Indirect industrial effects from space investments

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Abstract
Many impact assessments have been carried out to evaluate the economic and social effects of public investments in space. This paper focuses on ex post analyses of indirect industrial (intra-firm) effects, a sub-type of the impact assessments. A number of existing country-wide analyses report the ratio of the indirect industrial effects deriving from space-related contracts to the value of the space-related contracts placed with companies by governmental agencies (in Europe, mostly by the European Space Agency). This ratio is a widely accepted measure of the economic impact of the space contracts. The aim of this paper is to assess the usefulness of the ratio, a spin-off multiplier, for international benchmarking of the efficiency of space investments. The paper is the first attempt to provide an in-depth analysis of the methodological foundations of different country-wide studies on the spin-off multiplier performed in Europe. The country-wide studies have formulated different metrics and relied on different approaches to gathering quantitative data. The current paper discusses data quality issues that may result in a biased estimate of the spin-off multiplier. Data gathering techniques used in the studies tend to result in overestimated economic benefits. Even though the values of the spin-off multipliers are high in countries like Norway or Denmark, the confidence interval of the estimates is wide. The paper discusses time considerations to be taken into account for a standardized ratio as there is a time lag of several years until research and development becomes operative. Despite several methodological limitations, measuring the indirect industrial effects is a valuable tool for governments, especially for smaller ESA member states, as such studies can be implemented at low cost and provide information on spillovers from space programmes.

1. Introduction
Governments are the overall driving force of economic activity in the space sector: funding research and development (R&D), acting as an anchor customer for the space industry, and managing the regulatory environment [1]. In Europe, the main sources of public investments in the space domain are the European Space Agency (ESA), the European Commission, the European Defence Agency (EDA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and national and regional organizations (e.g. national space agencies or space offices, regional development organizations). European public institutions were responsible for 52% of the European space industry’s sales in 2013, whereas ESA procurement alone represented 35% (2.4 billion euros) of the European space industry revenues [2].

ESA is the dominant source of the public investments in space in Europe, especially in smaller ESA member states. ESA’s budget for 2015 (including third-party activities and European Cooperating States agreements) amounted to 4.4 billion euros [3], mainly consisting of national contributions to mandatory and optional programmes of ESA. The national contributions to the ESA budget are aligned with strategic goals of the countries, including industrial policy objectives. The national contributions to ESA transform into contracts with entities of the country through the ESA procurement system. Thus, the latter ESA contracts constitute the core of public space investments for the smaller ESA member states.

ESA spends around 8% of its budget on direct R&D, an activity mandated in the ESA Convention. The actual share of R&D in the ESA budget is even higher. ESA typically procures single products with superior specifications for successful space missions. The Frascati Manual allows for including the costs of the design and construction of such products in R&D costs [4]. According to one study, the share of the value of ESA contracts with Danish entities which required the development of new technologies was 72.4% between 2000 and 2007 [5]. From an ESA contractor’s viewpoint a
majority of contracts can be seen as R&D activities.

Space projects belong to a broader class of mission-oriented programmes [6,7]. The mission technology policy paradigm assumes that the public sector should perform R&D in service of well-specified missions in which there is a public interest not easily served by private R&D [8]. This renders space projects similar to R&D subsidies, a supply side instrument of innovation policy, which also focus on the development of new technologies and not on the diffusion of the generated technology [9], even though ESA mostly operates by awarding procurement contracts to industry and R&D organizations (thus being a demand side instrument of innovation policy).

Public R&D programmes are aimed at facilitating innovation and economic growth by supporting projects with the potential to generate high social rates of return. The neoclassical theory based on a positive externality (e.g. technology and knowledge spillovers) argument suggests that, because of the ‘public good’ characteristics of R&D activities (non-rivalry and non-excludability), the level of private R&D expenditure would be lower than the socially optimal level. This occurs since the benefits associated with R&D activities are easily and freely available to subjects that are not engaged in R&D efforts [10]. Even though the neoclassical approach can be criticized from different angles [11], the market failure arguments are widely used for justifying public funding for R&D programmes.

The role of governmental funding for university research is widely accepted and the subsequent effects on technical progress and economic growth are well established. Governmental subsidies to R&D activities performed by private companies is a more controversial topic, starting from the early findings by David, Hall, and Toole (2000) [12]. By surveying firm-level analyses conducted in the previous three decades, they observed that almost one-half of these analyses found no effect of public subsidy programmes on the R&D activity of firms. More recent evidence — firm-level empirical studies with different output variables (e.g. R&D investment, employment, sales, innovation activity, and welfare) — is similarly inconclusive (e.g. Ref. [13]).

Guerzoni and Raiteri (2015) [14] note that despite the theoretical and policy attention paid to the issue, the empirical evidence about the effect of innovative public procurement on innovation outcome is rather fragmented and mostly limited to case studies. Aschhoff and Sofka (2009) [9] have provided an empirical work on procurement with a large cross-sectoral dataset consisting of 1149 German firms. Their results highlighted that public procurement has heterogeneous effects on a firm’s innovation performance as measured by the share of turnover from new products and the public procurement was found to be particularly effective for smaller firms with limited resources.

With the international space community growing [15], a shift from the so-called trans-utilitarian approaches2 to more utilitarian approaches3 to the space investments [16] is witnessed. Investments in space programmes are perceived as any other public R&D investment and there is an obvious need for an impact evaluation of space programmes to help policy makers decide whether the programmes are generating the intended effects and how measured changes in welfare are attributable to a particular project or policy intervention.

The ratio of total indirect industrial effects deriving from space-related contracts to the value of the space-related contracts, a spin-off multiplier, has been one of the widely used indicators for impact assessments of public investments in space programmes. The spin-off multiplier provides an indication of intra-firm benefits to companies from space programmes due to internal technological spillovers, but fails to incorporate a wide range of social benefits related to the space programmes. The aim of the current paper is to assess the usefulness of the spin-off multiplier for international benchmarking of the efficiency of public space investments and also to give recommendations for the formulation of a standardized multiplier more suitable for benchmarking purposes.

The remainder of this paper is organized as follows: indirect industrial effects from institutionally funded space programmes are defined in Section 2; the latest empirical impact assessment studies of institutional space investments based on country-wide firm-level data and the methodological foundations of the studies are reviewed in Section 3; and factors hindering usage of the spin-off multiplier for international benchmarking are discussed in Section 4. The paper ends with conclusions.

2. Spillovers from space investments — typology and quantification

Griliches (1992) [17] concluded that ‘studies are all pointing in the same direction: R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates’. Hall, Mairesse, and Mohnen (2010) [18] note in their survey of literature that the social rates of return on R&D resulting from the sum of private rates of return on R&D and the R&D spillovers (e.g. knowledge spillovers) have been investigated mainly in two ways — case studies and econometric approaches. The authors point out that Bach et al. (1992) [19] represents an example of a case study describing the various ways in which the ESA programmes were beneficial to society on the basis of interviews with ESA contractors.

The econometric approaches have evolved around the early contributions by Griliches (e.g. Ref. [20]) and mostly depart from Cobb-Douglas production function augmented with knowledge capital, both internal R&D capital and R&D stocks from sources outside of the firm due to R&D spillovers. The latter approach has been recently applied by Graziola and Cristina (2013) [21] to establish the impact of technological spillovers from the Italian aerospace industry on the factor productivity increases in the Italian manufacturing sector based on a time series analysis, using the aggregate manufacturing sector data and panel data of 22 manufacturing sectors.

The econometric approach by Graziola and Cristina [21] succeeded into capturing R&D spillovers from R&D investments in the upstream space industry. The approach is hardly replicable in countries with smaller space industries, where only a few medium-sized firms and a few dozen small- and micro-enterprises are operating in space markets, due to the lack of data as the space economy, especially the downstream space sector, does not align well with standard industrial classification systems [22].

Graziola, Cristina and Di Ciaccio (2015) [23] elaborated a schematic framework compatible with Hall, Mairesse, and Mohnen [18] regarding how different types of benefits are combined to form the total social benefit of an innovation. They differentiate between internal benefits to the innovative firm and external benefits, including technology transfer, technology spillovers, and rent spillovers.

A different typology of spillovers and technology transfers was proposed in pioneering works on the impacts of institutional space programmes (Cohenet 1997 [24]):

1) Transfers within firms, between two departments or divisions.
2) The creation of a new department or division within a firm.
3) The creation of a new firm, such as a subsidiary.
4) Transfers between a space firm and a firm in the recipient sector; in the case of the granting of a license or patent, the market is sometimes divided up geographically or is shared on the basis of industrial sectors and/or the size of the customer’s orders.
5) The creation of a new firm in conjunction with a firm in the recipient sector (joint venture).
6) Technical assistance by the space firm in product development by a non-space firm.

These types can be further aggregated to intra-firm (the first three types\(^3\)) and inter-firm spillovers and technology transfer. While Venturini and Verbano (2014)\(^{[25]}\) provide a comprehensive literature review of the research on the inter-firm spillovers and technology transfer in the space domain, quite narrowly defined intra-firm spillovers (or internal benefits according to\(^{[23]}\)) — further on also ‘indirect industrial effects’ — are the focus of the current paper.

In the current study, the indirect industrial effects are understood similarly to the BETA framework\(^{[26]}\). The indirect industrial effects stem from the contractual relationships between the space agencies and the contracting bodies (companies and academia) that carry out a project. The indirect industrial effects include all the benefits in terms of technology, know-how, corporate image or business contracts, which the firms derive from their participation in institutional space (incl. ESA) programmes and which they are able to use elsewhere, resulting in increased (additional) sales and added value.

The impacts of R&D subsidy programmes can be assessed afterwards (ex post) or before they have taken place (ex ante). It has been noted that a very limited number of attempts to perform ex ante evaluations of R&D subsidy programmes has been recorded\(^{[27]}\). The BETA methodology is an ex post approach.

Four types of the indirect industrial effects are distinguished in the BETA methodology\(^{[24]}\):

- Technological effects corresponding to the transfer of technology developed during an R&D programme by the participants to it, such as derivatives from ESA products, new products, and product improvements;
- Commercial effects: i) network effects (the impact of the programme on the research and business connections of the participants involved); ii) reputation effects (ESA contracts can be used as a marketing tool or reference);
- Organization and method effects, such as changes to the organizational structure, adoption of novel quality control, experimental procedures, tests and measurement, and management methods; and
- Work factor effects, such as heightened qualifications and skills acquired by the personnel employed in public R&D programmes, which enable them to feed expertise into the company departments not directly concerned with the same activities, as well as building up a critical mass of specialists, scientists, engineers, and technicians.

In order to measure all these effects, BETA proposed a methodology of direct interviews with managers of space companies. In the BETA methodology, the final variable for expressing the indirect effects on a firm is value added, along with the estimated value that results from setting up and maintaining highly skilled design and production teams (defined as the ‘critical mass’). The quantification exercise thus consists of determining how the work carried out for ESA programmes affects these two parameters; the process is illustrated in Fig. 1. BETA methodology provides a minimal or a conservative estimation (lower bound) of the indirect industrial effects.

The BETA approach has received some criticism from researchers attempting to adopt it. Capron, Baudewyns, and Depelchin (2010)\(^{[28]}\) argue that managers that are presumably in the best position to answer such questions have difficulties providing the monetary value of the indirect industrial effects, especially in terms of value added.

Based on the data on the value of ESA contracts with companies and the indirect industrial effects, the BETA methodology introduced a construct — the ratio of the indirect industrial effects to the value of space-related contracts (by ESA) — to measure the impact of ESA contracts. This construct has been called a spin-off multiplier in the BETA approach. Table 1 summarizes the results of some early studies.

The spin-off multiplier is an intuitive construct based on the monetary value of benefits from space programmes and it is a seemingly good indicator for international benchmarking of the efficiency of institutional space investments. However, it must be noted that the construct has a number of intrinsic limitations. It does not convey any information on allocative efficiency nor does it provide a ranking of alternative policy options for public authorities. In addition, the direction of causality between indirect and direct industrial effects can be debated, even though the judgments from interviewed managers provide an estimate of the direction.

3. Country-wide assessments of the indirect industrial effects based on the BETA methodology

National contributions to ESA are the main source for funding space activities (mostly space-related R&D) in most European countries, and the importance of the contributions tends to be higher for smaller ESA member states. For example, the Danish contribution to ESA constituted 72% of the country’s total budget for space activities in 2004\(^{[5]}\), and Luxembourg’s space budget is essentially directed towards ESA which has constituted 87% of the country’s investment in space R&D over 2005–2011\(^{[29]}\). At the same time, just 39% of French space agency CNES’ budget was allocated to the French contribution to ESA in 2014\(^{[30]}\).

The complex industrial policy of ESA includes a specific element of equitable participation in ESA procurement by entities in member states proportionate to national contributions to the ESA budget (juste retour) and specifies the resulting procedural mechanisms. Exploitation of the advantages of free competitive bidding is also a basic rule of the ESA industrial policy. It is primarily these two elements that determine the geographical return (georeturn) coefficient\(^4\) of an ESA member state\(^{[31]}\).

The industrial policy objective set out in the ESA Convention is that the distribution of contracts placed by the ESA should ideally result in all member states having an overall georeturn coefficient of 1. In practice, the georeturn coefficient has remained below 1 for prolonged periods for several member states, including Finland\(^{[32]}\).

Institutional space funding is highly concentrated. For example:

\(^4\) The geographical return coefficient is the ratio between the share of a country in the weighted value of ESA contracts and its share in the contribution paid to the ESA.
assessments of space-related R&D programmes. In particular, the 4 largest beneficiaries of public space programmes received 50% of the total contract value and further 11 organizations received the next 30% [33]. The 10 largest beneficiaries of ESA contracts in Danish private sector were awarded 98% of the total value of ESA contracts in the period from 2000 to 2007 [5]. In Portugal, 17 entities (22% of the total number of contractors) accounted for around 80% of the total value of ESA contracts to Portuguese entities between 2000 and 2009 [34].

While econometric studies are routinely performed to estimate social rates of return for publicly funded R&D programmes, impact assessments of space-related R&D programmes are a special case as the usage of econometric methods is hindered by small study samples and limited availability of pertinent data. On the other hand, as the total number of ESA contractors in ESA member states is relatively small, especially in smaller countries, otherwise costly methods for impact analyses, e.g. methods based on interviews such as the BETA methodology, can be applied at affordable cost by policy-makers. The wide range of positive externalities for space activities implies the risk that more ambitious and broader approaches could become very extensive and costly [22].

OECD (2014) [1] outlined six national assessments of spin-off multipliers from space programmes (see Table 2). There are four ESA member states in Europe that have performed country-wide ex

post analyses of the indirect industrial effects that can be methodologically directly linked to the BETA methodology. The Norwegian [35], Danish [5], Portuguese [34], and Irish [36] studies have relied on narrow definitions of the indirect industrial effects similar to the BETA methodology, constructed simple output metrics (spin-off multipliers) built on the general logic of basic financial analysis (using monetary value of the indirect industrial effects), and collected input data directly from ESA contractors (primary data) through online surveys and face-to-face or telephone interviews.

The multiplier provided for UK was a Leontief-type multiplier (Type 2) based on input-output modelling which calculates the direct, indirect, and induced added value created by an additional unit of added value in the UK space industry [37]. The Belgian multiplier was built on an original methodology - a model built around a central assumption of fully rational agents (managers of space companies) in the presence of uncertainty [28]. An incentive-compatible inequality (as in microeconomic contract theory) is the starting point for the estimation of the indirect effects: the managers are estimating the expected benefits of space projects ex ante

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5 Norway is one of a few countries in Europe that has introduced substantial national measures for fostering space related R&D and space industry — funds managed by the Norwegian Space Centre (NSC).

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Table 1
Summary of the results of earlier BETA studies.

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<thead>
<tr>
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<tbody>
<tr>
<td>Number of firms in the panel</td>
<td>128</td>
<td>67</td>
<td>10</td>
</tr>
<tr>
<td>Spin-off multiplier</td>
<td>2.9</td>
<td>3.2</td>
<td>3.5</td>
</tr>
<tr>
<td>Nature of effects</td>
<td>Technological</td>
<td>50%</td>
<td>Commercial</td>
</tr>
<tr>
<td></td>
<td>Commercial</td>
<td>27%</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td>Organization and method</td>
<td>19%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Work factor</td>
<td>29%</td>
<td>54%</td>
</tr>
</tbody>
</table>

Source: Cohendet (1997) [24].

Table 2
Selected national assessments of spin-off multipliers to space programmes.

<table>
<thead>
<tr>
<th>Country</th>
<th>Spin-off multiplier (year)</th>
<th>Study periodicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>1.4 (2010)</td>
<td>Ad-hoc</td>
</tr>
<tr>
<td>Denmark</td>
<td>3.7–4.5 (2008)</td>
<td>Ad-hoc</td>
</tr>
<tr>
<td>Ireland</td>
<td>3.63 (2012)</td>
<td>Ad-hoc</td>
</tr>
<tr>
<td>Norway</td>
<td>4.75 (2013)</td>
<td>Annual, since 1992</td>
</tr>
<tr>
<td>Portugal</td>
<td>2 (2011)</td>
<td>Ad-hoc</td>
</tr>
<tr>
<td>UK</td>
<td>1.91 (2010)</td>
<td>Every two years</td>
</tr>
</tbody>
</table>

Source: OECD (2014) [1].
and embark on the space projects only if these lead to better economic outcomes than an alternative option. Spin-off multipliers of ‘first-order’ and ‘second-order’ effects were empirically estimated based on the data of 14 companies.6

3.1. Output metrics of the studies

The spin-off multipliers in Table 2 are often used in different national space strategies for benchmarking, but the multipliers are actually calculated rather differently and are directly incomparable. The main metric applied in annual Norwegian studies is a spin-off multiplier with an accumulated delay (3 years) defined as follows [35]:

\[
\text{Spin-off multiplier} = \frac{\sum_{1985}^{n} (\text{sales})}{\sum_{1985}^{n-3} (\text{value of ESA contracts} + \text{value of national support scheme contracts})},
\]

(1)

where \( n \) denotes a year for which the indicator is calculated.\(^7\)

The Danish study reported the spin-off multiplier which included both the indirect and direct industrial effects. The direct effects were equal to net value of ESA contracts\(^8\) placed with Danish organizations. The Danish multiplier can be expressed as follows:

\[
\text{Spin-off multiplier} = 0.83 
\times \frac{\sum_{2000}^{2007} (\text{indirect turnover} + \text{net value of ESA contracts})}{\sum_{2000}^{2007} (\text{net value of ESA contracts})},
\]

(2)

The main differences from the Norwegian methodology were:

- Introduction of a tax distortion coefficient (0.83) as a measure of allocative inefficiency (deadweight loss caused by taxation) – it must be noted that a major practical difficulty in measuring the deadweight loss for a system of taxes is that deadweight loss is a function of demand interactions that are very difficult to measure; therefore using a tax distortion coefficient is theoretically plausible, but assigning a value to it is always controversial as follows from a number of relevant papers [38].
- The analysis did not include a time lag between contracts and intra-firm benefits as introducing this in the analysis would have limited the observed period.

The Portuguese study used a similar approach to the Danish study by including direct effects in the reported multiplier:

\[
\text{Spin-off multiplier} = \frac{\sum_{2009}^{2009} (\text{indirect turnover} + \text{value of ESA contracts})}{\sum_{2009}^{2009} (\text{value of ESA contracts})}
\]

(3)

The Irish study reported a non-accumulative spin-off multiplier based on an assumption that the correlation between Irish public spending on ESA programmes and turnover derived directly from ESA related products or services suggests an average 5-year time-frame between investment and impact on turnover. Hence, the Irish spin-off multiplier can be expressed as:

\[
\text{Spin-off multiplier} = \frac{\text{ESA derived turnover}_{n-5}}{\text{value of ESA contracts}_{n-5}}
\]

(4)

It follows from (1)–(4) that the main departure from the BETA methodology is reliance on additional turnover, rather than additional value added in all these four studies. The ratio of value added to turnover can vary considerably across different actors in the space domain, depending on the industry and position in a relevant value chain and this is one of the causes making the spin-off multipliers in Tables 1 and 2 not directly comparable.

3.2. Input data of the studies

The data on space investments, i.e. ESA contracts with companies in a country as well as regarding national investments in space activities, were at the disposal of national space offices that commissioned the studies. The data was consistent, reliable, accurate, quantified on the level of relevant actors, available in time series and easily accessible.

Only the Irish study used both in-house databases (available at Enterprise Ireland) and self-reporting for estimating the total annual value of ESA contracts concluded with the Irish companies. The self-reported data was collected not for each year but for every third year (2003, 2006, and 2009) for the Irish study.

The definition of the indirect industrial effects has minor variations in the country-wide studies. The Norwegian methodology has the most precise specifications, stating that these effects comprise [35]:

- Sales of new products (incl. from other departments or subsidiaries) or additional sales of existing products that have undergone improvements based on the technology or expertise that has been developed in relation with ESA contracts.
- Sales of new or existing products due to the goodwill or reputation gained through involvement with the ESA activities.
- Increased subcontracting sales to ESA activities by other contractors.

In Ireland and Portugal, more concise definitions were applied. For example, the Irish study asked respondents to report ESA-
derived turnover which referred to sales of products or services developed as a direct result of ESA involvement (excluding direct ESA contracts).

The main data sources for the country-wide studies have been surveys and interviews to quantify the indirect industrial effects. While the Norwegian and Portuguese studies relied on both surveys (questionnaires) and interviews, the Danish study was based on interviews and the Irish study was based on a survey only. Table 3 gives an overview of the methodologies applied in different studies.

A variety of measures to validate self-reported data (e.g. for noticing irregular data entries) had been applied in the studies:

- Comparison with available secondary data (annual reports, public databases).
- Comparison with earlier survey data was one of the possible options in Norway.
- Validation of self-reported data based on the qualitative information collected during face-to-face interviews.
- Expert opinions of industry veterans were used in Denmark and Norway.

4. Benchmarking of the studies – methodological issues

Given the limited availability of data, the following spin-off multiplier can be constructed for comparing only the indirect industrial effects from ESA contracts in different countries:

\[
\text{Spin-off multiplier (T)} = \frac{\sum_{T}^{T+7} \text{indirect turnover}}{\sum_{T}^{T+7} \text{value of ESA contracts}}
\]

The reported Danish spin-off multiplier is modified by not using weights indicating the technological level of ESA contracts, and by dropping the tax distortion coefficient and the direct industrial effects from the Formula (2). Data for Norway can be extracted from annual Norsk industri og ESA-deltakelse reports. The poor quality and unavailability of relevant data does not allow construction of a spin-off multiplier according to the Formula (5) for Portugal and Ireland.

Resulting spin-off multiplier coefficients expressing only the indirect industrial effects are:

- 3.73 for Denmark (for 2000–2007) and
- 5.43 for Norway (for 2005–2012), including space-related R&D contracts placed by NSC.

The coefficients are even higher than reported in OECD (2014) [1], signaling that investments in space programmes lead to considerable economic benefits, but intrinsic limitations of the spin-off multiplier and several methodological issues – apart from the fact that the unit of measurement is not the additional value added for companies – must be considered before the final assessment on the efficiency of public space investments can be made.

4.1. Quality of input data – the indirect industrial effects

There are two main problems related to the data on the indirect industrial effects – issues with data consistency and exaggerated values of the effects.

Surveys have been a preferred mode of data gathering in the country-wide studies. Surveys have a number of merits: for example, they are relatively inexpensive and the gathered data can be easily processed. At the same time, surveys are widely considered to have a number of disadvantages, including problems with ambiguous questions.

The author performed a study compliant with the BETA framework in the Czech Republic and Estonia in 2015. Interviews with 25 ESA contractors confirmed that the respondents had difficulties with understanding the term ‘ESA-derived turnover’, judging from pre-filled questionnaires, i.e.:

- Differentiating non-ESA space sales from overall space sales or non-ESA space sales from non-space sales.
- Linking non-ESA space sales or non-space sales with outcomes of ESA contracts and identifying additional effects of the ESA contracts.
- Differentiating between the different types of indirect industrial effects (technological, commercial, organization and method, and work factor effects) – the differences could not be perceived and understood by the respondents, even though examples of the sub-types were provided in the questionnaire.

Clarifications during face-to-face interviews were essential to ensure that the respondents answered the questions in a consistent manner.

Impacts generally result from multiple causes. Within benefits identified as at least partly due to a space-based activity, there is a need to assess the proportionate contribution of that activity (the so-called ‘attribution problem’). The formulas in Section 3.1 do not include companies’ own investments in relevant space R&D, which can be substantial. The results of impact analyses based on case studies and interviews must be taken with some precaution, as it has been noted that there is a demonstrated, systematic tendency for

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Comparison of the studies – data collection methodology.</th>
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</thead>
<tbody>
<tr>
<td>Methodology</td>
<td>Survey, regular status meetings</td>
</tr>
<tr>
<td>Questionnaire design (indirect industrial effects)</td>
<td>Dedicated questionnaire for quantitative and qualitative data</td>
</tr>
<tr>
<td>Sample for face-to-face interviews</td>
<td>Regular (annual, bi-annual) interviews with executives by industry expert</td>
</tr>
<tr>
<td>Data validation</td>
<td>Comparison with primary data (regular interviews)</td>
</tr>
</tbody>
</table>

Source: compiled by the author.
When ESA places a multi-annual contract, the whole amount to be annually committed by ESA (and respectively by NSC in Norway) to commitments is considerable in the example of the Danish data. Fig. 3 shows that the annual variation of the values of ESA commitments is irrespective of the duration and a related number of instalments.

4.2. Quality of input data

Individual spin-off multipliers between 20 and 40[33] were reported in Norwegian studies. The high values of individual spin-off multipliers might be overestimated in the regular Norwegian studies (see Table 3) and it cannot be rejected that the respondents implicitly report discounted values, the reported indirect industrial effects could be overestimated in the Norwegian studies. The high values of individual spin-off multipliers might be an indication of the optimism bias, as some studies, such as [43] have shown that while a few innovations received most of the innovations’ returns (skewed distribution), most innovations obtained negative returns.

Even though several data validation techniques are applied in regular Norwegian studies (see Table 3) and it cannot be rejected that the respondents implicitly report discounted values, the reported indirect industrial effects could be overestimated in the Norwegian studies. The high values of individual spin-off multipliers (see Fig. 2) – there were companies in 2010 with the values of individual spin-off multipliers between 20 and 40[33] – might be an indication of the optimism bias, as some studies, such as [43] have shown that while a few innovations received most of the innovations’ returns (skewed distribution), most innovations obtained negative returns.

Fig. 2. The distribution the individual spin-off multipliers in Norway (accumulated delay of 3 years), 2010. Source: PWC (2012)[33].

4.2. Quality of input data – investments

In the Norwegian, Danish, and Portuguese studies, funds annually committed by ESA (and respectively by NSC in Norway) to national entities were used as values for a variable of investment. When ESA places a multi-annual contract, the whole amount to be paid to a contractor is accounted in the first year of the contract, irrespectively of the duration and a related number of instalments. Fig. 3 shows that the annual variation of the values of ESA commitments is considerable in the example of the Danish data.

For this reason, when long contracts are involved, the profile of the commitments can be quite different from the profile of self-reported data (e.g. in the Irish study). This was confirmed by the outcomes of the interviews conducted by the author with 15 ESA contractors in the Czech Republic in 2015.

If the spin-off multiplier is based on ESA commitments available to national space offices, the value of it may differ considerably from the value of the spin-off multiplier based on self-reported data (i.e. actual annual instalments of respective ESA contracts), unless the underlying period is long enough to compensate for the annual variation.

According to the Formula (4), in Ireland the underlying period for calculating the spin-off multiplier was one year. Because of the large annual fluctuations, using such a non-cumulative estimate for the spin-off multiplier might lead to inconsistent results, which make it a less useful indicator from the perspective of policy-making.

4.3. Time lag between investments and the derived effects

Under normal circumstances there is a time lag of several years until any R&D becomes operative. Introduction of a time lag in the metrics is therefore justified in the country-wide studies on the spin-off multipliers. In the Irish study a time lag of 5 years was used, while the respective lag was 3 years in the Norwegian study. It was implicitly assumed in the Danish and Portuguese studies that the indirect industrial effects of ESA contracts can be observed in the same year the contracts are given.

Omitting a time lag was justified in the Danish study, with the relatively stable value of the geographical return coefficient (nearly 1), as well as the stable level of public contribution to ESA (‘steady state’), even though the study report concluded that imposing a time lag between contracts and intra-firm benefits is justified, as operational space systems are characterized by average lead production cycles of 18–36 months[5].

The results of the interviews with 15 ESA contractors in the Czech Republic support introduction of longer time lags for the calculation formulas of the spin-off multipliers (see Fig. 4). At the same time, there is a possibility that in new ESA member states the time lag between ESA commitments and the deriving indirect industrial effects can be longer than in countries that are in the ‘steady state’, as a fair share of the ESA contracts in the new member states start from very low technology readiness levels[11] (TRL 2–4).

The interviews with the Czech industry also revealed that the time lag appears to be shorter for companies developing downstream services based on Earth Observation data and for companies providing contract manufacturing services, and longer for companies developing their own products. These results are in line with Ricard et al. (2015)[45], who showed that the time lag depends on

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9 The degree of optimism bias may differ depending on whether an appraiser is internal (a manager) or external.

10 Additionally, currency fluctuations must be taken into account. The Norwegian and Danish studies were based on local currencies for accounting the indirect impacts. The Norwegian krone to Euro exchange rate fluctuated more than 25% (highest vs lowest) between 2005 and 2012. The Danish krone joined the Exchange Rate Mechanism II (ERM II) in the beginning of 1999 and observes a central rate of 746.038 per 100 euro with narrow fluctuation margins of ±2.25%.

11 TRL9 corresponds to actual system flight proven, while TRL1 corresponds to basic principles observed [44].
the properties of a target market, as well as on the technological characteristics of the projects involved.

4.4. Sensitivity for estimates of spin-off multiplier

The only existing study that paid attention to the confidence interval for the estimate of the spin-off multiplier was the Danish study, as it had the smallest survey sample available for statistical analysis, due to the very high concentration of ESA contracts. The Danish study opted for the bootstrap method [46]. The variable analyzed in the Danish study was the sum of individual spin-off multipliers in bootstrap resampling weighted by the respective company’s share in the total value of ESA contracts.

Fig. 5 shows the empirical distribution of the spin-off multipliers in the bootstrap resampling based on the Danish sample. The red line shows a normal distribution with the same mean and standard variation. Statistical tests showed that the empirical distribution was not normally distributed on a 5% confidence level. The dotted lines represented the 5% and 95% confidence interval from the empirical distribution. Similar tests should be carried out for the other country-wide studies as well, but data for performing the tests are not available.

If a governmental agency responsible for space policy sets a certain threshold value for the spin-off multiplier for decision-making purposes (e.g., for deciding on an increased contribution to ESA), then there is a possibility that the actual value of the multiplier is below the threshold, given the wide confidence interval, even though the estimate of the multiplier is above the threshold.

12 For example, the Norwegian Ministry of Trade and Industry has defined the spin-off multiplier as an important key performance indicator for measuring the effect of public investments in space activities. The Ministry has set a threshold value of 4 for the spin-off multiplier. If the spin-off multiplier is above the threshold value (>4), the national space programme and contributions to ESA should be maintained or increased [36].
5. Conclusions

The spin-off multiplier measuring the impact of space investments on business activities of companies active in the space domain has been referred to in several prominent publications by the OECD and ESA on the space economy. The purpose of this paper is to highlight and analyze the methodological foundations of existing European studies on the spin-off multiplier.

Indeed, these studies are still weak for international benchmarking, as they are methodologically quite different:

- The calculation formulas differ from study to study. Some of the multipliers include direct industrial effects, while some are based purely on the indirect industrial effects.
- The studies have used different time horizons — the annually estimated Norwegian spin-off multiplier aggregates values over long time periods (30 years by now), while in the other country-wide ex post analyses of the indirect industrial effects the study covered a period of 8–10 years.
- Other minor methodological differences between the studies include, for example, the usage of a tax distortion coefficient as a measure of allocative inefficiency or reliance on undiscounted nominal data.

It can be argued that the spin-off multiplier calculated on the basis of time series longer than 20 years becomes less sensitive to the impact of current policies will be increasingly limited. On the other hand, a period of 8–10 years does not allow for introducing a time lag between an investment and derived effects in calculation formulas. Considering the long development and production cycles of the space sector, the time lag to be recommended for prospective country-wide studies is around 5 years. Given the time lag, the studies should cover a period of 10–15 years for providing reliable information about the spin-off multiplier of space investments.

Despite being intuitive and easy to understand in debates on economic policy, the usefulness of the spin-off multiplier for international benchmarking or policy-making purposes may be limited because of:

- Intrinsic limits of the spin-off multiplier as a measure of the benefits resulting from activities implemented under an ESA contract.
- Possible attribution problems and resulting overestimations of firm-level data that have been overlooked in the existing studies — this problem can be addressed by choosing proper data-gathering techniques. Face-to-face interviews should be preferred to surveys as in the latter case responses from target groups generate less consistent data. Interviewing is also affordable in smaller ESA member states, as study samples are small.
- Wide confidence interval of the estimate of the multiplier, as was demonstrated in the Danish study.

Measuring the indirect industrial effects is nevertheless a valuable tool for governments of ESA member states, as the other main metric — geographical return coefficient — is merely an indication of a country’s historical performance in the ESA procurement system and fails to capture and measure any spillovers. In smaller ESA member states, many companies involved in the space programmes originate from and/or actively operate in non-space domains. They bring along technologies from non-space industrial sectors that are further developed through their use in space, and then, if possible, transferred back to other industrial sectors, resulting in the indirect industrial effects. It is essential to identify the magnitude of the effects for effective policy-making.

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