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Assessing the full effects of public investment in space☆

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ABSTRACT

Many space-related impact studies have been carried out in the past, but there is no conclusive, comprehensive evaluation of the economic and social effects of public investments in space. Such evaluations are not easy to perform, for several reasons: the space sector is not a recognised category in official statistics; social benefits, which are likely to be very important, are hard to assess; and impacts from R&D are complex and occur in the long term. However, important steps can be made towards better evaluation of impacts. The full set of impacts of space investments may be simultaneously evaluated from both a 'bottom-up' and a 'top-down' perspective. In the bottom-up perspective, each effect is measured separately, while the top-down perspective provides a framework for integrating the effects. Although both perspectives have their own advantages and drawbacks, combining them yields both detailed and integrated results. Our discussion of the bottom up approach starts by identifying an extensive list of impacts. Next, data availability issues and methodological improvements are identified, leading to recommendations on programmes to collect data and perform case studies. Finally, suggestions are made for presenting impacts in the form of a scoreboard. The core of the top-down evaluation methodology proposed is social cost benefit analysis. Effects are weighted, where possible, on the basis of observed market prices or other estimations of monetary values. For effects that are hard to measure or monetize, multi-criteria analysis can be applied using surveys and expert opinion. Our core recommendations are to clearly define the space sector, to collect additional data, and to use improved methodologies. Social, strategic and environmental impacts deserve special attention, aiming at a more comprehensive coverage of impacts. Comprehensive evaluations can contribute to more upport for space expenditures.

1. Introduction

In 2012, two research reports were completed that designed methodologies to evaluate the economic and social benefits of public investments in space (Hof et al. [1]; Simmonds et al. [2]). These reports resulted from parallel studies, commissioned by ESA, and carried out respectively by SEO Economic Research in the Netherlands, and Technopolis Ltd. in the UK. The aim was to provide suitable, academically satisfactory methodologies for undertaking comprehensive assessments of the economic and social effects of public investments in space related activities in Europe. This article summarises results from these two studies.

Space systems are becoming increasingly important to society, with applications in, for example, consumer products, manufacturing industries, professional and government services, intelligence and defence. Major sectors of the economy and many citizens depend on space systems and space-based technologies. Many of the services we take for granted in everyday life depend on space to function properly, from telecommunications to television and from weather forecasting to global financial systems.

At the same time, in an economic crisis, almost every government outlay comes under scrutiny and space investments are no exception. When space investments are co-funded by many different countries, things become even more complicated, as each

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country obviously has a particular interest in the impacts on its own economy. However, evaluation of publicly-supported space activities has received much less attention than evaluation in other policy areas, such as transport, education or health. This is also the case if we compare space to other areas with extensive public support for science and R&D such as the EU Framework Programmes for research and technological development.

Many space-related impact studies have been carried out in the past, but these have a rather variable scope, ranging from:

- Individual countries, e.g. British National Space Centre [3]; Danish Agency for Science [4]; Davies [5]; Department for Business Innovation and Skills [6]; Ecorys [7]; FAA [8]; Futron [9]; Hallonsten et al. [10]; Goss Gilroy Inc. [11]; Oxford Economics [12]; RPA [13]; The California Space Authority [14]; UK Space Agency [15].
- Specific economic sectors, e.g. ASD-Eurospace [16]; Bullock et al. [17]; ESA [18]; European Commission [19]; Micus [20]; Patureau et al. [21]; Pira [22]; SIA [23]; VEGA and Booz Allen Hamilton [24].
- Space programmes, e.g. Booz & Co [25]; European Commission [26]; Hertzfeld [27,28]; NDP Consulting [29]; NIAG [30]; PWC [31]; PWC, ESYS, DNV [32]; Sadeh [33]; Schnee [34]; Smith et al. [35]; Tavana [36].
- Space centres, e.g. NASA [37–40].
- Macroeconomic studies which often work with rather general multipliers, e.g. Oxford Economics [12]; Department for Business Innovation and Skills [6]
- Microeconomics research which is often very informative but has a rather narrow focus (e.g. Amesse et al. [41]; Bach et al. [42]; Bach, Cohendet and Schenk [43]; Brendle, Cohendet and Larue [44]; Cohendet [45]).

There is no conclusive, comprehensive evaluation of the economic and social effects of space activity, and in particular the social effects of space investments are rarely studied. This is unsatisfactory, as this may be where space has a comparative advantage over other sectors competing for public investment. Moreover, the existing studies use different, incommensurate, and incomplete data, and therefore cannot be aggregated to provide a coherent, overall picture of the impact of the space sect OECD [46] asserts that “Many space-based services have positive impacts on society, but issues concerning economic data definitions and methodologies have to be resolved to allow the benefits to be identified and quantified more precisely”.

We recognise that the diversity of impacts of space investments renders meaningful quantification of all of them difficult or impossible, a situation common to the evaluation of public sector investments generally (see e.g. Stiglitz [47]). Our objective in this paper is to attempt a systematic articulation of the impacts and to put forward our assessment of the most appropriate methodologies for their analysis and evaluation.

Section 1 describes the broad range of impacts of civil space investments. Section 2 compares methodologies to assess these impacts, from both a bottom-up and a top-down perspective. Section 3 presents a proposal for better evaluation, and section 4 our broad conclusions.

2. Space investments and their impacts

2.1. Overview

In Europe, public investments in space are dominated by the European Space Agency and national space agencies. Other important sources of public investment are the European Union, EUMETSAT and regional agencies striving to stimulate economic development through support for their local space sector. In some countries, these civil programmes are complemented by substantial additional investment from defence ministries. The great majority of this investment is directed to the European space sector, i.e. the private businesses and public research organisations that design, build and fly space missions. It also includes (inter) governmental organisations, a proportion of which conduct substantial space activities in-house, whether that is carrying out research or running missions. Overall, the space sector comprises the following activities:

- production and operation of space infrastructure and systems
- technology development and service demonstration
- space-based research
- administration of space budgets.

Space investments result in physical space-based systems and services, and new knowledge that can then be deployed by a wider group of economic actors for further economic and social purposes. This flow of investments (inputs) through activities and outputs to impacts is illustrated in.Fig. 1. It should be stressed that the mechanisms relating inputs to impacts are frequently indirect and occur over variable timescales.

In assessing the effects of space programmes, it is important to clearly define the policies (projects) involved, and also the counterfactual: the situation without the policy. Appraisal of policies may take place after they have been implemented (ex post) or before (ex-ante). A core concept in appraisal is attribution: whether certain changes which occur are caused by space programmes or not.

2.2. Classification of impacts

As indicated in Fig. 1, impacts may broadly be divided into the economic, social, strategic and environmental. Table 1 presents an alternative overview of the impact categories, distinguishing between *quantifiable* and *unquantifiable* effects, and showing their links to specific economic actors – the space sector itself, other economic sectors and, through the wider economy, individual citizens.

Space investments impact on a number of economic sectors, both upstream as suppliers to the space sector (backward linkages) and downstream, as recipients of inputs from the space sector (forward linkages). Examples of the latter include telecoms, navigation, and other areas of aerospace (Deloitte [48]). Examples of the value of information provided by the space sector are given in Macauley [49] and Laxminarayan and Macauley [50]. In analysing benefits, it is very important that ‘double counting’, whereby essentially the same impact is credited to both space and the linked sector, is avoided.

Within quantifiable impacts, two types of economic impact may be identified. The *first type* comprises impacts which occur within markets, such as profits generated by the upstream and downstream space sectors (direct impacts), their supply chains and clients (indirect impacts) and subsequent impacts on the wider economy (induced indirect impacts). Included in this category are benefits from R&D which are traded in markets, such as in paying for the use of patented technology. As indicated above, in the analysis of these effects in different parts of the economy it is very important to avoid double-counting of benefits. The *second type* comprises economic effects that are not traded in markets (external impacts), and depend on the particular goods and services resulting from the public investments. Benefits in this category include cost savings and unpaid benefits of R&D, within the space sector (‘spin-in’) or elsewhere (‘spin-off’).

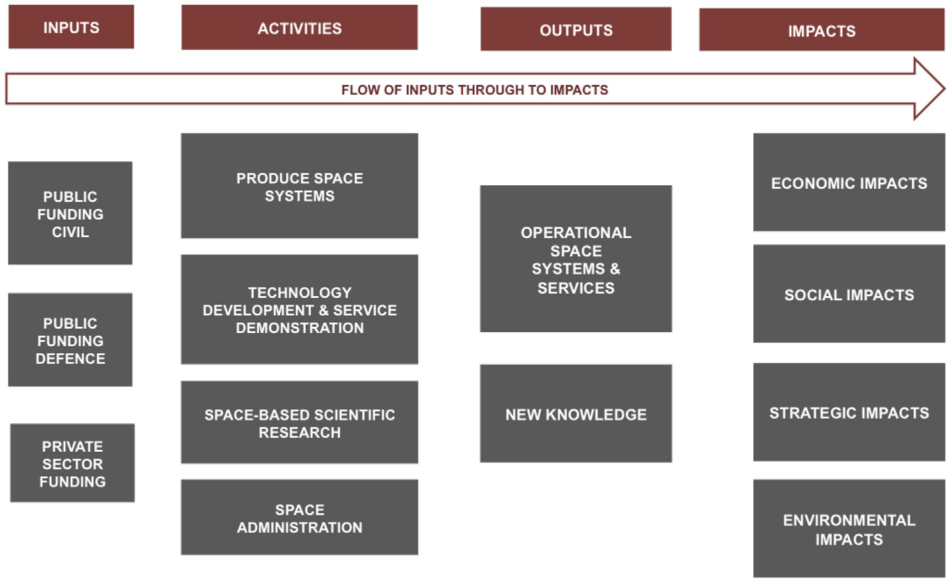

Fig. 1. Logical framework: flow from investments to impacts.
Source: Simmonds et al. [2].

Unquantifiable effects can be strategic, social or environmental. *Strategic* effects occur in defence, but may also consist of increased influence in international politics and science, and space exploration also offers a venue for countries to cooperate. There may also be long term effects on the position of countries and continents. *Social* effects covers impacts on the quality of life of individuals, for instance through education, health and happiness. An example of an unquantifiable *environmental* effect is the influence of space monitoring on awareness of global warming, which may inform attempts to reduce greenhouse gas emissions.

2.2.1. Quantifiable effects

2.2.1.1. Direct and indirect effects: production and spending. The categories delineated in Table 1 can be elaborated as follows:

- *Upstream direct effects* are the immediate impacts on incomes and profits in the upstream space sector resulting from the public sector purchasing space hardware, such as rockets or satellites in order to develop and operate space-related functions. *Downstream direct effects* are impacts generated in downstream space sector (which provide value-added services in fields such as navigation and satellite communications)

Table 1
Classification of actors and effects (examples in capital letters).

	Quantifiable effects		Unquantifiable effects		
	Direct / Indirect effects	External effects	Strategic	Social	Environmental
Space sector	Upstream direct Effects REVENUES LAUNCHER FIRMS / Downstream direct effects REVENUES COMMUNI-CATION FIRMS	COST SAVINGS THROUGH SPIN -IN (NOT PAID FOR)	INDEPENDENCE OF OTHER COUNTRIES		RISK CAUSED BY SPACE DEBRIS
Other sectors	Indirect back-ward linkages REVENUES MATERIALS FIRM / Indirect forward linkages REVENUES IN BROADCASTING	COST SAVINGS THROUGH SPIN-OFF (NOT PAID FOR)	COMPETITIVE ADVANTAGES		EFFECTS OF CLIMATE CHANGE ON PRODUCTION COSTS
Individuals	Induced indirect effects EQUITY PRICES / Other indirect effects EMPLOYMENT	CO2 EMISSIONS	LOWER RISK OF INTERUPTED SERVICES SUCH AS GPS	PRIDE IN SPACE ACHIEVEMENTS HEALTH IMPROVE-MENTS USING SPACE TECHNOLOGY	BETTER ENVIRONMENT TRHOUGH SPACE MONITORING

Source: Hof et al. [1].

directly dependent on data generated from publicly-financed upstream activities.
- *Indirect effects* result from the purchases and sales by the space sector. In Table 1, backward and forward indirect linkages are distinguished. Backward linkages are purchases by space sector companies from their supply chain *outside* the space sector, for instance computer processors for use in satellites. Forward linkages are effects generated for companies outside of the space sector and consumers who buy products from companies in the space sector - for instance, television broadcasting companies that offer satellite TV to their customers, the signals of which are provided by satellites operated by companies in the downstream space sector.
- *Induced effects* are benefits resulting from spending by individuals in receipt of wages/salaries from employment generated directly or indirectly by the space sector, whereby various areas of the economy are stimulated.

2.2.1.2. External effects. External effects are costs or benefits for society which occur because the actions of economic actors have effects on third parties that are not reflected in market prices of products and services. When *negative* externalities such as air pollution are present, a product or service will be overproduced by a competitive market, as the producer does not take into account the external costs when producing the good.

Examples of *positive* externalities are knowledge and market spillovers as identified by Jaffe [51]:

- *Knowledge spillovers,* where advances in scientific and technical understanding developed in the space sector diffuse into wider society to make possible, or cut the cost of, innovations in various areas. As far as knowledge is not protected by patents, the knowledge is a 'free good'.
- *Market spillovers,* often taking the form of 'consumer surplus', where consumers of a product find that they can purchase a product at a price lower than that which they are prepared to pay. Similarly, a *producer surplus* is generated where a product or service is sold at a price higher than that at which the producer is prepared to sell. We note that spending money on public investments in space not only creates these surpluses in space-related activities, but also reduces such surpluses in other spending, as other spending is reduced by taxation to pay for public investments in space. These effects are included in the indirect effects described above.

Knowledge spillovers are a particularly important category of both types of impacts (paid and unpaid) of space investments, as space technology stands at the forefront of science and engineering. Knowledge generation and sharing increases the pace of innovation and decreases production costs. Moreover space is becoming increasingly important with respect to the environment, climate change, health matters and matters of security.

Externalities are most likely to occur when property rights are not clearly defined, and hence individuals have no incentive to treat externalities efficiently. Policy measures, such as taxation, can be implemented to ensure that the externalities will be charged to the producer and the consumer, when the externalities are said to be internalised. Patents and licensing agreements are ways of internalising positive external effects of investments in new knowledge; the additional revenues from patents and licences will generate benefits within the investing firm and tend to stimulate R&D investment both within and outside it.

Impacts from new inventions/innovations produced in the space sector, enabling new activities to be undertaken, or costs reduced, within the sector, are included in the direct and indirect effects as far as they are paid for by companies, for instance through licences to use patents. Unpaid benefits are part of external effects.

2.2.2. Unquantifiable effects

Within the class of effects that cannot be quantified, we distinguish between strategic, societal and environmental effects, which are often omitted from economic analysis.

2.2.2.1. Societal and strategic impacts. Societal and strategic impacts of space activity are broad and wide-ranging. Eight types of impacts may be identified:

- Advances in understanding, through scientific research
- Strategic impacts: geopolitical influence gained as result of space activity. For example, with GMES, Europe has an autonomous system, which provides independent information on the global environment. Politically, at international level, an independent information source with visible, accepted quality controls helps Europe to occupy a position of credibility with respect to policy statements on global environment issues and associated international agreements [52].
- Competitiveness and reputation of countries and continents, and effects on the standing and reputation of companies.
- Defence: Military forces for instance benefit from secure communications, reconnaissance, location and navigation services, force tracking and remote operation of military assets. The US, in particular, invests heavily in military space activities; Europe has a stronger focus on civilian and commercial industries, but attention to the military aspects of space is growing rapidly.
- Civil security and protection, such as using predicting natural disasters, or satellite communication to provide healthcare in remote regions
- Cohesion and culture, such as a sense of European identity and opportunities to co-operate with other countries. Take for example the active partnership of Europe, Japan, Russia and the US in the International Space Station Programme.
- Societal effects, including education: the quality of life of individuals may be improved through space activity, for example through inspiring young people and attracting them towards careers in science. Another example is that European citizens may take pride in European space programmes or in the services that are offered as a result.

2.2.2.2. Environmental impacts. The primary purpose of some areas of space activity, notably earth observation systems, is to contribute positively to environmental issues by increasing understanding of environmental mechanisms and monitoring and providing early warning of environmental changes. Two closely related categories of positive impact, and one negative category may be discerned:

- Contributions to environmental policy-making, through problem identification and environmental status monitoring.
- Contributions to environmental improvements, from inputs to policy implementation and some downstream applications with fewer negative environmental impacts than competing terrestrial systems.
- Potentially negative environmental impacts of space activities, which, like knowledge spillovers, are often not traded in markets.

Some environmental impacts, such as CO_2-emissions are quantifiable. However it is very difficult, if not impossible, to estimate the true future damage caused by CO_2 emissions; one possible approach to quantification is to use estimates of the costs of reducing CO_2

Table 2
Studies of knowledge spillovers in space research.

Title	Description	Scope
Benefits of NASA spinoffs (Chapman Research Group [57])	Analysis of 259 technologies featured in the NASA Spinoff publication.	Benefits in terms of sales or savings quantified, classified according to end-use. Data from estimates by respondents in telephone interviews. Contributions to sales estimated at $21.3bn, and towards savings $315.7 m.
Benefits of stimulated Technological Activity (Midwest Research Institute [58])	Early study, based on Solow's 'residual' approach.	Estimates based on assumption that NASA's R&D expenditures had the same pay-off as 'average' R&D expenditures
Measuring the economic returns from successful NASA life sciences technology transfers (Hertzfeld [28])	Case studies of 15 companies in receipt of NASA funding for life science R&D in the context of space activity, reporting successful spin-off activity to non-space areas.	Life-science space (and spun-off non-space) applications, 1960–1997. Benefits found to be highly skewed, with 90% of benefits arising from 20% of the spinoffs (three cases).
A structure for capturing quantitative benefits from the transfer of space and aeronautics technology (Comstock et al. [59])	A review of analyses of economic impacts from NASA spinoffs.	Comparison of results of 8 studies shows generally high estimates of returns, but points out that much of the evidence is anecdotal.
measuring and managing spinoffs: the case of the spinoffs generated by ESA programs (Bach et al. [60])	Impact of spinoffs developed by ESA contractors.	Impact estimated on productivity and sales, business organisation and methods, and the workforce.

Source: Simmonds et al. [2].

emissions in other activities, e.g. electricity generation.[3] These costs, however, may be higher or lower than the true damage caused by CO_2 emissions, and the specific nature of spaceflight, whereby CO_2 and other gases are emitted into the atmosphere at (extremely) high altitudes, may require specific attention when estimating the damage caused or when monetising these emissions.

3. Methodologies and data – a summary of existing literature for evaluating impacts

In the course of our studies, we have identified a range of data sources and evaluation methodologies potentially relevant to the assessment of the impacts of public investments in space, although specific examples of applications to space expenditures are rather sparse. Examples of existing studies and data sources, and the current state of the art, are discussed below.

The discussion is in two parts. Subsection 2.1 considers methods appropriate to each of the individual impact categories identified in Section 1. Subsection 2.2 considers overall 'top down' approaches within which these 'bottom up' methodologies might be incorporated.

3.1. Methodologies for individual impact types

3.1.1. Economic impacts

3.1.1.1. Direct impacts. A measure of the direct economic impact of the upstream space sector is its value added (contribution to GDP). Europe-wide surveys of the sector (Euroconsult/ESA [53]; ASD-Eurospace [54]) are key sources for size and turnover, but do not explicitly indicate value added, and are primarily company-related, capturing only about one-half of public investments in space. The other half is for instance covered by non-profit organisations, hidden in military spending, or not recognized as "space spending' by companies lower in the chain.

Some national-level studies are available. For example, Oxford Economics [12] presents estimates of the size of the UK space industry; OECD [46] covers a number of countries but not all space activity is included.

Official (national) statistics based on standard industrial classifications do not identify 'space' as an individual sector, and their use to estimate the size of the upstream space sector is highly problematic. The downstream space sector (e.g. Euroconsult [55]), which is diverse and forms part of many different industries, presents even greater difficulties.

3.1.1.2. Indirect impacts. A potential source for estimating indirect economic benefits are input–output tables, showing values of flows of goods and services between industries, regularly compiled by EU member states. Multipliers show how an input change (i.e. an investment) affects total output in the short term in terms of immediate additional demands for the outputs of other sectors. The OECD has compiled an internationally consistent set of tables covering 44 countries, but as in the case of direct impacts, the high level of sectoral aggregation precludes ready identification of the 'space' sector. The data situation is somewhat less restrictive for the USA, where various input–output analyses have been carried out for the space sector in recent years (FAA [8]; Goss Gilroy Inc. [11]; NASA [39]).

Input-output structures are frequently incorporated into wider modeling approaches, where induced impacts and longer-term impacts such as spillovers and general equilibrium effects can be included (e.g. Lejour et al. [56]).

3.1.1.3. Induced impacts. Induced effects are typically estimated by simulating a 'pulse' of additional public expenditure in a macroeconomic model, although these effects might be expected to be similar for additional public investments in any area of activity. Results, however, are typically dependent on model structures, which can be underpinned by a variety of alternative economic theories, and outcomes can be extremely sensitive to the in-built assumptions.

3.1.1.4. Knowledge spillovers. ESA and NASA each produce summary documents on spinoffs – essentially new goods and services derived from their sponsored space R&D. NASA publishes a regular document in the public domain (NASA 'Spinoff' annual publication), while the ESA documentation is not in the public domain. Table 2 presents a number of impact studies mostly based on these data sources.

Of the studies listed, the BETA group[4] have carried out the most systematic analyses on ESA spinoffs within contractor organisations.

[3] In the EU, the Emissions Trading System (ETS) which caps total CO_2 emissions is covering more and more economic sectors. As far as the CO_2 emissions caused by space activities occur in these sectors, these emissions will be compensated by CO_2 reductions in other sectors within ETS. Therefore, CO_2 emissions under ETS are not indicative of an increased greenhouse effect, but of additional CO_2 reduction costs.

[4] Bureau d'Economie Théorique et Appliquée, based at the University of Strasbourg.

An important point here is that, apart from information on the award of ESA grants and the recipients of them, no secondary data is required. Being restricted to the 'in-house' impact on ESA contractors themselves, the analysis does not involve consideration of spinoffs to third-party organisations. The economic benefits identified are divided into four main groups – technological effects, commercial effects, organisational and methods effects, and work-factor effects. The problems of identification and attribution associated with 'external' spinoffs are thus avoided at the expense of limiting the coverage to contractor organisations.

The Space Policy Institute at George Washington University (Hertzfeld [27,28]) identified firms who had successfully marketed life-science products traceable to NASA R&D investments. By design a non-random sample biased towards successful cases was employed. NASA's spinoff and technology transfer publications were used as a starting point, and informal searches and interviews with NASA staff subsequently led to 41 companies for study. These included firms supported by NASA and also firms deemed to have adopted NASA technology but without formal ties to NASA.

Returns estimated in these studies are large. The BETA group estimated a 3:1 return,[5] while Hertzfeld [27] estimates the benefit-cost ratio of spin-offs resulting from NASA life-science R&D investments (1960–1997) to be 6:1.

3.1.1.5. Market spillovers

There are a few studies which address the issue of *market spillovers* (consumer and/or producer surpluses) derived from space activity. The RAND Corporation [61] gives an American perspective on the effects on consumer surpluses following introduction of the Galileo navigation system, and Macauley [49] presents a technique for valuing information (such as improved weather forecasts) from earth science data. Market spillovers from space activity have not, however, received much attention in the past, although the data required for such studies seems to be either available or in principle collectable.

3.1.2. Social and strategic impacts

In terms of the categories of social and strategic impacts of space that we identified, the current situation can be summarised as follows:

- Literature on the contributions of space research to advances in understanding is sparse; the US National Research Council [62] study referred to above ('Earth Observations from Space: the First 50 Years of Scientific Achievements') stands out among a small number of qualitative studies.
- On defence and security, there are very few studies in the public domain and many are rather narrow in focus, exploring the benefits of a change from one technology platform to another. Among the more substantive are a study on the military uses of dual-use space technologies (Steinberg [63]) and a cost-benefit study of the defence value of US military investments in basic R&D (Sciarretta et al. [64]); while not specifically space-related, it shows that a cost-benefit methodology can be used for determining military gains.
- A number of studies relating to civil protection provide either prospective assessments of the impacts of GMES[6] (references as in environmental impacts section above), or descriptive accounts of how satellite data has contributed to supporting disaster relief in specific areas (e.g. McCallum et al. [65], on the value of earth observation data in disaster recovery and reconstruction).
- The contribution of space to international relations is explored in numerous books and journal articles (e.g. Broinatowski et al. [66], which develops a framework for analysing space sector collaborations between two countries, and applies it to a case study of Italy and the USA; Peter [67], a case study of the EU's role in space diplomacy; Sheehan [68] exploring the history of international politics in space, with suggestions on ways to analyse/measure international relations).
- Space education and the public understanding of science is a social benefit whereby young people's understanding of the world can be improved, and people more generally excited and inspired. Anecdotal evidence and small-scale studies have suggested that including space in the curriculum has a measurable impact on the average performance of children in STEM subjects (e.g. Jarvis and Pell [69,70]). While generally regarded as important, data limitations currently constrain robust conclusions in this area.
- Space can aid social cohesion through satellite communications helping to close the 'digital divide' existing between Europe's urban core and some of its most remote, rural peripheries. Studies drawing general conclusions about the benefits of ICT bringing social cohesion include European Commission [71,72], ESPI [73].

3.1.3. Environmental impacts

Data on the environmental impacts of space investments are extremely limited. While it is widely acknowledged that space investments contribute to environmental impacts, there has been no comprehensive or systematic study of these impacts to date and there are no directly relevant data sets available on which to base assessments of impact. The relevant studies that have been identified are broad in scope, mainly of earth observation investments, that include environmental impacts along with other economic and/or social impacts. They include:

- A very small number of qualitative historical reviews of links between space and environmental protection (e.g. Lambright [74] on ozone depletion; US National Research Council [62] reviewing 50 years of Earth Observation).
- Prospective studies (ex ante impact assessments) of investments in earth observation, mainly relating to GMES (PWC, ESYS, DNV [32]; Booz & Co. [25]).
- Assessments of the impacts of earth observation (e.g. ACIL Tasman [75]).
- Assessments of positive environmental impacts of downstream use of satellite navigation systems (e.g. Hellstrom et al. [76] on minimisation of fuel consumption of trucks, partly based on GPS).
- Qualitative examples of technology spillovers deployed for environmental purposes (some examples in the NASA 'Spinoff' annual publication, and also available on the NASA Spinoff database (http://www.sti.nasa.gov/spinoff/database)).
- Negative environmental impact studies (e.g. Prather et al. [77]. on space shuttles' impact on the stratosphere; Brady et al. [78] on chemical reactions in the atmosphere generated by space launches worldwide; Ross et al. [79] on potential climate impact of black carbon emitted from rockets). Space debris is also widely regarded as posing very significant problems (Macauley [80]; Simpson [81]).

3.2. Broad 'top-down' approaches

This section discusses alternative overarching 'top-down' methodological approaches which attempt to capture the

[5] From Cohendet (1989): "on average, for the sample of firms studied, every 100 units paid by ESA to industry result in a minimum indirect economic benefit of around 300 units via the ESA contractors forming the sample".

[6] GMES is the system under development Global Monitoring for Environment and Security. It includes both satellite and ground based data sources.

individual impacts discussed in Section 2.1 in an overall framework, as covered in the SEO report (Hof et al. [1]).

In the literature, many methodologies can be found. Most of these, however, are alternative names, specific subtypes, or combinations of a limited number of methodologies. Some of these methodologies are of a monetary nature, such as computable general equilibrium analysis, cost effectiveness analysis, cost benefit analysis and social return on investment. These methods express all or most impacts in monetary terms. Non-monetary methodologies include impact assessment and multi criteria analysis.

3.2.1. Quantitative (monetary) approaches

3.2.1.1. Computable general equilibrium analysis. Computable General Equilibrium (CGE) analysis is a methodology in which the effects of economic shocks or policy measures are estimated using a model which simulates the entire economy. CGE models include factor (capital, labour) and commodity markets and model the behaviour of production sectors, households and governments. CGE models are often based on (aggregated) input–output tables, but they also adjust prices and wages to bring production and employment in the entire economy into equilibrium. CGE analysis is therefore an economy-wide impact analysis.

The major advantage of CGE analysis is that it yields results which take into account all indirect effects throughout the whole economy. Furthermore, CGE models are based both on a consistent theoretical model of the economy and on empirical data which describe national economies.

As detailed CGE uses input–output tables, it has the drawback of being subject to the demanding data requirements associated with such tables. Another limitation is that CGE models need to be very detailed in order to capture any impacts of space activities on the economy.

The assumption that the economy will end up in an equilibrium is only valid for the long-term; prices and wages do not adjust instantaneously to changes in the economy, and markets can be out of equilibrium during an adjustment period. Moreover, there might be institutional or market barriers which limit the efficient functioning of markets.

CGE analysis concentrates on direct and indirect effects; most CGE models do not take external effects such as R&D spillovers and unquantifiable effects into account. This is an important limitation in the appraisal of space programmes, as these programmes are expected to yield important external and strategic benefits, which are not in the scope of CGE Analysis.

No studies were found that estimate the effects of space activities on the economy using GCE analysis, perhaps because of its large data requirements and the complexity of the methodology.

3.2.1.2. Cost effectiveness analysis. Cost-Effectiveness Analysis (CEA) is a tool to compare different technological options or policy programmes which have identical objectives. It summarises the outcome of a comparison using a single quantifiable indicator, and provides a measure of the effectiveness of an option. The objective itself is not assessed. Cost-Utility Analysis (CUA) is an extension to CEA, in the sense that it uses a quality-adjusted indicator to describe the objective. One study by Mathematica [82] was found that applied CEA with respect to space investments.

CEA is simple and effective, and capable of taking both, quantifiable and unquantifiable effects into account. An advantage of cost-utility analysis over cost-effectiveness analysis is that a richer indicator, including more than one objective, can be used to determine a cost-effectiveness ratio. However, this has the drawback that the relative weight of the different objectives becomes obscured through the use of one single cost-utility measure.

The main limitations of CEA and CUA are that they do not take secondary or indirect effects into account, these being particularly important to space programmes. Another drawback of CEA is that only the cost-effectiveness is analysed, not the relevance of realising an objective.

3.2.1.3. Social cost benefit analysis[7]. A cost benefit analysis (CBA) can be conducted at several levels of detail. Different versions of the technique, such as cost analysis, indicative CBA and quick scan CBA, differ in their breadth and scope. The most comprehensive form is social cost benefit analysis (SCBA), discussed in this section

In SCBA all the costs and benefits of investments or policies are systematically evaluated and where possible monetised to make them comparable. In addition, SCBA can provide an overall picture of how the effects are distributed among stakeholders. In principle, SCBA has the potential to include and monetise all the effects of a policy, including societal and environmental effects.

In SCBA, the *willingness-to-pay* of firms and households is estimated for each impact of the project or policy. This is done market-by-market, with special care to avoid double-counting. If possible, existing markets are used, where the *willingness-to-pay* can be observed from choices made by suppliers and customers. Often, economic methods are used which describe specific markets (transport, energy) or the economy as a whole (Computable General Equilibrium Analysis, Input-Output Analysis). For impacts which are not related to markets, other methods such as surveys may be used. The value of impacts is calculated year-by-year, for a period of decades.

SCBA is based in economic science and is often used in practice. Several studies have applied SCBA to the space sector, most of which relate to GMES services (see Indra [83]; Whitelaw [84]; Whitelaw, Costa and Scott [85]; Ecorys [86]; AETS [87]; ESYS [88]; European Commission [89]; Booz & Co [25]; PWC [31] and NATO Industrial Advisory Group [30]). Almost all of these studies focus on the benefits to end-users and society in terms of cost-savings or additional production, without estimating the direct effects on the space sector. External and non-quantifiable effects are often not included or only qualitatively addressed. In addition, costs of infrastructure are not always included. Input data mainly consists of estimates on cost-savings and additional production.

SCBA works well when costs and benefits can be associated to existing markets, when consumers' and producers' surpluses can normally be accurately estimated. However, there may be several objections to the use of SCBA:

- Problems in attaching valuations to costs and benefits, especially when departing from existing markets. Techniques such as contingent valuation (surveys) are available, but not accepted as valid by all economists.
- SCBA may not (explicitly) cover everyone involved – inevitably there are a huge number of potential 'stakeholders' who stand to be affected (positively or negatively) by an investment decision. There is a risk that some groups might be left out of the decision process. Costs and benefits mean different things to different income groups. Those receiving benefits and those burdened with the costs of a project may not be the same. Are the losers to be compensated? This equity issue is important to policy makers.
- Social welfare is measured as the sum of the *willingness-to-pay* of individuals. This might not be an appropriate criterion in the eyes of policy makers.

[7] This text is based on two SCBA manuals: Zerbe and Bellas [90] and Eijgenraam et al. [91].

- Social cost-benefit analysis may seem like a 'black box', with outputs difficult to interpret. The fact that some benefits should be disregarded to prevent double-counting, is not always obvious to people who attach importance to specific benefits.

3.2.1.4. Social return on investment[8]. Social Return on Investment (SROI) can be seen as a special form of SCBA. The main difference between SROI and SCBA is the focus of SROI on societal and environmental impacts and the involvement of stakeholders. It overcomes some of the difficulties faced by SCBA in estimating social and environmental impacts by focusing on the most important sources of value as defined by stakeholders. We are unaware of any studies in which SROI has been applied to space activities.

The advantage of SROI is the emphasis on the embedding of the methodology in the decision making process which may lead to wide acceptance. Another advantage is that many factors can be taken into account, including societal and environmental effects.

The downsides of SROI are that, as in SCBA, societal and environmental effects are difficult to monetize and might need subjective assumptions to include them in the analysis. The involvement of stakeholders and the special attention to societal and environmental effects also imposes risks of subjectivity. The interests of strong stakeholders might be over-emphasized at the expense of the interests of smaller or less organised stakeholders. Strategic input from stakeholders can be partially overcome by a correct set-up of the survey or interview.[9]

3.2.2. Non-monetary methods

3.2.2.1. Impact assessment. The goal of an Impact Assessment (IA) is to give a clear overview of the effects of policy alternatives. In an Impact Assessment all effects are treated and presented separately, in quantitative or qualitative terms.

The IA applications that have been found in the literature differ in scope, for instance in terms of effects considered, industries taken into account or geographical range. The main data sources for these studies are surveys, workshops and interviews to estimate turnover, employment and/or costs and profits. While none of the studies comprises a comprehensive IA, many were found in which an assessment was made of a part of the economic effects of a space activity (Space Foundation [92]; RPA [13]; ASD-Eurospace [16]; Bullock et al. [17]; Patureau et al. [21]; British National Space Centre [3]; Davies [5]; SIA [23]; VEGA, Booz Allen Hamilton [24]; ESA [18]; Technofi [93]; Ecorys [7]). In only a few cases all economic effects (direct, indirect and induced) were included (Oxford Economics [12]; Department for Business Innovation and Skills [6] and California Space Authority [14]). In some studies economic effects were extended with external, societal or strategic effects (OECD [94]; UK Space Agency [15]; PWC [52]; Danish Agency for Science [4]; NDP Consulting [29]; NASA [37,38,40]; Schnee [34]; Sadeh [33]; Hertzfeld [27,28]; Technopolis [95]; Centre for Strategy & Evaluation Services [96]; Hallonsten, Brenner and Holmberg [10]). Several studies applied the methodology developed by the BETA group, as described above (Brendle, Cohendet and Larue [44]; Cohendet [45]; Amesse et al. [41]; Bach et al. [42]; Bach, Cohendet and Schenk [43]).

IA has the advantages that it can incorporate different kinds of effects and that the information is processed in an explicit way. IA is also capable of dealing with a variety of policies, criteria and actors. Another advantage of IA is that it is relatively simple analysis, with limited requirements for data and calculation.

A drawback of IA is that it does not provide a ranking of policies or a conclusion on attractiveness. Decision makers need to draw their own conclusions.

3.2.2.2. Multi criteria analysis. In Multi Criteria Analysis (MCA), policy alternatives (e.g. various space programmes) are first scored on different criteria, and the different criteria are then weighted. The main goal of MCA is to structure the effects of the alternatives to aid the decision maker. It provides a systematic way to measure and weigh effects for the relevant actors, where effects are not necessarily monetized (in contrast to Social Cost Benefit Analysis). It also provides a tool to aggregate the different effects.

MCA not only gives an assessment of the merits of an investment, but also provides a communication and interaction tool for the different actors that are involved. MCA can help to explicitly take account of conflicts between actors regarding the impacts of a plan. An example is a case where several actors agree that an alternative will have an estimated effect but disagree on the value of this effect. MCA might then be helpful in taking into account these different views by using different weighting schemes, proposed or inspired by the stakeholders, in turn. This shows how weighting affects the outcome of the analysis. Also, results may not change if the weighting is altered, yielding 'robust' results which are an important starting point for reaching consensus among stakeholders.

MCA has been applied to evaluate policy options and investments in space programmes, to prioritize space programmes and to benchmark space activities in different countries (RPA [13]; Smith et al. [35]; Tavana [36]; Futron [9]; European Commission [26,99]). The data with respect to the criteria and weights used mainly come from consulting experts

Advantages of the MCA approach include its ability to incorporate a very diverse range of information and that the information is processed in a very explicit way. Also, MCA offers flexibility in the number of policies, the criteria, the weighting and the involvement of stakeholders. The flexibility of MCA also constitutes a risk; it lacks methodological rigour, in that the weighting of the different criteria is difficult, and is open for subjectivity or even manipulation.

3.2.3. Aptness of methodologies

Relevant criteria used to assess the aptness of methodologies to assess the effects of space investments are completeness, feasibility, objectivity, clarity of calculations, clear advice and acceptability. Each of these criteria has been specified further in terms of specific questions. For instance, one of the questions with respect to completeness of a methodology is whether quantifiable and unquantifiable effects are both included. There is no 'ideal' top-down methodology: each approach has its own advantages and disadvantages, summarised in Table 3.

3.3. The current 'State of the Art'

Partly as a result of the space community's historical modus operandi, the 'toolbox' of specific methodologies and data sources necessary for evaluating the wider effects of public space investments is relatively underdeveloped. Other key factors here are the particularities of the space economy and its relative smallness, which militate against use of more general data sources to an extent that does not hold for certain other areas of high value manufacturing. Particular current deficiencies are:

- A shortage of required data, for example relating to:
  - Commercial and political sensitivities around the source and destination of particular portfolios of investments, which

[8] The description of the SROI methodology is mainly based on Boyle and Murphy [97], Steed and Nicholles [98].

[9] For space investments, the inclusion of strategic effects in SROI is nearly impossible. In SROI, as opposed to SCBA, the base case is not explicitly defined which can cause problems when calculating effects.

Table 3
Advantages and drawbacks of top-down methodologies in terms of criteria.

	Methodology features			Usability in decision process		
	Completeness	Feasibility	Objectivity	Clarity of calculations	Clear advice	Acceptability
Monetary methodologies						
Input-Output Analysis	± Only direct and some indirect effects.	− Limited: IO tables are only available for main activities, space sector has no separate entry.	± Causality tested. Objective due to use of standard IO tables. But only relevant for short-run and for small projects.	− Insight in parameters from IO tables but not in calculations behind it.	±Ranks policies.	−Strong assumptions needed about state of the economy. Also not all effects are taken into account.
Computable General Equilibrium Analysis	± Direct and indirect effects, some external effects.	- Requires complex calculations.	+Causality tested. Objective due to basis of IO tables.	−Calculations form black box.	+Discerns attractive and unattractive policies.	−Limited acceptability due to complex calculations.
Cost Effectiveness Analysis/Cost Utility Analysis	±Only main effect and costs are counted.	+ Limited data and calculations required.	+Causality tested. Main effect and costs are weighted adequately.	+Insightful calculations.	±Ranks policies.	−Focus on one effect. Not suitable for policies with more than one relevant effect.
Social Cost Benefit Analysis	+Some effects are hard to monetize but all effects are listed and taken into account.	−Substantial calculations necessary.	+Based in economics. Causality tested.	±Risk of black box effect.	+Discerns attractive and unattractive policies.	−Some assumptions hard to accept; high weights of high-income people & businesses.
Social Return on Investment	±Aimed at monetizing social, environmental effects as much as possible.	−Substantial calculations necessary.	±Based in economics. Causality tested. Risk of subjective parameters.	±Risk of black box effect.	+Discerns attractive and unattractive policies.	+High acceptability due to inclusion of stakeholders.
Non-monetary methodologies						
Impact Assessment	+Can be applied to all effects and actors.	+Limited data and calculations necessary.	0 Causality not always tested. No weights used.	0 No calculations made except for estimating separate effects.	−No ranking of policies and no attractiveness conclusion.	±Every decision maker can draw his/her own conclusions.
Multi Criteria Analysis	+Can be applied to all effects and actors.	±Depends on depth of analysis.	−Causality not always tested. Subjective weights.	+Process is clear.	±Ranks policies.	±Decision makers can apply their own weights.

Source: adapted from Hof et al. [1]

make it difficult to understand the full extent of public investments, in detail, and its primary purpose.
- The space economy itself, which in many respects is poorly defined. Space is not separately identified in national accounts, which presents a major analytical constraint. The downstream space sector in particular is poorly defined.
- Space-specific stylised facts, that can be applied to existing survey results to produce estimates of indirect and induced economic effects on the one hand ('multipliers') and similar rules of thumb that might be used to prevent double-counting and take account of macroeconomic effects.
- Consistent and comprehensive identification of 'spillovers' from space activity.
- Information on the role of data from space in forming public policy on the environment, and in reducing environmental degradation.
- Information on the social benefits from space activity.

• Partly as a result of these data deficiencies, past evaluations have tended to be partial and ad-hoc. They may, for example:
  - Include some economic impacts but not others.
  - Address some – but not all – of the benefits of spillovers.
  - Focus on economic benefits to the detriment of 'softer' areas, in particular environmental and social impacts. In the case of environmental impacts, this may be partly due to the perception that benefits lie mainly in the future, reducing the likelihood of identification of benefits from ex-post evaluations. Regarding social benefits, difficulties in quantifying benefits constrain the potential for useful evaluation, despite such benefits frequently representing the major motivation for important areas of activity such as space exploration.
  - A lack of *comparative* analysis, whereby benefits are estimated but not compared with the benefits available from other public expenditures. Evaluations have typically looked at *gross* benefits (with or without comparisons with costs) without consideration of the *net* benefits over and above those available from alternative uses of public resources.

Several 'top-down' methodologies, such as Input Output analysis and Computable General Equilibrium analysis, focus on sector effects. Here again, lack of data referring specifically to the space sector is a constraint. In principle there are possibilities to extract specific space activities from different sectors and put them in a separate space sector. However, this requires assumptions on the relation between the space activities and other sectors.

The impacts of space investments are very often investigated using Economic Effect Analysis, a subtype of Impact Assessment. Often these are direct effects in the upstream and/or downstream sectors or indirect effects for the end-users of space technologies (ESA [18]; SIA [23]). Social Cost Benefit Analysis has been mainly applied to GMES (Global Monitoring for Environment and Security), (PWC [52]; European Commission [89]). Some studies perform a Multi Criteria Analysis for various types of space investments, while only a few studies use Input-Output analysis. Research applying Computed General Equilibrium analysis was not found, probably because of the complex nature of the calculations and the extensive data needs of this methodology.

4. Proposed methodology

In the reports on which this article is based, Technopolis Group (Simmonds et al. [2]) and SEO Economic Research (Hof et al. [1]) follow different approaches in proposing suitable methodologies for the wide range of effects of space investments. Technopolis lists the effects and proposes appropriate methodologies for each one of them - a bottom-up approach. SEO, on the other hand, lists and compares aggregate methodologies and classifies effects within these methodologies - a top-down approach. The Technopolis and SEO approaches will be described here in turn.

4.1. Bottom-up approach

The Technopolis report makes recommendations in the areas of *data capture, methodological developments* and *aggregation* of the diverse range of benefits available from space investments. The proposals made in each of these three areas are briefly summarised below.

4.1.1. Improvements in data availability

There are several points where new or extended methods of *primary* data collection should be adopted, or where existing *secondary* data could be exploited. Suggested improvements in *primary* data collection include:

- For *quantifiable* impacts: extension of data collection beyond the classical space industry to include non-commercial upstream actors such as universities, PROs and space agencies; sampling of downstream sector actors; expanded and improved collection of data relating to spillovers.
- For *social* impacts: a survey of European scientists and engineers to assess the influence of space on their career choices; surveys of defence experts on the benefits of defence-related space work, to inform case studies.
- For *environmental* impacts: surveys of policy makers and other actors to gain understanding of perceptions of the role of space in identifying environmental problems and in informing policy development and tracking implementation.

Suggested improvements in use of *secondary* data include:

- For *quantifiable* impacts: use of Euroconsult statistics on public funding agencies; use of OECD patent data as a new source of information on spin-offs out of the space sector – and, if required, of spin-ins from other sectors into space.
- For *social and strategic* impacts: use of bibliometric data for measures of advances in understanding; use of the UN database of international space treaties for a network analysis to provide evidence of strategic impact.
- For *environmental* impacts: application of available information on environmental policies and treaties as a starting point for 'tracking back' case studies on the contributions of space.

4.1.2. Proposals for methodological development

Most of the methodological proposals are associated with the collection of primary data and application of secondary data, as described above. In addition, other proposed improvements are:

- Reconciliation of data on funding by public agencies on space with that on contractors' sales.
- Development of a series of (rolling) programmes to develop and publish impact case studies, which will observe broadly standard research processes, report on common criteria and cover the full extent of relevant space impacts within a given period (e.g. a 10-year cycle). Most classes of wider economic and social benefits might usefully be encompassed by this kind of qualitative research, including:
  - Knowledge and market spillovers.
  - Impacts on environmental policy-making and environmental parameters.
  - Advances in scientific understanding through discipline-level reviews.
  - Impacts of space-related educational programmes.
  - Impacts of space on military capabilities.
  - Use of models to analyse impacts (e.g. the Economic Environment Linkage and Integration Model – FeliX (IIASA [100]) for environmental (and some social) impacts, possible use of a macroeconomic model for economic impacts).

4.1.3. Aggregation and presentation of identified benefits

Annual presentation of results is suggested, with:

- Monetised estimates of direct, indirect and induced effects.
- Discounted monetised estimates of returns from knowledge and market spillovers, derived from case studies.
- Non-financial indicators of environmental and social impacts, where possible.
- Qualitative presentation of impacts not included in the above.

Another recommendation is to present the monetised benefits in the form of a scoreboard, and non-quantified benefits in a 'Space Highlights' table. Table 4 summarises the range of proposals.

4.2. Top-down approach

The core of the top-down evaluation methodology proposed in the SEO report (Hof et al. [1]) is Social Cost Benefit Analysis (SCBA). This provides a framework that covers all effects that are relevant for society. Effects are weighted, where possible, on the basis of observed market prices or other estimations of monetary values. However, the space sector has a specific nature. For some effects of space investments, putting money values on them may be impossible, or high quality estimations of money values may not be available. Also, if effects cannot be tied to individual investments, for example because they are far from markets, it becomes necessary to replace actual effect estimations by indicators that relate to investment effects, and in addition specific data may be unavailable. For these reasons, SEO advocates a combination of SCBA with multi-criteria analysis (MCA), a combination tentatively named "SCBA-plus". The plus indicates that the methodology includes effects that are hard to monetize or even hard to measure, like strategic effects not included in SCBA, societal effects and some environmental effects. The SCBA-part strives for objectivity in weighing effects where possible, whereas the MCA-part provides the necessary flexibility. Overall, SCBA-plus seeks to ensure that no effects are double counted or forgotten.

Fig. 2 gives an overview of the set-up of the SCBA-plus methodology, combining SCBA and MCA, with other methodologies such as input–output and computable general equilibrium analysis potentially providing more detail. In this sense, the choice for SCBA-plus is not a choice 'against' alternatives like I/O and CGE, and certainly does not exclude the use of data from, for example, surveys.

The methodology entails the following. For investments, or programmes of investments, a list of effects is drawn up that might be the result of the investment. For each of these effects, it is assessed whether objective measurement *and* money valuation is possible. If both are possible, the effect is measured and valued according to the SCBA-methodology. If either money valuation or objective measurement of the effect is impossible, the effect is treated according to an MCA-methodology. For some of the effects that are treated in the MCA-part of the SCBA-plus methodology, it may be possible to measure effects directly, while for others it may be necessary to introduce indicators of effects, and even to

Table 4
Table 4Proposed bottom-up impact assessment methodologies.

Impact	Methodological approach (Option A)
Economic: Direct	Extensions of current surveys to include: • Universities, public research institutes and internal ESA activities • Sampling of downstream sector, to better define the downstream sector • Reconciliation of data on funding with that on recipients' sales, using Euroconsult [55] global statistics on public funding agencies
Economic: indirect	Creation of input–output coefficients for the space sector, based on existing data supplemented by extension of current surveys to include information on volumes and sources of supplies into the space industry
Economic: induced	Extension of current macromodels, to incorporate a space sector (consistent with suggested developments on indirect impact)
Economic: knowledge spillovers	• Improved identification of cases of spillovers at national and EU levels • Improved data collection to capture more data on costs and benefits • Rolling programme of in-depth case studies of known examples, with estimation of gross and net (inclusive of opportunity costs) benefits • Use of OECD space patenting information to (a) highlight particular spillovers for investigation and (b) enable citation analysis for levels and trends in cross-fertilisation between space and other sectors
Economic: market spillovers (*producer & consumer surplus*)	• Structured compilation of *major* publicly-funded space initiatives from which novel devices or services are known to have been derived • Analysis of the results of the benefits of these devices or services in terms of market penetration, and per-unit benefits to consumers and producers accruing over time, along with use of net-present-value and discounting procedures • Inclusion of assessment of consumer and producer surpluses from new developments, as a routine component of ongoing programmatic and system level evaluation of public investments in space
Environmental: environmental policy-making	For impacts on policy makers and policy making • Design, test and implement a new periodical international survey of environmental policy-makers and other actors to determine people's perceptions of the role of space investments in (i) identification of environmental problems; (ii) policy development; and (iii) policy implementation • Design and implement a rolling programme of in-depth historical 'tracking back' case studies that reveal the nature and extent of space contributions to specific and important environmental policies or treaties
Environmental Positive effects on environmental parameters	For impacts on environmental parameters, combine micro and macro approaches: • Detailed case studies of identified benefits (micro level) • Application of the FeliX model (http:/www.geo-bene.eu/?q=node/2066) to space investments (macro level)
Social: advances in understanding	Bibliometric and citation analyses • Profile the volume and international standing of European space research using Web of Science (WoS) bibliometric data • Trace influence of space research on other disciplines, using bibliometric citations • Institute a rolling programme of discipline-level reviews
Social: strategic impact	For geopolitics: • Network analysis based on UN database of international space treaties For non-dependence • Analysis of secondary data collected in the ESA, EDA, EC Joint Task Force • Case studies of technologies that have been transformed by public investments from 'dependent' to 'non-dependent'
Social: space for education	'Eurobarometer' poll of European scientists and engineers to assess influence of space on their career choices as compared with other possibly important triggers Rolling programme of case studies to determine the cognitive and inspirational impact on young people of specific space-related educational programmes or visitor attractions and simulations
Social: civil security and protection	Mixed methods – a combination of a micro and macro approaches: • Detailed case studies of identified benefits (micro level) • Application of the FeliX model to space investments (macro level)
Social: defence	Rolling programme of case studies to determine the functional and economic improvements realised through the use of next generation space-enabled services, including assessment of the extent to which key aspects of military capabilities are now critically dependent on space
Social: externalities	Eurobarometer-style opinion survey to assess willingness-to-pay for specific externalities

Source: Simmonds et al. [2].

subjectively score indicators, using as much available data as possible to make these scorings strong.

The SCBA-plus methodology combines the outcomes of the SCBA-part and the MCA-part in a combined presentation for evaluation purposes. In order to arrive at this, the following steps are taken:

1. define the aim and scope of the evaluation;
2. identify and characterise the investments;
3. identify the assessment criteria: costs, possible effects and other criteria; and identify the actors involved;
4. quantify and score the effects;
5. weigh the effects;
6. calculate outcomes;
7. perform sensitivity analysis;
8. present the results; and
9. evaluate.

Steps 1–3 are general steps that do not depend on whether effects are assessed in the SCBA-part or in the MCA-part of SCBA-plus. However, in step 3 it should be decided *how* effects are going to be assessed in the steps that follow.

Steps 4–7 differ between the SCBA-part and the MCA-part. In step 4, effects are quantified in the SCBA-part. In the MCA-part, quantification is carried out where possible. If it is not possible, criteria are set up that have a relation to the effects, and these criteria are scored or subjectively rated.

Step 5 involves weighing of effects. Weighing in the SCBA-part implies putting money values on the effects, while in the MCA-part, it involves determining the weights of the criteria.

The outcomes (step 6) of the SCBA-part consist of the effects in their own terms and in money terms for target years; the effects in present values over the whole period; and the distribution of effects in the form of an actor analysis. The outcomes of the MCA-part are, first, the effects in their own terms, if available, and

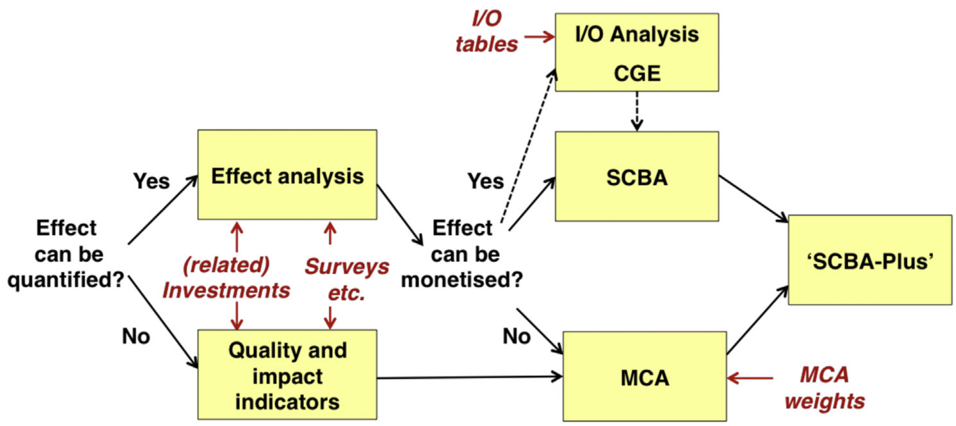

Fig. 2. Proposed SCBA-plus methodology.
Source: Hof et al. [1].

approximations of effects, and subjectively rated effects. Secondly, all these need to be measured on the same scale, for which we propose a rescaling to a simple 0 to 10 scale. Combining these scores with the chosen weights per score yields the MCA's final results.

For both the SCBA-part and the MCA-part, the outcomes of sensitivity analyses should be presented to assess the robustness of results.

In the final steps, results are combined and used for evaluation.

4.3. Strengths and weaknesses of the proposals — what can and cannot be expected from them

In summary, we believe that our proposals would significantly improve the veracity of assessments of the impacts of public investments in space, in particular through;

- Improved *definition* of the space sector, clarifying the boundaries of the activities whose impacts are to be included.
- Use of improved data and methodologies, thereby improving *reliability* of assessment of impact.
- Inclusion of environmental and social impacts in particular, improving the *comprehensiveness* of the coverage.
- Introduction of greater *consistency* of approach, for example by fostering greater awareness of the range of impacts and hence of factors potentially omitted from an evaluation, and through awareness of the importance of *comparative* analysis, including consideration of opportunity costs.

As pointed out earlier, evaluations of public space investment are less prevalent and less developed than evaluations of other areas of public investment. We hope and expect that our proposals would significantly reduce this discrepancy. That said, some characteristics of the space sector — for example its relatively small size, leading to poor specification in national statistics, and the 'intangible' nature of some of its key benefits — make it a relatively difficult area for evaluation. And of course, all the fundamental difficulties of policy evaluation in general — such as attribution problems, difficulties in establishing counterfactuals, data limitations — remain.

A further issue is that implementation of the proposals will entail costs. We believe that providing better evidence of the nature and extent of space impacts will produce both operational (steering) and political (funding security) benefits that will exceed the costs of developing the evaluation habit and underlying infrastructure.

The level of effort needed is an important aspect in making choices on evaluation. The wide range of effects of space activities implies the risk that the analysis could become very extensive, and therefore tedious and costly. To prevent this, the analysis may be based on a relatively simple approach via prioritisation of impacts. The analysis of economic effects may be based on the direct impacts on firms in the space sector and the effects on sectors using space services (space related sectors). Indirect benefits in other markets can be estimated by experts. For the external, societal and strategic effects, expert panels may be used who build up routine in estimating effects and comparing projects and programmes. The panels should consist of a mix of economists and space sector specialists from industry and public organisations. The overall goal is to base results as much as possible on objective measurements of identified effects. Measured effects provide a valuable result on their own and are also input to the expert panels identified above.

5. Conclusions

Broad conclusions from the research are that:

- public investments in space have wide-ranging economic and social benefits
- these benefits are not easy to measure, especially social benefits which are likely to be very important
- the space sector is not a recognised category in statistics, leading to a lack of consistent economic data
•R&D impacts occur in the long term and are difficult to link to specific space investments. Social effects are important but hard to measure.
- nevertheless, the research shows that important steps can be made towards better evaluation of impacts.

The impacts of space investments can be evaluated from both a bottom-up and a top-down perspective. In the bottom-up perspective, each effect is measured separately and presented next to other effects. The top-down perspective provides a framework for integrating the effects by measuring them in money terms where possible. Both perspectives have their advantages and drawbacks. However, by combining these perspectives yields both detailed and integrated results.

A possible way forward is to introduce the proposed top-down methodology as a 'way of thinking', a framework where existing research fits in and which shows what gaps should be filled. Efforts could then focus on collecting data and doing impact estimations of 'missing parts'. These data and impact estimates have an important additional value in themselves, and can also be used as inputs for the top-down methodology.

Efforts to obtain better data are very important. This could consist of co-operation between ESA, OECD, Eurostat and other organisations about possibilities to compile 'tailor-made' data which more explicitly shows the space sector and its relations with other economic sectors. Also, efforts to collect societal and environmental data are in order, using many indicators. Examples of indicators for societal effects are the income distribution and unemployment. Knowledge spillovers could to some extent be measured through patent citations or scientific publications although these are not ideal indicators. Environmental effects may be measured using for instance CO_2 emissions or ecological footprints.

The first follow-up step we advise is to apply the methodologies to one or two space programmes in a pilot study. Also, talks between ESA, OECD, Eurostat and other agencies should be started about defining the space sector and including it in statistics. The objective of these activities is to start generating a body of knowledge and the associated practical experience in assessing the benefits of European public investments in space. In the longer term, evaluation should become routine, using an established toolbox.

ESA's investments consist of programmes which are combinations of projects. Evaluation of impacts should start at the level of projects, because these allow detailed analysis. A practical approach is to analyse the most important projects within a programme, and to extrapolate from there. However, assessing programmes is not just a matter of adding up projects individually, because synergy between projects should be estimated separately and included in the results. The next step is aggregation from investment programmes to total space investments. The effects of programmes may be added up, if necessary taking account of synergy between programmes. Over time, 'standard ratios' will arise, for instance "€100 million of investment in R&D on average increases employment in the space sector permanently by 200 jobs". As the body of knowledge grows, it will become more feasible to assess more projects and programmes.

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