



The potential socio-economic impact of a breakthrough in the particle accelerators' technology

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1. The research question
2. A general cost-benefit analysis model for research infrastructures
3. Two applications: LHC and CNAO
4. From a micro-economic to a meso-economic perspective
5. A research agenda

Our research question

How to evaluate the socio-economic impact of a technological breakthrough in particle accelerators?

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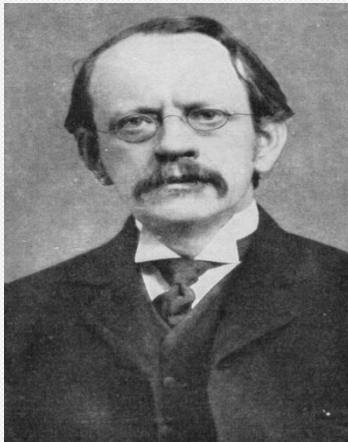
Source: Courtesy Oak Ridge National Laboratory

FROM SCIENCE TO SOCIETY

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Accelerators for America's Future (2010)

- “By research in pure science. I mean research made without any idea of application to industrial matters but solely with the view of extending our knowledge of the Laws of Nature. I will give just one example of the ‘utility’ of this kind of research, one that has been brought into great prominence by the War—I mean the use of X-rays in surgery...



Joseph John Thomson
(1856 – 1940)

- “Now how was this method discovered? It was not the result of a research in applied science to find an improved method of locating bullet wounds. This might have led to improved probes, but we cannot imagine it leading to the discovery of the X-rays. No, this method is due to an investigation in pure science, made with the object of discovering what is the nature of Electricity.”

J.J. Thomson (1911)

Our research question

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The question can be made more explicit as follows:

“ How can we predict and measure the benefits to different social stakeholders of a potential (uncertain) technological change that initially arises within a laboratory to solve scientific problems and then creates spillovers to technologies intended to solve socio-economic problems? “

- In an **ex- post perspective** the main problem is **causality**.
- In an **ex-ante perspective** the main problem is **uncertainty about costs, time and effects** of the change downstream, from the laboratory to the industries and public services.

History of CBA

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FRANCE

**“De la mesure de l'utilité des travaux publics”
(*Annales des Ponts et Chaussées*, 1844)**



Jules Dupuit (1804 – 1866)

HISTORY OF CBA:

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INTERNATIONAL ORGANISATION, USA AND UK

1936, Flood Control Act, **US Government**

1972, Guidelines for project evaluation, **UNIDO**

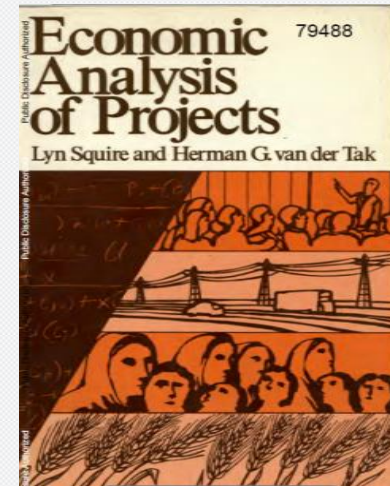
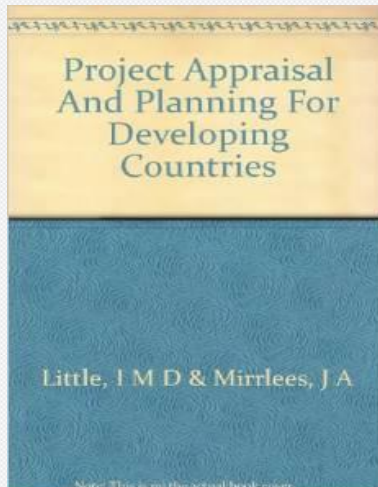
1974, Project appraisal and planning for developing countries by I.M.D. Little and J.A. Mirrlees, **OECD**

1975, Economic analysis of projects by L. Squire and H.G. van der Tak, **World Bank**

2003, **UK, The Green Book** – Appraisal and Evaluation in Central Government

2006, **OECD, Cost-Benefit Analysis and the Environment**, Pearce et al.

2013, **EIB, The Economic Appraisal of Investment Projects at the EIB**



HISTORY OF CBA IN THE EU

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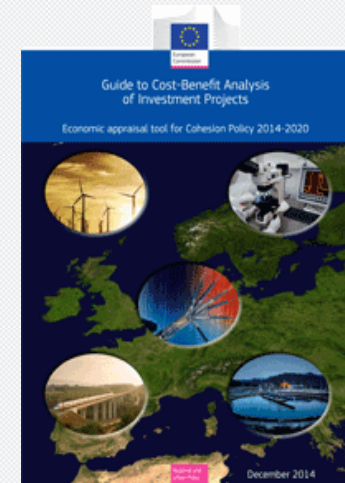
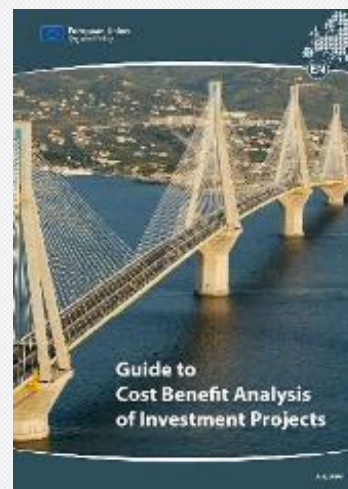
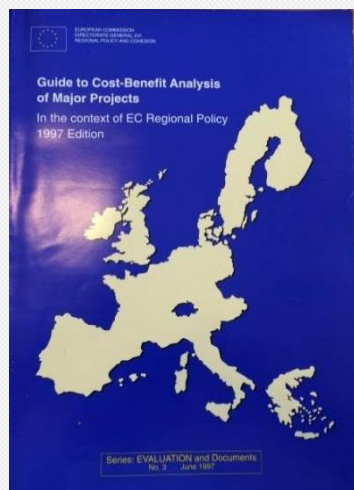
2014: 5th edition, 364 pages

2008: 4th edition, 257 pages

2002: 4th edition, 133 pages

1997: 2nd edition, 84 pages

1994: 1st edition, 28 pages



A novelty of the fifth edition of EC CBA Guide:
Ch. 7 - Research, development and Innovation

Towards a CBA model for RIs

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...A new CBA model
developed by the University of Milan
(DEMM and Dept. of Physics)
and CSIL



Cost-Benefit Analysis in the Research,
Development and Innovation Sector

Projects financed by EIBURS
the EIB University Research Sponsorship
Programme
Call for proposals
2012/C 162/10

December 2012 - December 2015

The Large Hadron Collider (CERN)



CNAO - National Hadrontherapy Center
for Cancer Treatment



PROJECT PERFORMANCE

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FINANCIAL

Financial Revenues

-

Financial Costs

=

Financial Profits

p_t = market prices

q_{ot} = output

q_{it} = input

$$FNPV = \sum_{t=0}^T \frac{p_t q_{ot} - p_t q_{it}}{(1+i)^t}$$

t= year

i= financial discount rate

Financial Discount rate:
i= 4% for all EU Member States



From market to shadow prices

Market prices are unreliable or not existent for many RDI projects' outputs.

ECONOMIC

Social Benefits

-

Social Costs

=

Social Net Benefits

p^*_t = shadow prices

q_{ot} = output

q_{it} = input

$$ENPV = \sum_{t=0}^T \frac{p^*_t q_{ot} - p^*_t q_{it}}{(1+r)^t}$$

t= year

r= social discount rate

Social Discount rate:
r=5% is used for major projects in Cohesion countries
r= 3% for the other EU Member States

The CBA model for RIs

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$$NPV_{RI} = NPV_u + B_n = (PV_{B_u} - PV_{C_u}) + B_n$$

[1]

PV_{B_u} = present value of use-benefits

B_n = non use-benefits

PV_{C_u} = present value of costs

The expected economic net present value of the RIs infrastructure [NPV_{RI}] over the *time horizon* (T) is defined as the difference between expected *benefits* and *costs* valued at shadow prices and discounted at the *social discount rate* (r).

Costs

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PV_{C_u} = the present value of COSTS

is the sum of

- **economic value of capital** (K)
- **labour cost of scientists** (L_s)
- other **administrative and technical staff** (L_o)
- other **operating costs** (O)
- **negative externalities** if any (ε).

$$\mathbb{E}(NPV_{C_u}) = \sum_{t=0}^T s_t \cdot (k_t + l_{st} + l_{ot} + O_t + \varepsilon_t)$$

[2]



Discounting process is represented by T terms

$$s_t = 1/(1+r)^t$$

Benefits

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Use
Benefits B_u

FIRMS



Technological externalities
(T_t)

EMPLOYEES: early career researchers



Human Capital Formation
(H_t)

CONSUMERS



Social benefits to consumers
of services (A_t)

SCIENTISTS



Cornell University Library

Celebrating the 1 Millionth Paper
January 2015

Knowledge output (S_t)

VISITORS



Cultural effects (C_t)

Non Use
Benefits B_n

?



Quasi option value (QOV)

TAXPAYERS



Existence value (EXV)

CONSUMERS

Use Benefits

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PV_{B_u} = the present value of use-benefits

is the sum of

- benefits to firms, defined as **technological externalities** (T);
- benefits to staff, particularly students, arising from **human capital accumulation** (H);
- benefits to users of the RI services including the **value of publications for scientists** (S),
- **cultural effects** (C);
- benefits of applied research to **external users or other consumers** (A)

$$\mathbb{E}(NPV_{B_u}) = \sum_{t=0}^T s_t \cdot (T_t + H_t + S_t + C_t + A_t)$$

[3]

Benefits to firms: Technological spillovers

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The present value of technological spillovers T is given by the discounted incremental social profits Π_{jt} by companies (j) of the RI's supply chain or other economic agents, who have benefitted from a learning externality:

$$T = \sum_{j=1}^J \sum_{t=0}^T s_t \cdot \Pi_{jt} \quad [4]$$



Benefits to employees: Human capital formation

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Human capital accumulation H is valued as the increased earnings (I) gained by former RI's students and former employees (z), since the time (ϕ) they leave the RI project, against a suitable counterfactual scenario:

$$H = \sum_{z=1}^Z \sum_{t=\phi}^T s_t \cdot I_{zt} \quad [5]$$



Benefits on users: knowledge output

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Celebrating the 1 Millionth Paper

January 2015

The social value of knowledge output is measured
by:

- the **sum of the present value of papers signed** by RDI's scientists (P_{0t}) and the **value of subsequent flows of papers produced** by other scientists that use or elaborate of the RDI's scientists' results
- **divided by the number of references** they contain ($\frac{P_{it}}{k_{it}}$, with $i = 1, \dots, n$), and the **value of citations each paper receives**, as a proxy of the social recognition that the scientific community acknowledges to the paper (Q_{it} with $i = 0, \dots, n$)

$$S = \sum_{i=1}^n \sum_{t=0}^T s_t \cdot P_{0t} + \sum_{i=1}^n \sum_{t=1}^T \frac{s_t \cdot P_{it}}{k_{it}} + \sum_{i=0}^n \sum_{t=1}^T s_t \cdot Q_{it} \quad [6]$$

Benefits on users: cultural effects

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Outreach activities carried out by RI produce **cultural effects** on the general public (g), which can be valued by estimating the willingness to pay W_{gt} for such activities.

$$C = \sum_{g=1}^G \sum_{t=1}^T s_t \cdot W_{gt} \quad [7]$$



Social benefits to consumers of services

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Provision of Services

Some RDI infrastructures provide services to external users. They may pay a fee for accessing and using the infrastructure's equipment and/or specific services offered.

Social benefits of RDI services for target groups of consumers

Some RDI infrastructures are expected to use new knowledge to deliver innovative services and products addressing specific societal needs. Benefits arise to users who are better off by the delivery of the innovative service or product.

$$A = \sum_a^A \sum_{t=0}^T s_t \cdot a_t \quad [8]$$

These services are project specific and each of them ultimately is related to the WTP for them by users



Summing up:

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The CBA model for pure and applied research infrastructures turns into the following equation:

$$NPV_{RI} = \left[\left(\sum_{j=1}^J \sum_{t=0}^T s_t \cdot \Pi_{jt} \right) + \left(\sum_{z=1}^Z \sum_{t=\varphi}^T s_t \cdot I_{zt} \right) + \left(\sum_{i=1}^n \sum_{t=1}^T \frac{s_t \cdot P_{it}}{k_{it}} + \sum_{i=0}^n \sum_{t=1}^T s_t \cdot Q_{it} \right) + \left(\sum_{g=1}^G \sum_{t=1}^T s_t \cdot W_{gt} \right) + \left(\sum_{a=1}^A \sum_{t=0}^T s_t \cdot a_t \right) \right] + (EXV_0) - \left[\sum_{t=0}^T s_t \cdot (k_t + l_{ot} + o_t + \varepsilon_t) \right] \quad [10]$$



If the **marginal cost of scientists' labour input in publications is taken as a proxy of the value of knowledge outputs produced by scientists**, then l_{st} in equation (2) and P_{0t} in equation (6) **cancel each other (under the reasonable assumption of linearity of the cost function)**

CBA RESULTS (1)

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The CBA test could produce **three possible baseline results** (i.e. without considering explicitly their probability distributions):

1. The net present use-value of the research infrastructure NPV_u (all the terms except the last one) is **greater than zero**, i.e. $PV_{B_u} > PV_{C_u}$ hence $NPV_u > 0$;
2. The net present use-value of the research infrastructure is **equal to zero net of the unknown non-use effects**, $NPV_u = 0$;
3. The net present use-value of the research infrastructure is **negative net of the unknown non-use effects**, $NPV_u < 0$.

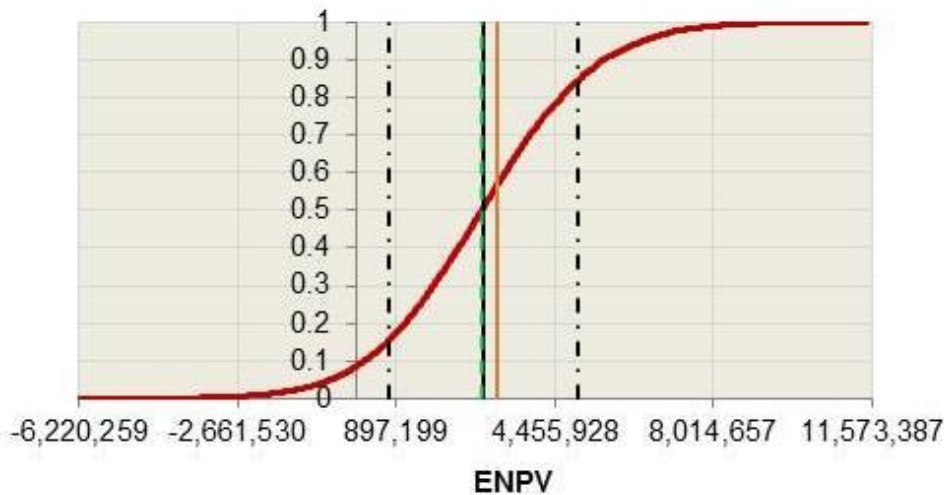
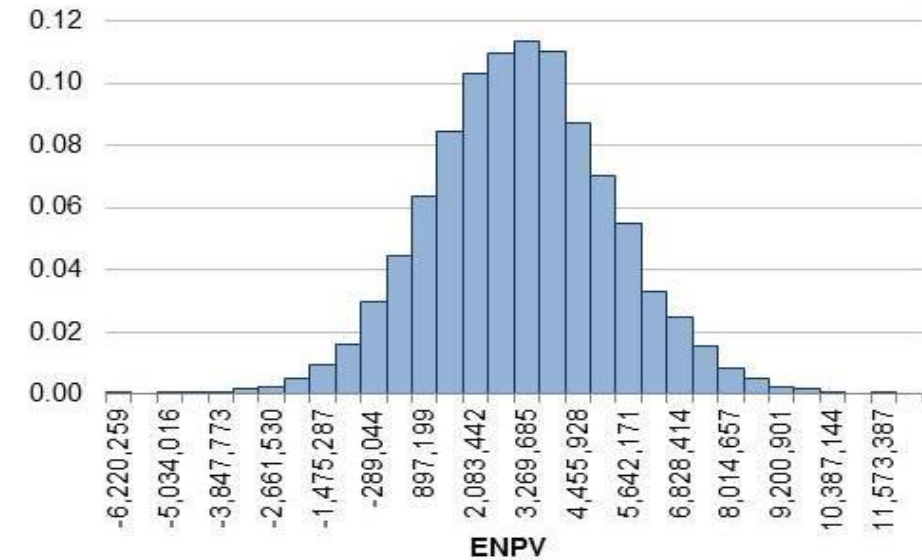
CBA RESULTS (2)

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- In the first two cases the RI passes the ex-ante CBA test if the evaluator *guesses* that the uncertain B_n would be at least nil, so that the total NPV_{RI} cannot be expected negative (within a range of associated probabilities). *No further need to try to estimate B_n as long as it can be excluded that non-use effects are non-negative.*
- In the third case, which may be typical of fundamental research, the RI project passes the CBA test if and only if B_n is positive and large enough to compensate for the negative net use-effects. *An estimation of the willingness to pay for the pure value of discovery as a public good is needed.*

The Large Hadron Collider: CBA results

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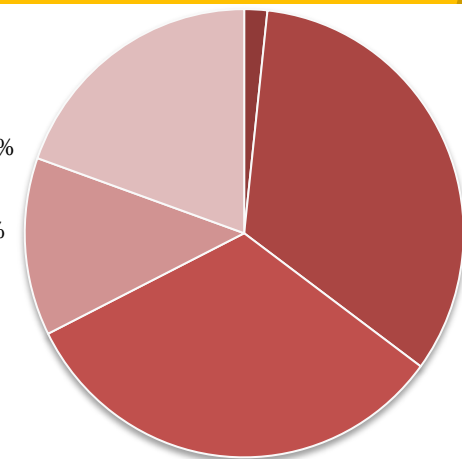


— Cumulated probability
— Mean
- - - Std. Dev. from mean
— CBA reference value
- - - Median

PROBABILITY DISTRIBUTION OF THE LHC NET PRESENT VALUE

Own estimate of the Present Value PDF resulting from a Monte Carlo simulation (10,000 random extractions)

- Scientific publications 2%
- Human capital formation 33%
- Technological spillovers 32%
- Cultural effects 13%
- Existence value 20%



ESTIMATED PARAMETERS OF DISTRIBUTION

Mean	2,855,528
Median	2,825,860
Standard Deviation	2,134,763
Minimum	-6,220,259
Maximum	11,573,387

Estimated probabilities

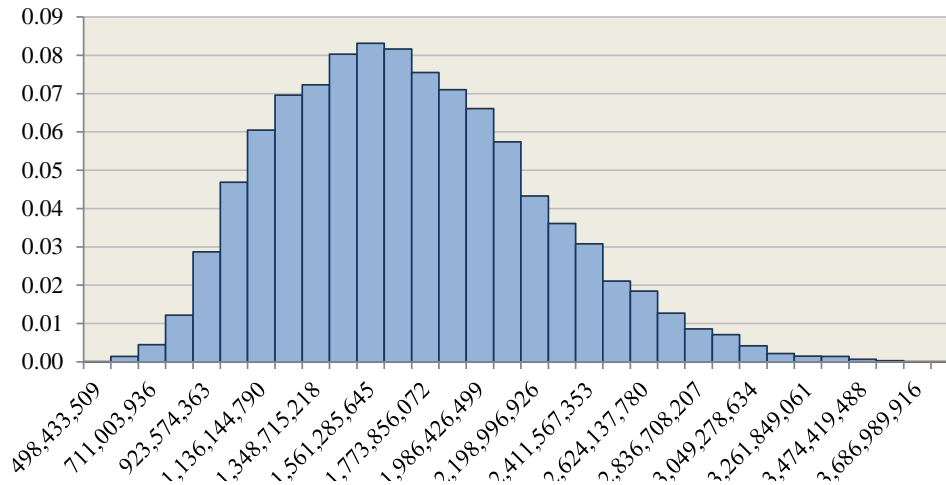
Pr. ENPV ≤ 0	0.086
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Values in Thousands EUR, 2013

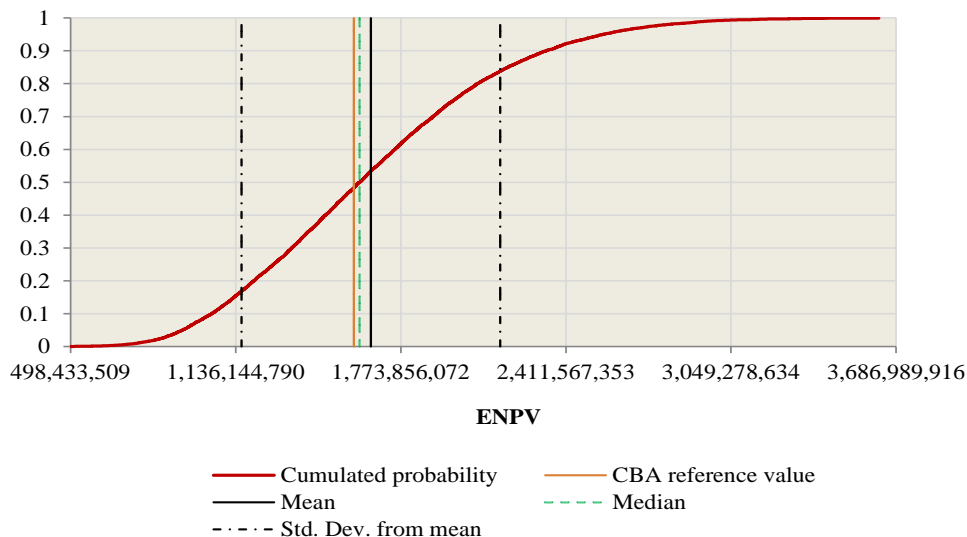
CNAO - Hadron Therapy: CBA results



ENPV Probability Density Function



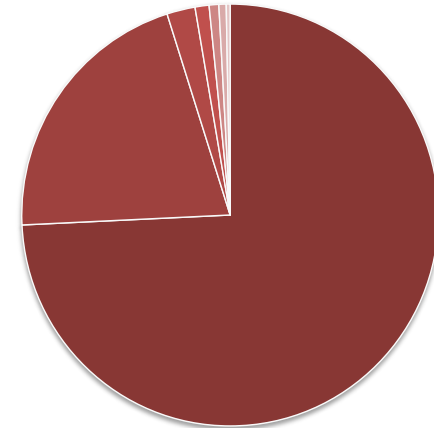
ENPV Cumulative Distribution Function



PROBABILITY DISTRIBUTION OF THE CNAO NET PRESENT VALUE

Own estimate of the Present Value PDF resulting from a Monte Carlo simulation (10,000 random extractions)

- Carbon Ion Therapy 74.2
 - Proton Therapy 20.9%
 - Revenues 2.2%
 - Benefit of Technological Spillovers 1.1%
 - Benefit of Human Capital Generation 0.7%
 - Benefit of Knowledge Creation 0.6%
 - Benefit of Cultural Outreach 0.3%
- Health benefits**



ESTIMATED PARAMETERS OF DISTRIBUTION

Mean	1,658,358
Median	1,615,046
Standard Deviation	499,225
Minimum	498,433
Maximum	3,686,989

Estimated probabilities

Pr. ENPV ≤ 0	0.000
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Values in Thousands EUR, 2013

Back to the research question

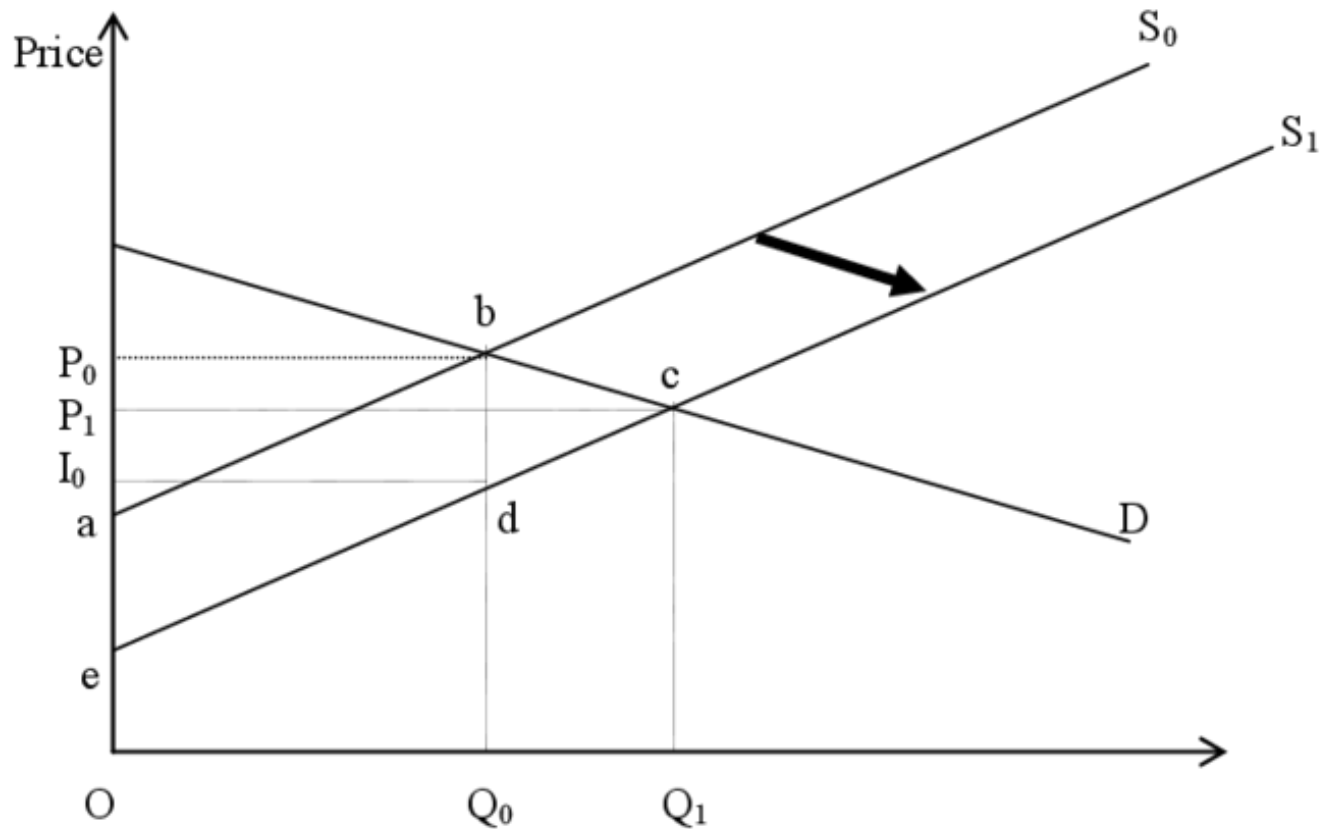
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We are not willing to evaluate a single research infrastructure but a breakthrough that can have an impact on several uses of particle accelerators.

One can start by a partial equilibrium perspective

Net benefits of a cost saving technological change

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The global market for PAs (1)

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Sessler, A. and Wilson, E., 2014.

Engines of discovery: a century of particle accelerators. World Scientific.

- There are some *200 high-and medium energy machines* and probably as many as *16,000 smaller accelerators*.
- **200** are to produce radioisotopes for medicine; almost **8,000** are employed in the therapy of cancer, and another **8,000** for industrial processing, ion implantation, modification of surface and bulk materials and for sterilization of food....

The global market for PAs (2)

American Physical Society (2013)

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- 10,000 cancer patients daily treated in the US with beams from accelerators.
- 10 million diagnostic medical procedures and 100 million laboratory tests every year with short-lived radioisotopes.
- \$20 billion business annually of **nuclear diagnostic medicine and radiation therapy**.
- The **multi-billion-dollar semiconductor industry** relies on **ion beams** from accelerators to add special atoms in semiconductors.
- **X-ray lithography with intense beams** etches microchips and other semiconductor devices.
- **Nondestructive dating of archeological samples and art objects**, for **unraveling DNA structure**, and for **pharmaceutical research**.

Industrial applications: (1)

Hamm and Hamm (2012)

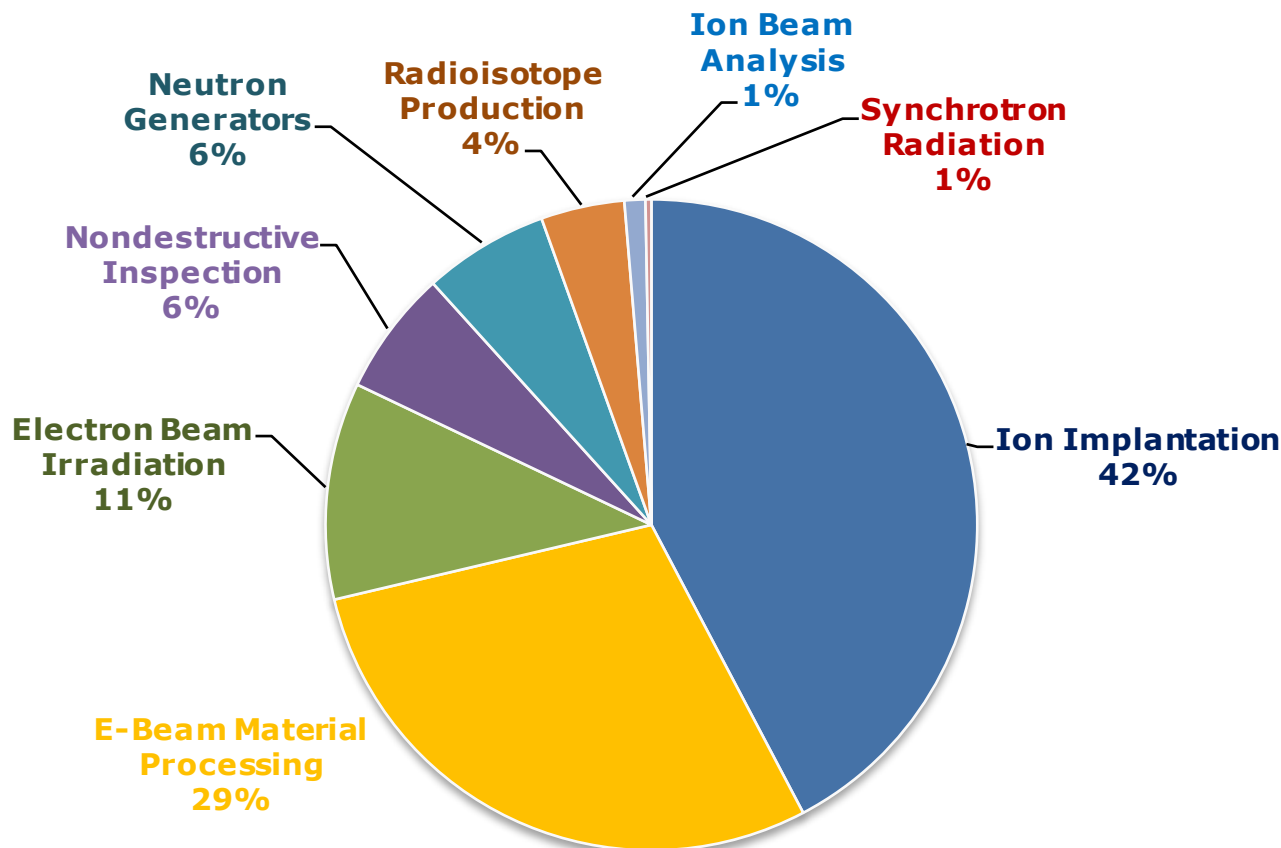
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“Any charged particle accelerator that generates an external electron or ion beam for any beam process other than direct medical treatment or basic research to be an industrial accelerator. We do not include self-contained low-energy devices such as cathode ray tubes, X-ray tubes, radio frequency and microwave power tubes, and electron microscopes in this category even though they are used mostly for industrial purposes. However, we do consider the accelerator production of therapeutic or diagnostic radionuclides for nuclear medicine an industrial application because these are either stand-alone ingredients or end products that are for the most part produced by for-profit businesses using commercially-built accelerators”.

*Source: Hamm, R.W. and Hamm, M.E., 2012.
Introduction to the beam business. Industrial Accelerators and their Applications.*

Breakdown of the cumulative number of industrial accelerators according to the application categories

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Source: Adapted from Hamm, R.W. and Hamm, M.E., 2012

- More than **24,000 particle accelerators** over the past 60 years for use in the industrial processes. More than **11,000 particle accelerators** exclusively for medical therapy with electrons, ions, neutrons, or X-rays.

Industrial applications: (2)

Hamm and Hamm (2012)

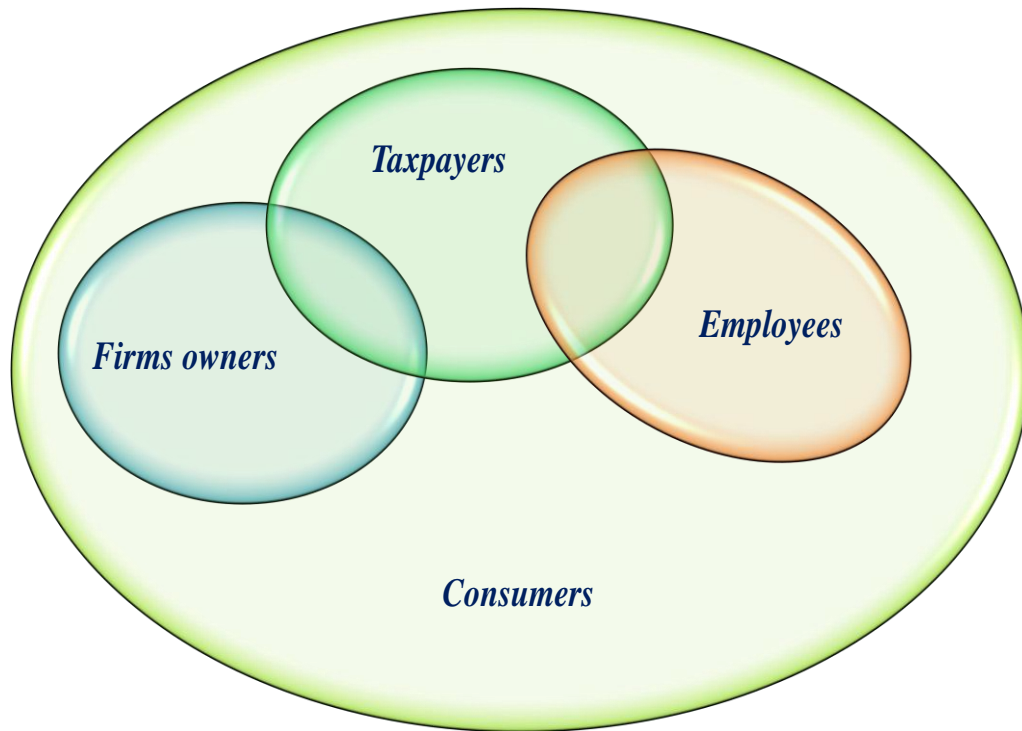
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- **Useful lifespan of 20 to 40 years and more than 75% of those built are still in operation today.**
- **At least 70 companies and institutes around the world.**
- **A few large vendors in North America, Europe, and Japan, but the number of vendors in Russia, India, Korea, and China is growing rapidly.**
- **H&H estimate that collectively these accelerator manufacturers ship more than 1100 industrial systems per year — almost twice the number produced for research or medical therapy — at a market value of ~US 2.2B.**
- **The annual sales of ion implanter accelerators alone is greater than US 1B and the market value of semiconductor devices produced is approaching US 300B worldwide.**

A taxonomy of benefits in RIs

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Customary partition of economic agents in the applied welfare economics literature:



- **Firms:** profit maximization (producer surplus).
- **Consumers:** maximizing their utility (consumer surplus).
- **Employees:** maximizing their income for a given amount of efforts.
- **Tax-payers:** adjusting their decisions as a consequence of the existing fiscal constraints to minimize the burden of taxation.

Some evidence from literature:

- **Drèze, J. and Stern N. (1990).** *Policy reform, shadow prices and market prices*, Journal of Public Economics.
- **Johansson, P-O and Kriström, B. (2015).** *Cost-Benefit Analysis for Project Appraisal*, Cambridge: Cambridge University Press.

A research agenda (1)

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A future agenda of a research on the Socio-economic impact of a breakthrough in accelerator technology should include:

- **Adapting a social cost-benefit analysis of research infrastructures** to the specific topic of an entirely new concept: a) A long-term forecast of the global demand for particle accelerators; b) probability of discovery and scenario analysis of the technological change; c) assessment of the potential socio-economic net benefit of the transition to new technologies.
- **Review of the existing information on the global stock and demand of particle accelerators.** The estimate of more than 30,000 accelerators is often reported but not very precise and updated: *in which application fields there will be the grater impact?* It would be needed to estimate the existing stock and demand drivers of the accelerators worldwide in the different sectors, and second to focus particularly on those accelerators which are potentially of specific interest for a technological change if and when new types of accelerators will be available in future.

A research agenda (2)

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- Given the uncertainty surrounding the field, a **specific technology forecasting exercise**, based on state-of-the-art approaches (following Delphi approach) should be performed, involving an international panel of scientists and experts in the R&D of acceleration industry. The specific objective is to generate a subjective (Bayesian) probability distribution of different technological scenarios, conditional to existing information.
- **Combining the demand scenario for particle accelerators of the type potentially influenced by a technological breakthrough, and the R&D scenario**, the cost-benefit analysis will be based on the simple concept that the main potential net socio-economic benefit is driven by the difference between the cost trajectory of the current technologies and the cost trajectory of the new technologies.

A research agenda (3)

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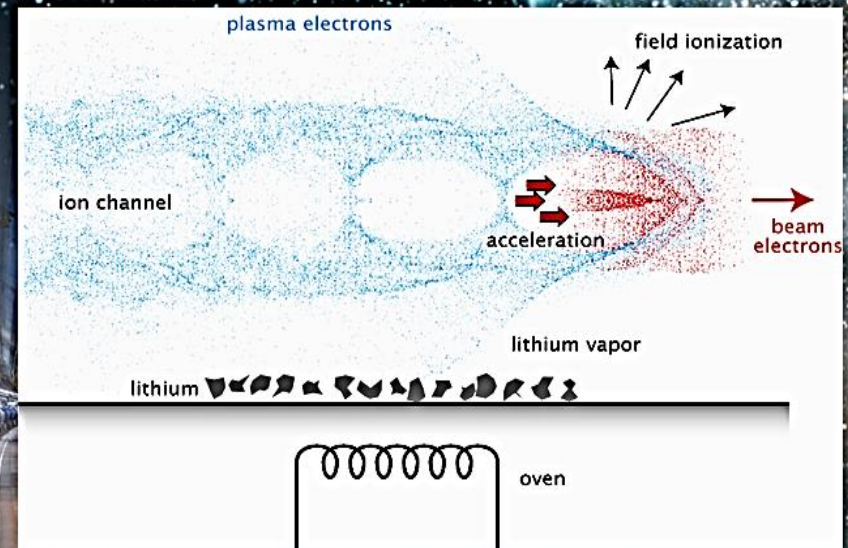
- Other benefits may include the effects on human capital (PhD students), technological spillovers, cultural effects. These concepts will be captured quantitatively by the expected net present value (NPV) of such difference, over a suitable long-term intertemporal integration, given a social discount rate (currently the EC recommend 0.03 in real terms).
- Given the high uncertainty surrounding both the demand drivers and the cost savings, several variables in the forecasting model will be treated as stochastic and the final result will be expressed in the form of a conditional probability distribution of the NPV after a suitable Montecarlo exercise.

Suggested Readings

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- Florio M., Forte S., Pancotti C., Sirtori E., Vignetti S. (2016), **Exploring cost-benefit analysis of research, development and innovation infrastructures: an evaluation framework**, <https://arxiv.org/ftp/arxiv/papers/1603/1603.03654.pdf>
- Catalano, G., Florio, M. and Giffoni, F., (2016), **Willingness to pay for basic research: a contingent valuation experiment on the large hadron collider**, <https://arxiv.org/ftp/arxiv/papers/1603/1603.03580.pdf>
- Chapter 7 of the **Guide to Cost-Benefit Analysis of Investment Projects. Economic appraisal tool for Cohesion Policy 2014-2020**, European Commission, DG Regio, 2014.
- **Special Issue on The social impact of Research Infrastructures at the frontiers of science and technology**. 2016. Guest editors: Chiara Del Bo, Massimo Florio and Stefano Forte.
- Camporesi, T., Catalano, G., Florio, M. and Giffoni, F., 2017. **Experiential learning in high energy physics: a survey of students at the LHC**. European Journal of Physics, 38(2), p.025703.
- Florio M. and Pancotti C. (2017), **Evaluating knowledge projects and R&D infrastructures with BCA with an example**, chapter forthcoming in Farrow S. Teaching Benefit Cost Analysis.



THANK YOU
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