivity benefits.	X	●●○○○

Note: * London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Source: London Economics' analysis of relevant literature

Of studies which consider full benefits, a duration of at least 15 years is often seen, with some of the studies which report a shorter duration than this not considering all benefits or not considering benefit duration of relevant infrastructure systems. However, the number of times this parameter is reported is not sufficient to conclude a duration of 15 years is likely with any degree of certainty.

4.4.4 Leveraging/Crowding in

Leveraged investment, or crowding in, describes a situation where initial domestic public investment results in increased investment levels, whether from the private sector (domestic or foreign) or foreign public sector (ESA). This investment partnership between the domestic public sector and, often, the private sector, is an indicator of the possible commercialisation opportunities of a programme, with leveraged investment occurring more in theory when investing parties see a potential to deliver strong future returns.

Of relevant studies in our database, 10 mention leveraged investment, with 8 of these providing or implying a quantitative measure of leverage. The range of leveraged investment as a percentage of initial investment is between 12% - 312%.

Table 9 Summary of Leverage for Space-Related Studies and Strength Assessment

Author(s) and year	Programme(s)	Leveraged Investment (%)	Methodological notes	LE Inferred?	Strength Assessment*
Hertzfeld (1998)	NASA Life Sciences R&D	Domestic private crowding in: 312%	Percentage figure not calculated in report.	X	●●●●○
Åström et al. (2010)	Swedish National Space Technology Research Programme	Domestic private crowding in: 100% (1:1 ratio of public funding to leveraged funding)	-	X	●●●●○
Oxera (2015) **(Confidential)**	[redacted]	[redacted]	[redacted]		[redacted]
Faugert & Co Utvärding AB (2012)	Swedish National Space Board's National Earth Observation Programme	Domestic private crowding in: 15.5%	Implicit assumption that all "co-funding" is based on domestic private source.	✓	●●●●○
NASA and Bay Area Economics (2010)	NASA Ames Research Centre and NASA Research Park	Domestic public and private: 12%	No differentiation between what constitutes the public leverage and the private leverage.	✓	●●●○○
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%	Assuming that private sector pays for all equipage and procedures costs. In reality, this may be an upper bound.	✓	●●●○○
Warwick Economics and Development (2013)	Feasibility Studies Programme of the Technology Strategy Board	Domestic private crowding in: 39%	Across all the project types in the study, not just space innovation.	✓	●●○○○
SpaceTec Partners (2012a) and Knight et al. (2012)	EO and Copernicus Downstream Services for the Agriculture Sector	Some amount	Leverage not explicitly mentioned, but heavily implied as private investment wouldn't work without public provision of Copernicus.	X	●○○○○
PwC (2001)	Galileo GNSS	Some amount	It is hoped that a "significant proportion" of deployment would be privately financed.	X	●○○○○

Note: * London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Source: London Economics' analysis of relevant literature

When leveraged investment is reported, it is reported reasonably well, with the strength of the parameter relatively high. This is possibly due to the ease of which leveraged investment can be inferred (all that is needed is the investment breakdown), or perhaps because authors view it as an especially relevant parameter.

The effect of leverage on the Rate of Return is interesting. With leveraged investment present, not only are direct and/or spillover benefits generated, but the public Rate of Return multiplier is likely to be larger than a purely public investment, as the Departmental Expenditure Limit required to create the benefits is decreased. This is evidenced in assessed literature with two of the highest public Rates of Returns we have found (**[redacted]**; 19.3, NASA Life Sciences R&D, Hertzfeld (1998)) having benefitted from leveraged private investment (Table 9).

There is enough evidence to claim that public space investments can “crowd in” further private investments, and that it could positively affect the public Rate of Return in doing so, but not enough evidence to attempt to predict how much this leveraged investment will be for certain programme types.

In reality, it likely depends on the nature and the framework the investment, i.e. whether there is collaboration between public and private sectors in the planning of the investment, and the extent to which the outputs of the programme can be commercialised, with private companies more willing to join in an investment partnership with the public sector if they believe they can profit out of doing so. The flip-side of this is the pure space science, manned space flight and (non-prospecting) space exploration, where the private sector is unlikely to be willing to contribute any funding without a clear commercialisation opportunity – but rather, would seek a full economic cost recovery contract value.

4.4.5 Displacement/Crowding out

Displacement, or crowding out, describes a decrease in private sector activity, or an obstruction to potential private sector activity, in a market due to the size of, or an expansion of, public sector (government) expenditure.

Displacement isn’t explicitly reported on once in any of our relevant studies for space science and innovation, and of the 57 total summarised sources, only once has a figure for displacement been inferred; resulting in a negligibly small displacement figure (*see ESA Membership*).

Whilst this lack of information may appear to detract from the credibility of any conclusions drawn on this parameter, it is in fact telling in itself. If there were evidence of private businesses being crowded out by public expenditure, it would likely have been picked up on by at least one of our studies.

This lack of any substantial evidence of displacement in the space industry in literature reviewed, leads us to conclude that public space investments/expenditure do not crowd out private businesses. However, this is a generalised assessment of the parameter, as a conclusion drawn from an absence of evidence can only hold so much credibility compared to an evidence-based conclusion.

4.4.6 Leakage

Leakages can be defined as benefits that accrue from outside the geographic area the study is considering. All studies considered have a geographic location in which the programme has taken place or the investment originated, but they are not geographic-centric in the same sense the ESA Membership studies are. This leads to leakages being evenly more poorly reported for space science/innovation studies than for ESA Membership studies, with the one and only value of leakage we have in Table 10 below.

Table 10 Summary of Leakage for Space-Related Studies and Strength Assessment

Author(s) and year	Programme(s)	Leakage	Methodological notes	LE Inferred?	Strength Assessment*
PwC (2006)	GMES/Copernicus	41.5%	The study identifies benefits that occur within Europe, leakages are assumed to be 100% minus these.	✓	●●●●○

Note: * London Economics' strength assessment of the particular parameter in question: ●○○○○ (weakest) to ●●●●● (strongest). For full definitions, please see section 2.5.

Source: London Economics' analysis of relevant literature

Further, differences in the location of the study (whether America, UK, Europe or other) create inconsistencies in defining or inferring a leakage value, due to countries with more diversified space industries, or export-import barriers surrounding space technologies (e.g. ITAR), not needing foreign subcontractors, leading to differing leakage values for otherwise similar programmes.

For the above reasons, and because we only have one reported value, it would not be wise to attempt to estimate a general figure of leakages for space-specific investment programmes.

4.4.7 Wider benefits

Wider benefits are a reasonably well reported impact of space investment programmes, and can broadly be divided into **environmental benefits** and **social benefits**, although there are **other benefits** that don't quite fall into these criteria. Wider benefits are often qualitative in nature, although there do exist some quantitative estimates for them.

Environmental benefits

Environmental benefits positively impact natural resources on Earth, whether that is the atmosphere (through reduced carbon emissions), quality of soil (through reduced soil exhaustion due to improved farming techniques), quality of water (through water resource management), or forest density (due to improved forestry techniques).

Selected examples of environmental benefits reported in identified studies include:

- An improved response to climate change leading to AU$300m per year in economic benefits, due to Earth Observation usage in Australia (ACIL Tasman, 2010);
- The Global Earth Observation System of Systems (GEOSS) would provide cost savings related to algal blooms in the North Sea of €74,000 per week, for the 10 weeks of the year in which this rapid increase in algae occurs (McCallum et al., 2010, and Bouma et al., 2009);
- Between 15% and 20% of the damage from hurricanes (annual losses being between US$1.2–4.8 billion) can be prevented through sufficient advance warnings, using data from National Oceanic and Atmospheric Administration (NOAA) (Williamson et al., 2002);
- Use of the Aura satellite's Ozone Monitoring Instrument saved between US$24m and US$72m in avoided revenue losses due to unnecessary delays and aircraft damage costs after the Eyjafjallajökull volcano erupted in Iceland, April 2010, and the resulting ash

clouds devastated the global aviation industry. If the data from this satellite had been used as soon as the eruption started, then the total cost savings would have been around US$200m (Applied Sciences Program NASA Earth Science, 2012);

- Un-quantified benefits from increased accuracy of climate monitoring, from EPS/Metop-Second Generation (SG) meteorological satellite across Europe (EUMETSTAT, 2013)
- Undertaking forestry measurements using data from the Indian Remote Sensing (IRS) programme is around 80% more cost effective than the alternative, and IRS data also allows for a 40 percentage point increase in the success rate for finding groundwater and water management. Other environmental benefits from this programme include biodiversity characterisation and coastal zone mapping (Sridhara Murthi et al. 2007);
- The Copernicus Earth Observation programme would lead to environmental benefits including increased quality of air, more efficient land use, and improved quality of water resources (SpaceTec Partners, 2013);
- In a different study, Copernicus was said to result in a decrease in deforestation and soil exhaustion, as well as a reduction in nitrogen emissions into the soil (SpaceTec Partners, 2012a).

Social benefits

Social benefits accrue indirectly to the wider society or general public, and can come in many forms, including educational or inspirational benefits, benefits which directly improve the standard of living of the general populace, the provision of public goods, and decreased emergency response times/disaster relief.

Below is a selection of examples concerning social benefits:

- Meteosat satellites contributed 17% to the meteorological industry improvements of 5-10% from 1980-1990. These improvements led to around €11m/year of fuel savings and €30m/year of agricultural savings (Robinson and Westgaver, 2000);
- Many wider benefits to society and the medical establishment have been created in the form of spinoffs from NASA Life Sciences R&D (e.g. ability to quickly sterilise dental equipment, an instrument used for measuring pressure in the carotid artery, equipment that can analyse and separate gases in order to reuse chemicals used by the pharmaceutical industry as a more efficient way of manufacturing medicines). Other wider benefits from investment in NASA's Life Sciences programme include technology to cool helmets of racing drivers and motion sickness technology in use at theme parks (Hertzfeld, 1998);
- More than 27% of NASA's spin-offs are in the medical industry, improving healthcare techniques, whilst "Common R&D" will develop techniques to provide healthcare for an aging population and secure access to clean water around the world (Technopolis Group, 2010);
- The Malaria Early Warning System (MEWS) prototype through Earth Observation resulted in 105 avoided cases of Malaria in Botswana in 2008 and 2009, which, when applied across 28 sub-Saharan countries, shows potential of around 660,000 to 7 million malaria case reductions (Applied Sciences Program NASA Earth Science, 2012);
- The Swedish National Earth Observation programme stimulated international collaboration with Swedish research groups, and created projects based on Earth Observation, boosting the knowledge of Swedish graduates (Faugert & Co Utvärding AB, 2012);

- FP7-funded GNSS R&D created a positive impact primarily on public safety and security, and quality of life. It also led to an increase in public access to information and knowledge around GNSS, and made STEM careers more attractive (London Economics, 2013);
- EUMETSAT's EPS-Second Generation Programme is estimated to lead to cost savings from the protection of property and infrastructure of around €6.0 billion (2010 prices) (EUMETSTAT, 2013);
- Increased regional integration and economic development across Africa can be achieved with the development of an SBAS for use in aviation, or extending the coverage of EGNOS to Africa, as this would lead to 87% of African land being closer than 250km to an airport with Instrument Landing Systems (European Commission, 2010b);
- Impacts derived from the use of Copernicus could lead to more effective urban development programmes, as well as social inclusion and protection of particular groups, and increased public health and safety (SpaceTec Partners, 2013).

Other wider benefits

There are several other wider benefits mentioned in identified literature on a case-by-case basis.

Increased tax returns:

- ESA's Meteosat, Telecommunications and Ariane programmes had created tax revenues exceeding state contributions by 50% around 25 years after the projects were created (Robinson and Westgaver, 2000);
- Federal tax revenues were between 1.5 to 3 times the cost of the programme, meaning costs were recouped without even considering economic benefits (Douglas Johnson et al., 1977);
- US$448m in federal, state and local taxes were generated from NASA operations in Florida alone (NASA, 2010).

Wider employment effects:

- The US Commercial Space Transportation Industry indirectly impacts jobs in seemingly unrelated industries, e.g. 18,630 jobs in the Education industry, 78,590 jobs in the Accommodation and Food Services industry, and 2,130 jobs in the Mining industry (Federal Aviation Authority, 2010);
- There is an employment multiplier due to NASA activity in Florida of 2.26, meaning that each job for NASA in Florida (primarily at Kennedy Space Centre) generates another 1.26 full-time equivalent jobs (NASA, 2010);
- One employee in the general space industry can have an employment multiplier of 3.6, meaning an employee in the space sector can support 2.6 additional jobs in other industries (Booz & Co., 2011).

Leveraged access to space:

- Canadian investment in the successful Canadarm robotic arm programme resulted in Canadian scientists' access to the International Space Station for research purposes, as well as 14 flights of the Space Shuttle for Canada involving 9 Canadian astronauts (British National Space Centre,2009).

Summary of wider benefits findings

As mentioned numerous times previously, a recurring theme is that the wider benefits of space investments are wide, complex and varied and hard to value, though known to be significant.

Space technology is already woven into the fabric of modern daily life in the UK, becoming an integral part of the everyday lives of UK citizens and enabling an increasingly diverse range of commercial applications. Space is a catalyst for technological advancement and productivity growth, with expansive catalytic effects: all nine UK national critical infrastructures rely on space, and almost all sectors would be disrupted in the absence of space services.

As a result, when assessing the productivity-enhancing nature of many space applications, using a narrow lens to look at the benefits can often lead to significant underestimation of the benefits.

Due to the very nature of “wider” benefits, there exists a large range of impacts considered in this section, making it hard to draw conclusions from this analysis. However, two points in particular seem prevalent from analysing relevant literature:

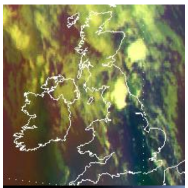
1) Environmental benefits come almost exclusively from investment in satellite infrastructure and the downstream use of satellite data. This specifically applies to Earth Observation and Remote Sensing satellites, which produce the bulk of environmental benefits in our literature. This may be indicative of Earth Observation and Remote Sensing programmes creating more environmental benefits, or it may suggest that these programmes simply benefit from more comprehensive literature.

3) Studies on investment programmes that deal with R&D spin-offs (particularly spin-offs from NASA R&D) appear to have the largest impact on the healthcare and medical industries. The fact this applies more to NASA than ESA or private companies, can be explained by considering the necessary investments in “in-space healthcare” to support a manned spaceflight programme; NASA’s manned spaceflight programmes have always been relatively larger than ESA’s, whilst private manned spaceflight, as of yet, hasn’t materialised.

5 Case Studies of selected UK public space investments

Eight case studies have been selected across the range of the UK Space Agency's activities to give applied insight to calculation of the return on public investment in projects under different auspices (UK-only, UK-focused ESA missions, large-scale international and EU missions). Three studies cover benefits **forecasted into the future**, while five studies cover benefits generated **'to date'**, so we classify the case studies in two different groups along this important distinction.

'Forecasted into the future' case studies



EUMETSAT and Weather forecasting

Image credit: EUMETSAT

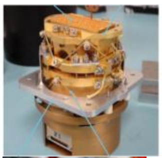
Copernicus (formerly GMES)

Image credit: ESA

EGNSS: EGNOS & Galileo

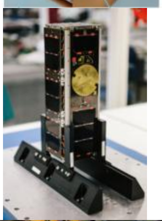
Image credit: ESA

'To date' case studies



Spectral and Photometric Imaging Receiver (SPIRE) in Herschel

Image credit: Griffin et al.



UKube-1

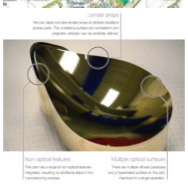
Image credit: Clyde Space

ExoMars

Image credit: ESA

KORE (Knowledge Observation Response Evaluation)

Image credit: ESA



Precision Optics

Credit: University of Durham

5.1 'Forecasted into the future' case studies

The case studies presented in this section are based on large-scale professional evaluations that consider the vast majority of lifetime benefits of the space infrastructure.

5.1.1 EUMETSAT & Weather forecasting[24]

[Redacted due to confidentiality of information]

[24] Based on recent (unpublished) analysis undertaken by London Economics.

5.1.2 Copernicus (formerly GMES)

Copernicus (formerly Global Monitoring for Environment and Security - GMES) is Europe's system for Earth Observation, which has been funded by the Member States of ESA and the European Union. The objectives of the system include "strengthening Earth observation markets in Europe with a view to enabling growth and job creation"; and "supporting the European research, technology and innovation communities."[25]

COST	Public investment: **£1.8bn** (1998-2030)	Inferred from **£1bn** in total from 1998 to 2020[26] plus **£0.8bn** derived at UK share (£600m) of 2014-2020 costs (€4.8bn) applied to 2021-2030 costs (€6.7bn). The result is in discounted 2010 prices.
	Private investment: **Very low**	Companies will do R&D to win work but no leveraged investment beyond that according to stakeholder consultation
BENEFIT	Direct benefit: **Low**	Due to limited UK industrial involvement
	Spillover benefit: **£1.6bn-£16.1bn** (2014-2030; discounted 2010 prices)	Cost reduction benefits to the **EU of €42.0bn**[27] **(~£29.3bn)** or cost reduction benefits to the **EU of €120bn**[28] **(~£85.6bn)**, both over 2014-2030.[29] Both estimates are based on the same raw input data, but the latter estimate takes into account "the interrelationship between environmental, economic and social ecosystems," which increases benefits by a factor of 2.9. As benefits are environmental cost reductions; apportioning to the UK follows geographic parameters i.e. share of EU land area: 5.5%; share of EU coastline: 18.8% and share of EU Exclusive Economic Zone (EEZ): 18.6%. As a sense check, it is noted that UK employment in EO companies amounts to 13.3% of EU total as per EARSC Industry Survey 2012.
	Other wider benefits:	■ *not available*
	Additional information:	■ Lag: **10 years** (pre-operational services); **16 years** (fully operational services) ■ Benefit duration: **7 year** lifetime of Sentinel satellite (benefit estimates assume replenishment until 2030) ■ Deadweight: **None**[30] ■ Displacement: **None**[31] ■ Leakage: *not available*
RoR	Aggregate:	■ Rate of return – Public return **1998-2030**: **[-0.11; 7.9]**[32] ■ Rate of return – Direct benefits **1998-2030**: *not available* ■ Rate of return – Spillover benefits **1998-2030**: *not available*

[25] European Earth monitoring programme; http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=URISERV:ev0026&from=EN

[26] Response from UKSA to Ofcom consultation on "The future role of spectrum sharing for mobile and wireless data services", http://stakeholders.ofcom.org.uk/binaries/consultations/spectrum-sharing/responses/UK_Space_Agency.pdf

[27] booz&co. (2011) Cost-Benefit Analysis of GMES, European Commission: Directorate-General for Enterprise & Industry

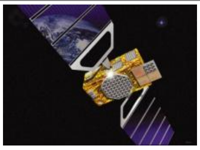
[28] European Space Policy Institute (2011) The Socio-Economic Benefits of GMES, A Synthesis Derived from a Comprehensive Analysis of Previous Results, Focusing on Disaster Management, http://www.espi.or.at/images/stories/dokumente/studies/ESP_Report_39.pdf

[29] Both conversions using prevailing exchange rate on 27 July 2015 from http://ww.xe.com; 0.71243 £/€

[30] "[U]ncoordinated provision of Earth observation services at Member State level would lead to duplications and would render the monitoring of the implementation of EU environmental legislation on the basis of transparent and objective criteria difficult or even impossible" quotation from: COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT *Accompanying the document* Proposal for a Regulation of the European Parliament and of the Council establishing the Copernicus Programme and repealing Regulation (EU) No 911/2010, SWD(2013) 190 final

[31] "The action proposed for the operational phase of GMES/Copernicus does not replace existing services at national or regional level, but rather complements and optimises them, coordinates them or ensures their continuity" quotation from: COMMISSION STAFF WORKING DOCUMENT IMPACT ASSESSMENT *Accompanying the document* Proposal for a Regulation of the European Parliament and of the Council establishing the Copernicus Programme and repealing Regulation (EU) No 911/2010, SWD(2013) 190 final

[32] The width of the range is caused by uncertain apportioning of benefits to the UK. The lower bound uses UK share of EU land area (5.5%) and the lower benefits estimate while the upper bound uses UK share of EU coastline (18.8%) and the higher benefits estimate.



5.1.3 EGNSS: EGNOS and Galileo

EGNOS is the European Geostationary Navigation Overlay Service, which provides additional performance of existing GNSS signals in terms of accuracy and integrity, with Galileo being Europe's independent, civilian operated GNSS. The objectives of the systems include an "aim to maximise the socioeconomic benefits of the European satellite navigation systems, in particular by promoting the use of the systems."[33]

COST	Public investment: **£1.7bn-£3.4bn**	Based on total costs of EGNOS and Galileo over 1999-2030 of €20bn-€30bn[34] UK share of ESA and EC GDP over 1999-2015 of 12%-16%,[35,36]
	Private investment: **Very low**	Companies will do R&D to win work but no leveraged investment beyond that according to stakeholder consultation
BENEFIT	Direct benefit: **£169m** (GVA)	**>€700m** (>£500m) of contracts awarded to UK companies (2007-2013),[37] GVA share of **33.7%** in space manufacturing[38]
	Spillover benefit: **£6.4bn-£9.2bn**	■ Based on communication from the European Commission saying benefits to the EU are in the range of **€60bn-€90bn** over **15 years** of Galileo service (from early services in 2016). Assuming the UK's share of EU GDP accurately reflects benefits in the UK, this would imply UK benefits of between **€9bn and €13bn**.
	Other wider benefits:	■ Benefits from the resilience offered by Galileo have not been quantified. Critical infrastructure operators could benefit greatly from the robustness of using multiple GNSSs. Similarly consumer applications currently incorporating both GPS and GLONASS would benefit from further GNSS access as current receivers treat inputs equally resulting in significant disruption if one GNSS fails.[39] ■ Benefits deriving from second generation of Galileo are not included.
	Additional information:	■ Lag: **10 years** (EGNOS certification in 2009, funding approved in 1999); **17 years** for Galileo ■ Benefit duration: **12 years** lifetime of Galileo satellite, replenishment of constellation assumed in cost and benefits estimates ■ Deadweight: **None** (Benefits are net of deadweight; GPS and GLONASS generate more than 90% of all GNSS benefits in the UK)[40] ■ Displacement: **None** (No private entity would undertake similar infrastructure projects) ■ Leakage: *not available*
ROR	Aggregate (1999-2030):	■ Rate of return – Public return **1999-2030**: **[0.93; 4.5]** ■ Rate of return – Direct benefits **1999-2030**: *not available* ■ Rate of return – Spillover benefits **1999-2030**: *not available*

[33] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:347:0001:0024:en:PDF
[34] Present value with base year 2014 and discount rate of 4% based on a compilation of multiple sources: ESA annual reports (1999-2007), EU Regulation 683/2008; EU Multiannual Financial Framework 2014-2020 (http://ec.europa.eu/budget/mff/index_en.cfm); EC Memo/13/718, "Galileo, Europe's GPS, opens up business opportunities and makes life easier for citizens" http://europa.eu/rapid/press-release_MEMO-13-718_en.htm; plus estimates related to FP6, FP7, Horizon2020 and other R&D support programmes alongside operating costs of ESSP, GSC, GSA, EC, ESA and other related bodies and private compliance cost of regulation.
[35] http://ec.europa.eu/eurostat/data/database [database: nama_10_gdp])
[36] Using prevailing exchange rate on 27 July 2015 from http://ww.xe.com; 0.71243 £/€
[37] UK Space Agency (2015) Annual Report 2014/15
[38] London Economics (2015) *The Case for Space 2015*
[39] Please see: http://www.bbc.co.uk/news/science-environment-26957569 and http://www.insidegnss.com/node/3979 for more.
[40] LE proprietary knowledge.

5.2 'To date' case studies

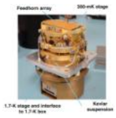
The case studies in this section only estimate current and past benefits, without quantification of future impacts. Future benefits of space infrastructure or commercialisation projects are inherently variable as the vast majority of benefits of space infrastructure are expected to accrue in the shape of benefits from use. Without detailed understanding of the future uptake of the services in question, a forecast of benefits cannot be performed robustly, but it should be noted that all these cases have the potential to fill a gap in existing markets, and in time generate substantial spillover benefits.

5.2.1 The KORE project

[Redacted due to confidentiality of information]

5.2.2 Spectral and Photometric Imaging Receiver (SPIRE) in Herschel

Herschel was an ESA mission funded in 1997/98, launched in 2009 and decommissioned in 2013 as planned. The UK (specifically Cardiff University) lead the development of the SPIRE instrument, intended to increase human understanding of the far-infrared range.



Cost	Public investment (1998-2016): **£16.5m**	Funding from Science and Technology Facilities Council and UK Space Agency
	Private investment: **£2m**	Salaries to academic staff involved in SPIRE across The Rutherford Appleton Laboratory; Cardiff University; The Mullard Space Science Laboratory; The UK Astronomy Technology Centre; Imperial College London; and The University of Sussex. Assuming 30% of FTE for six academics for ten years
Benefit	Direct benefits: **£5.6m**[41] contribution to GVA	■ STFC funding to analyse Herschel data: **£3m** (45 Post Doc Researcher Years) ■ FP7, HELP: €2.5m, of which **£891k** to Sussex, Cardiff and Cambridge ■ FP7, VIALACTEA: €2m, of which **£285k** to Cardiff and Leeds ■ FP7, DustPedia: €2m, of which **£427k** to Cardiff ■ Horizon 2020, CosmicDust: €1.8m, all of which to Cardiff University, **£1.3m** ■ FP7, SPACEKIDS: €2m, of which **£285k** to Cardiff University ■ GVA share assumed to be **90%** due to labour-intensive nature of projects.
	Spillover benefit: **£4.05m** GVA	■ Spin-out company, QMCi's sales: **£0.4m** (2008-2015: 100% SPIRE related) ■ Space Manufacturing average GVA:turnover ratio (Case for Space2015): **34%** ■ Feasibility contract for Chinese weather satellite: **£250k** ■ Feasibility contract for Airbus Defence and Space EO satellite: **£250k** ■ Follow-on contract from Airbus Defence and Space: **£4m**[42] ■ GVA share assumed to be **90%** due to labour-intensive nature of projects.
	Other wider benefits:	■ **200-300** undergraduate students in research-led teaching programmes and a **2,000-3,000** students in lecture-teaching programmes drawing on SPIRE ■ Around **10** Postgraduates directly involved in SPIRE and **50** relying on its data ■ UK ATC, proving flight heritage with SPIRE, which helped them win European leadership on the MIRI instrument for the James Webb Space Telescope ■ SPIRE science and technology injection of skilled and educated people into the workforce and thus contributed to UK productivity ■ Inspiration of young people to study STEM subjects ■ Greater understanding amongst the public of how the Universe works ■ 782 papers using SPIRE data (72% have UK authors; 24% are UK-led) [Feb 15]
	Additional information:	■ Deadweight: **Low** (little or none) ■ Displacement: **30% at most** (share of SPIRE team that was permanent staff) ■ Leakage: **Very low** (industrial), **medium** (benefits, e.g. non-UK papers- 28%) ■ Lag: **10 years** (from agreement to first outreach programmes) ■ Duration: **50+** years (due to STEM outreach and continuous benefits thereof)
RoR	Aggregate	■ Rate of return – Public return **to date**: **-0.54** ■ Rate of return – Direct benefits **to date**: **1.8** ■ Rate of return – Spillover benefits **to date**: **1.03**

[41] Using prevailing exchange rate on 27 July 2015 from http://ww.xe.com; 0.71243 £/€

[42] Both feasibility studies and follow-on contract awarded to consortium of Cardiff University, QMCi and Thomas Keating Ltd

5.2.3 UKube-1[43]

[Redacted due to confidentiality of information]

[43] Based on consultation with UK Space Agency.

5.2.4 ExoMars

ExoMars consists of two missions under the European Space Agency's Aurora programme, with an objective to develop and place a European rover on Mars. The UK's main involvement is leading the rover vehicle, two scientific instruments and a parachute sub-system.

COST	Public investment: **£205m**	UK Space Agency[44]
COST	Private investment: **Very low**	Companies will do R&D to win work but no leveraged investment beyond that according to stakeholder consultation
BENEFIT	Direct benefit: **£67.5m**[45]	**£200m** worth of business within the UK – at the average GVA:turnover share of space manufacturing of 33.7% (Case for Space 2015), this amounts to **£67.5m**
BENEFIT	Spillover benefit: **£21.9m GVA**[46,47] plus GVA derived from military contract and potential cost savings of **£100m per annum**	■ Buggies that could be used for airport transport, a market worth **€42.5m** (~**£30.3m**) could be addressed by UK companies, contributing **£10.2m** to GDP ■ Navigation sensors used in areas with no GNSS access, a market worth **€30m** (~**£21.4m**) could be addressed by UK companies, contributing **£7.2m** to GDP. ■ Software architecture used on Shannon class lifeboats (RNLI), a market worth **£10.4m** could be addressed by UK companies, contributing **£3.5m** to GDP. The software is also deployed on Warrior armoured vehicles resulting in **multi million pound** contracts. ■ Ultrasonic welding technique used to manufacture aluminium drinks cans could save 12% on raw materials (estimated at **£100m** by UKSA). The benefits could be shared between producers and consumers (if some savings are passed on). Rexam PLC (20% of world market) could have saved £242m on raw materials in 2014 if it had implemented the technique globally.[48]
BENEFIT	Other wider benefits arising from:	■ Applying control systems to water pipe clearing; ■ Using the miniaturised Raman instrument to investigate nuclear waste or characterise degradation of active ingredients in pharmaceuticals; ■ Re-using sterile environments created for ExoMars for other applications; ■ Mission technology used to extract petroleum from rocks and treat heavy oil; ■ Applying algorithms designed for ExoMars to a melanoma detection instrument that could improve efficiency; and ■ Using laser based technology to identify defects in cast steel production.
BENEFIT	Additional information:	■ Deadweight: **Very low**[49] ■ Displacement: **None**[50] ■ Lag: **8 years** (from mission started: 2005 to Shannon Class lifeboat: 2013) ■ Duration: **50+ years** (due to STEM outreach and benefits thereof) ■ Leakage: *not available*
RoR	On aggregate	■ Rate of return – Public return **to date**: **-0.56** plus further cost savings possible ■ Rate of return – Direct benefits **to date**: *not available* ■ Rate of return – Spillover benefits **to date**: *not available*

44 https://www.gov.uk/government/case-studies/exomars
45 Mars and Rosetta Spin out presentation received from UKSA.
46 Mars and Rosetta Spin out presentation received from UKSA.
47 Using prevailing exchange rate on 27 July 2015 from http://ww.xe.com; 0.71243 £/€
48 Rexam PLC (2015) Annual Report 2014, https://www.rexam.com/files/reports/2014ar/
49 Spillovers are generated in existing markets where the space derived technology fills a gap. (LE subjective assessment)
50 Given the scope, scale and complexity of the mission, it is an unlikely endeavour for private operators. (LE subjective assessment)

5.2.5 Precision optics

The Centre for Advanced Instrumentation (CfAI) in University of Durham's Physics department has the capability to manufacture Integral Field Units (IFU's), where a wide field of view is covered by multiple optical lenses. CfAI is the only facility in the UK that can manufacture and text complex shapes with surface form errors of 10-20nm and a surface roughness of 5-10nm. The facility was completed in 2006 as part of the CfAI programme on precision instrumentation for the James Webb Space Telescope.

COST	Public investment: **£1.6m**	Public investment University Science Research Investment Fund (SRIF), STFC rolling grant support, and Regional Development Agency funds
	Private investment: **£0.25m**	Research Excellence Framework 2014, Impact case study (REF3b)
BENEFIT	Direct benefit: **£0.2m**	Contract to produce instrument on James Webb Telescope of **£0.47m**. GVA share of **44.3%**[51]
	Spillover benefit: **£1.05m**	■ Additional sales of technologies developed for JWST (ophthalmics, automotive optics, microstructures for backlit displays and InfraRed optics): £2m. GDP contribution of **£0.89m** ■ Additional sales of technologies developed for JWST (new type of bifocal glasses that neither have a reading pane nor progressive focus): £0.35m. GDP contribution of **£0.16m**
	Other wider benefits:	■ *not quantified*, spectacles created using the JWST technology could be used to combat illiteracy in the Third World by removing the need of an educated professional prescribing glasses because the prescription of the glasses can be made variable. Further benefits could be the ability of several people to share one pair of glasses and thus reduce cost on NGOs.
	Additional information:	■ Lag: **2 years** ■ Benefit duration: *data relate to first **five** years of operation* ■ Deadweight: **Very low** (no existing capability before JWST, probably no similar development in near term) ■ Displacement: **Very low** (no existing capability before JWST, probably no similar development in near term) ■ Leakage: *not available*
RoR	Aggregate (benefits for first 5 years):	■ Rate of return – Public return **to date (5 years)**: **-0.375** ■ Rate of return – Direct benefits **to date (5 years)**: **-0.2** ■ Rate of return – Spillover benefits **to date (5 years)**: **3.2**

5.3 Summary of Case Study findings

Positive public Rates of Return are estimated for space missions that have several properties in common. The key property is that **large-scale, professional evaluation studies** have been performed on the missions and that these have taken into account **time periods well beyond the construction** of the infrastructure. EGNSS and Copernicus have generated very few of their promised benefits yet. Copernicus became operational in 2014 and Galileo is expected to provide initial capabilities by 2016.

[51] Sourced from The Case for Space 2015 for "Research and Consultancy" organisations

For all positive Rate of Return studies, we find that direct benefits and industrial ripple effects amount to a very small proportion of the total benefits. **Spillovers**, in the shape of producer and consumer surplus and externalities (e.g. knowledge transfers), on the other hand constitute the vast majority of impacts.

Conversely, the public Rate of Return for the studies that are estimated **'to date'** is always **negative**. However, as some of these programmes have not yet begun operations (e.g. ExoMars is yet to launch), this is hardly a surprise.

The market understanding and information required to accurately define the assumptions that are necessary to estimate these parameters is not readily available. This lack of information is a key reason underpinning the (currently assessed) negative Rate of Return. In the case of ExoMars, for example, sufficient take-up of just one of the technologies that have come out of the project could instantly convert the public Rate of Return from negative to positive, and mean benefits in a single year could cover all costs.

For ExoMars (which has not been launched yet), if the UK drinks can manufacturer Rexam plc were to adopt the ultrasonic welding technique developed for ExoMars across its global operations, the savings on raw materials in a single year would exceed the total cost of ExoMars to the UK by more than 20%. In addition, reduced global demand for aluminium could result in lower prices on other goods containing the metal and could also entail positive environmental externalities resulting from lower production requirements, which have **not been quantified**.

Similar considerations are relevant for the precision optics case, where the monetary value of improving literacy in the Third World by producing spectacles of variable prescription is **impossible to quantify**. Such spectacles would remove the requirement to have trained medical professionals prescribe glasses because they could be adjusted by the user, and further benefits can be imagined as the glasses may be shared between a whole family.

The purpose of the programme does also appear to impact the resulting Rate of Return across our case studies. The EU projects (Copernicus and EGNSS) both have clear objectives to maximise socio-economic impacts, and are therefore geared for exploitation with a clear strategy and significant funding available.[52] Conversely, most of the 'to date' missions for which a negative public Rate of Return is estimated are science missions at the core, where commercial and spillover benefits are prioritised.

Science missions have been assessed to have a **long duration**, with both SPIRE and ExoMars directly impacting the UK's productivity and innovation for at least the length of the careers of the students involved in the project. In fact, longer duration is likely for both missions as innovation by individuals involved could affect the industrial landscape of the UK.

The missions with aims of maximising socio-economic impacts generally tend to have **shorter duration** as the space assets (Galileo, Sentinel) only provide the core service during operational life, and the scientific impact of the missions is limited by construction.

In the majority of cases, **leveraged private investment** is very low.

[52] For Copernicus open and planned funding options at the EU level amount to €51m-€56m available in 2015 (http://www.copernicus.eu/main/tenders-grants [accessed 04/08/2015]) while €25m have been set aside for Galileo under Horizon2020 (http://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/calls/h2020-galileo-2015-1.html)

For the majority of case studies data on **leakage** has been unavailable. At the direct, industrial stage, it is likely that leakage occurs because some raw materials are simply not available in the UK. The findings from the case studies suggest that industrial leakage is low due to deliberate attempts to avoid it. At the benefits stage, on the other hand, leakage is much more likely. The UK's success at exporting space capabilities means that foreign users will benefit from its technologies. Furthermore, the scientific output of science missions is available to all researchers following an agreement between ESA and NASA,[53] which implies that UK instruments can generate benefits outside the UK. Although given the reciprocity of the agreement, the converse holds as well.

The **lag** of the benefit accumulation varies across the different missions studied. For the large-scale European missions (Copernicus, and EGNSS) the lag is approximated by the time from agreement to completion of the infrastructure in the range **9-17 years**, with Galileo spillover benefits forecasted to accrue the latest. The ESA science missions (SPIRE and ExoMars, which also includes ROSCOSMOS), the lag is at least **8-10 years** before benefits accumulate. The similarly commercially oriented precision optics case had a shorter lag of only **2 years**.

Considering the case studies by benefit phase is slightly misleading, due to the ongoing progress of all of the cases. ExoMars is firmly in the manufacturing phase with no benefits estimated for operation and legacy phases, which could partly explain its negative public Rate of Return. Estimates of benefits from EGNSS, and Copernicus consider both the manufacturing and operational phases, and have larger public returns than ExoMars.

Benefits accruing after project termination are considered for SPIRE and precision optics, as these programmes have finished, but the lack of quantification for future benefits means the legacy phase will be underestimated.

Table 11 Classification of Case Studies

Case	Sign on public RoR	Timeline	Scale (funding)	Purpose	Exploitation strategy	Evaluation method
GMES/Copernicus	Positive	Forecasts of future	30 European countries	Commercial/ spillover*	Clear and backed by substantial public funding	Large-scale professional studies
EGNSS: EGNOS & Galileo						
Spire in Herschel	Negative	To date	21 European countries	Scientific exploration	Low (if any)	Stakeholder consultation
ExoMars			22 European countries	Scientific exploration		Internal UKSA material
Precision Optics			UK progress on NASA-ESA collaboration	Scientific exploration	UK exploitation strategy via REF	REF 2014, Impact case study (REF3b)

Note: *: The objectives of the EU space programmes include (among others) the maximisation of socio-economic benefits.

Source: London Economics analysis

5.3.1 Lessons learnt from the Case Study process

In terms of accessing the necessary information to conduct a case study and calculate a Rate of Return, the following lessons have been learnt:

- When large-scale professional studies have been conducted we found that

[53] Based on stakeholder consultation.

- Almost all information is available, including an estimate of spillovers (though not comprehensive);
- Estimates consider time periods beyond the completion of the project/mission.

- When basing a case study on primary interviews and secondary sources we found:
    - Cost is accessible (mostly through written material, if not from interviews)
    - Direct benefits are tracked and available;
    - Direct and indirect supply chain industrial 'ripple' effects are accessible, but mostly through consultation (e.g. SPIRE);
    - Wider spillover effects are almost never available, and if categories are, they are not quantified, which would require assumptions on future uptake that are never made and rarely available as a point-in-time estimate;
    - The available time period is confined to 'to date.'

6 Conclusions and recommendations for future research

This research has identified, reviewed and synthesised the available evidence on the returns from public investments in space. The evidence base is useful in itself, but the last step is to conclude on the most appropriate assumptions to model the impact of public investments in space.

We compare the robustness and appropriateness of the newly-gathered space-specific evidence in view of estimates available for science and innovation generally from a recent comprehensive review of rates of return to investment in science and innovation prepared for the Department for Business, Innovation and Skills (Frontier Economics, 2014). We conclude with a recommended set of assumptions to be used henceforth as the default assumption for each impact parameter to model the impact of public investments in space.

Finally, based on the lessons learned and identified gaps and weaknesses in the space-specific evidence base, we present a range of recommendations for future research to improve evaluation of public (and private) investments in the space sector.

6.1 Recommended space-specific assumptions

6.1.1 Ideal: Investment-specific assumptions

In all circumstances, the ideal situation would be to have robustly estimated investment-specific information on the profile of expected impacts.

Such information could come from detailed research study undertaken to support the investment proposal, though it is unlikely that this would be comprehensive – some parameters are more easily assessed (e.g. the lag is directly related to the duration of the construction/manufacturing stage, plus risk of slippage) than others (e.g. spillover benefits are almost impossible to identify and value fully in advance). In all cases, it is important to evaluate the robustness (appropriateness should be guaranteed by their specific nature) of the investment-specific assumptions against the space-specific evidence and the generic science and innovation estimates before use.

6.1.2 Rates of Return

Rates of Return estimates are mostly derived from our literature review as consultees were, in general, unable to give figures for returns, and case studies were not numerous enough.

Space-specific evidence	**Evaluations of ESA membership** **Public:** In general, analysis in the reviewed studies has been limited to the direct (industrial) benefits, with little or no valuation of spillover benefits. Adjusted for methodological robustness of evaluations, our analysis suggests a (direct-only) rate of return of **3.0-4.0** per £1 of public investment. The period of analysis varies (either a single year or an aggregate of years) but, assuming constancy of annual Member State contributions, this rate can be used as either a lifetime or an annual rate of return. However, this return is an **underestimate** due to the exclusion of wider 'spillover' benefits, though it can be used as a starting point for further analysis examining the wider societal impact of ESA membership: Drawing on evidence (Frontier Economics, 2014),that spillover returns from public investment in science and innovation are typically 2 to 3 times larger than private/direct returns, which studies often focus on,

we may estimate typical returns as **£3-£4 (direct) plus £6-£12 (spillover)** per £1 of public investment.

Spillover: N/A*

Direct: N/A*

*Reviewed literature considers investment in this scenario to be in the form of Member State contributions to ESA, so there is no room for leveraged investment or findings on direct or spillover Rates of Return.

Evaluations of space science and innovation investments

It is important to recognise that all Rate of Return estimates indicated below constitute un-annualised, multi-year/aggregate Rates of Return. Also note that evidence (Frontier Economics, 2014) suggests that spillover returns from public investment in science and innovation are typically 2 to 3 times larger than private/direct returns, which reviewed studies typically focus on. This ratio is used to upgrade direct/private return estimates below.

Public: The public Rates of Return to space science and innovation types of public space investments display a high degree of variation. A key differentiating factor underlying this variation is different space applications:

- **EO:** The empirical evidence provides conservative estimates of the returns to Earth Observation programmes ranging from approximately **2.0-4.0**, covering direct/private returns almost exclusively. With complete benefit consideration, the true return from EO programmes is likely much larger than this range, which suffers from underestimates due to unquantifiable benefits and incomplete reporting. Based on the direct : spillover ratio, we may estimate typical returns as **£2-£4 (direct) plus £4-£12 (spillover)** per £1 of public investment in EO.
- **Telecoms:** The literature reviewed displays a significant degree of variation in the public Rate of Return to investments in the telecommunications sector. Based on the few studies analysing benefits from telecoms investments, it appears sensible to estimate a return per £1 of public investment of between **6.0 – 7.0**, covering direct/private returns. However, due to the inherently commercial nature of telecommunications, a highly leveraged investment programme in a near-market telecoms innovation will result in returns significantly larger. Furthermore, although providers are very good at extracting and commercialising the value of satellite communication, there will still be additional spillover benefits. Using a reduced (1-2 : 1) direct : spillover ratio, we may estimate typical returns as **£6-£7 (direct) plus £6-£14 (spillover)** per £1 of public investment.
- **Navigation:** Literature-based sources generally expect that the social returns to investments in satellite navigation might range between **4.0 – 5.0** per £1 of public investment. As satellite navigation investments tend to include a heavy public contribution (owing to the public good characteristics of some services), evaluation studies tend to include some estimate of spillover benefits, but the coverage remains limited. Using a reduced (1-2 : 1) direct : spillover ratio, we may estimate typical returns as **£4-£5 (direct plus partial spillover) plus £4-£10 (spillover)** per £1 of public investment.
- **NASA programmes:** While not forming a recommended parameter, NASA programmes provide useful information for Rates of Returns from public space investments. Literature suggests a return per pound of public investment of between **6.0 – 9.0** for NASA investment programmes.

Spillover: N/A*

	Direct: N/A* *A lack of transparency and narrow breadth of study in most existing literature prevent us from estimating direct and spillover Rates of Return.
Recommended space-specific default	**Evaluations of ESA membership** ■ £3-£4 (direct) plus £6-£12 (spillover) per £1 of public investment **Evaluations of space science and innovation investments** ■ **Earth Observation:** £2-£4 (direct) plus £4-£12 (spillover) per £1 of public investment ■ **Telecoms:** £6-£7 (direct) plus £6-£14 (spillover, lower as commercial) per £1 of public investment ■ **Navigation:** £4-£5 (direct plus partial spillover) plus £4-£10 (spillover) per £1 of public investment

Recurring evidence in the literature review (in particular, but not exclusively, in relation to membership of ESA), and interviews with several consultees, has highlighted the existence of a **cumulative duration effect** within space investment programmes. These information sources suggest quite consistently that the longer a membership of a space-specific organisation (e.g. ESA), or the longer a programme continues with consistent funding (e.g. NASA R&D, UK space science), the greater the Rate of Return. Put simply, there appears to be a positive relationship between project duration and the size of the returns from that project.

Further, a nation-wide investment programme in a small, undiversified, space industry will require the imports of technology and knowledge (i.e. leakages), reducing domestic benefit and the Rate of Return; as compared to investment by a larger nation where these leakages wouldn't occur. This can extend to differences in the Rate of Return between investments placed by ESA compared to NASA, with literature suggesting NASA investments lead to a higher Rate of Return. This can be explained by considering the age of NASA compared to ESA (the Duration Effect as above), NASA's larger budget leading to more capability in the US space-industry supply chain, or potential inefficiencies caused by ESA investments being required to obey a rule of geo-return.

6.1.3 Leverage

Owing to the fact that leveraged private investment is often a condition of the grant of public investment funding (e.g. matched funding under ARTES), it is likely that the most appropriate and robust information on leverage will be specific to the investment being evaluated – and available to the evaluator in the form of the proposal or business case.

Space-specific evidence	**Evaluations of ESA membership** N/A – no evidence to confirm or contradict the science and innovation assumptions. **Evaluations of space science and innovation investments** Evidence exists that public space investments did leverage private investment, boosting the public Rate of Return. However, there is not enough evidence to predict how much leveraged investment would be for certain programme types. In reality, it depends on the nature of the programme (e.g. the extent to which the outputs of the R&D/innovation can be commercialised will influence private companies' willingness to invest). Therefore, it seems sensible to use investment-specific information in the first instance and, where this is not available, to split 'near-market innovation' (using

	the generic estimate) and 'pure science' (using an assumption of no leverage) investment types. There is not enough information available concerning leveraged investment from a foreign source to support any conclusion on a space-specific parameter.
Recommended space-specific default	**Evaluations of ESA membership** ■ **Leverage:** N/A ■ **Foreign leverage:** N/A **Evaluations of space science and innovation investments** ■ **Space science, (non-prospecting) exploration and manned spaceflight:** **Leverage:** No space-specific, leveraged private investment found, an adoption of programme-specific knowledge is recommended. **Foreign leverage:** No space-specific, foreign leveraged private investment found, an adoption of programme-specific knowledge is recommended. ■ **Near-market innovation:** **Leverage:** No space specific evidence found.

6.1.4 Lag

If the investment being evaluated is a near-market innovation, with a clear commercialisation plan, it is likely that the most appropriate and robust information on the expected lag for direct benefits (to the investing and/or innovating organisation) will be investment-specific – and available to the evaluator in the form of the proposal or business case. In the absence of such information, and as a useful validation of such information, the following assumptions should be adopted.

Space-specific evidence	**Evaluations of ESA membership** As discussed, studies tend to consider Member State contributions and the ESA contract sum to be constant, resulting in no lag. Just two studies track contributions and benefits over time (i.e. a 'follow-the-money' approach); the lag applied for benefits to commence in this instance is 3 years in both cases. **Evaluations of space science and innovation investments** The reporting of lags is generally inconsistent and poorly standardised in the literature, making a conclusion hard to draw. Of 53 summary tables, only 13 refer to a time lag from initial investment to commencement of benefits. We had expected the literature to support a hypothesis of longer lags for more heavily exploratory or deeper development infrastructure-based projects, and shorter lags for technologies that are more developed and closer to commercialisation. However, despite there not being enough empirical evidence to confirm or reject this, the intuition has been confirmed in the process of our consultations. Based on these consultations, it is recommended to split investments by objective: pure science and exploration (e.g. instrument development; space craft or rover design, build and launch); infrastructure formation (e.g. constellation of satellites); and innovations of existing technologies (e.g. application development). It is also proposed, based on consultation findings, to adopt an approach based on phases [construction (manufacturing), exploitation (operational and legacy)] for pure science and exploration, as benefits may be expected during the construction phase

	(e.g. novel materials or techniques applicable to other industries) as well as the exploitation phase (e.g. value-added applications of data and knowledge).
Recommended space-specific default	<u>**Evaluations of ESA membership**</u> ■ **Lag:** 3 years, if adopting a 'follow-the-money' approach (space-specific = generic). <u>**Evaluations of space science and innovation investments**</u> ■ **Pure science and exploration:** **Construction (manufacturing) phase:** 2 years (space-specific). **Exploitation (operational and legacy) phase:** 10 years (space-specific). ■ **Infrastructure formation:** 5 years (space-specific). ■ **Innovations of existing technologies:** 2 years (space-specific).

6.1.5 Benefit duration and depreciation

The space-specific empirical evidence typically adopts a simple 'window of benefits' approach, which certainly has its limitations and flaws, but this mismatch makes inferring assumptions from the empirical evidence more difficult.

If the investment being evaluated is a near-market innovation, with a clear commercialisation plan, it is likely that the most appropriate and robust information on the expected **duration of direct return** (to the investing and/or innovating organisation) will be investment-specific – and available to the evaluator in the form of the proposal or business case. The **duration of spillover return** is much more difficult to estimate *ex ante*, so it is recommended to use the following default assumptions.

Space-specific evidence	<u>**Evaluations of ESA membership**</u> **Benefit duration:** Studies typically only calculate benefits for a certain time window (in some cases, a single year), if at all, rather than the full duration of one or more benefits from a particular starting point – but again, this is an artefact of the methodology rather than a reflection of reality. **Depreciation:** No study considered depreciation of the ESA membership effect – in fact, a number of studies repeated in a later time period suggest that the return tends to increase over time with a Member State's continued membership of ESA. However, the appreciation of the returns to ESA membership will only continue as long as ESA membership contributions continue. If ESA membership were to cease, it is likely that there would be depreciation in returns over time. Unfortunately from an empirical evidence perspective, there has not been a study of such a case to date so it is not possible to estimate the rate of depreciation. As ESA membership combines elements of science and innovation investment, it is recommended to use a combination of the generic science/innovation estimates. <u>**Evaluations of space science and innovation investments**</u> **Benefit duration:** Duration of benefits was one of the most poorly and inconsistently reported parameters throughout our review - the majority of studies simply analyse a particular window or timeframe. Of studies which consider full benefits, a duration of at least 15 years is often seen, with some of the studies which report a shorter duration than this not considering all benefits or not considering benefit duration of relevant infrastructure systems. However, the number of times this parameter is reported is not sufficient to conclude a duration of 15 years is likely with any degree

	of certainty. For this reason, it is recommended to use the below assumptions based on the generic science and innovation evidence. **Depreciation:** It is recommended to use the below assumptions based on the generic science and innovation evidence.
Recommended space-specific default	<u>**Evaluations of ESA membership**</u> ■ **Benefit duration:** Duration of ESA membership plus the lag of 3 years. ■ **Depreciation:** **Period of ESA membership plus lag:** 0% per annum (space-specific). ***after which:*** **Period of depreciation:** No space specific evidence found. <u>**Evaluations of space science and innovation investments**</u> ■ No space specific evidence found.

6.1.6 Wider benefits

Wider benefits are inherently varied in nature, and can be sub-categorised as benefits that impact on the environment, society, or a third, loosely-defined category if they do not fall into these two (e.g. impact on tax receipts, employment multipliers). Environmental benefits accrue mostly from satellite (especially Earth Observation & Remote Sensing) programmes, either indicative of the fact that these sorts of programmes do, in fact, create more environmental benefits, or instead that they enjoy more comprehensive literature. Further, in studying the social benefits sub-category, it is apparent that spinoffs from investment programmes mostly affect the **healthcare** industry, which can be explained by the large amounts of R&D necessary to support manned spaceflight.

6.1.7 Displacement (crowding out)

Displacement is not explicitly reported once in any of the studies reviewed, and many consulted stakeholders believed that public investment has the opposite effect (to leverage private investment, or crowding-in). Nonetheless, the absence of references to displacement is suggestive that public space investments do not crowd out private businesses.

6.2 Recommendations for future research

Our review has highlighted a number of important limitations, caveats and gaps across the evaluation literature on the returns to public investment in space. Based on these insights, we have derived a number of recommendations for future research to complement the existing literature and facilitate a deeper understanding of the channels, nature, extent, influences, and value of returns to public space investments.

Our recommendations can broadly be categorised into three themes:

- Recommendations to improve and standardise the methodological approach used for future analyses;
- Suggestions to widen the scope of future analyses to ensure comprehensive coverage of all relevant costs and benefits; and
- Propositions on how to maximise the use of the evidence base on the returns to public space investments and facilitate continuous learning from future analyses.

6.2.1 Methodological recommendations

Our literature review identified a range of important methodological discrepancies across studies (e.g. differences in terminology, estimation methodology, data sources/collection, impact metrics). These significant underlying differences render it difficult to draw any useful and like-for-like comparisons of Rate of Return estimates derived across different strands of the literature, and even across individual studies within each individual strand. Hence, it is recommended to establish a set of **internationally agreed and accepted standards** (most likely led by the OECD or International Astronautical Federation Space Economy Technical Committee) for estimating the returns to public space investments to include:

- A unified set of terminology and definitions used throughout public space investment evaluations;
- A standard typology of programme phases and impacts;
- A standardised definition of the space value chain;
- An agreed set of output metrics and measures; and
- A common methodological approach towards evaluating costs, benefits and output metrics.

All future researchers should be encouraged (and required in the case of publicly tendered contracts) to follow such an agreed framework, so as to ensure comprehensive coverage, consistent quality of the research, and facilitate comparisons of findings across the literature (e.g. along the lines of the approach underlying the Research Excellence Framework for assessing the quality of research undertaken in UK Higher Education Institutions).

In addition, the existing literature highlights the importance of:

- Establishing cost-effective data collection mechanisms which are targeted at conducting economic evaluations, and facilitate the comprehensive quantification of benefits. In this respect, a **dedicated UK Standard Industrial Classification of Economic Activities (UK SIC) Code** for the space industry would make a key contribution to measuring the benefits associated with public space investments.
- **Consistent and transparent reporting of research outputs**, including detailed explanations of the underlying assumptions, methodology and typology employed by each evaluation. Apart from providing methodological clarity and facilitating learning from existing analyses, a commitment to more detailed reporting will highlight the scope, limitations and caveats of each analysis, thus providing an important measure of self-evaluation and transparency.
- Establishment of a **causal link between the public space investment under consideration and the estimated net benefits**. As outlined above, the vast majority of studies do not explicitly consider deadweight (i.e. the extent to which the benefits measured are *additional* to what would have happened in the absence of the particular public investment) or displacement effects (i.e. the decrease in private, third sector and foreign public investment as a result of the domestic public investment). Analyses of these effects, and the establishment of causality between public space investments and benefits, are paramount in informing the design of future public policies and investment programmes.

6.2.2 Scope of analysis

Review of the available evaluation studies highlights the need to extend and deepen the scope of analysis of public space investments, such as:

- Adopt a **long-term evaluation strategy for public investments in space programmes** and projects (as has been recently announced by the UK Space Agency[54]), intended at measuring benefits and costs in a continuous and consistent manner throughout a project's entire investment lifecycle. It is considerably easier and more accurate to collect information as the investment proceeds rather than retrospectively try to piece together what happened. The long-term approach should also include a requirement for all such investments to be subjected to *ex ante* and *ex post* evaluation, to allow for comparisons in estimates across the lifetime of each investment. These comparisons of estimates over time will also provide crucial insights into the presence of any optimism bias (i.e. under-valuing the investment costs required, and over-valuing the benefits) expected in *ex ante* impact assessments.
- **Quantify the 'unquantified benefits'** using dedicated research to better understand the extent, nature and value of wider impacts and spillover benefits associated with public space investments. Such impacts are currently excluded from benefit valuations and are only being described qualitatively, which leads to the systematic underestimation of the true returns to public space investments. By drawing on the findings of additional targeted research, future evaluations could give a fairer estimate closer to the true rate of return; and reduce any artificial disparities between space applications driven by the quantifiability of wider benefits (e.g. Earth Observation vs. Satellite Telecoms).
- Undertake additional research into the **factors driving the returns to space investments** (e.g. focusing on the optimal mix of public and private investments, the relative effectiveness of different modes of public investment (i.e. procurement, loans, grants, guarantees etc.), and non-financial support (e.g. regulation or business incubation programmes)), to inform future policy and programme design.
- Additional research to better understand the **time profile and dynamics of benefits**, and influencing factors thereon, would be very valuable. The evidence suggests that different types of benefits come on-stream at different times (e.g. direct benefits may start sooner, whereas spillover benefits may start later, but last longer), but our understanding of the lag for different types of benefits is weak, and how this varies by type of investment (e.g. benefits of a near-market innovation incubation programme may start quickly but be limited to innovative applications of an existing technology, whereas benefits of a science or exploration mission requiring development and testing of new technologies may take longer to start, but give rise to a new field of applications of the novel technology for much longer). The rate of depreciation of the intellectual property created over time is also largely unknown for space technology.

6.2.3 Evidence base

Finally, in terms of making maximum use of and facilitating continuous learning from the existing literature and future analyses to come, we would propose to:

[54] UK Space Agency (2015) UK Space Agency evaluation strategy, Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/456513/Evaluation_Strategy_August_2015_FINALv2.pdf

- Establish a **comprehensive and regularly updated database and repository of evaluation evidence** of space projects and programmes. This proposition is based on the above-mentioned difficulty in finding and accessing some of the relevant literature, as well as the fact that relevant analyses of the returns to public space investment are relatively sparse. An accessible database of this literature would enable a complete outlook on existing studies in the field, and be of use to a range of stakeholders (including future researchers, potential private investors, national space agencies, Central Government, etc.), informing future analyses and policy decisions while reducing stakeholders' search costs.
- **Increased use of benchmarking of returns against alternative investments**, to inform a better understanding of the range of estimates available on the returns to public space investments.
- Use existing literature and conduct **a series of new evaluation studies for individual space programmes**, projects or investments, subsequently collating these into a **meta-analysis** in order to be able to provide an **overall Rate of Return per £1 of public investment spent.**

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