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# Title: State of play – Literature review

RI PATHS
Research Infrastructure imPact Assessment paTHwayS

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|---|---|
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**Abstract:** This report contains a critical literature review of the most common methodologies currently employed for the socioeconomic impact assessment (IA) of research infrastructures (RIs). The review is intended to pave the way for the development of a conceptual framework IA model. There are a wide array of existing approaches and methods to assess the socio-economic impact of RI. While the majority of the reviewed approaches cover the main expected socioeconomic impacts of RIs, such as the production of knowledge, human capital accumulation, increased innovation, productivity or effects on GDP, they differ in the way such impacts are measured, treated, and aggregated. Moreover, some of the reviewed methods are complementary, some are substitutes; some have broad applicability, while others are quite narrow in their scope and potential informative power. The review makes a systematic assessment based on six assessment criteria: reliability, validity, accuracy, cost/time needed, relevance for policy makers, relevance for RI managers. The review highlights that there is not a single methodological approach that can appropriately answer all the questions that a socio-economic IA addresses. Rather, a smart and rigorous combination of approaches can add value compared to existing methods.


EFIS european future innovation system centre — Csil CENTRE FOR INDUSTRIAL STUDIES — EUROPEAN SCIENCE FOUNDATION — Fraunhofer ISI — EMBL — CERN — ALBA — DESY


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## List of acronyms / abbreviations used in this document

| ABBREVIATION | MEANING |
|---|---|
| ASIRPA | Assessment of Socio-Economic Impact of Public Agricultural Research |
| BBMRI | Bio-banking and Biomolecular Research Infrastructure |
| CERN | European Organization for Nuclear Research |
| CIS | Community Innovation Survey |
| ESFRI | European Strategy Forum on Research Infrastructures |
| EU | European Commission |
| EVARIO | EVAluation of Research Infrastructures in Open innovation and research systems |
| FP7 | $7^{th}$ Framework Programme |
| FTE | Full time equivalent |
| GDP | Gross Domestic Product |
| GVA | Gross Value added |
| IA | Impact Assessment |
| INRA | Institut National de la Recherche Agronomique (French National Institute for Agricultural Research) |
| IOA | Input-output Analysis |
| I-O | Input-output |
| KPI | Key Performance Indicator |
| MSA | Main Statistical Areas |
| OECD | Organisation Co-operation and Development |
| OECD GSF | Organisation Co-operation and Development - Global Science Forum |
| PFA | Production Function Approach |
| Q1 - Journals | Quartile 1 Journals |
| R&D | Research and Development |
| RIs | Research Infrastructures |
| RIFI | Research infrastructures: Foresight and impact |
| SEIRI | Socio-Economic Impact of Research Infrastructures |
| S&T | Science and Technology |
| STI | Science, Technology and Innovation |
| TFP | Total Factor Productivity |
| ToC | Theory of Change |
| WP | Work Package |

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# 1 Introduction

**RIs are a cornerstone of European research and innovation and play a pivotal role in sustaining the world-class excellence of European research.** They are at the core of knowledge creation by assembling a critical mass of people, data and financial resources, and facilitating international cooperation in science. In order to ensure scientific progress, remain competitive with respect to global competitor and tackle societal challenges, the EU is increasing investment in RIs as a strategic component of public policies.[1]

The need to assess the socioeconomic impact of science arises from the **increasing amount of public money invested for research facilities at a time of tightening budget constraints**. Governments and research funding agencies are under increasing pressure to justify their investments by demonstrating the value added to society that RIs provide. While the dominant decision-making mechanism in science policy remains the consideration of the scientific case based on a peer review exercise, international practise shows that decision making processes for funding new or upgraded/expanded RIs may be prone to lobbying. Investments in expensive RIs are usually advocated by a coalition of scientists often supported by peer reviews exercise claiming a scientific case to be supported by public funds.[2] All **these elements come together in generating a strong interest and demand for methods for evaluating the socioeconomic impact of RIs.** There is consensus among most EU and OECD countries on the need to promote evidence-based strategies for coordinated investment in RIs and to closely link them to evaluations and impact assessments.[3]

While it is thus clear that impact assessments play an increasing role in decision-making processes on RI investments, **currently there is no unified framework for the socio-economic IA of investment in RIs**.[4] A heterogeneous set of approaches is applied to capture observable (and non-observable) direct and indirect effects of RIs, their long-term impacts and reflecting different information needs of funding institutions, policy decision-makers and RI managers. While such approaches usually address the same broad categories of impacts (scientific, economic, human capital, technological, cultural), there is no consensus even in the way such impacts are defined. The most challenging traits of assessing the socioeconomic impact of RI (with respect to traditional infrastructures) and of science in a broader sense are related to: the intangible nature of benefits, their long timespan, their high uncertainty and related risks (especially in relation to the probability of breakthrough scientific discoveries) as well as the high occurrence of externalities and spill-over effects. This has led to the proliferation of ad-hoc modelling and forecasting exercises, tailored to the uniqueness of the unit of analysis and often focusing on specific type of impacts, rather than drawing from more comprehensive conceptual frameworks.

Within this context and far from touching all the spectrum of existing methodologies that have been employed over time to assess the contribution of RIs to economy and society, **this literature review aims at critically reviewing the existing, most commonly used theoretical frameworks and evaluation methodologies** for such a purpose. The ultimate goal is **to lay the foundation for building a new, robust and empirically grounded framework to be used for evaluating the socioeconomic impact of RIs.**

**This document is structured in three parts.** The next section identifies the objective and defines the boundaries of this literature review; the central part of the document (Sections 3, 4, 5, 6, 7 and 8) presents the evaluation approaches and critically reviews

[1] ESFRI (2018; 2016b); Eiroforum (2017);
[2] Flyvberg et al (2007); Flyvberg (2003);
[3] OECD (2019); ERIC (2018); ESFRI (2016a); Kowalski A.M (2016);
[4] OECD (2019); ESFRI (2016b);

them on the basis on the criteria presented in the next section. Section 9, the third part of the document, concludes. It provides a general assessment of the evaluation frameworks and indicates the suggested approach to be adopted for the IA model.

# 2 The scope of the socioeconomic appraisal of publicly funded RIs: what are we exactly interested in knowing?

RIs are different in nature, scope and reach. Designed to address specific scientific missions in their own field (climate change, sustainable energy, heritage science, advances in the knowledge of the universe, resource efficiency and raw materials, etc.), **RIs can have profound impacts on social, economic, and cultural condition of agents** (citizens, firms, scientists, RIs users) **that spread over time and space** beyond the boundaries of their mission. Possible impacts associated with a RI project can vary considerably depending on its core mission and the nature of the project.[5] More generally, science and its mission to search for the new frontier of knowledge has such an evocative power that has traditionally inspired different approaches of investigation on the way it works and affects people and society.

Among all the possible range of approaches, methods and levels of investigations that have been used to study RIs, we focused only on those assessing impacts (thus not merely addressed to the generic understanding of the performance over time of RIs if not linked to considerations about the generation of impacts) and those relevant from a socio-economic perspective (thus we are not interested in other dimensions of impact, such as organisational, philosophical or ethical issues).

**We grouped relevant contributions from the literature in six main approaches**: 1) socioeconomic assessment based on impact multipliers; 2) methodologies applying the knowledge production function; 3) cost-benefit analysis; 4) approaches based on multi-methods, multiple partial indicators; 5) theory-based approaches; and 6) case studies.

For each approach, we highlight key assumptions and objectives. More importantly, **each approach is assessed according to six evaluation criteria** as shown in Table 1.

5 For instance, technology advances and innovation, outreach and cultural impacts, scientific and knowledge outputs, human capital accumulation can depend on the type of RI (single-site, distributed, virtual, mobile), size, scientific domain.

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## Table 1: Criteria for assessment of the reviewed IA approaches

| EVALUATION CRITERIA FOR THE IA APPROACHES REVIEWED IN RI-PATHS LITERATURE REVIEW |
|---|
| **RELIABILITY (methodological quality/consistency)** |
| The reliability considers how much the approach is methodologically sound. It refers to the extent to which the approach is robust (i.e. builds on a well-established theory), ensuring internal consistency and replicability. Examples of reliability questions are:<br>• Is the approach based on a sound and well-accepted theory?<br>• To what extent the theoretical framework can be used to interpret results and link observed/expected impacts to RI?<br>• To what extent does the conceptual framework allow for replicability?<br>• Can the approach be generalised to different typologies of RIs? |
| **VALIDITY (comprehensiveness in covering relevant effects of RI)** |
| Validity is related to the capacity of the approach to identify measure and account for all the socio-economic impacts attributable to a RI. Considerations should be also given to whether the approach is able to acknowledge all the relevant characteristics of RI activities that can generate different impacts. Examples of validity questions can be:<br>• Does the approach address all the observed/expected impact of a RI?<br>• What kinds of impacts is the approach able to measure?<br>• Is the approach able to account for all the relevant characteristics of RI activities? If not, why? |
| **ACCURACY (objectivity in describing and measuring impacts)** |
| Accuracy refers to the capacity of the approach to objectively represent the impacts, leaving limited room for evaluators' interpretation about how impacts are defined, described and measured. Accuracy can be assessed through the following questions:<br>• Does the approach correctly describe the impact, avoiding possible double-counting and overlaps? To what extent does the approach limit over or under estimations of the impacts?<br>• Is the approach able to objectively measure impacts?<br>• Does the approach give a comprehensive and clear judgment about the socioeconomic impact of a RI? |
| **COST/TIME NEEDED** |
| This criterion refers to the amount of resources (in terms of time, financial resources, expertise and data intensity) with which the method can be implemented. This should be assessed not only for the researcher/consultant point of view, but also from the RI perspective. |
| **RELEVANCE FOR POLICY MAKERS AND FUNDERS** |
| Considerations should be given whether and to what extent the approach fits with the type and nature of information need by policy makers, thus referring to the strategic policy objectives that the RI is called to achieve and to providing sufficiently reliable information for evaluation. |
| **RELEVANCE FOR RI MANAGERS** |
| This criterion should convey consideration about the fit of results stemming from the evaluation approach with information required by RI managers, thus referring to the internal management of RI usually addressing a cost-effectiveness concern and how to operatively manage their organisation. |

*Source:* ***authors***

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# 3 The socioeconomic IA based on impact multipliers

## Idea and scope

**Impact multipliers are used to measure the effect of an investment** (e.g. an additional EUR invested) **in a sector or economic activity** (direct impact) or **on the whole economy** (indirect and induced impacts). They adopt a macroeconomic perspective as they look at interrelationships between various industries in a country or region and focus on the ultimate effect that an initial change in one industry/sector produces on the whole economy. They express the impact in terms of effects on aggregated macroeconomic variables such as regional/national GDP, gross value added or employment[6].

An economy-wide impact is the sum of direct, indirect, and induced impacts, which are calculated by applying different impact multipliers.[7] **Direct impacts** are those initiated by the investment in the upstream manufacturing sectors as producers react to the investment stimulus to meet the increased needs. They typically capture initial capital investment and its first order effects (e.g. direct employment, and effects generated by its output on industry/sector GDP/GVA where the intervention takes place**). Indirect effects** arise from changes in activity of suppliers, i.e. the impact that the intervention further generates along the upstream value chain causing a ripple effect in the economy (e.g. impacts from changes in sales by suppliers to the directly-affected businesses). Indirect effects are also known as secondary or second round impact. '*Type I multipliers*' are typically used for quantifying the combined effect of direct and indirect impacts caused by the interdependency only within the industrial sector where the intervention is implemented. **Induced effects** measure downstream shifts in the economy activity via spending on goods and services as a consequence of increase of households/people income throughout the economy caused by direct and indirect effects. Induced spending supports industries/sectors beyond those where the initial intervention takes place and may include housing, retail outlets, companies producing consumer goods and a variety of service industries. '*Type II multipliers*' or other ad-hoc multipliers are usually used to estimate the induced impact on the economy.[8]

Accordingly, the idea behind impact multipliers is that **the effect of an investment project at any one point in time is transmitted to the rest of the economy step-by-step via the chain of transactions (multipliers) that link the whole system together.** An IA based on impact multipliers traces the public spending through an economy and measures the average cumulative effects of that spending in terms of cascaded economic activity. **Welfare/economic effects that cannot be captured by the financial/transactional accounting systems (e.g. production externalities) are disregarded.**

## Theoretical background

Impact multipliers were firstly developed by Leontief in the Thirties. In his introduction to '*The Structure of American Economy 1919-1929'*, the first systematic presentation of what was to became input-output analysis (IOA), Leontief described his work as '*an attempt to apply the economic theory* (i.e. mathematical formulation) *of general equilibrium to an empirical study of interrelations among different parts of a national economy as revealed*

[6] A typical result of an IA study that applies this approach is that: 'the estimated value added/ GDP value (direct + indirect + induced effect) of the project generated over a given time span is EUR X, while the total funding was EUR Y (with X >Y). The EUR Y invested in the project is estimated to have boosted total employment by *around Z persons in that time span'*.

[7] Miller (2009); Miller et al (1991); Leontief (1986; 1936). For an overview of the IOA see United Nation (2017).

[8] Simmonds et al (2013). Classification of multipliers is a naming convention and application varies across reviewed literature. Type II multipliers are generally calculated by measuring spending in the economy on consumer goods and services.

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*through covariations of prices, outputs, investments and incomes'*.[9] **Leontief's I-O model quantifies mutual interrelationships between various sectors of an economy and uses national or regional statistics of inter-sectorial transactions to build a statistical picture of an economy in matrix form.** Interdependencies among sectors are described by a set of linear equations - from which multipliers are calculated - expressing the balances between the total input and the aggregate output of each commodity and service produced and consumed over a defined period of time, typically a year (Box 1).[10]

**Box 1. The input – output model**

The Input-Output model depicts inter-industry relationships of an economic system. The flow of inputs and outputs between the sectors is schematised through an inter-industry matrix in which each column shows the monetary value of inputs to each sector and each row represents the value of each sector's output.

Say that we have an economy with $n$ sectors. Each sector $i, (i = 1, \dots, n)$ produces $x_i$ units of a single homogeneous good, whose price is $p_i$. Assuming a constant relationship between inputs and outputs, the coefficient of production $a_{ij} = \frac{x_{ij}}{x_j}$ represents the units of inputs from sector $j$ to produce 1 unit of the good in the sector $i$. For each sector, we have that part of the output is sold to other sectors and part is for final demand (consumption and investment) so that the total output equals intermediate output plus final output:

$$x_i = a_{i1}x_{i1} + a_{i2}x_{i2} + \cdots + a_{in}x_{in} + d_1 \quad (1)$$
$$p_i = a_{i1}p_{i1} + a_{i2}p_{i2} + \cdots + a_{in}p_{in} + v_1 \quad (2)$$

where $d_i$ is the final demand in the $ith$ sector and $v_i$ is its value added (wage and profits). If we let **A** be the matrix of coefficients $a_{ij}$, $\boldsymbol{X}$ be the vector of total output, $\boldsymbol{D}$ the vector of final demand, $\boldsymbol{P}$ the vector of prices and $\boldsymbol{V}$ the vector of the total value added, the model can be written in matrix form as follows:

$$\boldsymbol{X} = \boldsymbol{AX} + \boldsymbol{D} \quad (3)$$
$$\boldsymbol{P} = \boldsymbol{PA} + \boldsymbol{V} \quad (4)$$

And the solution is:*

$$\boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{D} \quad (5)$$
$$\boldsymbol{P} = \boldsymbol{V}(\boldsymbol{I} - \boldsymbol{A})^{-1} \quad (6)$$

The matrix $(\boldsymbol{I} - \boldsymbol{A})^{-1}$ are the multipliers of the model (also known as Leontief inverse(s)). They allow solving for the production vector $\boldsymbol{X}$ given the final demand $\boldsymbol{D}$ (the sectoral production capable of satisfying the final demand as in the Keynesian view) and the vector $\boldsymbol{P}$ of sectoral prices consistent with a given sectoral coefficients of value added $\boldsymbol{V}$. Alternatively, the model can search for the vectors of the final demand $\boldsymbol{D}$, when $\boldsymbol{X}$ is considered as a given exogenous variables (as in the neo-classical view) and for the vector $\boldsymbol{V}$ given $\boldsymbol{P}$.

*The solution is unique and non-negative if and only if the Hawkins- Simon conditions are satisfied. See Nikaido (1970).

Since the Leontief's pioneer work, the IOA has experienced several evolutions and nowadays embraces a set of models such as Supply and Use Tables (SUTs), Input-Output (I-O) Tables and Social Accounting Matrix (SAM) which are all based on the seminal concept of multipliers developed by Leontief in 1936.[11] The nature of the problem determines also whether to use one model or the other. For example, SAM models are useful in case the focus is on distributional issues or SUTs and I-O Tables in case of different purposes.

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[9] Leontief (1941). In an article written for Scientific American (Leontief, 1966), he made reference to his previous works discussing this matter, when he pointed that '*nowadays we have in Economics a high concentration of theories without facts and facts without theories*'.

[10] Miller (2009); Miernyk and Rose (1989); Leontief (1986).

[11] Suomalainen (2006); Miller (2009); Leontief (1986). For SAM see Defourney and Thorbecke, (1984). Computable General Equilibrium (CGE) models are descended from IOA as well, but assign a more important role to prices (Robson and Dixit, 2015; Wing, 2004). For instance, where Leontief assumed that, say, a fixed amount of labour was required to produce a ton of iron, a CGE model would normally allow wage levels to (negatively) affect labour demands.

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Originally intended to functionalise the Warlas' neoclassical model of general equilibrium, the **Leontief's approach fits both the neoclassical and the Keynesian vision of the economy** [12] It is an '*algorithm for translation'* of inputs into outputs that permits moving from one theoretical frame of reference to another. Specifically, if - as in Keynesian economics - it is recognised that demand has a driving role, the demand (i.e. consumption and investment) becomes the exogenous control variable and the levels of supply (i.e. production) align themselves accordingly. In contrast, when the emphasis is on alternative use of scares resources - as in (neo-) classical (and marginalist) model - it is the level of production which determines the performance of the whole economic system and creates sufficient levels of demand.[13]

Although the Leontief's model is based on a precise understanding of the role that demand and supply may have in the economy, **most of empirical applications are limited to the use of an 'open', more simplistic version of the model** (i.e. the use of already calculated multipliers) and they do not touch the solution of the problems related to the relationships between the productive aspect of the economic system and those aspects related to consumption and accumulation.[14] Therefore, **the IOA remains empirically a neutral frame of reference for representing and reasoning about an economic system.** It can be used in centrally-planned economies where the public sector plays an important role (closer to the Keynesian understanding of the economy) as well as in laissez-faire and market-oriented ones (as in the neoclassical vision). Nowadays, the IOA is one of the most widely used instrument for the economic policy assessment at national and regional level and, very recently, at global level.[15] Usually applied at macroeconomic level (e.g. impact on a country or group of countries), the IOA can be carried out also at meso-level (i.e. a region) depending on the detail of available data and purpose of the assessment.

### Application to RIs impact assessment

**In the field of RIs socioeconomic appraisal**, the IOA has been extensively employed since the early 2000s with different levels of depth and using several sources of data. **At least two types of IOA applications can be identified**. Table 2 collects a sample of evaluation studies which are broken down according to the type of application used to assess the IA of some RIs.

**The first type includes the set of studies that make use of existing I-O impact multipliers.** They estimate the socioeconomic impacts of the RI under assessment by applying multipliers from already existing sectoral, regional or national I-O statistic tables or multipliers embodied in I-O software to RI's own data. This first option is the most accessible and used by evaluators since I-O multiplier tables or software are available. For

[12] Ruiz and Pellet (2011); Marangoni (2000); Miernyk and Rose (1989). See also Miller and Blair (2009).

[13] Classical and marginalist economists hold that full employment and the full utilisation of capital will be achieved if the economy is free to work untrammelled by restrictions, while the Keynesian economists deny the existence of automatic and efficient mechanisms for the equilibrium of the market. These opposing conclusions are linked to the acceptance of rejection of the Say's Law according to which 'supply creates its own demand' (Say, 1817).

[14] The 'closure' of the model would require introducing additional assumptions and take on (Neo)classical or Keynesian line of reasoning. In an open Leontief model only the productive sectors of the economy are assumed to be endogenous, i.e. determined by factors inside the productive system. Type II multipliers can be calculated, once households are added to the input-output table as if it were another industrial sector. As mentioned above, in addition to direct and indirect (Type I multipliers), Type II multipliers describe also induced effect by endogenising households in the model and closing the Leontief's model.

[15] In Europe, Denmark, France, Germany, the Netherlands, Norway, Spain and the United Kingdom estimate I-O matrices every five years, Switzerland every three years and 18 countries produce IOTs annually (Ruiz and Pellet 2011; Eurostat, 2008). Moreover, 21 compile 'product by product' tables and nine compile 'industry by industry' tables. Four (Belgium, the Czech Republic, Hungary and Italy) produce both types of table. See also Eurostat website http://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/methodology/symmetric-input-output-tables.

USA, India, Japan and Russia have a long tradition of producing I-O Tables. In Latin America I-O Tables are estimated in Argentina, Colombia, Costa Rica, Cuba, Mexico and Puerto Rico (Ruiz and Pellet, 2011). At global level see United Nations (2017). I-O Tables are mainly used as a tool for national and regional economic planning. For instance, to identify economically related industry clusters, key or target industries (i.e. industries that are more likely to boost an economy). Moreover, by linking industrial output to satellite accounts articulating energy use, effluent production, space needs, and so on, IOA has extended the approaches application to a wide variety of uses.

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instance, the IOA for Berkeley Lab carried in 2010 calculates the socioeconomic impacts of the laboratory by running its own data (e.g. capital expenditure, payroll, purchasing) through the IMPLAN model (IMpact Analysis for PLANning), a widely accepted I-O model developed by the U.S. Department of Agriculture. IMPLAN provides a software system and geographic-specific data regarding economic sector interactions for calculating economic impacts. The IMPLAN model was also used to calculate the return of investment of the Human Genome Project to the US economy (see Table 2). Similarly, and very recently, the IOA was applied to the European space programme 'Copernicus' by using the Cambridge Econometrics' E3ME Model for the modelling of the wider knock-on effects on the European economy. Dedicated modelling of the space supply chain was carried out in order to provide the E3M3 model with spending inputs associated with non-space industrial sectors. While I-O tables and packages for simulation are widely available, resources and skills increase when simulators are used rather than already available I-O tables.[16]

**The second type of IOA applications makes independent calculations** (by evaluators' themselves) **of impact multipliers and estimates indirect and induced impacts.** This option requires time, depth and broad consideration of all the potential effects (market, financial, technological, and so on and so forth) of the RI, and for that reason they are rarely performed. For instance, a study for evaluating the IA of the John Innes centre carried out in 2009 uses this route to estimate the direct, indirect and induced economic impacts.[17] The analysis uses the profile of supplier expenditures to estimate the indirect impacts. Induced economic impact is estimated by modelling the household income from direct and indirect employment using an average consumer profile across people from UK.

Table 2: Socioeconomic impact studies by the type of application of IOA

| REFERENCE CODE | TITLE OF STUDY | AUTHOR(S) | CONTRACTING AUTHORITY/INSTITUTION (COUNTRY) |
|---|---|---|---|
| **Assessment based on already existing I-O impact multipliers** | | | |
| **Atkinson et al (2017)**** | Socio-economic Assessment of SKA Phase 1 in South Africa | D. Atkinson<br>R. Wolpe<br>H. Kotze | Council for Scientific and Industrial Research (South Africa) |
| **KPMG (2016)** | Assessment of SNOLAB - Final Report | KPMG | SNOLAB (CA) |
| **IDEA Consulting (2015)** | Economic footprint of 9 European RTOs | IDEA Consulting | EARTO - European Association of Research and Technology Organisations (BE) |
| **Booz and Company (2014)** | EVALUATION OF SOCIO-ECONOMIC IMPACTS FROM SPACE ACTIVITIES IN THE EU | Booz and Company (with SpaceTec Parteners) | European Commission - DG GROW (EU) |
| **NRCC (2013)** | Return on Investment in Large Scale Research Infrastructure | HAL Innovation Policy Economics | National Research Council Canada (CA) |
| **AEG (2011)** | The Economic Impact of Fermi National Accelerator Laboratory, | Anderson Economic Group | University of Chicago (USA) |
| STFC (2010)* | New Light on Science<br>The Social and Economic Impact of the Daresbury Synchrotron Radiation Source, (1981 - 2008) | **Science and** Technology **Facilities** Council | **Science and** Technology **Facilities** Council (UK) |
| MMK Consulting (2009) | ECONOMIC AND SOCIAL IMPACTS OF TRIUMF | **MMK Consulting** | TRIUMF (Canada's particle accelerator centre) (CA) |
| EISS Group (2002) | ITER at Cadarache: Socio-economic environment Task SE1 deliverable 1, June 2001 | EISS Group | ITER (International Thermonuclear Experimental Reactor) (FR) |
| **EC (2016)***** | Study to examine the socioeconomic impact of Copernicus in the EU<br>Report on the socio-economic impact of the Copernicus programme | PricewaterhouseCoopers | European Commission - DG GROW (EU) |

[16] For instance, IMPLAN package costed of around $70,000 depending on the detail of the geographical coverage. See CBRE CONSULTING (2010) mentioned in the Table for details.
[17] Webb and White (2009).

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| REFERENCE CODE | TITLE OF STUDY | AUTHOR(S) | CONTRACTING AUTHORITY/INSTITUTION (COUNTRY) |
|---|---|---|---|
| Battelle **Technology Partnership Practice** (2011) | Economic Impact of the Human Genome Project | Battelle Technology Partnership Practice | Life Technologies Foundation (USA) |
| CBRE CONSULTING (2010) | BERKELEY LAB - ECONOMIC IMPACT STUDY | CBRE CONSULTING | LAWRENCE BERKELEY NATIONAL LABORATORY (USA) |
| **Assessment based on independent multipliers calculation** | | | |
| Webb and White (2009) | Economic impact of the John Innes Centre | DTZ | The John Innes Centre (UK) |

***Source:*** *authors*. ** Indirect and induced impacts not calculated
*See also STFC (2014) Impact Framework and Evaluation Strategy http://www.stfc.ac.uk/stfc/cache/file/B5D5D5C7-809A-44F3-990FBDC045835BAC.pdf ** Indirect and induced impacts not calculated
*** See also EC (2016). Study to examine the socioeconomic impact of Copernicus in the EU. Report on the Copernicus downstream sector and user benefits.
http://www.copernicus.eu/sites/default/files/library/Copernicus_Report_Downstream_Sector_October_2016.pdf
EC (2016). Study to examine the socioeconomic impact of Copernicus in the EU. Market Report
http://www.copernicus.eu/sites/default/files/library/Copernicus_Market_Report_11_2016.p

It worth noting that by construction (see Box 1), and whatever the type of application, **impact multipliers describe how the economy/sector works on average** and assess the RI's impact by taking as input the amount of (capital) expenditure associated with the RI. Such expenditure determines a larger impact because it circles through the economy: RI pays suppliers, suppliers buy goods and services from other firms in the supply chain and pay workers, workers and firms buy goods and services by other firms in other markets, and so on. This is the 'average' multiplier effect. **Therefore, multipliers show average effects, not marginal effects.** Sector characteristics (e.g. unused capacity, technological change) and the RI's characteristics causing the observed/expected impacts are not truly considered or are not precisely identified[18].

Moreover, multiplier (e.g. direct) effects can rapidly materialise. Other multiplier effects such as boosts to consumption (e.g. induced impacts) may take time to be fully realised. The IOA assessment only informs on the aggregate impact in a given time span (one year or more) without giving any insight about the timing impacts materialise. From a more operational point of view it has to be stressed that there are a number of issues related to availability of data and models which limit their actual use for the analysis of individual investments: i) not all countries have (up to date) IO tables; ii) they are usually available at country level, with limited possibility to calculate regional multipliers.

## Assessment

### Reliability

Impact multipliers approaches are highly reliable since they are based on a well-defined and accepted theoretical foundation: methodological and mathematical foundations have been deeply studied since the Thirties. IOA is a tool that has been largely applied in RIs IA related literature. Thanks to available, standardised, and consistent I-O tables and software based on real data, **IOA represents a reliable means of analysis**. It is clear, produces replicable and comparable results over projects, industries and time and can be generalised to different typologies of RIs.

### Validity

**The validity** of the IOA to caputre all the socioeconomic impacts expected by a RI **is limited by the fact that this approach focuses on a small range of aggregated impact while leaving outside considerations on, for example, environmental externalities and**

[18] IOTs are often the result of a transformation model run on the SUTs. Most countries derive IOTs on the basis of the 'product technology' assumption, whereby each product has its specific technology irrespective of the industry that produces it. Other countries use the 'fixed product sales structure' assumption and some also use the hybrid assumptions. See for details http://ec.europa.eu/eurostat/statistics-explained/index.php/Review_of_national_supply,_use_and_input-output_tables_compilation

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**non-monetary cultural and wider societal impacts**. Capital initial spending and downstream spending are the main drivers through which transactional direct, indirect and induced effects of changes within the economy (on GDP, employment) materialise. Therefore, relevant RIs characteristics and impacts related to scientific performance (knowledge advances, and diffusion), human capital accumulation, education outreach, environmental and production externalities are accounted for only as far as they translate into indirect or induced effects. Hence, the validity of IOA for the IA of RIs is limited.

**Accuracy**

**The IOA is effective to assess transactional economic impact of RIs investments.** Effects, being direct, indirect or induced are clearly defined by the theoretical framework. The latter also explains how they should be calculated and measured. Moreover, the approach leads to a synthetic judgment about the overall impact of the project, which is expressed in terms of how much money the project has generated for the economy and/or how many jobs it has created (see above). **This informative power is however somewhat threatened by the concept of multiplier itself**, as well as data availability. Multipliers show average effects and are not enough accurate to isolate precisely the factors leading to a given impact. Impact multipliers show the aggregated effects once all secondary effects (indirect and induced) have gone through the economic system. They are summary measures for predicting the total impact on all industries in an economy caused by an intervention in any one industry. Important sectorial specific features such as economies of scale, unused capacity or technological change are not considered. The timescale for impact to materialise and the calculation of indirect and, mainly, induced impacts represents an additional limitation of IOA. Some studies indicate a preference to limit assessment to the direct economic effects expressing reservations about the validity of the estimation of indirect and induced effects. In addition, when calculations of indirect and induced impacts are based on multipliers that are not derived from official statistics (as in the second type of application in Table 2), they tend to make either partial or inflated estimations often arriving to unrealistic results.[19] Double-counting of the output multiplier with potential overlapping between indirect and induced effects is an additional problem which threatens the accuracy of the IOA results.[20]

**Cost/time needed**

While from the perspective of the RI the required amount of data to perform the IA is quite limited (e.g. the amount of the investment, the amount of contracts with suppliers), large amount of industrial statistics are needed to build I-O Tables at international, national, or regional level. That is why I-O Tables and impacts multipliers are often not available or updated. **Bringing the I-O methodology into practice may be costly and time consuming depending on the degree of depth of the assessment**. Its application enables to make quite straightforward project appraisals based on RI data where detailed information on impact multipliers is already available. Costs increase and data collection can be cumbersome when indirect and induced impacts need to be calculated with dedicated software packages or with primary or secondary data.

**Relevance for policy makers and for RI managers**

The IOA is a macroeconomic approach and it is particularly useful when estimating the regional/national socioeconomic effects of RIs on economic quantities such as GDP, GVA, or employment. This makes the **IOA a powerful informative tool for policy makers**, who are used to face policy objectives formulated in terms of GDP, GVA and employment. In contrast, the IOA is less informative for RI managers, because it does not offer relevant information about the internal performance of the RI.

[19] EC (2016), Simmonds et al (2013).

[20] Some studies argue that double-counting is a minor problem because it can be easily off-set by using gross value added multiplier instead of GDP multipliers.

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# 4 Methodologies grounded in the Knowledge Production Function Approach

## Idea and scope

**The production-function approach (PFA) to innovation is conceptually rooted in the economic growth theory,** which was primarily motivated by an attempt to account for the way in which economies grow, and in particular to answer the question: what factors account for the observed growth in the economy and to what extent? As the founding father of neoclassical growth-theory, Solow[21] showed that the aggregate economic output of an economy ($y$ -e.g. GDP) and its growth over time is a function of physical capital ($K$) and labour ($L$) as follows:

$$y = A\, f(K, L) \tag{1}$$

where the '*multiplicative factor $A$ measures the cumulated effect of shifts over time*'[22] The shifts in the production function was named as '*total factor productivity* (TFP)' and referred to imply '*technical change*'.

Solow showed that the accumulation of physical capital can account only for short-run growth because of decreasing returns to scale to capital accumulation. In the long-run only increase in the TFP can generate positive growth effects. Although Solow made a case that the origins of TFP-growth lay in technological progress, neoclassical growth model does not explain technological progress as an outcome of economic activities. Rather, it takes the rate of technological change as exogenously given. Thus, the model leaves the technological change essentially unexplained.

**Later works, culminating in the development of the endogenous growth theory, showed that the purposeful and deliberate R&D activities can indeed sustain long-term growth.**[23] Therefore, the idea is that the central economic activity undergirding technological progress are activities related to research and development (R&D), which firms engage in to maximize their dynamic profit rate and/or governments support to maximise the social return from such activities (see below).

## Theoretical background

**An important approach** to estimate the economic value of R&D follows the initial PFA, and **consists of three important elements**:

- **The output**, which is typically a scalar and can, depending on the level of analysis (microeconomic or macroeconomic) reflect some level of economic output (e.g. GDP, value added), performance (e.g. firm-level productivity, turnover, profit) or knowledge (e.g. patents);
- **The inputs**, which are typically multidimensional and on the one hand include traditional inputs (e.g. capital and labour) and innovation-related inputs (e.g. R&D) on the other one;
- **An economic law** according to which inputs are transformed into the output.

A more generic mathematical description of the production function is as follows:

$$y = f(x_1, x_2, c) \tag{2}$$

where $y$ is the output, $x_1$ is a vector of inputs, $x_2$ is a vector of innovation-related inputs, $c$ is vector of control variables (e.g. variables related to the context) which affect $y$ but

21 Solow (1956).
22 Solow (1957).
23 Romer (1990); Aghion and Howitt, 1990).

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cannot be interpreted as inputs, i.e. direct production factors. Based on observed data, Equation (2) can typically be estimated by regression-techniques. The interest is then typically in the sign and size of the term $x_2$. **In 1984, Pakes and Grilliches[24] proposed a seminal implementation of the PFA as the knowledge production function, where $y$ is a measure of knowledge output (e.g. patents) and $x_2$ refers to R&D.** Since then, this notion has received wide attention and was implemented in many studies and extended to the notion of innovation production function.[25] Studies in this branch of the literature find positive associations between innovation and productivity and innovation and employment and growth.[26]

While the original PFA approach relates business R&D or innovation activities to firm-level outcomes and therefore largely focuses on the privatised returns to innovation, already in the Sixties, some studies[27] emphasised that **knowledge**, in particular basic knowledge**, is subject to positive externalities implying that the market does not provide sufficient incentives for producing a socially optimal amount of basic research.** Therefore, most advanced economies support basic R&D through financial incentives for firms. More prominently it is the creation of publicly financed research organizations that provides a constant stream of basic knowledge for the economy. Such organizations are universities, extra-university public research organizations or RIs. **A direct extension of the PFA allows estimating the returns of public R&D-related activities by incorporating a measure of public R&D** in $x_2$ in Equation (2). In practice, a wide variety of measures is conceivable depending on whether analyses focus on the firm or the macroeconomic level.[28] Despite the methodological and the data differences, the combining element of the PFA applied to public research is that $y$ in Equation (2) represents some output of desirable economic outcome of the unit under observation and $x_2$ represents some indicator or measuring the degree of deliberate use or exposure to public scientific knowledge. **The PFA extended to public research has been used both on the microeconomic level of firms and macroeconomic levels**, e.g. regions. We start by reviewing the macroeconomic literature.

## Application to RIs impact assessment

### 4.2.1. Impact at macroeconomic level

Arguably, **analyses applied to macroeconomic units of observation (e.g. countries, regions) are better suited to estimate the macroeconomic effects because issues of technological and knowledge spill-overs or interdependence between micro-level units (e.g. firms) are only implicitly taken into account** by modelling them through simplified or restrictive assumptions about the multidimensionality of the R&D activities.[29] For instance, R&D is often modelled as the amount of dedicated resources in a country/region without accounting for sector specificities or technological domains and durability, or as the number of firms with a R&D business unit in a given country/region without accounting for the type of firm (size, specialisation, the market structure in which it operates, and so on). Therefore, while useful, such analyses do not easily allow for the estimation of such

[24] Pakes and Grilliches (1984).
[25] Mairesse and Mohnen (2002) and Crepon et al. (1998).
[26] Hall et al. (2009), Hall et al. (2008) Griffith et al. (2006). It should be noted that works following the tradition of Mansfield et al. (1977) have identified the private and social value of R&D and innovation based on formal economic modelling. While some authors have labelled this approach a production function approach, its conceptual roots are rather based in welfare economics rather than production functions *per se*. We do not present this approach here in detail also because it has only been used to measure the returns of private R&D-projects but not of public research organizations.
[27] Arrow (1962).
[28] Such measures include: firm expenditures for projects commissioned to public research organizations (Comin et al. 2018), binary indicators of firm collaboration with research organizations (Maietta 2015), regional intensity of public research activities (Schubert and Kroll 2016) or national regional public R&D expenditures (Guellec and De la Potterie, 2002).
[29] See Comin et al (2018).

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identifiable macroeconomic multi-dimensional returns (effects of R&D by sector, type of firm, market structure) because of a large amount of restrictive assumptions.

Recently, a few studies have tried identifying the (positive) macroeconomic returns based on the knowledge PFA. Instead of starting from the firm-level and then aggregating the results at the macroeconomic level,[30] these studies rely on regional macroeconomic data. Conceptually, a generic version of Equation (2) still applies, but instead of using it on the level of the firm, the regression model is specified on the level of the region. While coarser in nature, these studies evade the problem that science-industry collaborations may positively affect the focal firm but negatively affect the focal firm's competitors. In addition, the knowledge PFA on the regional level is better apt to identify knowledge spill-overs. The earliest application investigates the role of universities in USA by estimating inasmuch as they affect regional development in 312 Main Statistical Areas (MSA) and finds significantly positive effects.[31] Extending the regional PFA, Schubert and Kroll[32] analyse the effects of universities on the GDP in Germany. There results indicate that, on average, universities increase GDP per capita by EUR 8,300. In a different study in 2013, Schubert and Kroll[33] estimate the total annual GDP contribution at around EUR 190 Billion, which corresponds to about 10% of German GDP for the period. For the case of Fraunhofer-Gesellschaft, its effect on the annual GDP has been found to be around EUR 20 Billion,[34] which is large compared to Fraunhofer's annual budget of approximately EUR 2 Billion.

### 4.2.2. Impact at micro level

**Pure firm-level analyses give useful insight into the economic impacts on specific** (typically collaborating) **firms, by looking more in depth** (but still simplified), **at the type of R&D and research activities.** A large literature followed the knowledge PFA **is mostly applied to the case of universities and shows that a positive effect of university research on firm performance appears**.[35]

While a substantial literature exists on the effects of universities, **only few studies exist that analyse the effects of extra-university research organisations including RIs**. Two recent studies on this topic, which make use of a generic knowledge production function like Equation (2) point to the existence of a positive long-term impact on firms' economic performance associated with a technological procurement relation with CERN. Specifically, by building a unique dataset based on survey data on about 670 CERN suppliers firms, Florio et al. (2018a) finds that that collaborative relations between CERN and its suppliers improve suppliers' performance and increase positive spill overs along the supply chain. Similarly, by gathering balance-sheet data for more than 350 CERN LHC suppliers from 1991 to 2014, Florio et al. (2018b) assess, in quantitative terms, whether becoming a CERN supplier induced greater R&D effort and innovative capacity, enhancing productivity and profitability. The findings indicate a statistically significant correlation between procurement events and company R&D, knowledge creation and economic performance.

[30] Comin et al. (2018), Robin and Schubert (2013).
[31] Goldstein and Renault (2004)
[32] Schubert and Kroll (2016)
33 Schubert and Kroll (2013)
[34] Frietsch et al. (2016)
[35] See Comin et al. (2018). For example, Monjon and Waelbrock (2003) show that at least the subgroup of very innovative firms benefit from collaboration projects with universities. Lööf and Broström (2008) corroborate this finding for manufacturing firms. Miozzo and Derwick (2002) present similar results for firms in construction. Darby et al. (2004) show that firms benefit in terms of patenting from the participation in the Advanced Technology Program by the US Commerce Department when a university is also part of the project. Belderbos (2004) provides evidence that cooperation with universities has a positive effect on the share of turnover due to new products. Toole et al. (2014) show that collaborations with universities also increase employment growth. Maietta (2015) shows that R&D collaborations between firms and universities affect process innovation positively, in particular when there is close geographical proximity. Cardamone et al. (2015) provide additional evidence and show positive effects of collocation with universities on firm innovativeness.

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Comin et al[36] present analyses using the PFA approach for the specific case of the Fraunhofer-Gesellschaft. They show that the firms interacting with Fraunhofer through research contracts increase their performance and this is substantially driven by the interactions. In particular, 22% of the turnover growth of interacting firms can be explained by the interaction. For productivity growth, the respective figure is 11%. A comparable study[37] used data from the German dataset of the European Manufacturing Survey (Modernisation of Production) and matched it with Fraunhofer internal databases listing all formal research projects commissioned to Fraunhofer by private firms. The results show that Fraunhofer interactions primarily have a positive effect on the probability to introduce new products.

## Assessment

**Reliability**
In general, **the strengths of the knowledge PFA lie in the rigour of its theoretical foundation leading to consistent and generalizable results**. At macroeconomic level endogenous economic models in growth theory all point to the key role played by technology in generating economic development and growth.[38] At microeconomic level, these models are more effective in showing that technology, differently measured and treated, does play a substantial role in the growth of firms.[39] **However**, in both cases, **they usually rely on simplified assumptions about the properties of technology** (technological domains, durability, and so on). As yet, no reliable or comprehensive variables (e.g. indexes) to be used as input in Equation (2) has been developed to reflect multidimensionality of the public funded research, even less the potential multidimensionality of RIs. Some attempts have been made to measure the economic impact of universities, public funded R&D, or some RI but their multidimensional nature is disregarded. Indeed, these models only look at the unidimensional link between an input variable (e.g. scientific publications, amount of R&D investments, being a RI supplier) and outputs (firms' sales, changes in GDP). Thus, the degree of reliability for the IA of RIs is somewhat threatened because of these theoretical (and subsequent empirical) limitations.

**Validity**
**The knowledge PFA approach addresses only a small share of the possible range of the expected socio-economic impacts of a RI**. The models are able to estimate both private and social return of investment in research, recognising that returns of such investments could flow and spread out from individual organisations that implement the investment to the society as a whole. Returns are mainly measured in terms of changes in macroeconomic variables (GDP) or microeconomic outputs (firms' profitability, sales, cost reduction, development of new products, technologies, and patents). Broader social benefits or purely qualitative impacts cannot be incorporated by construction. This underscores the limited usefulness of the PFA approach for the socioeconomic evaluation of RIs.

**Accuracy**
Empirically, the estimation of the production knowledge function is carried out through econometric techniques. Econometric studies focus on large-scale patterns and are effective in providing an aggregate picture of statistical regularities among countries, regions, firms and in estimating the rate of return to research and development. Results can, however, be misleading. **Econometric approaches can be too simplistic in the way they explain causal chains and involve unrealistic assumptions about the nature of RIs.** There are numerous empirical difficulties in measuring scientific knowledge and its contributions to economic or social welfare. In particular, there are problems of drawing

[36] Comin et al. (2018)
[37] Frietsch et al. (2016)
[38] Lucas (1988); Grossman and Helpman (1994; 1991); Aghion and Howitt (1995).
[39] Verspagen (1993); Salter and Martin (2001).

inference from non-experimental data (potentially leading to biased estimations of the impacts) and in tracing the extent to which the results from research contribute to any particular output.[40] Such models should incorporate the role of institutions such as universities, RIs, funding agencies in supporting economic development.

**Cost/time needed**

**The amount of resources** in terms of time, expertise and data intensity to implement the approach **is one of the disadvantages of this approach**. All dimensions for which quantifiable indicators exist can be included, however the process of compiling such data and analysing them require high statistical/econometric expertise. Moreover, if comparisons between different RIs are planned comparable data may not even exist or be disclosed.

**Relevance for policy makers and for RI managers**

**The PFA approach delivers largely statements about the size of the impacts of investments in research** (e.g. elasticities in terms of GDP, value added, or firm performance gains), but it does not deliver detailed information on the precise mechanisms of the generation of the impacts. **This restriction may be less important for policy-makers**, who are often interested in an aggregate measure of economic impact of an investment in RI (because of which we regard the informational fit for policy-makers as high), **but it is less revealing for RI managers**. Managers often require more detailed insight into the improvements of governance and management structures. Resulting from the black-box character of production functions, the PFA gives only generic and broad information about the causes of the possible impacts and therefore says little about how to improve management. We regard the fit with managerial information needs as low.

[40] Nelson (1998, 1982); Mazzoleni et al. (1998); Martin and Tang (2006). They argue that these models should incorporate the role of institutions such as universities, RIs

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# 5 Cost-Benefit Analysis (CBA)

## Idea and scope

CBA is an **analytical tool for assessing the social desirability of an investment decision by investigating on its costs and benefits in order to assess the net welfare change attributable to it.**[41] CBA has therefore the ultimate purpose of appraising the project's contribution to social welfare, which differs from financial measures such as GDP, value added or other aggregated financial outputs. **The key concept of the CBA is the use of shadow prices**[42] to reflect the social opportunity cost of goods and services, instead of prices observed in the market, which may be distorted for several reasons.[43] In particular, fiscal corrections, specific techniques for translating market prices into shadow prices and the evaluation of non-market impacts and goods (externalities, cultural impacts) are used to assess welfare changes. This allows including into the analysis intangible impacts not reflected in monetary transactions (e.g. benefits by goods or services provided for free, environmental externalities, etc.).

After identifying all the relevant social costs and benefits occurring at different times are valued. The idea is that the socioeconomic impact of an investment project is given by the difference over time of the benefits accruing to different agents thanks to the project and the costs of producing such benefits. Costs typically include investment costs, operating costs as well as any other social costs such as for example negative environmental externalities. The analytical framework underpinning the approach allows for a precise identification of the benefits and costs, avoiding possible double counting and overlapping benefits/costs. It also allows for expressing them in a unique metric (i.e. monetary values) reflecting the marginal value for society, thus making it possible summing them in order to calculate a total, discounted net effect. In that way, the CBA investigates whether social benefits accrued from a project exceed its social costs, thereby assessing whether the project generates a net benefit to the society. **The net benefit is expressed through the Net Present Value (NPV)**: positive values indicate a positive welfare change (positive contribution to social welfare); negative values indicate that social costs are greater than the social benefits and therefore that the project is likely to be detrimental for the society.[44]

Since its origins in the mid-19th century at the French École National des Ponts et Chaussées,[45] **CBA has been widely used by governments and economists worldwide to evaluate the socioeconomic impact of investment projects** in sectors such as transport, environment (e.g. water and waste infrastructures), energy, health, education, research development and innovation (RDI) and space.[46] CBA is a traditional tool for public investment appraisal and it is widely used by many funding agencies and international

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[41] EC (2014).

[42] Theoretically, the shadow price of a good is defined as the social value generated by an incremental provision of that good when the economy is at its constrained optimum (Florio 2014; Drèze and Stern 1987) or alternatively when the economy is in an initial equilibrium position (Johansson and Kristrom 2018). Suppose, for instance, the maximum price that a business should be willing to pay for one additional hour of work of an employee. The shadow price of the extra hour is the cost of paying overtime an employee to stay on the job and operate a production line for one additional hour. The cost of the extra hour (the shadow price of labour) does not necessarily coincide with the market wage, i.e. the prices of labour.

43 Sources of market distortions can be: non-efficient market structures; administered tariffs for utilities may fail to reflect the opportunity cost of inputs due to affordability and equity reasons; some prices include fiscal requirements (e.g. duties on import, excises, VAT and other indirect taxes, income taxation on wages, etc.); for some effects no market (and prices) are available (e.g. reduction of air pollution, time savings). See EC (2014: 55) for details.

[44] The project overall performance is also measured by additional indicators, e.g. the economic (internal) rate of return (ERR), which allows comparability and ranking for competing projects or alternatives and the cost-benefit ratio. See EC (2014) for details.

[45] Dupuit (1844).

[46] See EC (2014) for applications in transport, environment, and energy. For RDI see EC (2014); Jaspers (2016; 2013; 2009); Link and Scott (2004). See Viscusi and Aldy (2003) and World Health Organization (2006) for health. On cultural projects see DCMS — Department for Culture, Media and Sport (2010). Applications in space sectors are in Pwc – PriceWaterHouseCoopers (2006); Booz and Company (2011); ESPI – European Space Policy Institute (2011).

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institutions such as the World Bank, the European Investment Bank, the European Commission and other national institutions.[47] It is the mandatory methodology for assessing major infrastructure projects, including those in the RDI sectors, applying for funding by ESIF.[48] It is also the recommended tool by the ESFRI Roadmap 2018.[49]

## Theoretical background

In welfare economics, **a standard CBA theory for the estimation of projects' value to society is well established** (Box 2).[50] It is based on the following principles:

- **Microeconomic perspective** to project evaluation. Its theoretical foundation starts with an (indirect) social welfare/utility function which depends of prices, wages, exogenous income, firms' profits taxes and public goods.[51] The monetary valuation of the welfare change produced by a (large) project can be approximated through the conventional rules of adding consumer, producer, and taxpayers surpluses.[52] Therefore, starting from the primary market(s) of the project and identifying its direct users, the CBA aggregate up through individual actors to markets with attention to dynamic processes. This is the main difference with IOA analysis, including Computable General Equilibrium models, which focuses on pure aggregated components such as the consumption and investment functions. **In terms of project assessment, the microeconomic nature of CBA means that indirect (i.e. on secondary markets) and wider effects (e.g. induced impacts or effects on national and supranational GDP) are often excluded.** The reason is threefold. Firstly, most indirect and/or wider effects are usually transformed, redistributed and capitalised forms of direct effects; thus, there is the need to limit double counting issues; secondly, there is little practice on how to translate wider effects into robust techniques for project appraisal. The choice is thus avoiding that the analysis would rely on assumptions whose reliability is difficult to check. Thirdly, CBA is based on the idea that GDP is a distorted measure of social welfare. For this reason, shadow prices, estimated according to a precise set of rules and methods, are adopted to value costs and benefits. It should be noted however that, although impacts on GDP are not explicitly part of the assessment, the CBA implicitly considers them through the estimation of shadow prices (e.g. shadow wages – the shadow price of labour - are used to estimate the benefit form the creation of new jobs and employment).
- **All benefits and costs are expressed in monetary terms** (e.g. EUR) and are obtained by multiplying quantities by prices. This does not mean that only 'financial' effects are considered. On the contrary, as explained above accounting prices in the CBA are not necessarily market prices, either because many goods are 'non-market' goods[53] or observable prices do not truly reflect the social effect of the availability on an additional unit of a given good (i.e. the opportunity cost). For instance, the estimation of the benefit resulting from an improvement in the health conditions citizens thanks to the advanced medical treatments enjoyed in a RI, or the improved stock of human capital stemming from researchers spending a training period at a RI, require ad-hoc techniques for attaching a price to such 'non-marketable goods'. Most research projects as well as projects in more traditional sectors (environment, transport, cultural, and health) generates valuable outputs for which there are no observable prices. In that case, the CBA recurs to empirical estimations of opportunity costs (or

[47] See EC (2014); European Investment Bank (2013); World Bank (2010); Baum and Tolbert (1985).
48 European Commission implementing regulation (EU) 2015/207. See also Articles 100-103 of Regulation (EU) No 1303/2013 of the European Parliament and of the Council (17 December 2013)
[49] See ESFRI Roadmap 2018 Guide pag. 9 and the Questionaire for submission of proposals Available at: http://www.esfri.eu/sites/default/files/u4/ESFRI_Roadmap_2018_Proposal_Submission_Questionnaire_Public.pdf
[50] See e.g. Johansson and Kriström (2016); Florio (2014); Pearce et al. (2006); Johansson (1993); Drèze and Stern (1987).
51 See Florio (2014) for details.
[52] See for details Johansson (1993).
[53] They are goods for which a market does not exist and therefore a price does not exist.

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shadow prices), usually estimated by the people's willingness-to-pay or marginal production costs.

- **Long-term perspective.** RIs' benefits to society may materialise very far in the future. CBA uses a long-term outlook (e.g. from 30 to 50 years). Depending on the perspective of the assessment (ex-ante, mid-term, ex-post), the CBA requires to: set a proper time horizon; forecast future costs and benefits (looking forward); adopt appropriate discount rates[54] to calculate the present value of future costs and benefits; account for uncertainty by assessing the project's risks analysis (see below for details).
- **A risk assessment must be included in the CBA.**[55] This is required to deal with the uncertainty that always permeates the appraisal of investment projects, including the effects that exogenous and external factors may have on the project, assumptions about the estimation of the value of non-market goods, and uncertainty associated with forecasts especially in ex-ante evaluations. The risk analysis returns the NPV as an expected value from a probability distribution and is an example of 'mitigation' measure that CBA employs to face these challenges.
- **The incremental approach.** CBA compares the scenario with‑the‑project with a counterfactual baseline scenario without‑the‑project. The counterfactual scenario is defined as what would happen in the absence of the project. The CBA only considers the difference between the flow of benefits and costs in the with‑the‑project and the counterfactual scenarios. The performance indicators (e.g. NPVs) are only calculated on the incremental flows.

**Box 2. PE and GE in Cost-Benefit Analysis[56]**

There are two schools of practice for applied CBA: the partial equilibrium (PE) and the general equilibrium (GE) analysis. While there exist some theory and literature in common and attempts to bridge the two practices have been done, each school still has its own additional literature and practitioners.

**Among divergences between PE and GE** there is the fact that the PE approach (institutionalised in US Government guidance for policy analysis) precludes consideration of 'indirect or multiplier' effects. In contrast, the GE framing (more widely accepted in Europe) involves a high level of aggregation and models direct and (to some extent) indirect effects transmitted through a chosen number of input and output markets along with the intervention expenditures. For instance, intangible social benefits and costs such as externalities and people's willingness-to-pay for non-market goods have a reasonably long history of inclusion in GE framework. **In practice, the dichotomy PE versus GE impact evaluations may be mirrored in the dichotomy small versus large projects**. Major projects or large-scale government programs implemented to expand the economy are not small changes where effects occur in only one or a few markets. For such questions a GE framing seems appropriate. Other policies, including many regulations or small investment projects, may require modelling at a high level of detail which may be difficult to analyse using a GE approach. It is worth mentioning here that in any case neither PE nor GE includes indirect effects which are not related to or are far from the primary market of the project and induced effects. All these are usually missing in CBA (see the above microeconomic principle).

In contrast, **both the PE and the GE approaches to CBA share the principles discussed above**.

54 The discount rate for valuing the contribution of the project to the social welfare is the Social Discount Rate (SDR), which reflects the social view on how future benefits and costs should be valued against present ones (EC, 2014: 55).

55 Article 101 (Information necessary for the approval of a major project) of Regulation (EU) No 1303/2013. The recommended steps for assessing the project risks are as follows: sensitivity analysis, qualitative risk analysis, probabilistic risk analysis, risk prevention and mitigation (CE, 2014: 67).

56 Farrow and Rose (2018).

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## Application to RIs impact assessment

**A CBA framework for assessing the socioeconomic impacts of RIs and tailored to their specificities has been recently developed.**[57] As a follow up of such recent developments, the 2016 ESFRI roadmap recognised the contribution of CBA in providing robust evidence on the assessment of socioeconomic impacts of RIs. Moreover, the H2020 Work Programme 2018-2020 now explicitly indicates the CBA as a basis for the Preparatory Phase of new ESFRI projects.[58]

The model proposed in 2016 by Florio and Sirtori[59] is a **CBA model for RIs** which remains consistent with the CBA economic principles and relies on the identification of direct users of RIs, as ultimately a CBA **aims at tracing the social impact of a change on individual socioeconomic agents or their aggregates.** According to the model, the RIs' NPV (i.e. the net contribution in terms of net present value of a RI to the social welfare) can be represented as the (discounted) sum of all the benefits accruing to its users net of its costs in a long-run perspective: Specifically:

$$NPV_{RI} = [T + S + H + C + A] + B_n - [K + L_s + L_o + O + E] \qquad (3)$$

Benefits include:

- **benefits to firms** (T). This refers to benefits accruing to firms in the RI's supply chain (e.g. firms in the procurement chain and upstream industries) and to other firms (e.g. in the downstream industry) or professional organisations that benefit from learning externalities. In both cases, these effects can be described as technological or, more in general, knowledge externalities and can be measured by the (discounted) incremental social profits experienced by those firms thanks to the RI;[60]
- **Scientific impacts** (S). This includes two kinds of impacts. Firstly, the stock of knowledge output generated by the RI (scientists) in the forms of publications, preprints, participation to conferences. The social value of such knowledge creation is obtained by computing the marginal cost of producing such publications or attending conferences and by looking at the track record and citations in the literature.[61] Secondly, possible increases in the productivity of scientists (efficiency gains) referring to the benefit of reducing the time and effort of scientists when performing their research activities thanks to, e.g. new data, methods, and tools. 'Avoided costs' and 'willingness-to-pay' are traditional concepts used in CBA to estimate the social value of these benefits;
- **Human capital accumulation** (H) captures benefits to students, researchers, scientists arising from increasing capacities and skills accruing to them from having been trained by the RI's (research) activities. Human capital accumulation is valued as the (expected) increased earnings gained from those people during their working lifetime;[62]
- **Cultural and outreach effects** (C). This includes impacts from visiting the RI, its related exhibitions, its website, including social media. This also includes the value of other RI's dissemination activities. The social value of these different cultural and outreach effects on the wider public can be estimated by applying the concept of people's willingness-to-pay for such activities (e.g. by calculating how much

[57] See the research project 'Cost/Benefit Analysis in the Research, Development and Innovation Sector' sponsored by European Investment Bank Institute and carried out by the University of Milan in partnership with CSIL www.eiburs.unimi.it . See also Florio et al (2016a).
[58] ESFRI (2016b; p. 19; Horizon 2020 - Work Programme 2018-2020, European research infrastructures (including e-Infrastructures), p. 9.
[59] Florio and Sirtori (2016).
60 See on this point Florio et al. (2018b); Florio et al. (2018a); Florio et al. (2016).
61 See Carrazza et al (2014).
62 Camporesi et al (2017); Florio et al . (2016); Camporesi (2001).

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people spend to visit the RI's related exhibitions or estimating the value of time they spend on the RI website);

- **Benefits accruing to external users** (not scientific/academic users) or to **other citizens/consumers** (A) stemming from the RI research activities and/or its services. These benefits are strongly project specific (e.g. the value of cancer treatment services provided by a RI in the health sector or the value of innovation produced by a firm thanks to the RI research activity) and each of them is ultimately related to the willingness-to-pay for them by users;
- **Scientific discovery as public good** ($B_n$). This benefit refers to the value of possible effects of any discovery that RIs might find and the pure value of discovery *per se*, as a public good. Publicly funded RIs are ultimately supported by taxpayers, therefore their willingness to financially contribute for science reflects the price people attach to the RI activities, even if taxpayers will never use the RI or its services. [63]

The present (discounted) value of costs – each one valued at its shadow price - is the sum of:

- economic value of capital (K), i.e. the initial investment;
- labour cost of scientists ($L_s$);
- labour cost of other administrative and technical staff ($L_o$);
- other operating costs ($O$);
- negative externalities if any ($E$)

In principle, **this general CBA model has been designed to be tailored to any RI** in the sense that benefits and costs are project specific and are estimated according to the type of RI under assessment and its users. The model has been empirically validated in 2016 by applying it to CERN LHC in Switzerland and the CNAO, the National Centre of Oncological Hadrontherapy in Italy.[64] A 3-year CBA study of the socio-economic impact of CERN accelerator HL-LHC and the feasibility of the FCC-HH is currently in progress.[65]

## Assessment

**Reliability**

Micro-foundation makes CBA one of the most scientifically robust and methodologically sound analytical frameworks to support decision-making on public major investment decision and it is commonly accepted among policy-makers and economists worldwide. Moreover, **CBA is a reliable empirical methodology** for a systematic comparison of positive and negative socio-economic impacts of an investment in RI and there is an increasing consensus that it provides guidance on how to trace the potential of a RI to generate specific socio-economic impacts thanks to the identification of all the expected beneficiaries of the projects. However, the casual chains of events from costs/inputs to benefits/output are not among the output of the model, for which additional tools, such as qualitative approaches based on causation theories could be used as a complement. The latter could also help shed light on factors determining the performance of the project, but are not fully grasped by the CBA (e.g. context factors).

**Validity**

**CBA has the potential to capture most of the effects expected by a RI.** Estimations of shadow prices or willingness-to-pay are largely used in CBA for quantifying the price of goods in distorted markets or non-market goods. While there is an existing CBA model specifically developed for RI, further research is needed to test this theoretical model on existing RIs and tailor the traditional toolbox of CBA to the specificities of RIs. In particular, while there is consolidated body of literature on the evaluation of social

[63] On this point see Florio and Giffoni (2017) and Catalano et al. (2018).
[64] For CERN LHC see Florio et al. (2016b). For CNAO see Battistoni et al (2016).
[65] The study is carrying out by the University of Milan in partnership with CERN. See Bastianin and Florio (2018).

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benefits in the Education, Environmental and Cultural sectors that can be largely used to value specific benefits of RIs, additional work is needed to develop tools and methods to value other types of benefits as well as to develop reference values and parameters tailoring RIs specificities.

**Accuracy**

**CBA is extremely accurate at project level enabling the assessment of the incremental contribution of individual RI investment decisions to the society in a long-term perspective**. It captures direct benefits and costs accruing to a well-identified set of stakeholders (i.e. beneficiaries being they companies, researchers, students, taxpayers) who are ultimately the fabric of the society and can be affected by the investment in various ways. At this point, CBA asks the question whether the positive welfare effects are greater than social costs. All benefits and costs are expressed in monetary terms and summarized/aggregated in a single, comprehensive indicator, i.e. the economic NPV. The CBA test is passed when the economic NPV is greater than zero. The risk analysis contributes to keep accuracy high by facing uncertainly that can emerge from different sources (e.g. assumptions underlying the quantification of the value of non-market goods and shadow prices, forecasts in the monetary flows of costs and benefits along the time horizon).

**Cost/time needed**

Fairly technical, the CBA requires adequate financial, data and human resources available either from the evaluator and RI side. Indeed, **a project appraisal with CBA poses specific challenges that can be costly and time consuming**. The procedures used for the assignment of a (shadow) price to intangible items are often highly technical and require skill in economic analysis and availability of specific economic and cost data. Moreover, time is needed for forecasting cash flows along the entire time horizon foreseen by the analysis and additional expertise (e.g. engineering, statistical), beyond the economic one, is often required. While it builds on a number of performance indicators which are customarily collected by the RI (i.e. number of publications, volume of procurement contracts, number of researchers, visitors, and so on), it may also require to perform ad-hoc data gathering activities (e.g. surveys to supplying firms, to former researchers, etc.) and to work out a number of working hypotheses to provide a monetary value to the observed impacts.

**Relevance for policy makers and for RI managers**

CBA is a tool for assessing whether or not the costs of an RI investment can be justified by the outcomes and impacts. It can be used for identifying projects that offer the highest rate of return and for calculating the necessary financial resources to run the project in a long-term perspective. Therefore, **the CBA highly fits the information required by policy makers** at project level. Additional tools may be necessary for considerations about objectives at macroeconomic level. In some case, the CBA can be also used as a tool for informing decisions about the most efficient allocation of resources, for instance when alternative designs of the investment are compared with each other or different counterfactual scenarios are account for. From the point of view of RI managers it can also provide evidence about the conditions and assumptions underpinning the materialisation of some effects or to account for the relative contribution of different types of benefits to the total net effect.

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# 6 Approaches based on multi-methods, multiple partial indicators

## Idea and scope

**This approach** combines science policy with contributions based on management literature and it is the only one among those discussed in this literature review that **was born to evaluate the socioeconomic benefits from publicly funded (basic) research**. It moves from the idea that **investments in research are multi-faceted in nature and leads to a large variety of effects. Therefore, in order to capture this multidimensionality a range of indicators/mix of methods need to be used**. The underpinning rationale is that a single indicator of research output or performance would only reveal a small part of the multidimensional picture. This argument is based on the stream of literature drawing back to the seminal contributions by Ben Martin[66] and the following developments by the Science Policy Research Unit (SPRU) at University of Sussex (UK) and by Kostoff, who argued that '*most of the research evaluation community has to come to believe that simultaneous use of many techniques is the preferred approach*'.[67]

## Theoretical background

Largely atheoretical, the methodology based on indicators for the IA of research was born to accommodate at least two evaluation challenges.[68]

**Firstly, all research projects and organisations generate diverse types of research outputs**, which '*may results in social benefits*'.[69] According to Martin and SPRU scholars, they are mainly related to:

- **Scientific,** i.e. contributions to the stock of knowledge, which occur both in the originating field and in other scientific fields. They can be theoretical, empirical or methodological, or, using a different categorisation, can be incremental knowledge advances or breakthrough, revolutionary discoveries;
- **Educational,** i.e. contributions in terms of skills and trained personnel (human capital). It refers to skills and other person-embodied or tacit knowledge and competencies (e.g. the ability to solve complex problems);
- **Technological,** i.e. contributions to the development of new or improved technologies and include new products, processes and services; new firms (e.g. spin-offs) new or improved tools, and new techniques perhaps applied outside the initial research field in the development of innovations;
- **Cultural,** i.e. contributions to the wider society stemming either directly or indirectly from the research activity (e.g. through books).

**Secondly**, research outcomes and their effectiveness depend not only on the research activity but also on external context factors which are often insufficiently accounted for. Therefore, **all quantitative measures of research are, at best, only partial indicators. Nevertheless, selective and careful use of such indicators is surely better than none at all**. Accordingly, Ben Martin[70] suggests a list of indicators (mainly related to scientific outputs) based on conceptual distinctions with the aim of helping understand what the indicators actually are able to measure. He distinguishes indicators for measuring scientific activity, production and progress; indicators for tracking record of publications and citations and their quality and importance and other indicators to measure other factors.

[66] Martin (1996)
[67] Kostoff (1995); Martin (1996); Salter and Martin (2001); Martin and Tang (2007)
[68] Martin and Tang (2007); Bozeman (2000); Kline and Rosenberg (1986)
69 Martin (1996:346).
70 Martin (1996:347). See also Martin and Tang (2007)

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Furthermore, he argues that as '*all the indicator are, at best, only partial indicators, […] the most fruitful approach would involve the combined use of multiple partial indicators*' or, in other words, **the methodology of converging partial indicators.**[71] Some converging indicators may be also used in combination to lead to some sort of index for valuing groups of effects rather than individual effects.

The methodology of partial indicators was employed in the Eighties to assess investments in radio astronomy observatories, large optical telescopes, electron and proton accelerators.[72]

### Application to RIs impact assessment

Drawing from SPRU scholars' inception, as of today, the use of indicators (or in general of mixed methods) for the IA of RIs has been declined in various forms. In this section, two current approaches can be examined under the perspective of multiple methods or multiple partial indicators literature are discussed. The first one is the OECD approach (Reference framework for assessing the scientific and socio-economic impact of research infrastructures – hereafter only Reference Framework)[73] the second one is the EvaRIO project (Evaluation of Research Infrastructures in Open Innovation and research systems), a coordination and support action project funded by the EC under the 7th Framework Programme (FP7).

**The OECD project** aims to '*… provide funders, decision-makers and RI managers with a generic and versatile tool, based on current community practises, to evaluate the achievement of scientific and socio-economic objectives in a realistic way*' by listing and describing relevant indicators for each category of the (RIs) strategic objectives (see below).[74] **The Reference Framework is based on a philosophy built on 6 points,** which are briefly summarised: [75]

1. RI socio-economic impact is broader than scientific output. The former includes cultural, educational, economic, and social impacts that an IA should account for. ;
2. Potential users of the framework can be both RI management wishing to monitor the impact of their RI and external stakeholders interested in evaluating RI impact vis-à-vis of agreed objectives;
3. The assessment of RIs must be linked to their mission and strategic objectives;
4. To be useful, indicators have to be easy to measure, collect, user-friendly, reliable and meaningful. They should be collected over several years to compare achievements over time;
5. Economic impacts indicators are selected among commonly recognized indicators (induced turnover, innovation, start-ups, direct and indirect employment, etc.);
6. Social/societal impact indicators are more difficult to design and to interpret and require more in-depth validation. Narratives can be considered as alternatives.

Based on current use and acceptability, the Reference Framework has produced a set of **standardised indicators as follows:**

- **a list of 25 Core impact indicators (CIIs)**: this is not a mandatory, but a restricted list of indicators considered as representative and which can provide a general picture of the socio-economic impact of a RI in a point-in-time;
- **a more complete list of 58 standardised indicators** (28 CIIs and 30 additional indicators) sorted by 7 strategic objectives. They are: 1) Be a national or world scientific leading RI and an enabling facility to support science, 2) Be an enabling facility to support innovation; 3) Become integrated in a regional cluster/in

[71] Martin (1996:51).
[72] Martin and Irvine (1981; 1983); Irvine and Martin (1983);
[73] OECD (2019)
[74] OECD (2019, page 2)
75 OECD (2019, page 12).

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regional strategies / be the hub to facilitate regional collaborations; 4) : Promote education outreach and knowledge diffusion; 5) Provide scientific support to public policies; 6) Provide high quality scientific data and associated services; 7) Social responsibility.[76]

Moreover, following the rationale of the framework and the specific character of each RI, the set of standardised indicators can be complemented by ad-hoc indicators representing the specificities of individual RIs. RI stakeholders and managers can use to monitor RI activities to perform socioeconomic IA and to deliver inputs to communication strategies. Indeed, the OECD framework distinguishes between '*Core impact indicators (CIIs)*' which focus on the socioeconomic impacts of the RI and can be more relevant for external stakeholders (e.g. policy makers) and '*Key Performance Indicators (KPIs)*' which are dedicated to the internal performance of the RI and thus are likely to be more relevant for the RI's managers. KPIs are determined by comparing their actual value against thresholds defined ex-ante and are dedicated to monitor the process and its efficiency in delivering the outcome by measuring the performance effectiveness.

Overall, the OECD recommends a long list of about 60 '*easy-to-collect*' indicators with the ambitious of capture the multidimensionality of RIs investments. Indeed, the suggested indicators are related to various RI's objectives (improving internal/external processes) defined with different metrics (e.g. monetary values for procurement contracts, absolute number for other dimensions) and referring to differing things (e.g. both costs and benefits which are not truly distinguished). Moreover, indicators can be adapted for different types of RI and deal with the timing of RIs' impacts in that they are relevant, also, for annual appraisals.

Although OECD recognises that indicators are sometimes not very good proxies for IA, one important point that the Reference Framework emphases is the recommendation of selecting and linking indicators to the specific strategic objectives of the RI.

**The second framework discussed in this section is the methodology underpinning the EvaRIO project.**[77]

Developed between 2011 and 2013, **EvaRIO aimed at developing an evaluation method suited to RIs by exploring** and taking into account **their particular role in a new environment based on open innovation and research systems**. **The underlying idea is that** science and technology knowledge creation in general and **knowledge creation through RIs** in particular **result from a cumulative and interactive learning process**. Accordingly, EvaRIO adapted the BETA approach (see Box 3) for socioeconomic evaluation to the context of RIs along two lines:

- ***BETA Mapping***: a comprehensive mapping of direct and indirect effects that can be generated by or thanks to RIs. Direct effects refer to what was targeted when the RI project were designed and launched; in contrast, indirect effects are related to further exploitation of various types of knowledge, network, modes of organisation, etc. developed or acquired during these projects. The typology of effects are further categorised according to the type of actors (Table 4);
- ***BETA core method***: the development of methods and indicators allowing the identification and the quantification of some of these effects. It is based on the use of different methodologies and metrics according to the type of effects and actors. Quantifiable direct and indirect effects deal with the evaluation of the economic impact of building and operating RIs on supplier firms, visitors, purchases, and employees' expenditure and are expressed in monetary terms. Input-output analysis is suggested for measuring the impact generated via the level

76 See OECD (2019, Appendix 4, Table 6 page 51) for details.

77 http://evario.u-strasbg.fr/the-project

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of expenses injected into the economic system, generally in a determined geographical location. In contrast, indicators are suggested to assess and measure the performance of RI operations in terms of cost, productivity, access, quality, services, etc. and they are mainly related to monitoring activities. Measurement via ad-hoc tools and methods specific to each domain, but relying on welfare gains such as those due to long life expectancy, productivity increase and cost savings, consumer surplus and profits for suppliers and consumers are indicated to account for wider societal and economic impacts (e.g. the impact of a new family of drugs or of given therapeutic treatments on mortality).

**Box 3. The BETA Approach**

The BETA (Bureau d'Economie Théorique et Appliquée) is a joint research laboratory of the UdS (Université de Strasbourg) and of the French CNRS (Centre National de la Recherche Scientifique).
The BETA approach to evaluation has been used for ex-post evaluations of some of the economic impacts of a large variety of programmes launched by public authorities to support research and innovation. Today, the BETA method is one of the acknowledged methods for the socioeconomic evaluation of projects in the field of R&D and STI policy.

In this approach, direct effects were usually distinguished from indirect effects on the basis of the objectives of such R&D projects. Hence, beyond the direct effects (corresponding to what was targeted when these projects were designed and launched), the focus has always primarily been on indirect effects (further exploitation of various types of knowledge, network, modes of organisation, etc. developed or acquired during these R&D projects). Basically, this approach tends to identify (and to measure the impact of) various types of learning processes triggered by the participation in R&D, which are the heart of the knowledge creation and diffusion dimensions in the innovation processes.

Since the context of RIs is most probably different and richer than the context of standard public programmes supporting R&D projects, the aim of EvaRIO is to adapt the BETA approach to the context of RIs.

***Source:*** *http://evario.u-strasbg.fr/topics/beta-method*

Table 3: Crossing categories of effects and categories of actors in the EvaRIO project

| EFFECTS | ACTORS | | |
|---|---|---|---|
| | RI OPERATOR(S) are given some money (whatever sources of funding) in order to build, maintain, enhance the resources and to perform its activity of operator | RI SUPPLIERS are given some contracts in order to supply goods or service to the RI and contribute to the building, maintenance and enhancement of the resources | RI USERS are using the RI for achieving some research activity which is part of a more or less large set of research activities, typically a research project or programme |
| **Direct effects** | volume of activities corresponding to the building and operating of RI | volume of activities corresponding to the supplying of resources open as RI | • volume of activities corresponding to the research projects using RI<br>• direct advantage from using the RI |
| **Capacity effects** (capacity: assets + capacity to mobilize and make them evolve) | change in the capacity due to the operating of the RI, in the field of S&T, Network, Organisation & Methods, Reputation, Human Capital | change in the capacity due to the supplying of resources to the RI, in the field of S&T, Network, Organisation & Methods, Reputation, Human Capital | change in the capacity due to the use of the RI, in the field of S&T, Network, Organisation & Methods, Reputation, Human Capital |

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| EFFECTS | ACTORS | | |
|---|---|---|---|
| **Effects on performance** of RI-related activities | exploitation of the capacity for enhancing the performance as operator of the RI | exploitation of the capacity for enhancing the performance as supplier of the RI | exploitation of the capacity for enhancing the performance as user of the RI |
| **Indirect effects** | exploitation of the capacity for generating economic benefit for the actor "out of RI" : • same research field of actor but not on RI • in other field of research of actor • downstream market/society applications | exploitation of the capacity for generating economic benefit for the actor "out of RI" : • same research field of the actor but not on RI • in other field of activity of the actor • downstream market/society applications | exploitation of the capacity for generating economic benefit for the actor "out of RI" : • same research field of the actor but not on RI • in other field of research of the actor • downstream market/society applications |

***Source:*** *EvaRIO, Final Report, Synthesis of results, December 2013 (Table 2, page 20).Reference named as EC- EvaRIO (2013).*

While relying on the most common indicators already collected by RIs, in an attempt to suggest a rather simple and operational tool, **these frameworks produce a set of organised statistics describing trajectories of performance over time and on different dimensions rather than providing a measure of the impact of a RI.** Moreover, lacking a theory on how to define and measure in a consistent way the identified impacts, but calling for the use of different possible metrics and methods for the quantification, including very different approaches ranging from micro to macroeconomic assessment, it has a limited reliability and is open to inconsistencies and possible inaccuracies. For example, there is a risk to mix considerations on the use of resources (i.e. the cost side) with the one on the production of resources (i.e. the benefit side). Their reliability and accuracy remain then limited. For example, the OECD Reference Framework cannot be used for comparison between RIs, rather such indicators are '*meaningful when compared with the RI's objectives*' and can be used to '*evaluate trends/progresses (yearly comparison) than to interpret absolute numbers*'. In the same way, the EvaRIO project highlights that[78] '*aggregation of the different types of effects is impossible, whatever the grouping of actors (users) or of single RIs. This is due to the fundamental differences in the intrinsic nature of the effects*', methods and metrics. Moreover, '*the aggregation is a very complex issue because of the multiple levels at which it can be envisage*', i.e. inputs, outputs, processes.

## Assessment

### Reliability

**The assessment of the methodological quality and the consistency of the use of multiple indicators has pros and cons.** Among the pros there is the fact when indicators are based on a sound data collection, e.g. involving formal surveys and interviews with RIs stakeholders, their informative power is high. Among the cons, the reliability of multi-indicator/multi methods approaches depends on whether they rely on an appropriate and applicable intervention logic built on the rationale of the investment. Only where the purported intervention logic coincides with and suitably reflects the actual mission of socioeconomic engagement pursued will the multi-indicator system, in its entirely, would increase its reliability[79]. Moreover, reliability is related to the existence of a consistent and well accepted theory on how to define and measure impacts.

### Validity

[78] EC – EvaRIO (2013, page 24, 25).
[79] Martin (1996)

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The approach aims at describing and if possible quantifying by means of different methods/metrics/indicators a wide range of impacts produced by a research infrastructure, including societal effects. To some extent, **the validity of the approach relies on its ambition to capture the multidimensional nature of RIs investments** and to meet the evaluation needs set out in the 'theoretical background' section. However, the broad range of indicators and data sources used can be to the detriment of accuracy.

**Accuracy**

**Multi-indicator approaches to impact assessment can result in limited accuracy** for at least three reasons.[80] Firstly, there is the tendency to define too many indicators some identifying costs, some referring to benefits/impacts and there is little regard for precisely which aspects of research they are capturing and which they are neglecting. Often, there is a trade-off between picking the optimal or desired indicators and having to accept the indicators, perhaps poorly defined or 'soft' indicators, which can be measured using existing data. This represents a strong element of arbitrariness and leads to possible double-counting and overlaps.[81] Secondly, as highlighted by EvaRIO project (see above) there is a problem of aggregation. Rather than attempting to provide a comprehensive and synthetic judgment on the socioeconomic impact of RIs projects, the approach delivers a multidimensional set of indicators. Sometimes, contrasting indicators are flanked, which make the evaluation decision-making process difficult and impractical. Thirdly, indicators are often not a measure of the final socioeconomic impacts but rather signposts of (yearly) change along the path to development or the impact pathways. Indicators are what we observe in order to verify whether – or to what extent – it is true that progress is being made towards our goals, which define what we want to achieve (impacts). For instance, indicators such as the number of spin offs or collaborative activities are not yet a measure of impacts. For example, in case of spin offs a small number of spin-off can generate a significant positive impact on the economy if their survival rate is high and they generate high added value to the economy. Similarly, collaboration *per se* is a proxy of a possible positive result in terms of increase scientific production or learning externalities but not necessarily already the impact itself.

**Cost/time needed**

**Cost ranges from low to medium**, depending on number of indicators collected, the frequency and quality of information sought, and the comprehensiveness of the systems. Similarly, the time required depends on the extent of participatory process to define indicators and the project complexity. Compared to the approaches such IOA, CBA or knowledge PFA either cost or time is lower.

**Relevance for policy makers and for RI managers**

IA assessments based on multiple partial indicators have been commissioned by RIs and government institutions (e.g. EvaRIO, and the OECD Reference Framework ). Therefore, in principle, **this approach would fit the information required by both policy makers and RI managers. Possibly, the usefulness for RI managers surpasses that for policy makers.** Indeed, indicators are effective means to measure progress toward objectives, to facilitate benchmarking comparison over time, and to identify problems and design corrective action to be taken. However, the abovementioned shortcomings with regard to reliability and accuracy limit their current utility in both domains. Hence, improvements are needed at the level of indicator definition and the overall conceptual framework.

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[80] EC – EvaRIO (2013); World Bank (2004); Martin (1996).

[81] According to Martin (1996), the positive aspect for favouring the use of a wide range of indicators is the transparency of the evaluation, i.e. the minimisation of the risk of manipulation of effects. With a number of indicators for each effect, it is more difficult to manipulate all the indicators.

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# 7 Theory-based approaches

## Idea and scope

**Theory-based approaches to impact assessment were motivated by the need to identify the mechanism behind the change generated by a policy intervention,** and less by the need to measure (net) effects. They provide explanations why and how impacts occur and '*may be best thought of as a logic of inquiry for explaining interventions that can complement and be used in combination with other* (data processing) *designs and data collection techniques*'[82] (e.g. indicators, impact multipliers, econometric and statistical techniques, or even CBA). While designs of (qualitative and quantitative) causal inspection may differ, all theory-based approaches share common denominators. They are:

- the identification of impacts pathways, i.e. mapping the effects generated or expected by a (policy) intervention and account for its specificities;
- the recognition of the need to understand and account for wider context, e.g. external factors that may impact on the performance of the intervention;
- the methodological neutrality, i.e. these approaches typically return conceptual maps for 'thinking', thus the IA is 'issue' driven, rather than 'method' driven.

## Theoretical background

**The search for connections between causes and effects is built around a Theory of Change (ToC)**, i.e. a set of assumptions about how an intervention achieves its goals and under what conditions. The ToC emerged in the Nineties at the US Aspen Institute Roundtable on Community Change as a means to model and evaluate comprehensive community initiatives.[83] This type of thinking continues to inform various flowchart-like representations of causal and impact pathways, which show the linkages between the steps from activities to impact.

**There are different ways to build a ToC.** Weak approaches (e.g. logical framework approaches or 'logframes')[84] include nothing more than a logic model that expresses the intentions of policy makers and do not account for the actions and intentions of other stakeholders and conditions in which the intervention is situated (Table 5, Column A). In contrast, advances in the methodologies of theory-based approaches offer avenues for charting impact pathways in a more rigorous manner and distinguish between four main types of causal inference (Table 5, Column B).[85] Each of these types of causal approaches has different requirements for implementation and potential strengths and weaknesses. Regularity frameworks require high numbers of diverse cases; otherwise it is not possible to capture sufficient diversity (or difference). Experimental approaches are good at giving insight into a particular case, but weak on generalisation (external validity). '*Both experiments and regularity/statistical association approaches work best when causal factors are independent*', but none of them '*are good at dealing with contextualisation*'. Multiple causation approaches are '*good at dealing with limited complexity and interdependence but not at unpicking highly complex combinations*, while generative causation may be '*strong on explanation but weak on estimating quantities or extent of impact*.[86]

[82] Mayne (2012a,b).
[83] Weiss (1995). Nothing as Practical as Good Theory: Exploring Theory-Based Evaluation for Comprehensive Community Initiatives for Children and Families in 'New Approaches to Evaluating Community Initiatives'. Aspen Institute.
[84] Hummelbrunner (2010)
[85] Stern et al. (2012); Befani (2012).
[86] Sentences in Italic are from Stern et al. (2012).

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Table 4: Logical frameworks and theory-based approaches

| (A) TYPICAL WEAKNESSES OF LOGFRAMES | (B) THEORY-BASED APPROACHES: TYPES OF CAUSAL INFERENCE |
|---|---|
| **Mechanistic rationale**, i.e. assuming a linear progression of effects which takes place quasi-automatically irrespective of the actors involved or contextual conditions | **Regularity frameworks**: depend on the frequency of association between a cause and an effect; basis for statistical approaches to impact assessment; question – Did the intervention make a difference? Which factors made a difference to the outcome? |
| **Long impact chains**, where causes and effects are rather distant from each other, either in time or in their functional relations | **Counterfactual frameworks**: depends on the difference between two otherwise identical cases; basis for experimental and quasi experimental approaches to impact assessment; questions – Did the intervention make a difference? How much of a difference did the intervention make? |
| **External factors** are considered almost **irrelevant**, leading to a tendency for 'tunnel vision' | **Multiple causation**: depends on combinations of causes that lead to an effect; basis for 'configurational' approaches to impact assessment; questions - Did the intervention make a difference, for whom and under what circumstances? Which factors made the difference, for whom and under what circumstances |
| | **Generative causation**: depends on identifying the 'mechanisms' that explain effects; basis for theory-based approaches to impact assessment; questions - How did the intervention make a difference? What is it in the intervention that made it (not) work? |

***Source:*** *Authors*

**Theory-based approaches are therefore based on the concept of 'causation' and aim at bridging the gap between data and interpretation of that data.** The most popular theory-based approaches such as contribution analysis, realist evaluation, process tracing, and systemic inquiry are briefly described in Table 6. The next subsection focuses instead on the theory-based logic of inquiry applied to the IA of RIs.

Table 5: most popular theory-based approaches

| THEORY | DESCRIPTION |
|---|---|
| Contribution Analysis | The main idea is that a policy intervention is just one of the factors that '*contributes*' to outcomes and often cannot be isolated. Therefore, the aim is to be able to make credible causal claims about the contribution an intervention is making to observed results.<br>The approach concentrates not on the process of reconstructing the assumptions underlying the ToC, but on the assessment of their validity. Even if research results often show that there have been outcomes of an intervention, it is not equivalent to the intervention bringing these outcomes about.<br>It is a narrative approach aiming to build a reasonable contribution argument by drawing on a variety of principles and data sources. Six steps are necessary to implement a contribution analysis: 1) Setting out the cause-effect issue to be addressed; 2) Developing the postulated ToC and risks to it, including other influencing factors; 3) Gathering the existing evidence on the ToC; 4) Assembling and assessing the contribution claim, and challenges to it; 5) Gathering new evidence from the implementation of the intervention; 6) Revising and strengthening the contribution story.<br>The demanding nature of data collection for rigorous application of the method and associated costs are thought to be the main reasons of the limited use of this approach. |
| Realist Evaluation | The main idea is that an intervention has a potential to generate specific outcomes, but eventually the involved stakeholders, who are operating in a specific context (e.g. organisational, political, financial) are either able or unable to carry out the desired mechanism of change. Thus, realist evaluation is based on representing impact pathways as Context-Mechanism-Outcomes (CMO) configurations. Rather than seeking generalisable lessons or universal truths, it recognises and directly addresses the fact that the 'same' intervention never gets implemented identically and never has the same impact, because of differences in the context, setting, process, stakeholders and outcomes. Instead, the aim of realist review is explanatory: what works for whom, in what circumstances, in what respects, and how.<br>It is a logic of inquiry and combines both qualitative, theoretical notions and empirical evidence. Initially, the conceptual territory is mapped out by developing a ToC. Further, work on searching and appraising evidence is undertaken to populate the theoretical framework by locating, integrating, comparing and |

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| THEORY | DESCRIPTION |
|---|---|
| | contrasting empirical evidence. It is designed to learn from real-world phenomena, systematically engaging stakeholders and documenting, formalising and testing insider understanding. |
| Process Tracing | It is defined as '*theoretically explicit narratives that carefully trace and compare the sequences of events constituting the process...These causal chains are represented graphically as causal maps or neural networks*'.* <br> The fine-grained causal chain description relies on both qualitative and quantitative data. Process tracing requires finding 'diagnostic evidence' that forms the basis for elaboration of causalities. The identification of evidence that can be interpreted as 'diagnostic' depends on 'prior knowledge', thus it is important to connect findings from the process tracing with their actual theoretical starting point (ToC). The types of prior knowledge is distinguished into the following four categories: 1) Conceptual frameworks, i.e. the sets of interrelated concepts that are identified as meriting analytic attention; 2) Recurring empirical regularities, i.e. established patterns in the relationships among phenomena; 3) Theory-I: more tightly connected recurring regularities that allow to build theory by collecting carefully verified, interconnected hypotheses; 4) Theory-II: includes not only interconnected empirical regularities (Theory-I), but also explanatory statements. <br> Various tests are applied to determine the credibility or raise doubts about the observed causal inferences (adapted and elaborated by Bennett 2010, Collier 2011, Befani, 2016). |
| Systemic Inquiry | It acknowledges that multiple factors working as 'a package' can influence the outcomes of policy intervention in very indirect and non-linear ways. Therefore, the attention is placed on understanding the way in which also the relationships between factors contribute to change. |

***Source:*** *Authors. For Contribution Analysis see: Mayne (1999; 2012a; 2012b); Stern et al. (2012); Delahais and Toulemonde (2012); Befani (2016); Hermann-Pawłowska and Skórska (2017). For Realist Evaluation see: Pawson and Tilley (1997); Pawson et al (2004). For Process Tracing see: * Amnizade (1993); George and McKeown (1985); Bennett (2010); Collier (2011); Befani (2016). For Systemic Inquiry see Arnold (2004); Gallart (2006); Williams (2015); Befani et al. (2015); Grove (2015).*

## Application to RIs impact assessment

While logic model thinking is very common in IA practice, the application of theory-based approaches to IA of RIs is still rare. An ad-hoc logic model approach has been used in the evaluation of Bio-banking and Biomolecular Research Infrastructure (BBMRI). Evaluators have reconstructed the programme logic based on the available documentary evidence and conversations with BBMRI managers. Through this evidence gathering process evaluators have identified BBMRI objectives and differentiated them into project outputs, outcomes and impacts.[87]

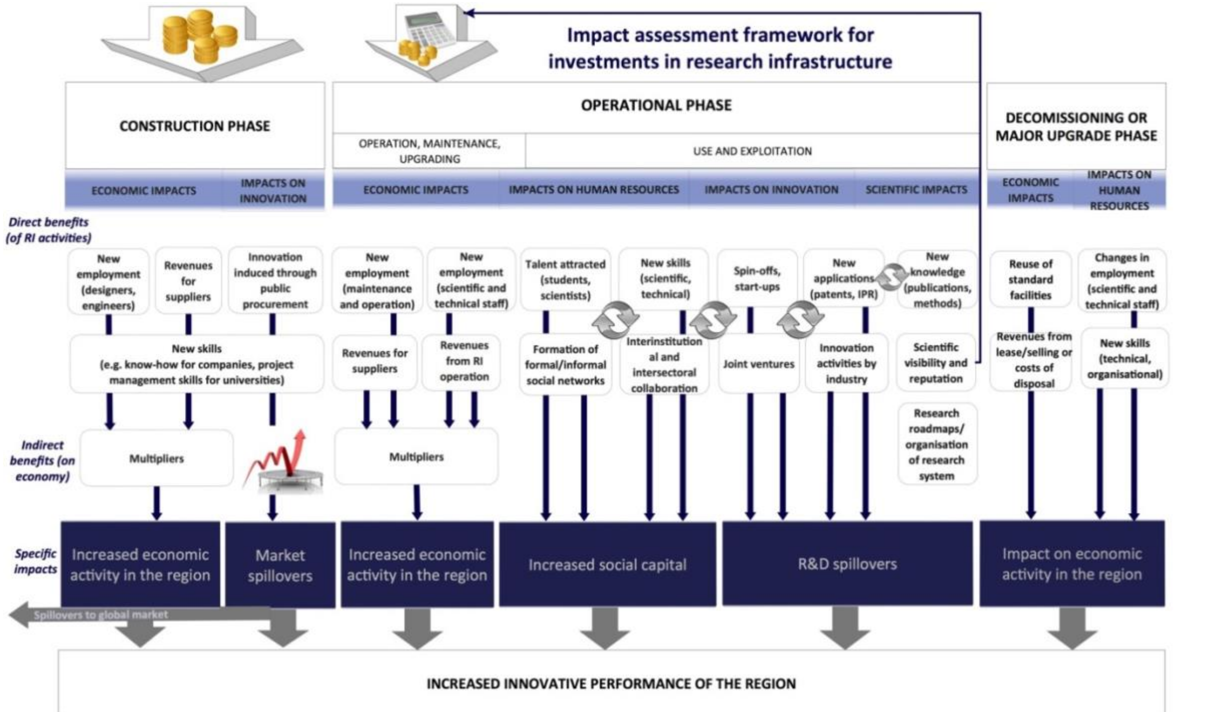
The linkages from investment in large RIs and innovation outputs have been explored in detail by Simmonds et al.[88] The report is based on an in-depth literature review on innovation impacts of large-scale research facilities and additional interviews with RI stakeholders. While the literature review was structured along four types of RIs (single sited, distributed, mobile, virtual), the majority of publications (and thus also results) were concerned about the socio-economic impacts of large single-site facilities. The study mapped logical impact chains of socio-economic effects of a RI in a single diagram. The focus of this mapping has been to schematically represent the causal links of impact pathways for innovation.

**A more generalised logic model of the socio-economic impact of RI has been developed by Griniece et al.**[89] The model mainly attempts to graphically map the main impact pathways that are observed during construction, operational, as well as decommissioning or major upgrade phase of a RI (Figure 1). Impacts are traced in terms of their distance from the funded activities. The model is depicting impacts that arise predominantly from single-sited RIs and covers impacts on economy, innovation, human resources and scientific impacts, but it does not reflect wider societal impacts. Descriptions are included

[87] See Meijer et al (2010) for details
[88] Simmonds et al. (2013)
[89] Griniece et al. (2016). The basis for constructing impact pathways has been documentary evidence from available case studies and analytical reports, as well as hands-on experience interacting with and advising managers of ESIF funded RI projects in Lithuania in the period 2010-2014. Further expert feedback has been incorporated from exchanges at RI practitioner workshops and OECD SEIRI group meeting (2014-2016)

for all causal assumptions of the charted impact pathways. While the logic model does not reflect in detail wider contextual factors that can influence the outcomes of investments in a RI, it does acknowledge the interlinked and cumulative effects that arise in the areas of human resources, skills formation and networking, as well as intricate mechanisms behind and between impacts on innovation and scientific impacts.

Figure 1: Logic model for socio-economic IA of RIs




***Source:*** *Griniece, Reid and Angelis (2016)*

**The European FP7 RIFI (Research infrastructures: Foresight and impact)** project,[90] can be considered an additional logic model that can be placed under the heading of the theory-based approaches. It started in 2009, ran for two years, and was motivated by the fact that Central-East, and South-East Europe did not play a significant role as host countries for RI. The project aimed at developing an **integrated framework for the identification of RI investment opportunities and methods for their socioeconomic IA in order to support decision-making.** Beyond the identification of impacts as such, it sought to analyse the (potential for the) substantiation of RI impacts in national and regional contexts of Central-Eastern, and South-Eastern Europe.

**RIFI efforts thus build on the acknowledgement that RIs impacts are mediated through a diversity of channels** that require a complex Research Infrastructure Assessment Methodology (RIAM) to enable conclusions that can serve as a robust basis for policy making. In general terms (see Figure 2), the RIFI RIAM begins with a five-step Context Analysis, structured in the following modules: create a profile of the RI (A), create a profile of the host region (B), analyse the RI's business model (C), perform risk analyses, based on foresight (D), and develop a comprehensive SWOT (E). Subsequently, it continues with the Socioeconomic Impact Analysis proper, structured in six modules of Economy & Innovation System, Population and Labour Market, Infrastructures and Services, Environment, Culture, and Quality of Life, Networking & Cohesion, and Foresight and Long-term Impacts. Some of the modules are structured in up to ten (context analysis) or up to three (socioeconomic impact analysis) sub-modules.

[90] https://cordis.europa.eu/project/rcn/91271_it.html

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Figure 2: Structure of the FenRIAM methodology

| Part 1: Context Analysis | Part 2: SE Impact Analysis |
|---|---|
| **Module A: RI Profile**<br>A.1: General Description<br>A.2: Site Requirements<br>**Module B: Regional Profile**<br>B.1: Ecological and Geographic Environment<br>B.2: Political Environment<br>B.3: Legal Framework Conditions<br>B.4: Infrastructures and Services<br>B.5: Labour Market<br>B.6: Regional Economy<br>B.7: Research Environment<br>B.8: Networking and Clustering<br>B.9: Education<br>B.10: Social Environment<br>**Module C: Business Model**<br>C.1: Siting Conditions<br>C.2: Fit with Strategies / Agendas<br>C.3: Financial Management<br>C.4: Technical / Operational Management<br>C.5: Procurement / Supply Management<br>C.6: Management of External Relations<br>C.7: Human Resources Management<br>**Module D: Risk Analysis**<br>**Module E: SWOT Analysis** | **Module F: Economy & Innovation System**<br>F.1: Macroeconomic Study<br>F.2: Microeconomic Study<br>F.3: Micro-Model on Experimental Shadow Value<br>**Module G: Population and Labour Market**<br>G.1: Labour Market<br>G.2: Long-term Impacts on the Labour Market<br>G.3: Long-term Impacts on the Population<br>**Module H: Infrastructures and Services**<br>**Module I: Environment, Culture, and Quality of Life**<br>I.1: Study by Expert Opinions and Reference Sample<br>I.2: Study by Foresight Techniques<br>**Module J: Networking & Cohesion**<br>J.1: Networking<br>J.2: Progress towards Political Agenda Goals<br>J.3: Social Cohesion<br>**Module K: Foresight and Long-term Impacts**<br>K.1: Expert Panel for G.2<br>K.2: Expert Panel for G.3<br>K.3: Expert Panel for I.2<br>K.4: Expert Panel for J.3 |

***Source:*** *Presentation of the FenRIAM Methodology on 5th European RI Workshop (2011)*

Also this framework relies on a mix of quantitative and qualitative assessments and indicators[91] and, in total, has been applied to three case studies: the ELI (Extreme Light Infrastructure) - Nuclear Physics (Magurele, RO); the EURO-ARGO (Global Ocean Observing System) (distributed, BG); The Free Electron Laser FERMI@Elettra (Trieste, IT) of which only the second one was fully covered, i.e. including a context analysis.[92]

## Assessment

**Reliability**

The methodological quality and consistency of theory-based approaches rely on the acknowledgement that attribution of effects without explanation is insufficient for a robust and credible IA. Causal process designs such as contribution analysis and process tracing are essentially about understanding interrelationships. Causal mechanism designs such as realist evaluation and systemic inquiries embrace various perspectives and can be used to illuminate intrinsic stakeholder values and assumptions. In principle, **these approaches to evaluation** and their derivatives to the IA of RIs, their logic of inquiry and their implementation rules **are sound, allow for replicability and can be generalised to different typologies of RIs. However, different approaches** (e.g. contribution analysis, realist evaluation, and so on) **return different ToCs that can be weak or strong. This limits to some extent their reliability**.

**Validity**

Theory-based approaches map out the determining or causal (external) factor and the RIs' characteristics judged important for success and how they might interact with each other. **This makes such approaches a valid tool for the RIs socioeconomic impact evaluation.**

[91] The RIFI RIAM foresees document analysis, surveys, interviews and participatory techniques like focus groups and hearings. For the preparatory context analysis, collected data shall be analysed mainly through descriptive analysis / stories, network analysis, micro-models, risk analysis, and SWOT analysis. For the socioeconomic impact analysis proper, further proposed methods of analysis include input-output analysis, micro-models, network analysis, secondary data analysis, descriptive analysis, stories and participatory techniques.

[92] Additionally, a partial test of the RIAM was performed by the Czech ELI - Beamline and a survey of public opinion was conducted in La Palma about the Roque de los Muchachos Observatory (ES).

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**Indeed, although some framework does not cover the whole spectrum of the expected impacts and related factors** (e.g. wider societal impact), logic of inquiry on these impacts could be easily incorporated. Moreover, providing feedback about what is or is not working and why theory-based approaches can help also identify unintended side-effects of the investments in RIs.

**Accuracy**

The accuracy of theory-based approaches in describing and measuring RIs impacts can be examined from two viewpoints: firstly, the description of the causal chains from causes to effects (ToC) and, secondly, in terms of how effects/impacts are measured. Documentary and literature review, ethnographic observation and direct consultation of stakeholders are the main tools used to derive the ToC. Its **accuracy in describing how and under what conditions investments in RIs produce their socioeconomic impacts depends on the capacity to map the design of complex activities and mechanisms in a rigorous manner**, i.e. avoiding either too simplistic theories of causation or overly complex designs if an exhaustive list of factors and assumption is assembled. A problem of interpretation or arbitrariness can emerge when a change can be associated with multiple ToCs, or when stakeholders might disagree about which determining factors they judge important.[93] In this case, it is particularly important to test each possible theory against the real-world evidence by collecting and processing empirical data to assess whether the ToC is confirmed or not and to identify which theory better reflects reality. However, **theory-based approaches are neutral from the perspective of statistical/empirical inference** and a mix of statistical and narrative techniques (from multipliers to indicators, to case studies) are allowed. **This mix often leads to an inconclusive and unclear judgment about the best ToC and the impact of RIs**, particularly in a field such as IA of RI where data collection routines are not well-established yet.[94] Causal inferences are based predominantly on general observations from practice, fragmented evidence from the literature and individual case studies. Rigorous empirical analyses that seek grounded explanations of impact pathways are exceptions rather than a rule.

**Taking all together, we believe that** while the accuracy of theory-based approaches in their full methodological rigour *per se* may prove difficult to ascertain **there is an intrinsic value to starting with a good narrative or a timeline that lists the sequence of effects**. Causal ideas embedded in the narratives can be regarded as an initial stepping stones in the development of a theory of change. Teamwork between qualitative and quantitative methods can enhance the strength of the causal inference. For this reason, we regard accuracy of theory-based approaches as medium where they are combined with a robust tool for measuring impacts and testing the ToC.

**Cost/time needed**

Costs (and skills) to implement this evaluation approach depend on the depth of the analysis and especially the depth of data collection and empirical evidence undertaken to investigate the workings of the intervention. Similarly, the time can vary greatly, depending on the depth of the analysis. In general, the cost and time is somewhat low for building the ToC. They increase when the ToC has to be tested with empirical evidence.

**Relevance for policy makers and for RI managers**

Impact pathways based on strong causal inference can help reconstruct mechanisms how investment in RI leads to specific impacts. This information can meaningfully support RI managers in the design of operational strategies for enhancing impacts. While still important, the appraisal of mechanisms is perhaps less relevant from policy-maker and

[93] Mackenzie and Blamey (2005); Weiss (1997). Williams (2015) also reminds that '*Notions of holism and big picture can be misleading. In reality, an evaluation cannot consider everything, it cannot take everything into account. Every endeavour has to make decisions about boundaries, about deciding what is in and what is out*'.

[94] Delahais and Toulemonde (2012) state: '*Theory-based approaches are good at explaining impact mechanisms, but often inconclusive as to whether interventions do or do not work*'.

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funder perspective. **Thus, there is an inherent formative value for RI managers, which is somewhat reduced for policy-makers.**

# 8 Case studies

## Idea, scope and conceptual background

Case studies are one of the most wide-spread qualitative methodologies in the social sciences and their formal and systematic development starts in the 1960s. In spite of this long history, **there is still no single definition or understanding of what exactly constitutes a case study.** Essentially though, a case study is an in-depth investigation of a particular event or intervention, or '*the detailed examination of an aspect of a historical episode to develop or test historical explanations that may be generalizable to other events'*.[95] Yet, a case study '*may be understood as the intensive study of a single case where the purpose of that study is – at least in part – to shed light on a larger class of cases (a population)'* where a case '*connotes a spatially delimited phenomenon (a unit) observed at a single point in time or over some period of time'*.[96]

**Case studies as a research methodology can be extremely varied, and their exact design depends on the purpose of the study**. They can include a wide array of distinct research methods, such as desk research, surveys, interviews, but also statistical data collection and analysis. Categorising the case study approach as a 'qualitative' methodology is probably rooted in the more conventional understanding of cases as a narrative.[97] As far as impact assessments are concerned, often they employ the case study approach in order to aid policymakers or managers in their decision making. Their purpose can vary, but typically, case studies are used to communicate stories of success/failure in order to draw lessons for future action.[98]

## Theoretical background

**Case study approaches can be divided into two groups: within-case studies and cross-case studies.** Within-case analyses focus on one single case in-depth and draw inferences from that. Cross-case analyses, on the other hand, involve more than one case and use a comparative approach to draw conclusions. Most case studies use a mix of the two types, so as to keep the benefits of having detailed insights from a single case, but also to have a more solid basis for generalizations and theory building, especially when it comes to exploring causal relationships.[99] Both types of case studies call for the careful consideration of selecting cases. When working with a large sample of cases in a cross-case analysis, some form of randomization is likely to be introduced in case selection. In this way, the selection is more likely to be representative of the population.[100] However, case-study research normally uses small sample sizes, and as such, it calls for purposive (i.e. non-random) case selection. Table 7 lists nine techniques, each informed by the selected cases' relationship to the entire population. **The impact assessment should inform which technique to use when selecting cases.** Moreover, independently from the type of case study and taking the example of a typical project analysis, a useful hands-on guide to the basic steps of case study research design and execution based on three research phases is provided in Table 8.

[95] George and Bennett (2004: 5).
[96] Gerring (2007: 19-20)
[97] Actually, Gerring (2007: 30-33) suggests thinking of the association of case studies with qualitative methods as a 'methodological affinity', rather than a definition or categorisation.
[98] As suggested above, they can be used also to describe a 'typical' scenario that can illustrate impact pathways and explore and/or identify impact mechanisms. See, for instance, Reid and Miedzinski (2008).
[99] Brady and Collier (2004); George and Bennett (2004); Gerring (2007)
[100] Gerring (2007).

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Table 6: Types of case studies and relationships with population

| N | TECHNIQUE | DESCRIPTION |
|---|---|---|
| **1** | Typical | Cases are typical examples of some cross-case relationship |
| **2** | Diverse | Cases illuminate the full range of variation |
| **3** | Extreme | Cases exemplify extreme or unusual values |
| **4** | Deviant | Cases deviate from some cross-case relationship |
| **5** | Influential | Cases with influential configurations of the independent variables |
| **6** | Crucial | Cases are most-or least-likely to exhibit a given outcome |
| **7** | Pathway | Cases where X1, and not X2, is likely to have caused a positive outcome |
| **8** | Most-similar | Cases are similar on specified variables |
| **9** | Most-different | Cases are different on specified variables |

***Source:*** Gerring (2007)

Table 7: Hands-on guide to practically implement case studies

| PHASE | DESCRIPTION |
|---|---|
| **Preparatory phase** | This initial phase includes desk research and the planning of the research execution. It is recommended to start off by getting familiar with the case study method by reading previous studies and comparative analyses, preferably on the same or a similar topic, and to prepare an annotated report template. The accessible documentation on the project to be evaluated should be read, including project descriptions, reports, presentations, and evaluations if available. A preliminary list of interviewees (key persons/organisations) should also be drawn up in this phase, making sure they include subjects from different levels and parts of the project. Thorough preparatory work is the bedrock of the successful fieldwork, as it allows asking the most pertinent questions during the interviews to aid analysis and find missing pieces of information. |
| **Fieldwork phase** | Fieldwork mostly comprises doing interviews with various project stakeholders on-site, as well as visiting facilities to get a more tangible idea of the project and its outcomes. Interviews are typically semi-structured with open-ended questions and adjusted to the role the interviewee played in the project. Questions also need to be adjusted to time constraints. The primary focus should be on collecting factual data, but opinions can also greatly enrich the final analysis. Soon after the fieldwork, additional or follow-up interviews can be conducted over the phone |
| **Analytical phase** | A first draft of the case study should be written up as soon as possible after the fieldwork phase. It should include both descriptive and analytical parts, adding the researcher's own assessment, taking into account all the gathered information. This first version of the report should then be reviewed by a peer not familiar with the case, in order to identify gaps and opportunities for improvement. This feedback is helpful in shaping the final version of the case study report. |

***Source:*** Reid and Miedzinski (2008)

## Application to RIs impact assessment

**Case studies are widely used to the socioeconomic IA of RIs** because they are often considered to better reflect the uniqueness and complexity of RIs. There are however different possible approaches. The following are three examples of research papers that use a case study approach to assess RIs. The first one focuses on researchers' experience using RIs, the second one on a relatively small national facility, while the third one on an international, large-scale RI. All of theme share the fact of showing success stories (this is typical of case studies in this field), and are more focussed on factors and mechanisms through which the impacts can materialise rather than on impacts as such.

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### 8.1.1 Case studies on best practices.[101]

**This study uses the success case study approach to get insights into the understanding of research resources to research teams** at the University of Wisconsin (Madison) Institute for Clinical and Translational Research (UW ICTR). In particular, the study seeks to get an in-depth understanding of researchers' reactions to changes in research resources, their perceptions of contributions of UW ICTR to their own research programmes, and their opinions about ICTR support for career development. The study selected seven researchers 'cases' who have been deemed to follow successful career trajectories (i.e. advanced the translation of research discoveries into practice), hence applying the 'success case study' approach by using the purposeful sampling strategy.

This case study largely follows the typical steps outlined above[102] and operates with a **cross-case study approach**. Rather than focusing on one single case (researcher), the authors started identifying common themes and characteristics that emerged among the seven cases unfolded. This process allowed for drawing meaningful conclusions and setting up a narrative that became validated by pointing out overlaps and contrasts across the observed cases.

Using project-specific descriptions and data as well as the researchers' perceptions of the impact of improved research infrastructure, **the study concludes by providing through narratives a deep understanding of the (single) benefit accruing to scientists from research resources in terms of their research development and professional career**. In the conclusion the authors emphasise the value of doing case studies in order to gain insights into the first-hand experiences of those utilising and benefitting from RIs and the method's meaningful contribution and complementary character to *'tell the stories implicit behind quantitative data'*.

### 8.1.2 Opening the black box of (ideal-type) impact pathways in a public agricultural research organisation.[103]

**The study is a demonstration of the ASIRPA** (Assessment of Socio-Economic Impact of Public Agricultural Research) **approach to assessing impacts of public research organisations in the field of agriculture, and to identify typical impact pathways**. Specifically, it aimed at demonstrating ideal-type impact pathways at the public mission-oriented organisation INRA (French National Institute for Agricultural Research) in order to see how various societal impacts are generated. **The study conducted 32 case studies at INRA, where cases were instances of successful innovation**.[104] The theoretical approach comes into play in the analysis phase, which informs the development of a standardised method to analyse the cases. The study team came up with a standardised outline that was based on the logic of an impact pathway: productive configuration, outputs, intermediaries, and finally impacts. This approach allows for the highlighting of the main aspects of each case, while offering a common analytical framework. As such, it also helps to reduce complexities inherent to case studies, which makes it easier to generalise across cases.

[101] Hogle and Moberg (2014).

[102] Firstly, the authors conducted desk research by gathering information from a wide array of different documents: research descriptions from the university website; individual progress reports of the scholars', trainees' and pilot project awardees' research; recent publications; news reports; presentations to the ICTR External Advisory Committee; Google; as well as resource use and publication data from ICTR tracking systems and databases. The study team then conducted semi-structured interviews with each of the seven investigators separately, lasting about 60 minutes on average, which were recorded as audio.

[103] Matt et al. (2017). While this approach is certainly a theory-based one, rooted in Actor-Network Theory (ANT), it relies on '*standardized case studies which allow thick description of specific situations and typological analysis*' (Matt et al. 2017: 208).

[104] Case selection was '*based on a statistical PAM-k classification of a thousand salient research results from INRA's laboratories*' and on interviews with heads of departments (Matt et al. 2017: 208). Once the 32 cases – representative of INRA's specialisations - had been selected, each of them was explored via interviewing various stakeholders, on average seven of them per case. Additional sources of information were also used, such as websites, archival documents, official documents as well as various publications for validation of the information.

### 8.1.3 Case studies on the CERN

CERN is one of the most studied RIs in terms of socioeconomic IA over time and by many scholars.[105] **In 2014 CERN collaborated with the OECD to carry out a study on economic and societal impacts.**[106] The aim was to gain an external perspective on the laboratory's activities as embedded in economy and society, with the idea to use the results in shaping the organization's policies and procedures. **OECD study uses the case study method emphasizing the reliance on a qualitative approach, without being embedded in any particular academic school of thought**. The idea of including quantitative assessment (X unit of investment results in Y units of change of a particular indicator) was discarded due to methodological issues related to the inability to capture the multidimensional scope of the study and the potential inaccuracy in estimating 'soft' impacts such as '*increased in the quality of life indices*'.[107] A qualitative approach, supported by desk research and interviews with various stakeholders, on the other hand was considered more appropriate for its more flexible theoretical grounding and its ability to take into account context to a large degree.[108]

Six 'impact categories' were defined to frame the research and analysis, as shown in Table 9. Impact categories were grouped into two types, non-discretionary and discretionary. This distinction indicates the nature of the impact, as discretionary impacts typically need active involvement of managers and administrators in order to be achieved. Case studies were used to assess four impact-generating CERN activities in the categories V and VI, in particular (i) innovations needed for major CERN component development – the case of the LHC dipole magnets; (ii) innovations unrelated to the facility needs – the hadron cancer therapy; (iii) software applications; (iv) education and public outreach.[109]

Table 8: Types of case studies and relationships with population

| CATEGORY | DESCRIPTION | |
|---|---|---|
| **I** | Purely scientific results, intended to advance fundamental knowledge | Non-discretionary |
| **II** | Direct impact of spending for construction and operation of the laboratory | |
| **III** | Training of scientists, engineers, administrators, and other professionals | |
| **IV** | Achieving national, regional and global goals, strengthening international scientific co-operation | |
| **V** | Developing and diffusing technological innovations while pursuing the scientific mission | |
| ***V a*** | Innovations needed for major component development / procurement, with both high-energy physics (HEP) and non-HEP impacts | |
| ***V b*** | Non-HEP Innovations that can become external impacts with only minor modifications | discretionary |
| ***V c*** | Non-HEP Innovations that can become external impacts with major additional efforts | |
| **VI** | Education (of teachers and/or students) and various forms of public outreach | |

***Source:*** OECD GSF (2014:14).

**The outcome in all four cases is essentially a story that gives a detailed picture of various processes that resulted in certain impacts**, which, in turn, are described in qualitative terms. The information gained from this case study research is meaningful as in many cases it cannot be found anywhere else. This is all the more true when we take into

[105] See, among others, Åberg and Bengtson (2015); Autio et al. (2003); Bianchi-Streit et al. (1984); Schmied (1977).
[106] OECD GSF (2014).
107 OECD GSF (2014: 13).
[108] OECD GSF (2014: 12-13). The case study process involved a desk research (papers, articles, internal documents) and fieldwork phase (47 phone and face-to-face interviews with key individuals at CERN, non-CERN experts, as well as former and current employees of companies that collaborated with CERN).
[109] All four case studies are embedded in the given historical and economic context – for example, in the case of the dipole magnets, it is emphasized how the Cold War context in the 1970s-80s, coupled with economic competition between Europe and the US, moved forward the innovation process (OECD GSF, 2014: 21-22)

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account the fact that many of the results speak not of organizational structures or procedures, but emphasize the role of various actors (i.e. human agency) in bringing about impacts. Although they are not always related socioeconomic impacts, these pertain to themes such as the work culture, the importance of international knowledge networks, formal or informal; the advanced scientific knowledge of staff members; the flexibility of staff members (including management); the encouragement of having employees from different scientific backgrounds exchange ideas; the handling of risks; the role of trust in collaboration with industrial actors, to mention only a few.

### Assessment

**Reliability**
The existence of (standardised) implementation rules and practises positively influence the reliability of the case studies approach in IA, which is currently widely spread and accepted among policy makers, RI managers and funding agencies. However, as opposed to more quantitative approaches and theory-based frameworks, **there is an issue with the reproducibility of research results (even within the same typology of RIs), which, in turn, leads to problems related to the generalizability of results.** This concern is true both for cross-case studies (even if they usually draw up criteria for standardisation) and for within-case studies, whose component of subjectivity is very relevant. Moreover, subjectivity becomes an important issue of concern where 'soft' aspects (as those described above) are embodied in the IA, whose assessment is strongly related to individual perceptions. This somewhat limits the consistency of case studies approaches. All this makes case studies a less reliable tool (with respect to other approaches discussed in this document) for the RI-PATHS project, whose aim is to develop a general framework for the IA of different typologies of RIs.

**Validity**
**The main strength of the case study approach lies in its ability to account for the context in which RIs operate**. This allows for gaining truly in-depth insights into complex RIs activities, impacts, and phenomena that normally take place in a non-linear, interactive manner. By doing so, the approach is able to bring to the fore the role of various actors (users, firms, etc.) involved in processes and structures, something which is often lost in a purely quantitative or structured/standardized approach. Due to this, case studies are particularly apt to shed light on what is meant by particular RIs' aspects/concepts, thus unpacking existing and discovering new ones, and helping to develop a better grasp and understanding of them. Therefore, although case studies operate with a high level of subjectivity (low generalizability and reliability) this is exactly what allows for sensitivity to context (high validity within narrow boundaries).

**Accuracy**
Case studies are a powerful tool to communicate results. They produce simple, 'visual', and inspiring results by combining different methods and triangulating information throughout the research process. Against these pros, **there is the issue that, in the case of the IA of RIs, the analysis of successful cases is the most widespread and this may lead to a sort of optimism bias,** i.e. the increasing emphasis on positive 'impacts' and lack of attention on negative aspects of RIs (such as costs, potential negative impacts on environments, etc..). Moreover, **the robustness of such (success) stories often relies on lack of in-depth analysis, with the use of simple data easily understandable by a wide audience,** i.e. with the illustration of only positive effects supported by 'easy-understandable' positive statistics. From this viewpoint, case selection can also be tricky.

**Cost/time needed**
Case studies usually require the active involvement of stakeholders (e.g. through interviews) and consultation with users to develop an understanding of the power relationships, interests of the various people involved in an activity, to identify mechanisms, impacts, and to provide feedback about such impacts. Although, cost and

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time required to implement a case study can vary depending on scope and depth of application, **their drafting is likely to be less expensive and time consuming with respect to the above approaches.**

**Relevance for policy makers and for RI managers**
Narratives are increasingly becoming important for the IA of RIs as a (complementary) tool, especially with a view to their ability to secure funding in a highly competitive environment. They are able to be addressed to a larger audience than other methodologies, and thus the case study approach is certainly useful to build stories in order to learn about what makes a RI worthy for the society. While, on the one hand, this information may be relevant **for policy makers and funding agencies, the lack of technical aspects (e.g. related to the accountability and allocation of resources) reduces to some extent informative power of case studies for those stakeholders**.

# 9 Discussion and conclusions

This review has shown that there are a number of methodological approaches built on diverse streams of literature, analytical frameworks, data collection methods and types of evaluation exercises. T**hree broad analytical frameworks** can be identified. First, **economic approaches,** including both macro and micro perspective (IOA and multipliers approaches, the knowledge production function approach and CBA), have the advantage of being built on well-accepted and solid analytical frameworks. Such approaches are traditionally used to assess socioeconomic impact of public investments and their outcomes (e.g. contribution to GDP, employment creation, rate of return) are well understood by decision makers and the wider public. Their theoretical and conceptual foundations allow for internal consistency, replicability and generalisability for different typologies of RIs. Micro-economic approaches (CBA in particular) are more appropriate when dealing with individual investment projects compared to more aggregate measures of public spending in favour of scientific research more generally. In this regard, CBA is a more accurate approach for measuring long-term impacts attributable to a RI project than IOA or the knowledge production function. However, the types of impacts identified by the economic literature do not always reflect all the specificities of RI.

A **second category of approaches** places the emphasis of the multi-dimensional nature of impacts. They are **mixed approaches** combining science policy as well as contributions bases on management literature: the partial multiplier approach (such as for example the Reference Framework by OECD and the EvaRIO/BETA approaches). Multiple indicator frameworks aim at describing and quantifying (where possible) by means of different methods/metrics the wide range of impacts produced by a RI. While very ambitious, this goal leads often to a set of heterogeneous indicators which pose serious problems of aggregation and accuracy. Multiple indicators deliver a multidimensional set of measures and can provide contrasting messages in terms of assessment. In many cases, indicators are not direct measures of the impacts of a RI but a description of a trajectory over time of a specific performance dimension (scientific publications, creation of start-ups, patents), which needs further analysis to measure the socioeconomic impact (e.g. how many scientific publications are cited in their scientific community? How many start-ups survive and generate added value and employment? How many patents are commercialised and create a profitable product, service or process?).

**Finally, a third stream of approaches are those grounded on the causation** literature (theory-based approaches and case studies) with a strong orientation on qualitative narratives focused on causal mechanisms and factors underpinning successful performance. None of the above approaches deliver detailed information on the precise mechanisms of the generation of the impacts. **Causal process designs like approaches underlying impact pathways are quite accurate and essential about understanding**

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**interrelationships.** They emphasise the importance of, by one side, mapping all the impacts occurring during the entire lifecycle of a RI and, by the other side, to discover the causal mechanisms linking short with longer time impacts. **Theory-based approaches such as impact pathways are valid tools for explaining causality** and at uncovering why and how expected impacts materialise. **They also emphasise the role of context in determining the success or failure of a RI investment**. This information meaningfully supports RI managers in the design of operational strategies for enhancing impacts and can provide relevant input to policy-makers/funders in understanding the potential impact of funding channelled to new or existing RI.

**The cost, in terms of resources and skills, and time required to implement an IA assessment vary greatly depending on the scope and depth of application**. The process of compiling suitable data can be cumbersome in case of the economic approaches, although this is exactly what enhances the validity and the accuracy of such approaches. Specifically, the process is particularly demanding when quantitative data do not exist for many dimensions and therefore need to be created. This can pose the greatest bottlenecks as the field of the IA of RIs is new and RIs generally may have inadequate records of what has happened and what has changes over time. The implementation of a sound theory-based IA also requires great efforts for the quality and quantity of information required to reconstruct the theory of intervention. Finally, as far as multiple partial indicators and case studies are concerned, the participatory intensity, i.e. the active involvement of stakeholders to define goods indicators and produce sound case studies determines their amount of cost and time needed for implementation.

On the basis of our assessment of the existing approaches summarised in the table below, **we conclude that none of the existing methods in their traditional formulation provides a comprehensive and satisfactory solution to assess the socioeconomic impact of RI.** This **suggests the need for an analytical framework building on the most promising existing approaches and expanding and combining them to enable a more comprehensive method covering a broader range of types of impacts.**

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