UNIVERSITÀ DEGLI STUDI DI MILANO

Csil CENTRE FOR INDUSTRIAL STUDIES

COST-BENEFIT ANALYSIS OF THE LHC TO 2025 AND BEYOND: Was it Worth it ?

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EXAMPLES OF RESEARCH INFRASTRUCTURES

RESEARCH INFRASTRUCTURE	DESCRIPTION	APPROXIMATE TOTAL INVESTMENT COST (M EUR)	SOURCE
Superconducting Super Collider SSC (USA)	Particle accelerator with a planned ring circumference of 87 km. The project was cancelled in 1993.	13,460	Giudice (2010)
National Ignition Facility (USA)	Laser-based inertial confinement fusion research facility, built between 1997 and 2008 and operational since 2009.	3,350	GAO (2000) and press release
Large Electron-Positron collider LEP (CERN, CH)	Electron-positron accelerator. Commissioned in 1989 and closed down in 2000, it was the predecessor of LHC.	1,730	Schopper (2009)
Central European Institute of Technology CEITEC (CZ)	Centre of excellence conducting research in the field of life sciences, advanced materials and technologies. It is currently under construction.	310	Data provided by the EIB
Extreme Light Infrastructure ELI (HU)	The world's highest power laser, currently under construction.	310	Data provided by the EIB

COSTS

are high,

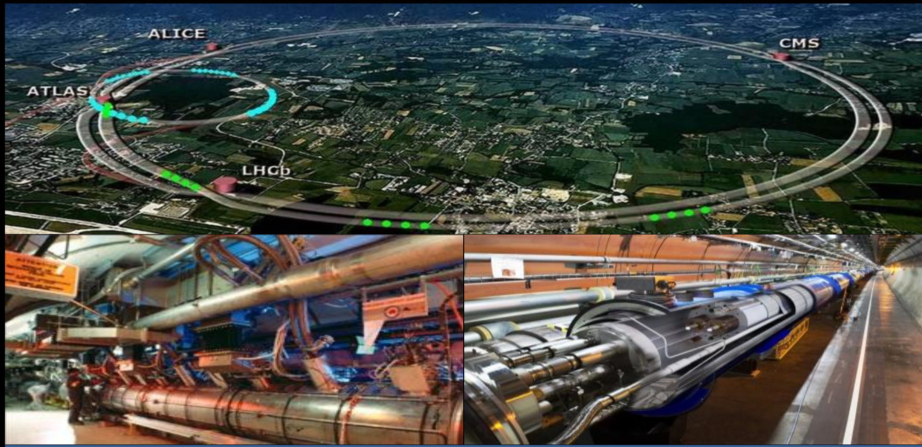
are increasing over time,

uncertain ex-ante

and even ex-post

SSC (abandoned)

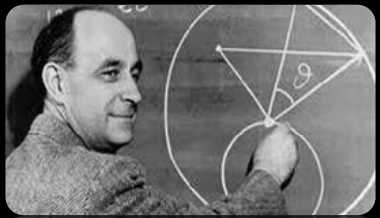
ISS International Space Station



From LEP to **LHC**

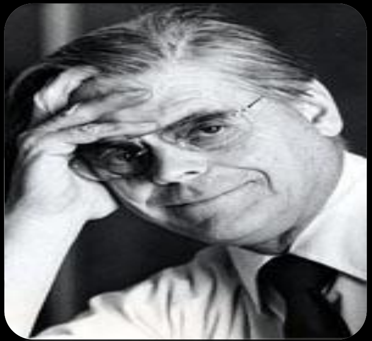
WHY A CBA OF RESEARCH INFRASTRUCTURES?

And here many people will raise a question: which practical consequences came or will come from such an increase in our knowledge about the inner structure of matter?



Enrico Fermi, 1930

- The usual argument by the scientific community is that science will in any case benefit the society in future. This is a form of rhetoric.
- It ignores the opportunity cost of a project against another project;
- the fact the in most cases some benefits are unknown;
- and that ultimately tax-payers foot the bill in the present against these uncertain, occasionally very long term, future benefits.
- However, MOST social costs and SOME social benefits can be valued and predicted
- Hence, let us measure what can be measured, and set aside what cannot be measured: **CBA** is about what is measurable.
- Our conjecture is that knowing what is measurable will help the decision-makers.

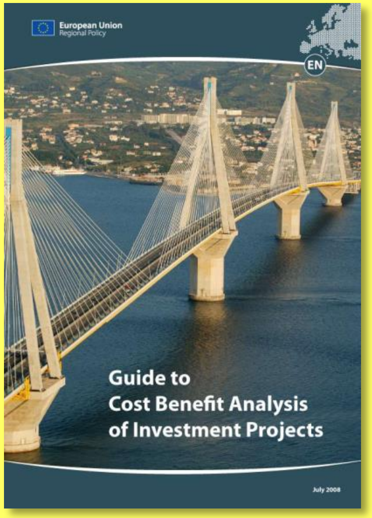


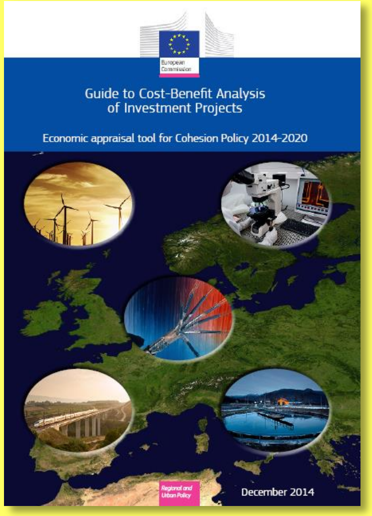
Robert R. Wilson, 1969

'It only has to do with the respect with which we regard one another, the dignity of men, our love of culture. [...] Otherwise, it has to do with: are we good painters, good sculptors, great poets? I mean all the things that we really venerate and honor in our country and are patriotic about. In that sense, this new knowledge has all to do with honor and country but it has nothing to do directly with defending our country except to help make it worth defending'

WHY A CBA OF RESEARCH INFRASTRUCTURES?

- CBA is a a structured way to measure the impact of a project on social welfare, when market prices and profitability do not convey the right signals
- early ideas developed initially for transport in XIX Century by Jules Dupuit (Ecole des Pons et Chaussées, Paris)
- then in Cambridge (UK) by Arthur Cecil Pigou ('The Economics of Welfare') in early XX Century (the notion of 'externality')
- first systematic application: hydraulic works in the US in the 1930s ('Green Book')
- after WWII research sponsored by OECD, United Nations, World Bank (A.Sen, J.Mirrlees, K.Arrow, J. Stiglitz, and many others)
- CBA is widely endorsed by governments (recent review by the OECD): transport, environment, energy, water, industry, health, education, cultural heritage, more recently climate change remedial actions, but very little progress on scientific projects
- strongly advocated by international organizations: mandatory for any EU grant beyond 50 million Euro (ERDF), five edition of EC CBA GUIDE (last one 2014), regularly performed by World Bank, EIB, ADB, etc.
- the core of the theory and applications is how to identify and forecast project inputs, outputs and their 'shadow prices'
- our research (3 years) is sponsored by the EIB after a competition for a grant: they asked to universities to develop and test a CBA model for research, development and innovation projects. We proposed to develop a new method and to test it on LHC and CNAO (Hadrontherapy).





THE CBA MODEL

The E(NPV) of research infrastructures over the **time horizon** $\mathcal{T}$ is defined as the **expected** difference between **benefits** and **costs** valued at **shadow prices** and discounted at the **social discount rate** r. It can be decomposed in two parts: the expected net present value of *use-benefits and costs* NPV_u and the expected (non-use) *social value of discovery* B_n. We drop the expectation operator, but all variables are to be considered as stochastic.

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

$\boldsymbol{B_u}$
= Knowledge creation
+ Technological spillovers
+ Human capital formation
+ Cultural effects

$\boldsymbol{C_u}$
= Investments
+ Operative costs

$\boldsymbol{B_n}$
= Existence value
+ Quasi option value

USE BENEFITS

The present value of use-benefits PV_{B_u} is the sum of the economic value of:

KNOWLEDGE OUTPUT
(S)

HUMAN CAPITAL FORMATION
(H)

TECHNOLOGICAL EXTERNALITIES
(T)

CULTURAL EFFECTS
(C)

NON-USE VALUE

The non-use benefits B_n captures two types of benefits related to the social value of discovery:

QUASI-OPTION VALUE (QOV)

EXISTENCE VALUE (EXV)

QOV. The option value arises from the knowledge that something may be useful in future. But we cannot claim that the observation of Higgs bosons will have any practical utility. Neither we can exclude that this will happen one day. Thus knowing now that the Higgs boson exists may or may not have a future practical use, and this is called a **quasi-option value**.

EXV. Protecting a species may have a value per se, because people are willing to pay to preserve for future generations something that they know exists. This is called **existence value**. By analogy we suggest that people may be willing to pay to know that something exists: this is the existence value of a scientific discovery.

In other words: in environmental CBA, the existence value is the benefit of preserving something known to exist; in our framework, it is the benefit of knowing that something exists.

As QOV is (usualy) unpredicatble in fundamental science, we set it to zero.

EXV instead can be empirically analyzed by appropriate empirical methods, drawing from applied environmental economics.

PARAMETERS WE USE FOR THE LHC CASE STUDY

TIME HORIZON	33 years: 1993 - 2025
UNIT OF ANALYSIS	the LHC and its experimental facilities
SOCIAL DISCOUNT RATE	3% in real terms (adopted by the EC Guide to CBA of Investment Projects)
SHADOW PRICES	proxied by marginal WTP or marginal costs
COUNTERFACTUAL	business as usual
QUASI-OPTION VALUE	assumed 0
NEGATIVE EXTERNALITIES	assumed 0

COSTS

The present value of costs $\boldsymbol{PV_{C_u}}$ is the sum of the:

- **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 (E).

EMPIRICS: COSTS

The **present value of costs** can be expressed as:

$$PV_{C_u} = \sum_{t=0}^{\mathcal{T}} \cdot \frac{(k_t + l_{st} + l_{ot} + \varepsilon_t)}{(1+r)^t}$$

where k_t are annual capital costs, l_{st} and l_{ot} scientific labour and administrative/technical labour respectively, o_t other operating costs and ε_t the value of negative externalities.

If the marginal cost of scientists' labour cost is taken as a proxy of the value of knowledge outputs produced by scientists, l_{st} on the cost side and P_{0t} on the benefit side cancel each other.

EMPIRICS: CERN+EXPERIMENTS COSTS

APPORTIONMENT SHARE OF LHC-RELATED COSTS COVERED BY CERN (1993-2013)

ACCELERATORS	
CLIC	0%
CNGS	0%
Consolidation	100%
Experimental Areas PS	0%
Experimental Areas SPS	50%
General R&D	0% before 2007; 50% from 2008
General Services	0% before 2007; 50% from 2008
R&D CLIC	0%
SPS complex	67%

LHC	100%
LHC injectors	100%
LHC injectors upgrade	100%
LHC upgrade	100%

OUTREACH	
Communication	70%
Exchange programmes	50%
Exchanges	0%
Knowledge and Technology Transfer	50%
Schools	0%

INFRASTRUCTURE	
Building construction	80%
Computing	80%
Energy	20%<2000, then 50%, 80% as of 2008
General Services	50%
Medical service	20%<2000, then 50%, 80% as of 2008
Site facility	72%
Technical infrastructure	80%
Waste management	70%

RESEARCH	
Computing	68%
Controls	80%
Data analysis	58%
Electronics	50%
EU supported R&D general	50%
General Services	50%
Grid computing	80%
LHC computing	100%
LHC detectors	100%
LHC detectors upgrade	100%
non-LHC physics	0%
Theoretical physics	50%

SERVICES	
Electronics	80%

APPORTIONMENT SHARE OF **FUTURE** LHC-RELATED COSTS COVERED BY CERN (2014-2025)

LHC PROGRAMME (INCL. PROJECTS)	
LHC machine and injectors	100%
LHC machine and areas reliability and consolidation	100%
LHC experiments	100%
LHC detectors consolidat.	100%
LHC computing	100%

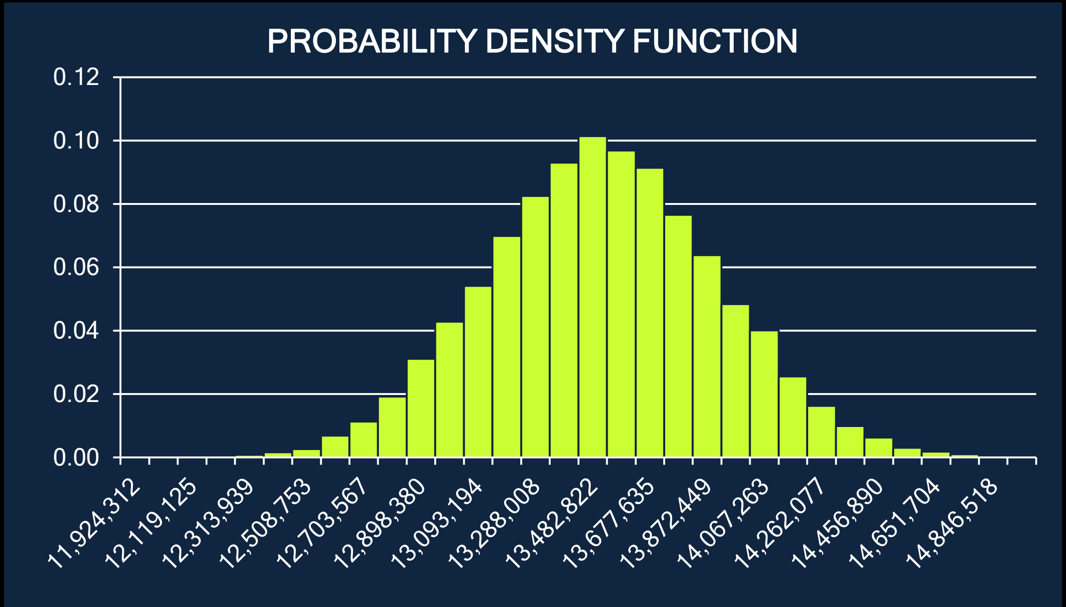
PROJECTS	
LINAC4	50%
LHC injectors upgrade	100% up to 2018; 0% afterwards
HL-LHC construction	100% up to 2014; 0% afterwards
HL-LHC detectors	100% up to 2018; 0% afterwards (but always 0% for upgrade cost - Phase 2)
Linear collider studies (CLIC, ILC, detector R&D)	0%
Future Circular Collider study	0%
High energy frontier	0%
ELENA	0%
HIE-ISOLDE	0%
TSR @ ISOLDE	0%
CERN neutrino platform	0%
R&D accelerators (including HP-SPL)	100% up to 2018; 0% afterwards
R&D for medical applications	0%
Other R&D	0%

OTHER PROGRAMMES (LHC SUPPORT AND NON-LHC PROGRAMMES)	
Non-LHC physics	0%
Theory	0%
Physics data centre	0%

PS and SPS complexes	0%
Accelerator technical services	0%
Accelerator consolidation	0%
Experimental areas consolidation	0%

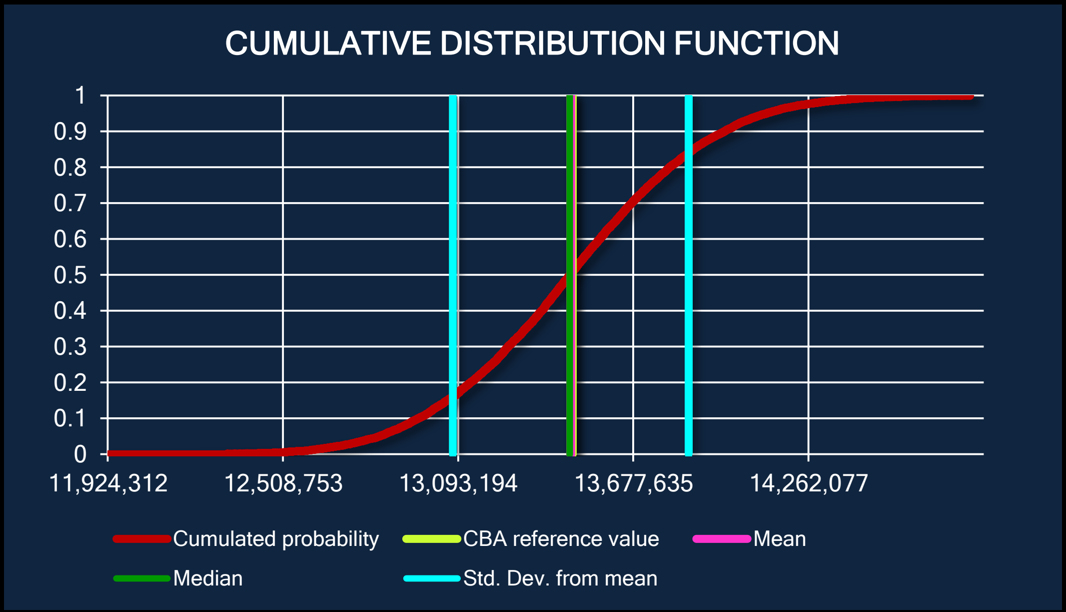
INFRASTRUCTURE AND SERVICES	
Manufacturing facilities (workshops, etc.)	20%
General facilities & logistics (site maintenance, transport)	20% (but Housing Fund 0%)
Informatics	20%
Safety, health and environment	40%
Outreach, scientific exchanges (students, associates) and KT	20%
Infrastructure consolidation, buildings and renovation	20%
Centralised expenses: TEF - Energy and water	80%
In-kind (financial and site)	80%

EMPIRICS: COSTS



PROBABILITY DISTRIBUTION OF THE LHC COSTS

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



ESTIMATED PARAMETERS OF DISTRIBUTION

Mean	13,467,999
Median	13,465,444
Standard deviation	393,437
Minimum	11,924,312
Maximun	14,846,518

KNOWLEDGE OUTPUT

The social value of knowledge output is measured by the sum of the present value of papers signed by RI's scientists (P_{0t}), the value of subsequent flows of papers produced by other scientists that use or elaborate of the RI'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 $i = 0, \dots n$):

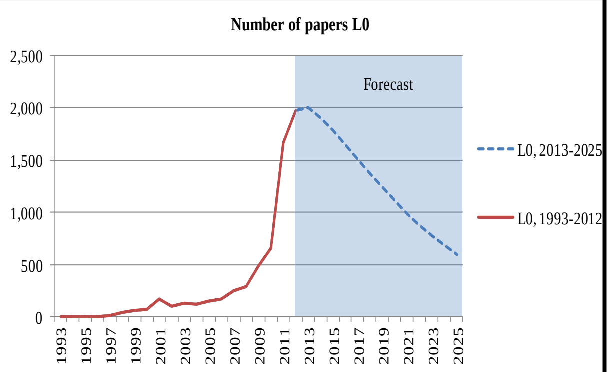
$$S = \sum_{t=0}^{\mathcal{T}} \frac{P_{0t}}{(1+r)^t} + \sum_{i=1}^{n} \sum_{t=1}^{\mathcal{T}} \frac{P_{it}}{k_{it}(1+r)^t} + \sum_{i=0}^{n} \sum_{t=1}^{\mathcal{T}} \frac{Q_{it}}{(1+r)^t}$$

We don't include P_0 on the benefit side, because we don't include the scientific personnel salaries on the cost side.

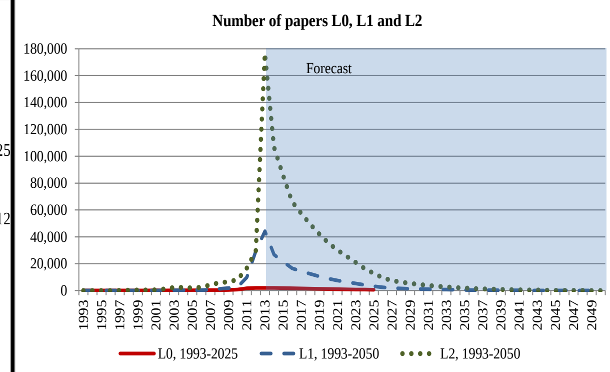
KNOWLEDGE OUTPUT

Valuation of the scientific impact

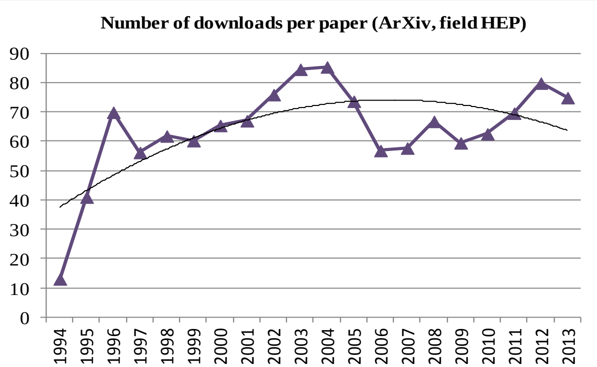
PAPERS PRODUCED BY LHC USERS (L0)

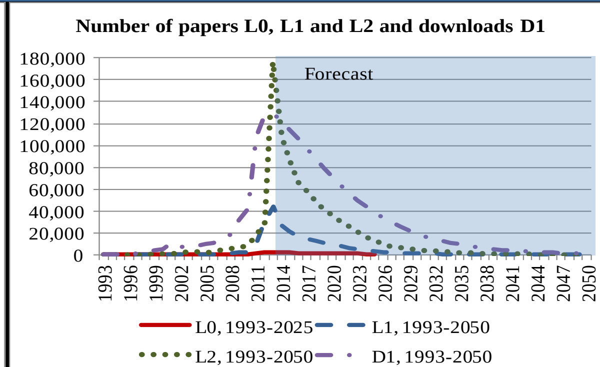


PAPERS PRODUCED BY NON-LHC USERS (L1 & L2)

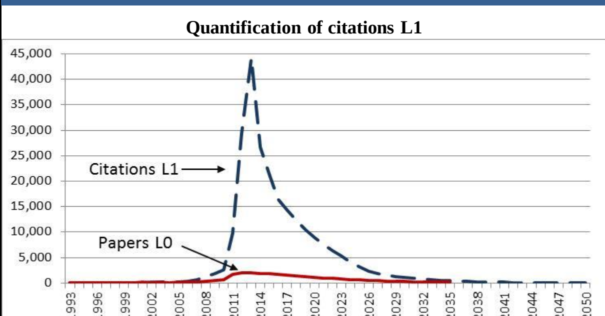


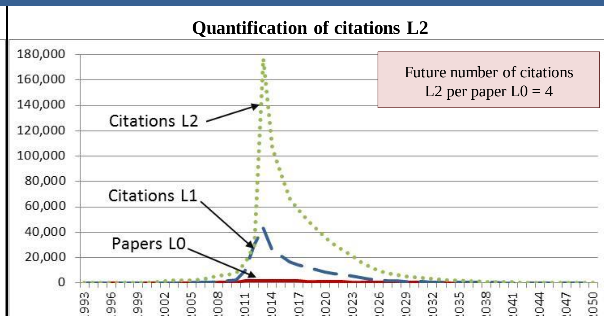
DOWNLOADS OF LHC PAPERS (D1)





TRACKING THE KNOWLEDGE OUTPUTS





Source: Preliminary scientometric analysis of INSPIRE database of papers and citations

VALUATION

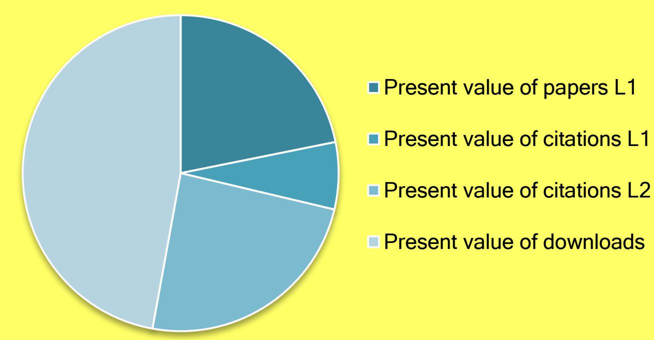
Unit economic value of papers L1

	Value	Source
Number of references in paper L1	35	Own assumption, based on an analysis of 41 research journals by Abt and Garfield (2002)
Share of time dedicated to research	65%	Own assumption. The remainder is for teaching and other non scientific activities
Number of paper (published and non) per year	3.5	Own assumption. It represents the number of papers to wich a scientist gives a real contribution
Average annual gross salary	59,289 €	Own elaboration based on PayScale data. It is the average salary for a scientists working in research centres and academia in the USA
Unit production cost per paper L1	315 € = (59,289 € * 65%/3.5/35)	Own estimation, based on the approach suggested by Florio and Sirtori (2014)

Unit economic value of citations and downloads

	Value	Source
Working hours per year	1,800 = 225 working days * 8 hours/day	Own assumption
Average hourly gross salary	33 € = 59,289/1,800	Own estimation
Hours per citation	3	Own assumption
Hours per download	3	Own assumption
Value of one citation L1 and L2	99 € = 33 € * 3	Own estimation, based on Florio and Sirtori (2014)
Value of one L0 paper downloaded but non cited	99 € = 33 € * 3	Own estimation, based on Florio and Sirtori (2014)

OUR PRELIMINARY RESULTS

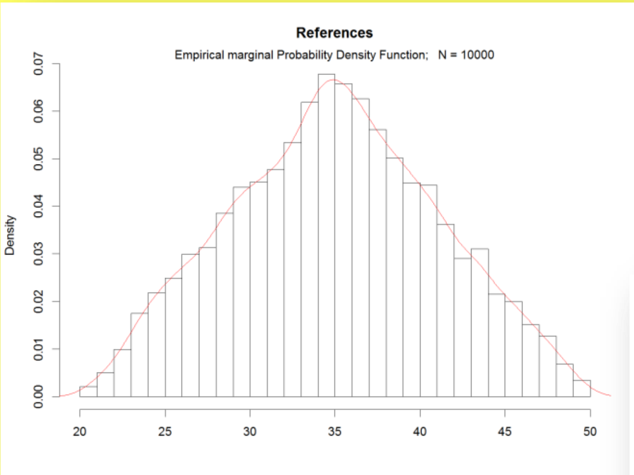


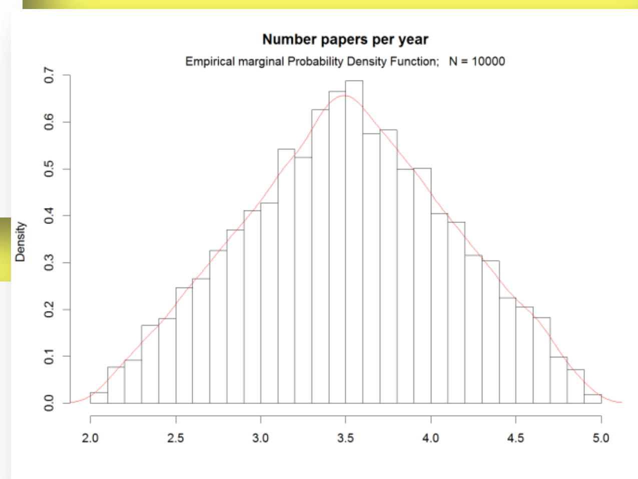
	million EUR
Total present value of knowledge output benefit	277

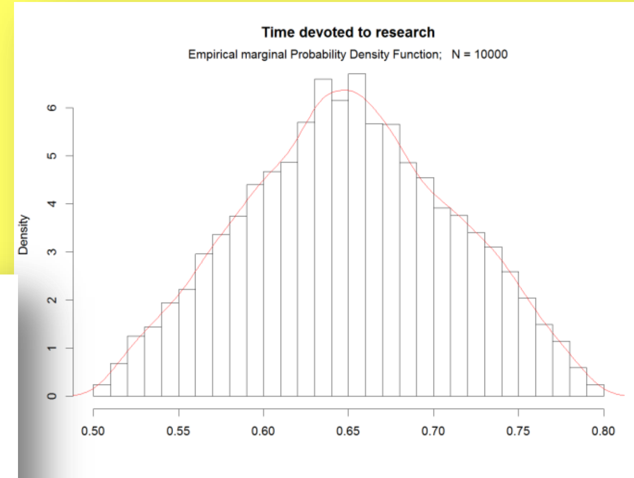
KNOWLEDGE OUTPUT

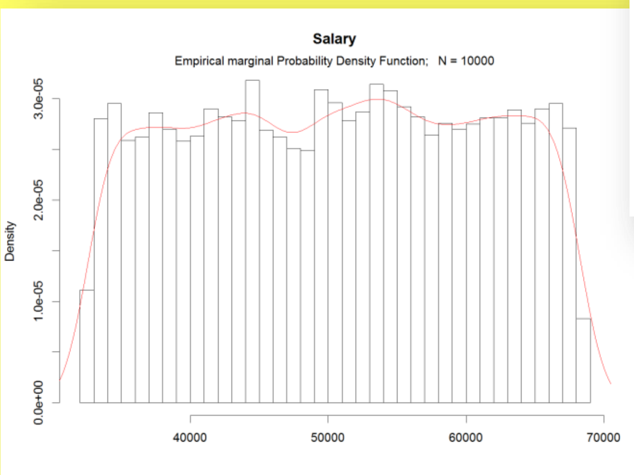
PROBABILITY DISTRIBUTION OF STOCHASTIC CRITICAL VARIABLES

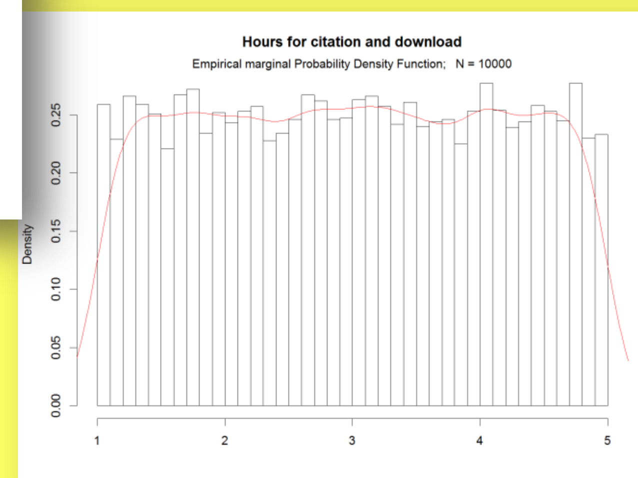
(10,000 random extractions)





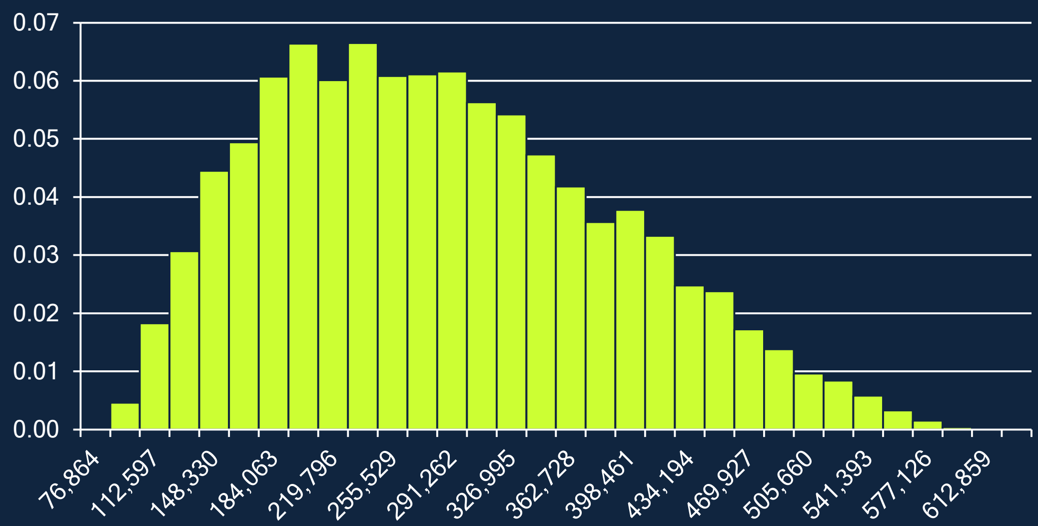






KNOWLEDGE OUTPUT

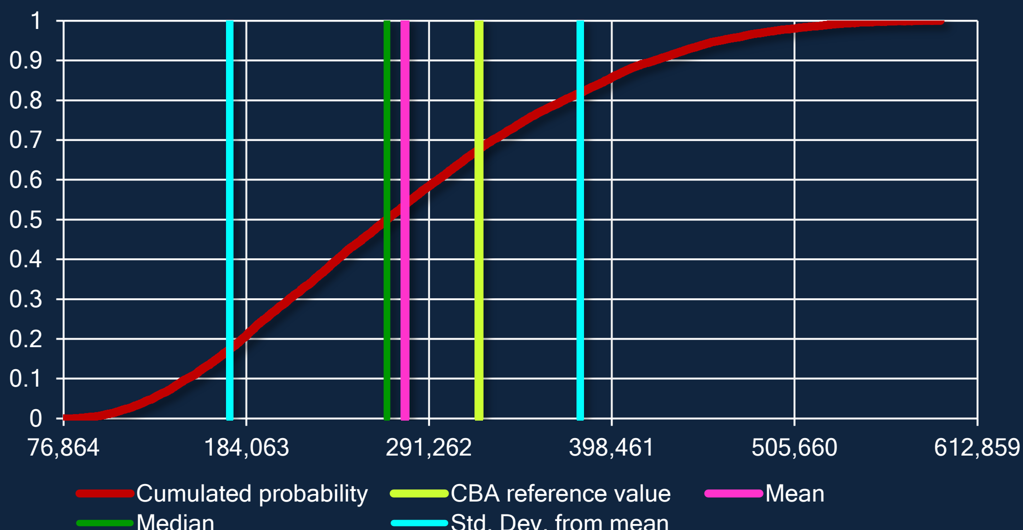
PROBABILITY DENSITY FUNCTION



PROBABILITY DISTRIBUTION OF THE KNOWLEDGE OUTPUT BENEFIT

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

CUMULATIVE DISTRIBUTION FUNCTION



ESTIMATED PARAMETERS OF DISTRIBUTION

Mean	277,051
Median	266,578
Standard deviation	102,768
Minimum	76,864
Maximun	612,859

TECHNOLOGICAL EXTERNALITIES

The present value of technological spillovers is given by:

- the discounted incremental social profits Π_{jt} generated by companies (j) of the RI's supply chain which have benefitted from a learning effect,
- and other externalities

$$T = \sum_{j=1}^{J} \sum_{t=0}^{\mathcal{T}} \cdot \frac{\Pi_{jt}}{(1+r)^t}$$

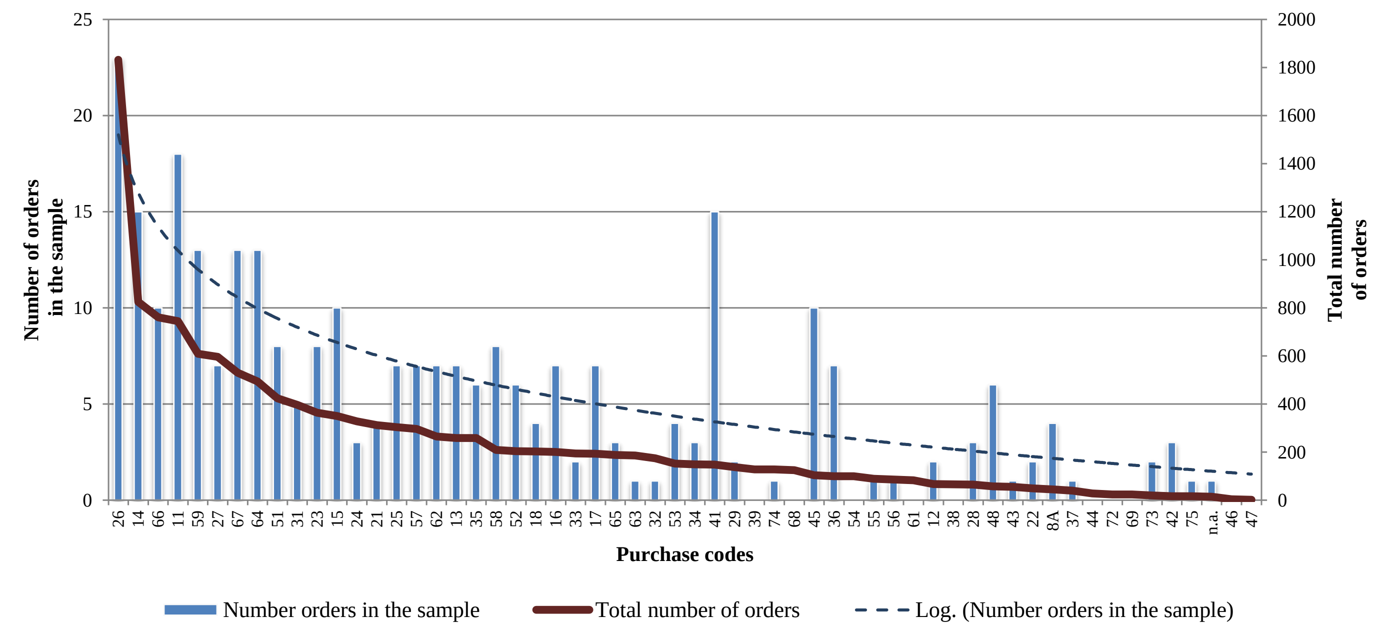
TECHNOLOGICAL EXTERNALITIES

Benefits to the supply chain

LEGEND OF CERN ACTIVITY CODES

11 building work
12 roadworks
13 installation and supply of pipes
14 electrical installation work
15 heating and air-conditioning equipment (supply and installation)
16 hoisting gear
17 water supply and treatment
18 civil engineering and buildings
21 switch gear and switchboards
22 power transformers
23 power cables and conductors
24 control and communication cables
25 power supplies and converters
26 magnets
27 measurement and regulation
28 electrical engineering
29 electrical engineering components
31 active electronic components
32 passive electronic components
33 electronic measuring instruments
34 power supplies - transformers
35 functional modules & crates
36 rf and microwave components and equipment
37 circuit boards
38 electronics
39 electronic assembly and wiring work
41 computers and work-stations
42 storage systems
43 data-processing peripherals
44 interfaces (see also 35 series)
45 software
46 consumables items for data-processing
47 storage furniture (data-processing)
48 data communication
51 raw materials (supplies)
52 machine tools, workshop and quality control equipment
53 casting and moulding (manufacturing techniques)
54 forging (manufacturing techniques)
55 boiler metal work (manufacturing techniques)
56 sheet metal work (manufacturing techniques)
57 general machining work
58 precision machining work
59 specialised techniques
61 vacuum pumps
62 refrigeration equipment
63 gas-handling equipment
64 storage and transport of cryogens
65 measurement equipment (vacuum and low-temperature technology)
66 low-temperature materials
67 vacuum components & chambers
68 low-temperature components
69 vacuum and low-temperature technology
71 films and emulsions
72 scintillation counter components
73 wire chamber elements
74 special detector components
75 calorimeter elements
8a radiation protection
n.a. not available

SAMPLE OF 300 ORDERS BY PURCHASE CODE COMPARED WITH ALL LHC ORDERS



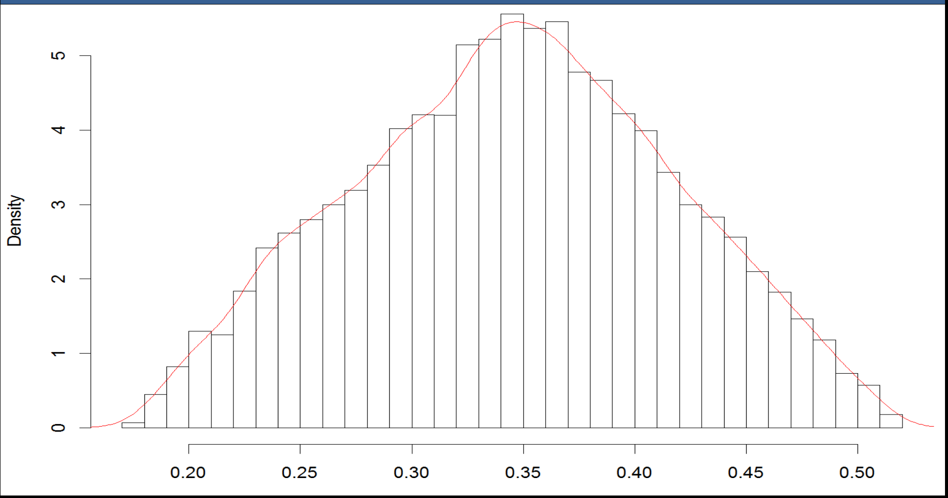
STEP 1. IDENTIFICATION OF HIGH-TECH ORDERS

ACTIVITY CODES FOR HIGH-TECH ORDERS	
POWER CABLES AND CONDUCTORS	CASTING AND MOULDING (MANUFACTURING TECHNIQUES)
MAGNETS	FORGING (MANUFACTURING TECHNIQUES)
MEASUREMENT AND REGULATION	PRECISION MACHINING WORK
ELECTRICAL ENGINEERING	VACUUM PUMPS
ELECTRICAL ENGINEERING COMPONENTS	REFRIGERATION EQUIPMENT
ACTIVE ELECTRONIC COMPONENTS	GAS-HANDLING EQUIPMENT
PASSIVE ELECTRONIC COMPONENTS	STORAGE AND TRANSPORT OF CRYOGENS
ELECTRONIC MEASURING INSTRUMENTS	MEASUREMENT EQUIPMENT (VACUUM AND LOW-TEMPERATURE TECHNOLOGY)
POWER SUPPLIERS - TRANSFORMERS	LOW-TEMPERATURE MATERIALS
FUNCTIONAL MODULES & CRATES	VACUUM COMPONENTS & CHAMBERS
RF AND MICROWAVE COMPONENTS AND EQUIPMENT	LOW-TEMPERATURE COMPONENTS
CIRCUIT BOARDS	VACUUM AND LOW-TEMPERATURE TECHNOLOGY
ELECTRONICS	OPTICAL AND X-RAY EQUIPMENT
ELECTRONIC ASSEMBLY AND WIRING WORK	

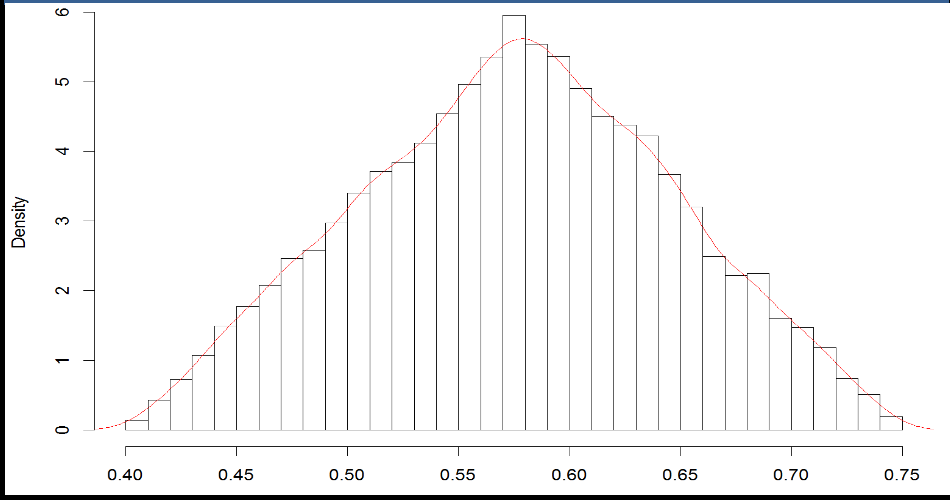
TECHNOLOGICAL EXTERNALITIES

Benefits to the supply chain

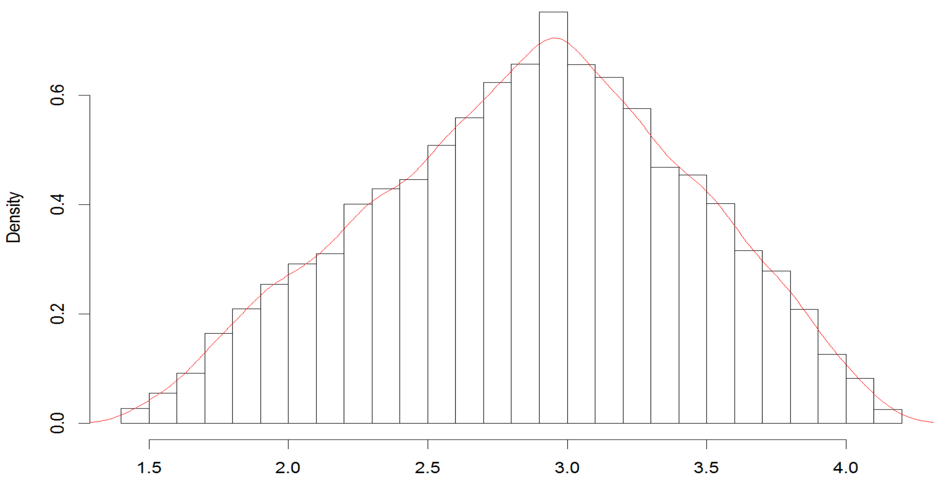
STEP 2. PROBABILITY DISTRIBUTION
SHARE OF HIGH TECH PROCUREMENT- CERN
Empirical marginal Probability Density Function ; N = 10,0000



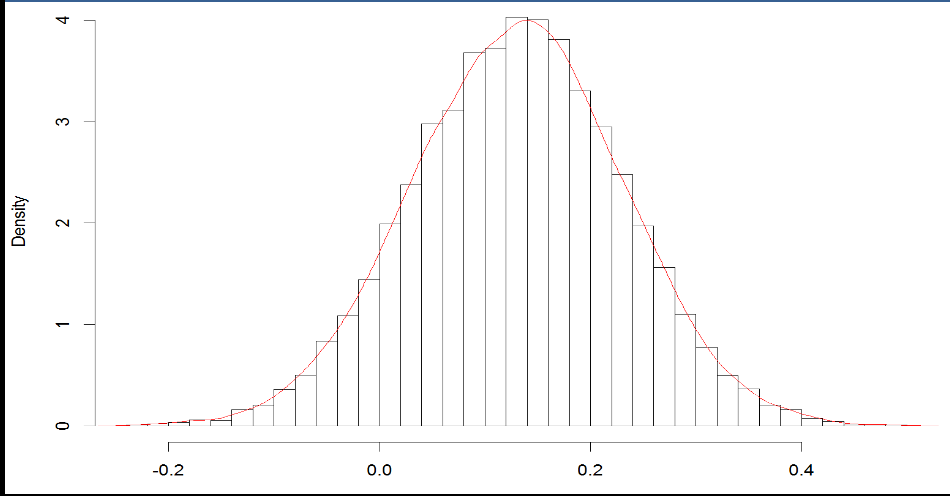
STEP 3. PROBABILITY DISTRIBUTION
SHARE OF HIGH TECH PROCUREMENT- COLLABORATIONS
Empirical marginal Probability Density Function ; N = 10,0000



STEP 4. PROBABILITY DISTRIBUTION
ECONOMIC UTILITY SALES RATIO
Empirical marginal Probability Density Function ; N = 10,0000



STEP 5. PROBABILITY DISTRIBUTION
EBITDA MARGIN
Empirical marginal Probability Density Function ; N = 10,0000



TECHNOLOGICAL EXTERNALITIES

Benefits to software users

LHC

ROOT
- Multivariate analysis tool for very large datasets
- Available since 1997
- External users: HEP community, industry

GEANT4
- Simulation software
- Available since 1999
- External users: HEP community, space agencies, industry, hospitals

TECHNOLOGICAL TRANSFER
Licenses, start-ups, collaboration agreements

VOLUNTEER COMPUTING
- Two projects to run simulations of particle collision
- Available since 2007 (SixTrack) and 2011 (Test4Theory)
- External users: general public

TECHNOLOGICAL BENEFITS (ROOT, GEANT4, TECHNOLOGICAL TRANSFER)

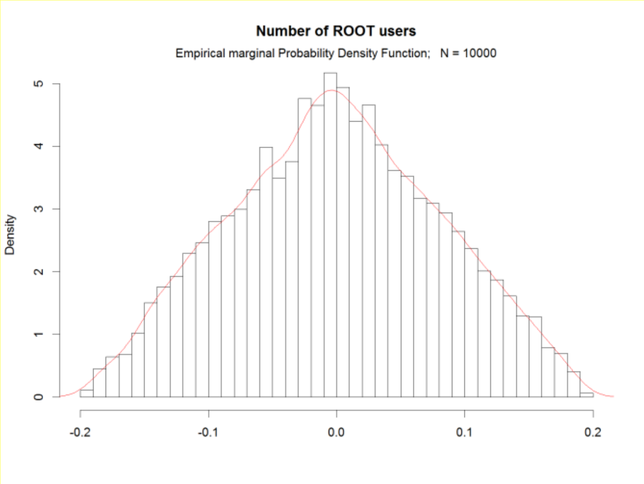
CULTURAL BENEFITS (VOLUNTEER COMPUTING)

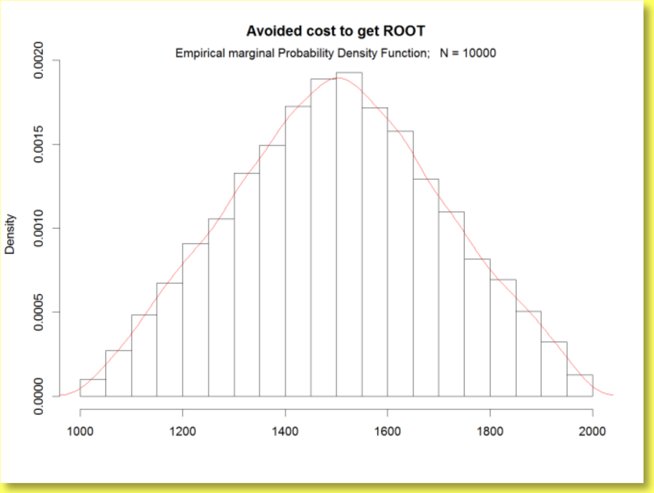
TECHNOLOGICAL EXTERNALITIES

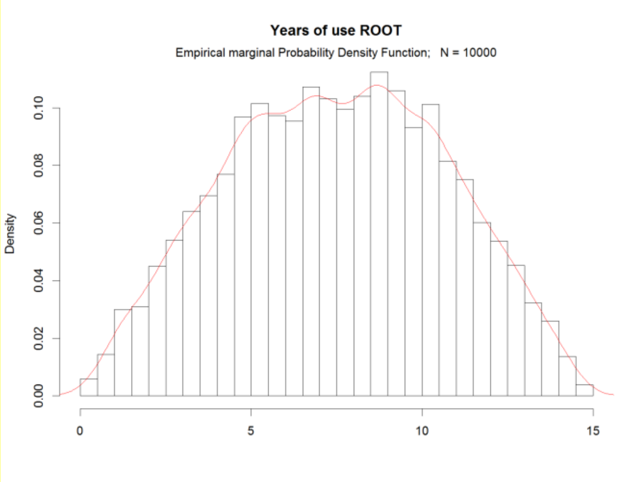
Benefits to software users

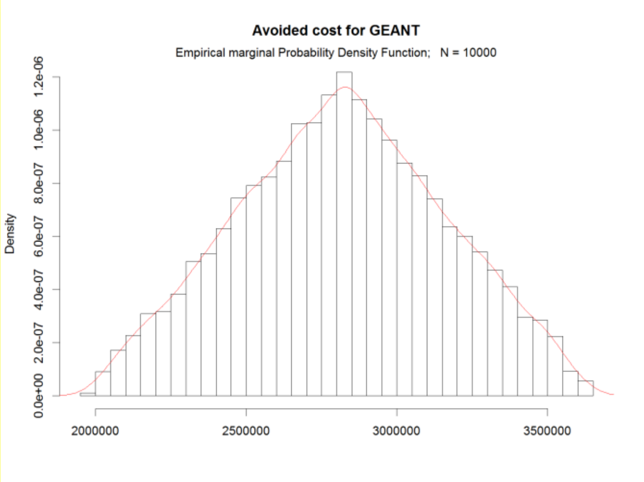
PROBABILITY DISTRIBUTION OF STOCHASTIC CRITICAL VARIABLES

(10,000 random extractions)

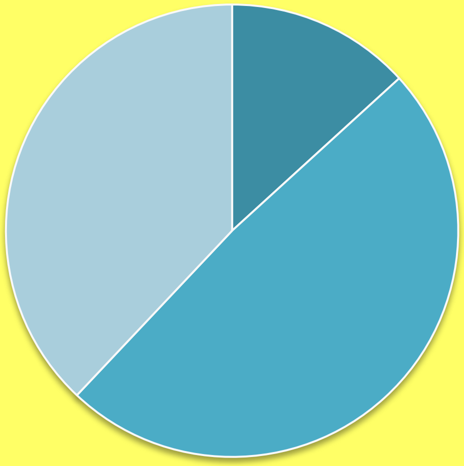






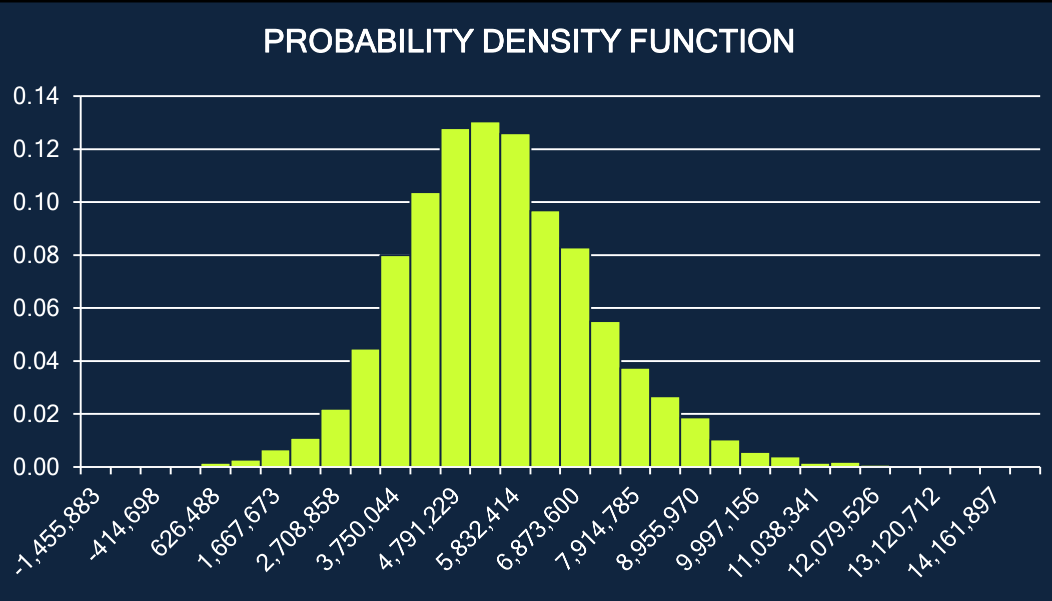


OUR PRELIMINARY RESULTS



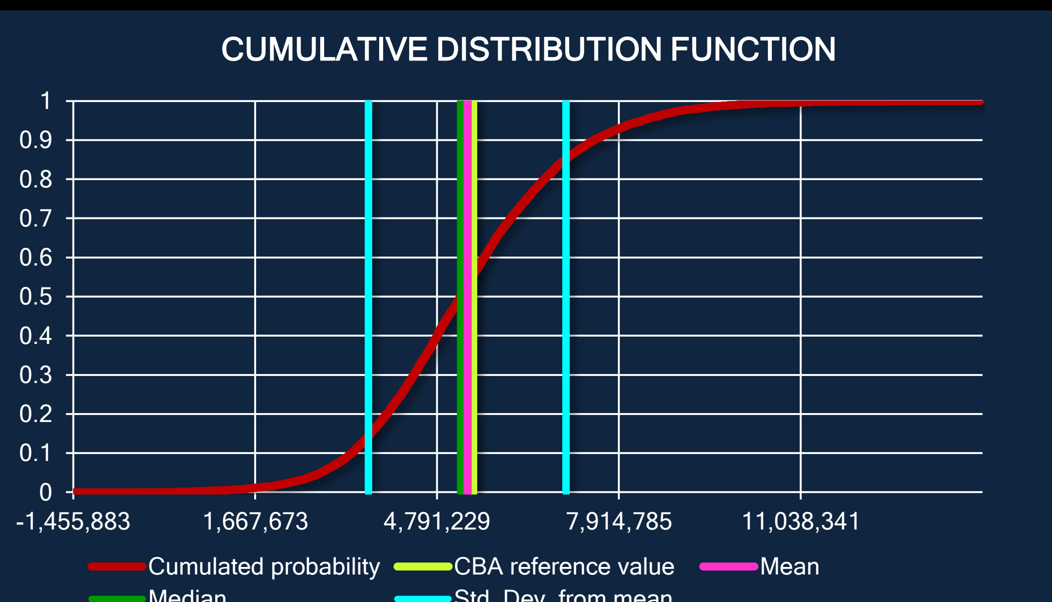
Total present value of technological spillovers	5,306	million EUR

TECHNOLOGICAL EXTERNALITIES



PROBABILITY DISTRIBUTION OF THE TECHNICAL SPILLOVERS

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



ESTIMATED PARAMETERS OF DISTRIBUTION

Mean	5,306,344
Median	5,188,553
Standard deviation	1,698,262
Minimum	-1,455,883
Maximun	14,161,897

HUMAN CAPITAL FORMATION

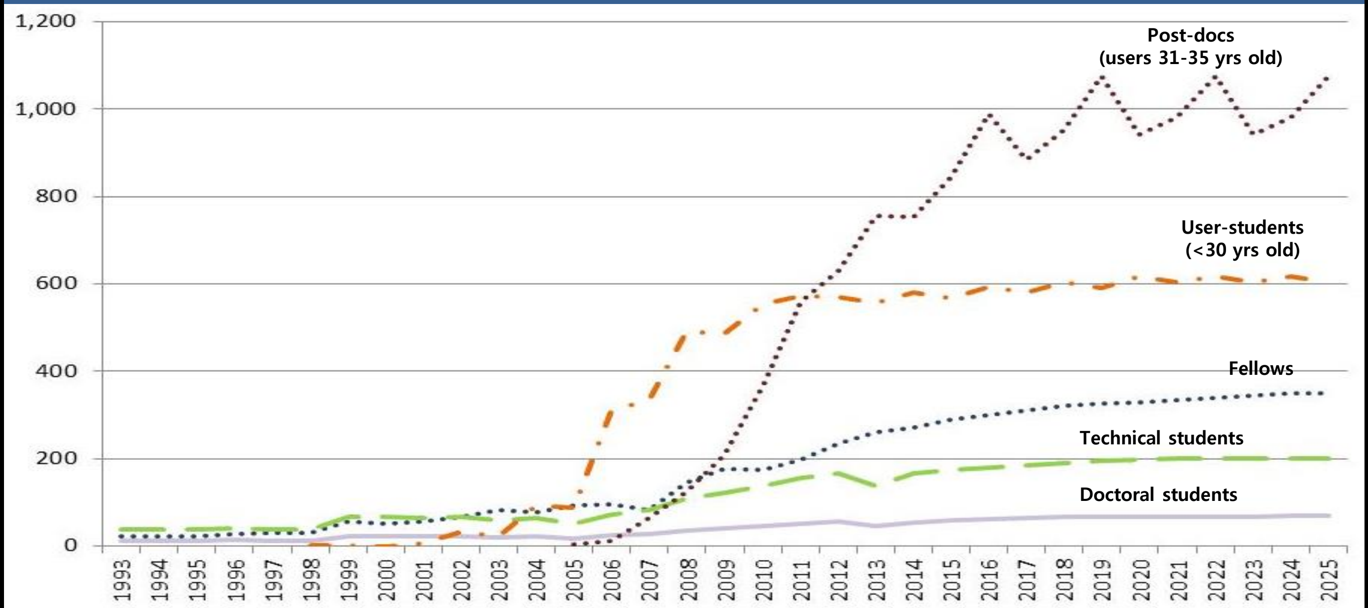
Human capital formation benefits are valued as increased earnings (I) gained by RI's students and former employees (z), since the moment (φ) they leave the project, against counterfactual scenario:

$$H = \sum_{z=1}^{Z} \sum_{t=\varphi}^{\mathcal{T}} \cdot \frac{I_{zt}}{(1+r)^t}$$

HUMAN CAPITAL FORMATION

Estimate

TYPES AND NUMBER OF PEOPLE BENEFITTING FROM TRAINING AT THE LHC



TYPES AND QUANTITIES OF PEOPLE BENEFITTING FROM TRAINING AT THE LHC

Variable	Number over the 1993-2025 period	Average staying at CERN
CERN fellows working on LHC	5,873	2 years
CERN technical students working on LHC	3,940	1 year
CERN doctoral students working on LHC	1,332	3 years
User-students working on LHC	14,225	3 years
Post-doc researchers (users) working on LHC	11,301	2 years
TOTAL	36,671	

Sources: - CERN personnel statistics; - Interviews to CERN staff

Main assumptions: - Future number of beneficiaries; - Number of users-students and post-docs among users (assumed based on their age group); - Incoming number of user-students and post docs

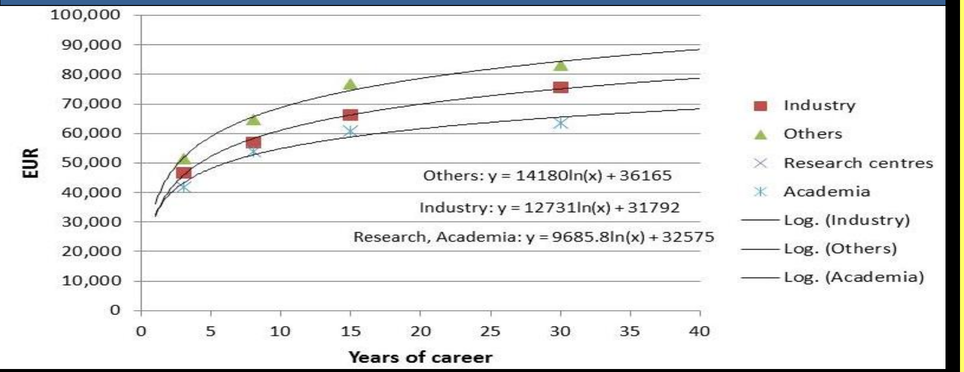
ASSUMED DISTRIBUTION OF FORMER LHC STUDENTS BY PROFESSIONAL SECTOR

Sector	CERN fellows	CERN technical students	CERN doctoral students	User-students and post-docs
Industry	20%	45%	20%	20%
Others (computing, finance, public administration, …)	20%	45%	20%	20%
Research centres	30%	5%	30%	30%
Academia	30%	5%	30%	30%
TOTAL	**100%**	**100%**	**100%**	**100%**

HUMAN CAPITAL FORMATION

Valuation

ESTIMATION OF FUTURE AVERAGE SALARIES



DETERMINING THE RETURN TO SALARY DUE TO LHC TRAINING

Sector	SALARY EFFECT (1)		SALARY BONUS FOR JOB EFFECT (2)
	CERN fellows, doctoral students, user students, post-docs	CERN technical students	
Research centres	9.3%		2.5%
Academia			
Industry			
Others (computing, financial, ...)			

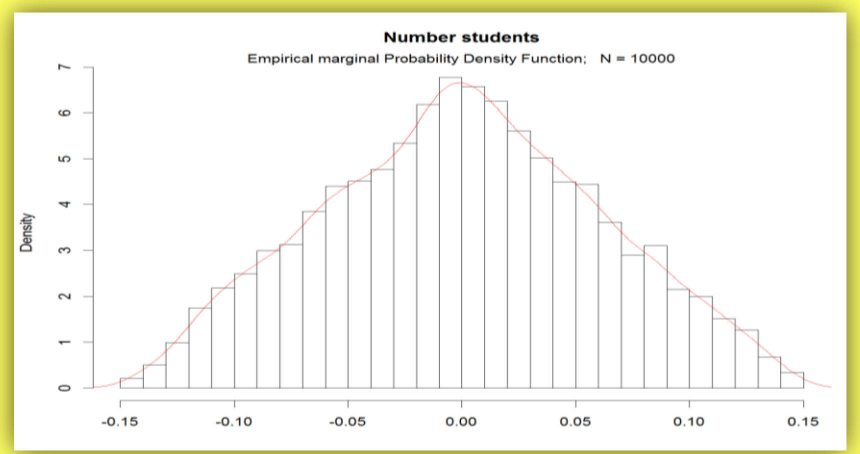
(1) Survey to 192 former LHC students (out of a total survey to 385 students and former students): declared salary impact of the experience at LHC on their current salary
(2) Own assumption based on survey results and Payscale salaries

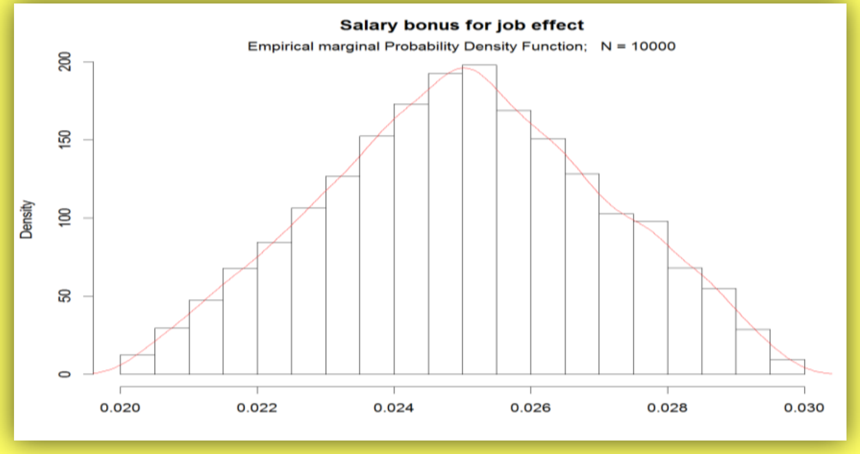
Main source:
Findings from the survey to LHC current and former students

Main assumptions:
- Same economic return regardless of the professional sector and type of student
- Same return over the entire work career (40 yrs)

PROBABILITY DISTRIBUTION OF STOCHASTIC CRITICAL VARIABLES

(10,000 random extractions)



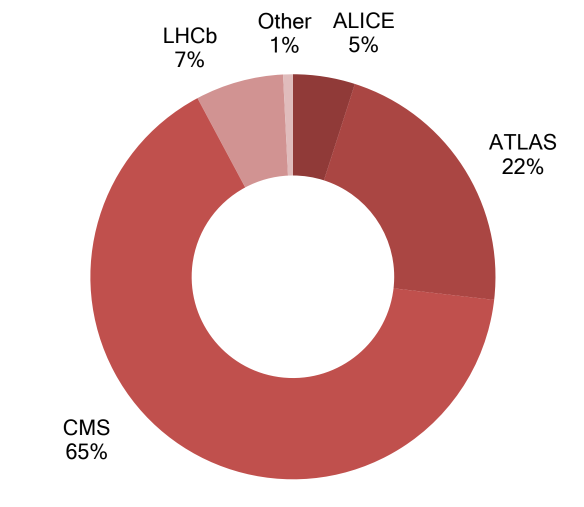


Total present value of human capital formation benefit	5,465 million EUR

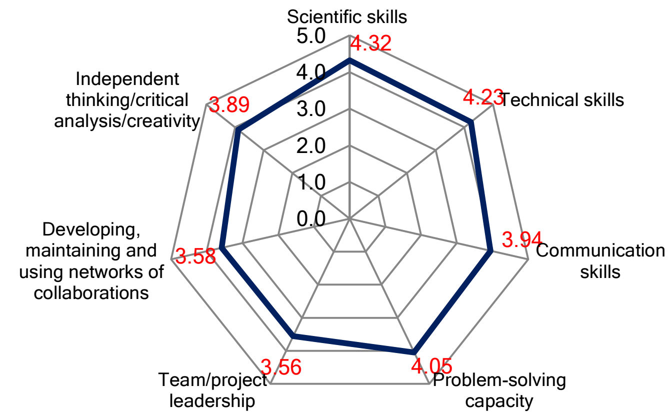
HUMAN CAPITAL FORMATION

Valuation

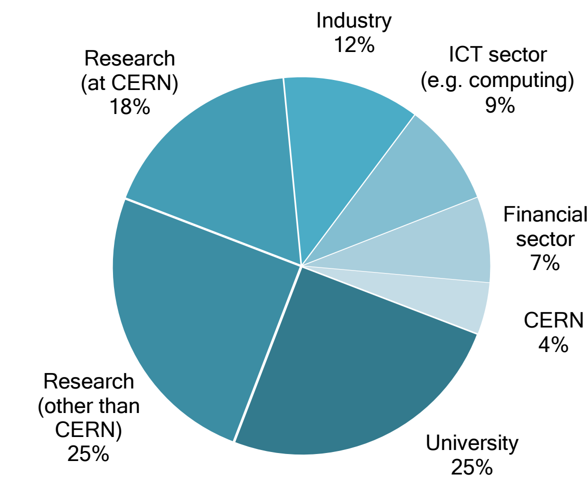
SHARE OF RESPONDENTS BY EXPERIMENT



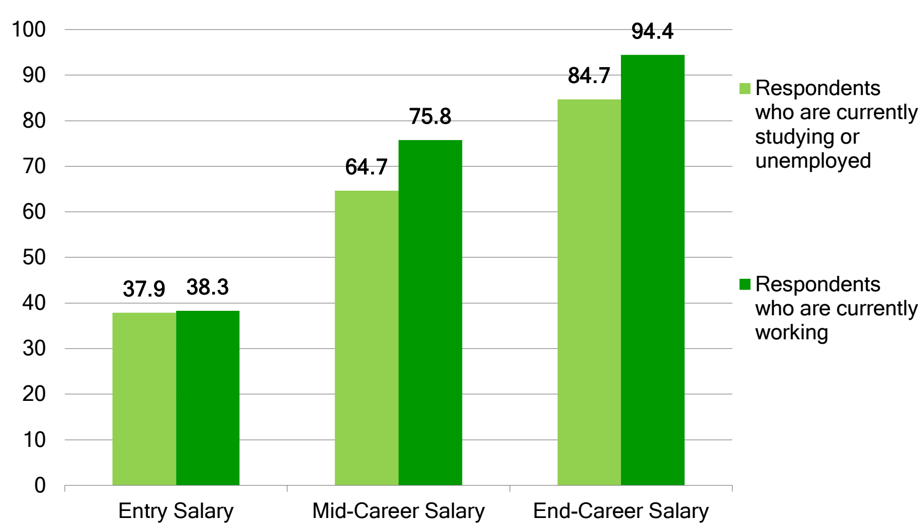
SKILLS IMPROVED THANKS TO THE LHC EXPERIENCE. AVERAGE JUDGEMENT



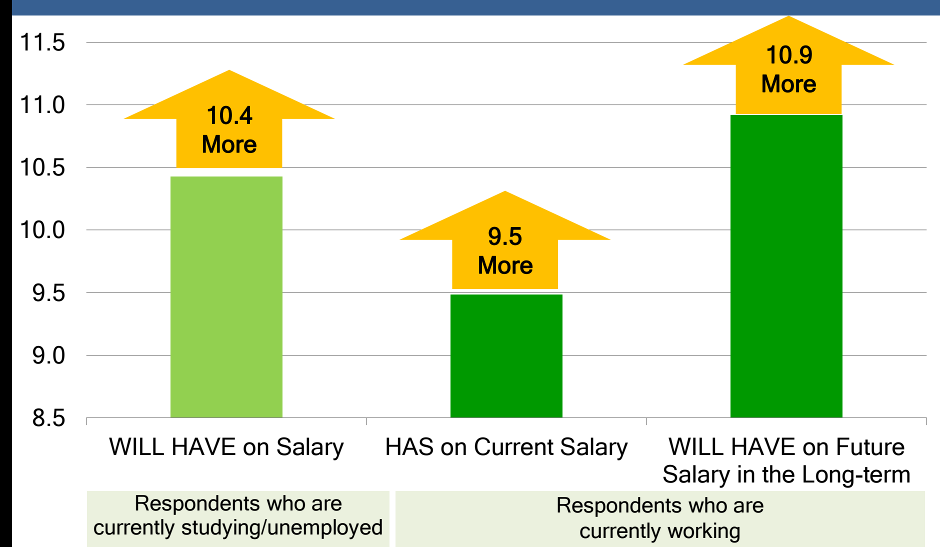
AN OVERVIEW OF CURRENT EMPLOYMENT SECTOR. SHARE OF RESPONDENTS



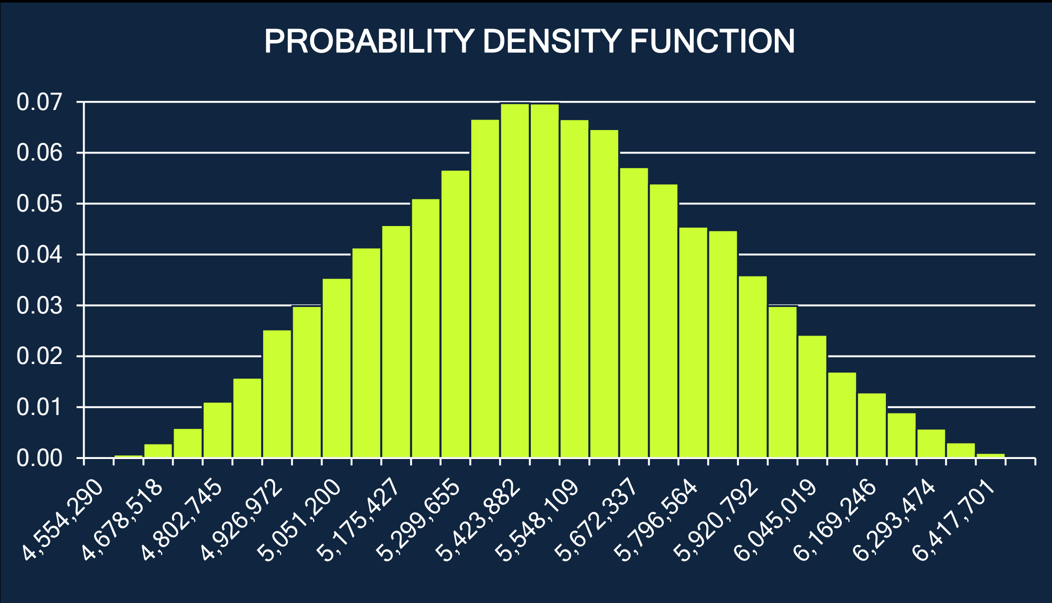
AVERAGE SALARY EVOLUTION: A COMPARISON BETWEEN THE TWO GROUPS OF RESPONDENTS (THOUSAND EUR)



THE IMPACT OF LHC EXPERIENCE ON SALARY (%)

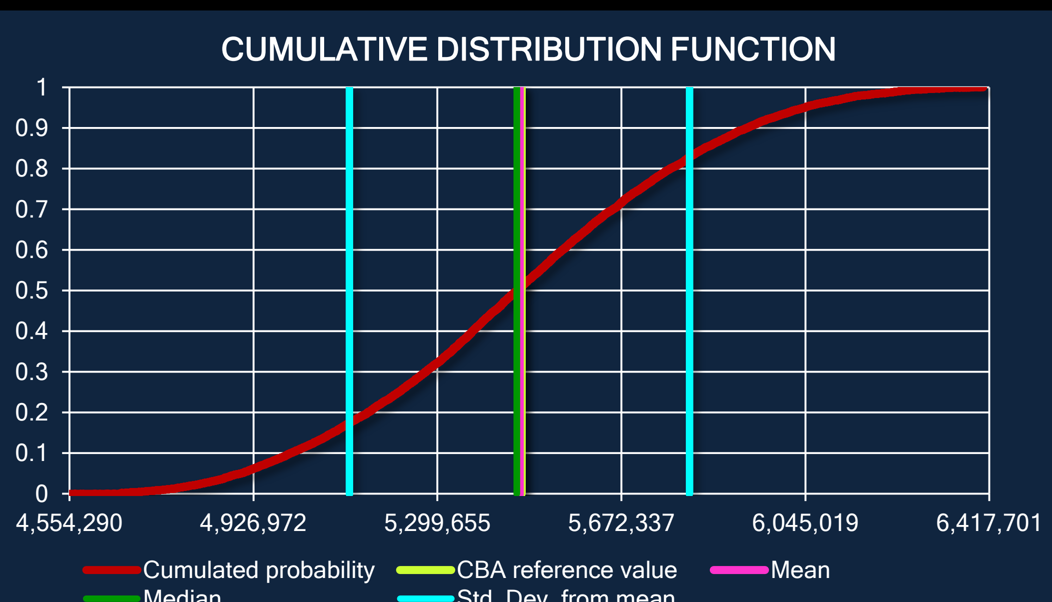


HUMAN CAPITAL FORMATION



PROBABILITY DISTRIBUTION OF HUMAN CAPITAL FORMATION BENEFIT

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



ESTIMATED PARAMETERS OF DISTRIBUTION

Mean	5,465,401
Median	5,460,616
Standard deviation	344,337
Minimum	4,554,290
Maximun	6,417,701

CULTURAL EFFECTS

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

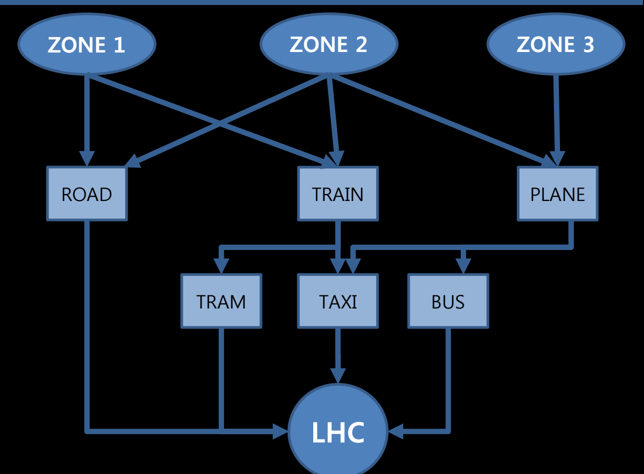
$$C = \sum_{g=1}^{G} \sum_{t=1}^{\mathcal{T}} \cdot \frac{W_{gt}}{(1+r)^t}$$

CULTURAL EFFECTS

Benefits

TRAVEL ZONES CONSIDERED

VALUATION THROUGH THE TRAVEL COST METHOD

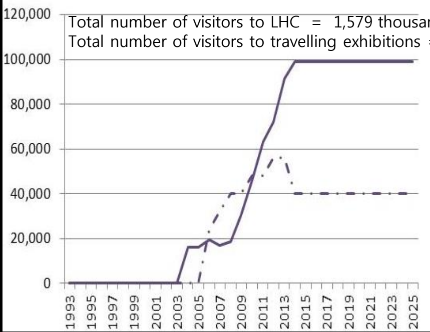


Main assumption:
- % of visitors by mode of transport
- Travel cost by zone

Source:
HEATCO values of travel time by modes of transport

Origin zone	Radius distance from CERN	Share of visitors	Source/ Assumption
Zone 1	500 km	24%	CERN
Zone 2	500-1,500 km	50%	Own assumption
Zone 3	Beyond 1,500 km	26%	Own assumption

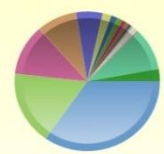
BENEFITS TO PERSONAL VISITORS: QUANTIFICATION OF VISITORS



Main source: CERN staff

Main assumption: Future number of visitors

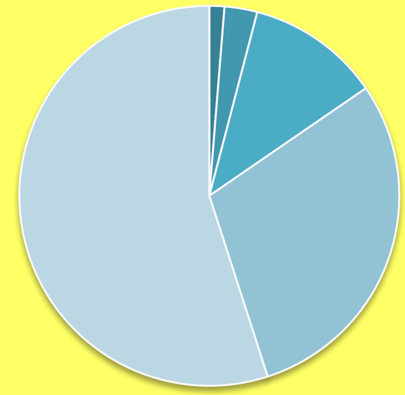
MASS MEDIA BENEFITS: NEWS BY MEDIA CHART



Color Name	Value	Pct.
Online, news and business	2301	34.69 %
Blog, consumer	1132	17.07 %
Newspaper	780	11.76 %
Online, consumer	599	9.03 %
Online, trade/industry	392	5.91 %
Television program	130	1.96 %
Wire service	93	1.40 %
Magazine, trade/industry	82	1.24 %
Newspaper, community	63	0.95 %
Magazine, consumer	56	0.84 %
Publication, college/alumni	30	0.45 %
Cable/satellite - network/station	25	0.38 %
Online, technical/scientific/academic	23	0.35 %
Television station	23	0.35 %
Magazine, news and business	22	0.33 %
Radio station	18	0.27 %
Magazine, technical/scientific/academic	8	0.12 %
News/Release Distribution Service	5	0.08 %
Newspaper publisher	4	0.06 %
Television network	4	0.06 %
Television program, national	2	0.03 %
Blog, news and business	1	0.02 %
Radio program	1	0.02 %
Syndicate	1	0.02 %
(None)	648	9.77 %
(International)	190	2.86 %

01/09/2008 to 18/09/2008

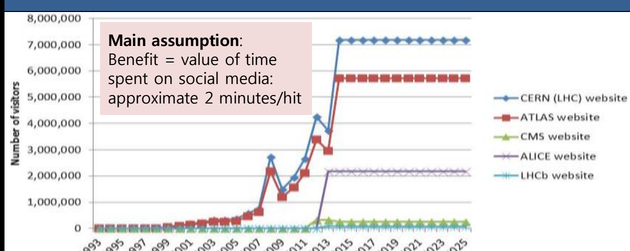
OUR PRELIMINARY RESULTS



- social media users
- volunteer computing
- website visitors
- mass media on general public
- personal visitors

Total present value of cultural effects	2,099.8	million EUR

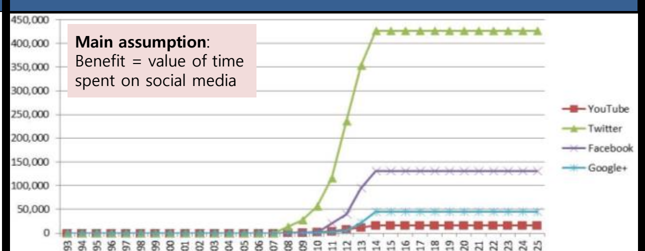
BENEFIT FOR WEBSITE VISITORS



Main assumption:
Benefit = value of time spent on social media: approximate 2 minutes/hit

	Estimated n. visitors until 2025
CERN (LHC) website	211,924,673
ATLAS website	168,746,259
CMS website	7,190,918
ALICE website	56,514,575
LHCb website	1,966,268
TOTAL	[illegible]

BENEFIT FOR SOCIAL MEDIA USERS



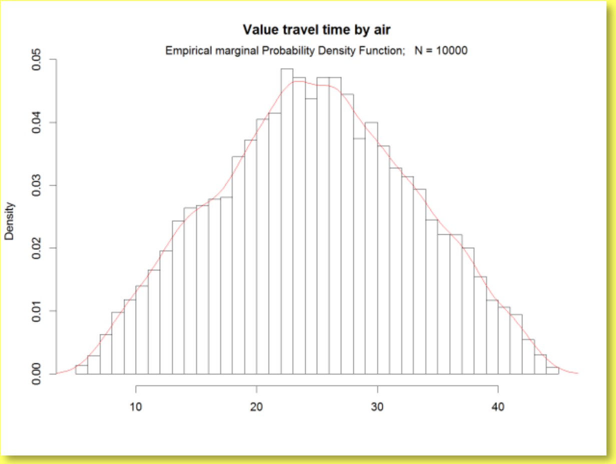
Main assumption:
Benefit = value of time spent on social media

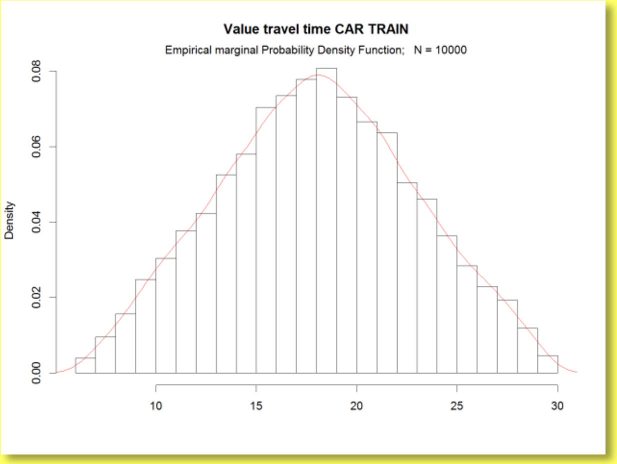
	Estimated n. Users until 2025	Average duration. Minutes/month
Youtube	436,350	0.5
Twitter	11,825,400	0.5
Facebook	3,460,698	0.5
Google+	1,139,964	0.5
TOTAL	16,862,412	

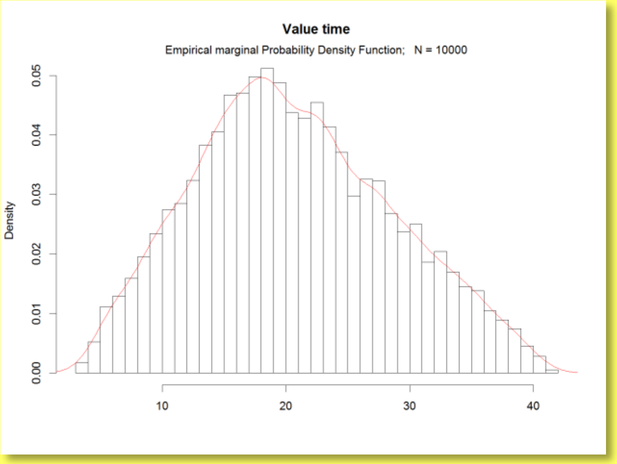
CULTURAL EFFECTS

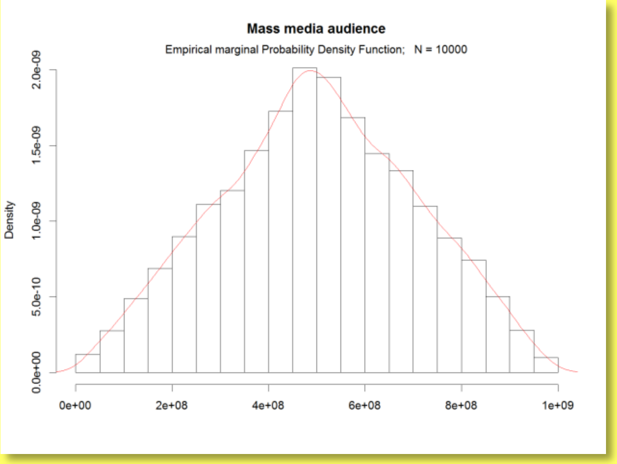
PROBABILITY DISTRIBUTION OF STOCHASTIC CRITICAL VARIABLES

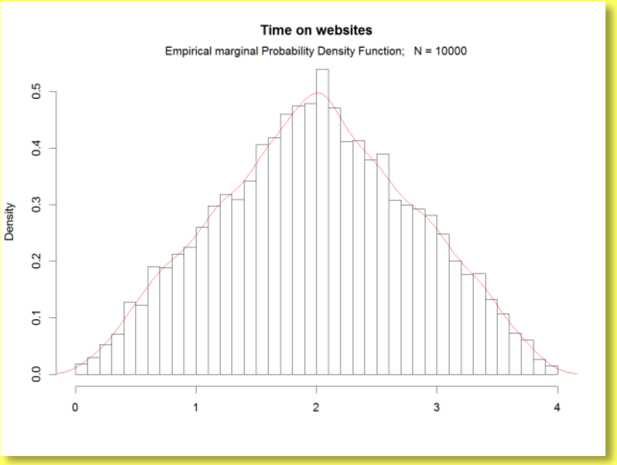
(10,000 random extractions)

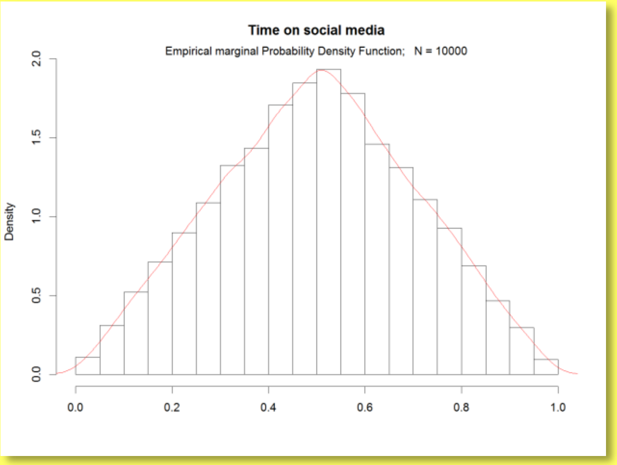




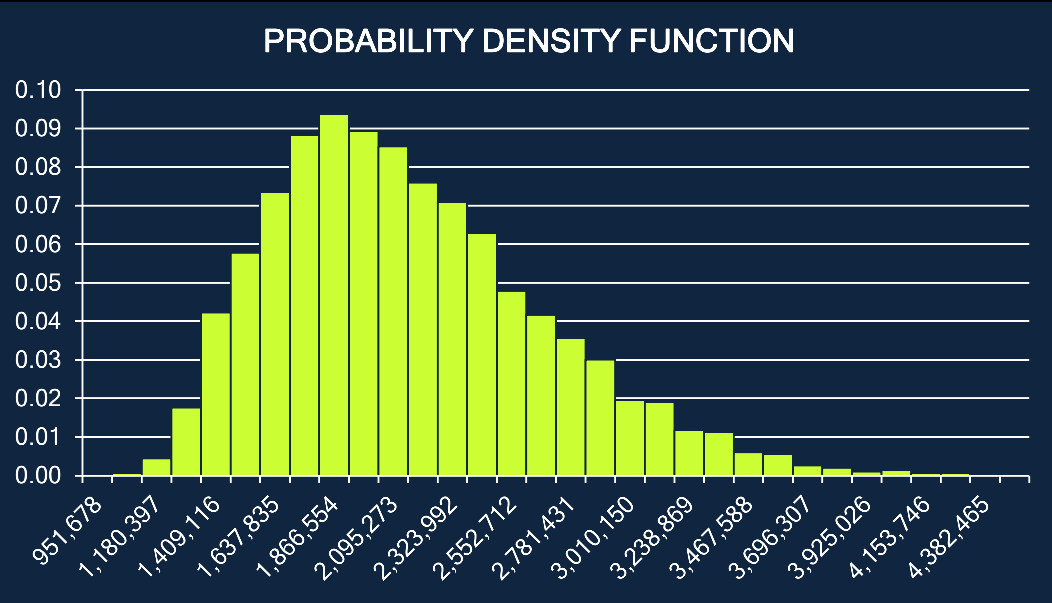






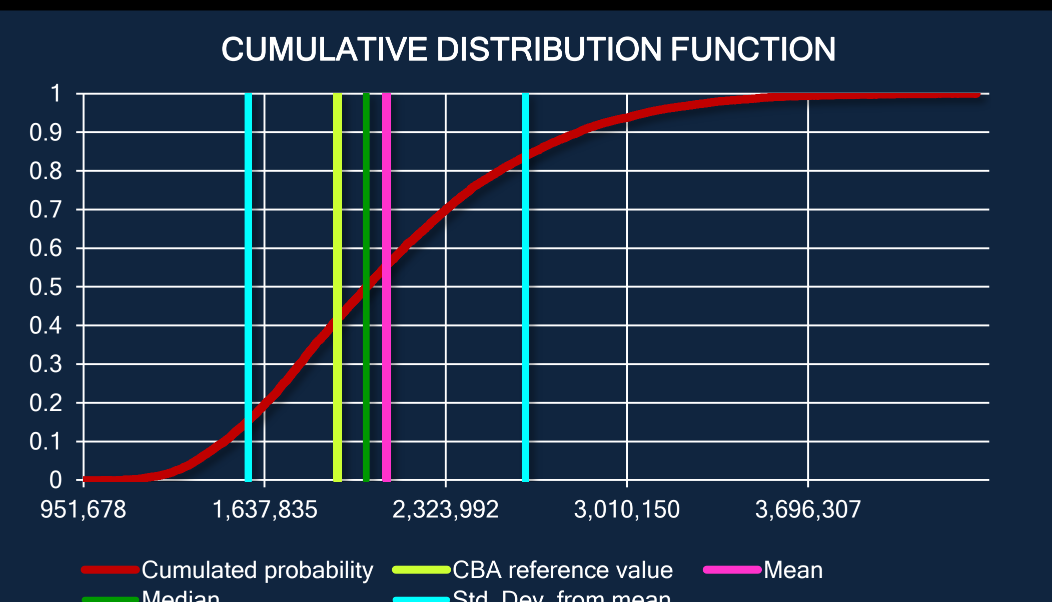


CULTURAL EFFECTS



PROBABILITY DISTRIBUTION OF THE CULTURAL BENEFITS TO GENERAL PUBLIC

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



ESTIMATED PARAMETERS OF DISTRIBUTION

Mean	2,099,812
Median	2,022,731
Standard deviation	524,892
Minimum	951,678
Maximun	4,382,465

THE NON-USE BENEFITS

$\boldsymbol{B_n}$ captures two types of benefits related to the **social value of discovery**: the **quasi-option value** (QOV_t) and the **existence value** (EXV_t):

$$B_n = QOV_t + EXV_o$$

Where:

- QOV_t is intrinsically uncertain and therefore not measurable, simply assumed to be non-negative and then skipped;
- the existence value, on the other hand, can be proxied by stated or revealed willingness to pay for scientific research, and/or through benefit transfer, borrowing ideas from **CBA** of the environment.

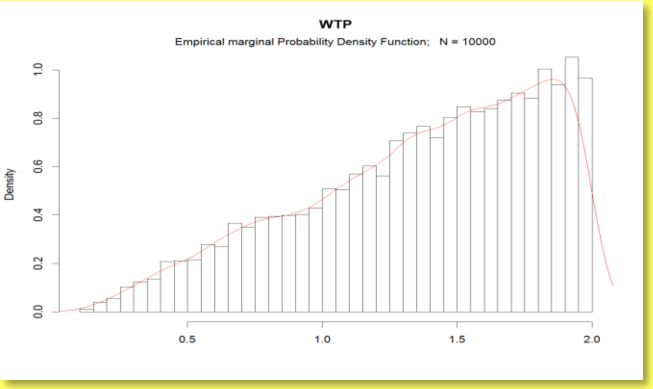
THE NON-USE BENEFITS

SURVEY RESULTS

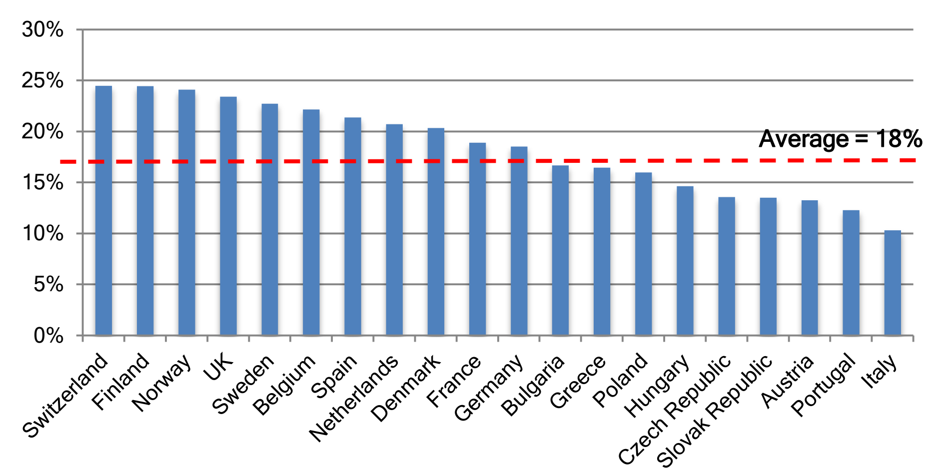
VARIABLE	STATE (DETERMINISTIC OR STOCHASTIC)	PROBABILITY DISTRIBUTION FORM	BASELINE / MEAN VALUE (EUR PER YEAR)	MINIMUM VALUE (EUR PER YEAR)	MAXIMUM VALUE (EUR PER YEAR)	SOURCE
Average WTP for LHC (at least > 0)	Stochastic	Trumcated Triangular	2.0	0.1	2.0	Survey to 1027 students in **Italy, France, UK, Spain**. On average, 73% of surveyed students has a positive WTP.
Adult population with tertiary education in CERN Member States (2013)	Deterministic		87,656,300			Eurostat. Only 73% of adult population with tertiary education is considered for the purpose of the benefit estimation: this should be a proxy of people with a positive WTP.
Adult population with tertiary education in non-Member States	Deterministic		18,562,265			Own estimate assuming that the general public from Non-Member States is proportional to the number of visitors coming from Non-Member States, i.e. around 20% of total visitors. Only 73% of population from Non-Member States has been considered for the purpose of the benefit estimation

PROBABILITY DISTRIBUTION OF STOCHASTIC CRITICAL VARIABLES

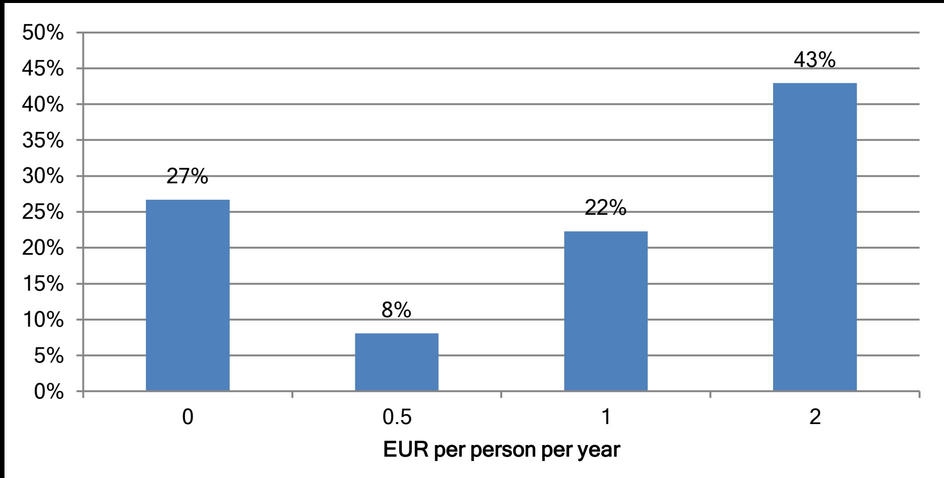
(10,000 random extractions)



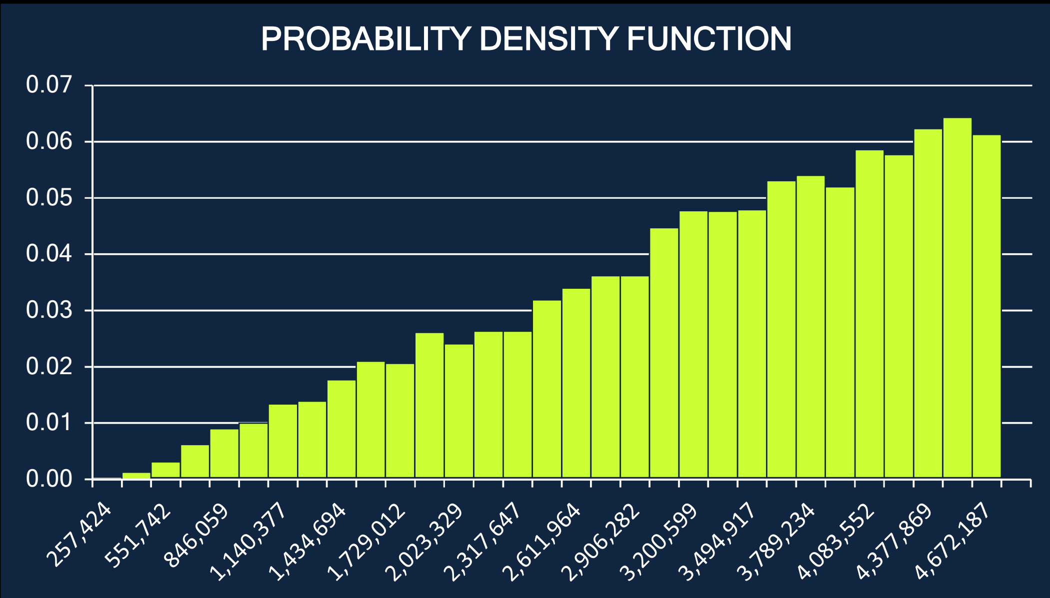
SHARE OF ADULT POPULATION (18-74 YEARS OLD) WITH AT LEAST TERTIARY EDUCATION



AVERAGE ANNUAL WTP

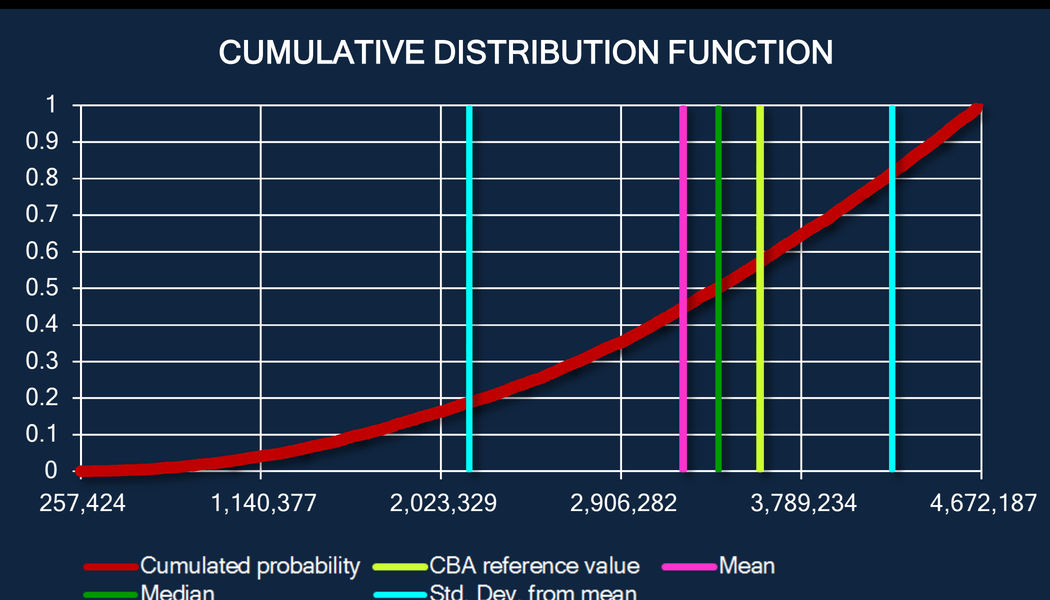


THE NON-USE BENEFITS



PROBABILITY DISTRIBUTION OF THE LHC EXISTENCE VALUE

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



ESTIMATED PARAMETERS OF DISTRIBUTION

Mean	3,197,227
Median	3,377,970
Standard deviation	1,039,558
Minimum	257,424
Maximun	4,672,187

SUMMING UP

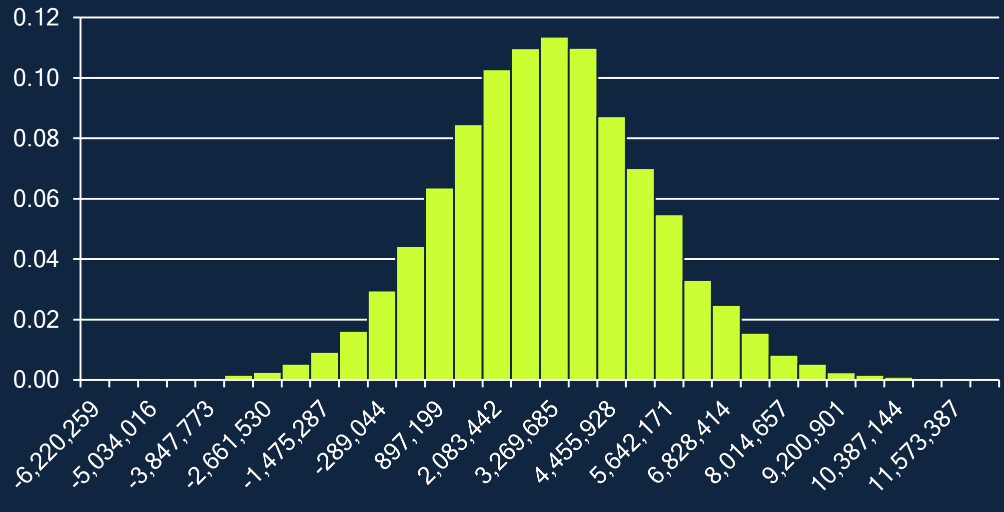
The **CBA** model for pure and applied research infrastructures turns into the following equation:

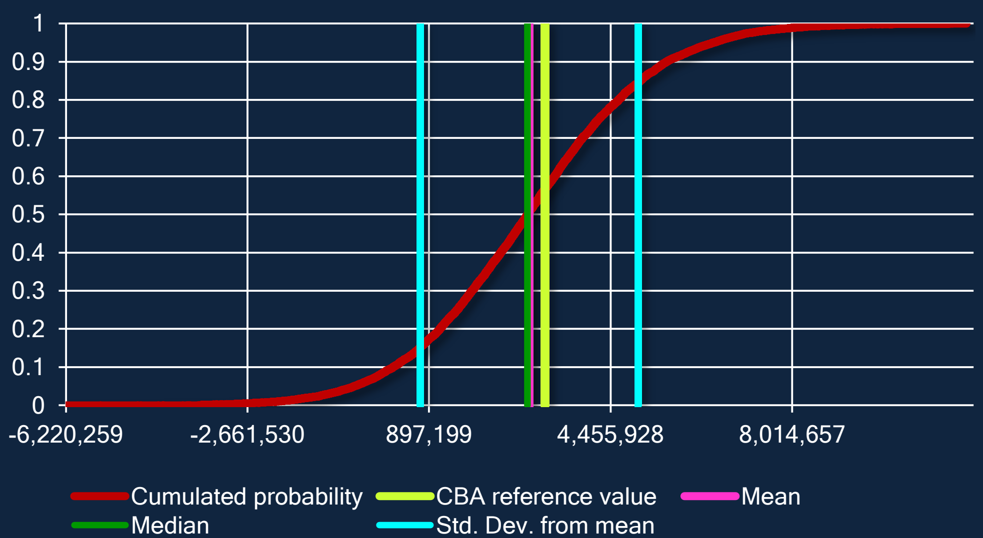
PUBLICATIONS (S)	TECHNOLOGY (T)	EDUCATION (H)	OUTREACH (C)	PUBLIC GOOD (B_n)	COSTS

$$NPV_{RI} = \left[\left(\sum_{i=1}^{n} \sum_{t=1}^{\mathcal{T}} \frac{s_t \cdot P_{it}}{k_{it}} + \sum_{i=0}^{n} \sum_{t=1}^{\mathcal{T}} s_t \cdot Q_{it} \right) + \left(\sum_{j=1}^{J} \sum_{t=0}^{\mathcal{T}} \cdot \frac{\Pi_{jt}}{(1+r)^t} \right) + \left(\sum_{z=1}^{z} \sum_{t=\varphi}^{\mathcal{T}} \cdot \frac{I_{zt}}{(1+r)^t} \right) + \left(\sum_{g=1}^{G} \sum_{t=1}^{\mathcal{T}} \cdot \frac{W_{gt}}{(1+r)^t} \right) \right] + (QOV_t + EXV_o) - \left[\sum_{t=0}^{\mathcal{T}} \cdot \frac{(k_t + l_{st} + l_{ot} + \varepsilon_t)}{(1+r)^t} \right]$$

As B_n will usually be non-negative, the test is trivially passed for $NPV_u \geq 0$, while for $NPV_u < 0$, then $NPV_{RI} > 0$ if $EXV_t \geq NPV_u$ and QOV_t is conservatively taken as zero.

SUMMING UP





PROBABILITY DISTRIBUTION OF THE LHC NET PRESENT VALUE

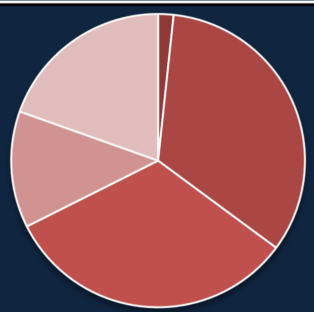
Own estimate of the Present Value PDF resulting from a Monte Carlo simulation (10,000 random extractions)

ESTIMATED PARAMETERS OF DISTRIBUTION	
Mean	2,855,528
Median	2,825,860
Standard deviation	2,134,763
Minimum	-6,220,259
Maximun	11,573,387

ESTIMATED PROBABILITIES	
Pr. ENPV ≤ 0	0.086

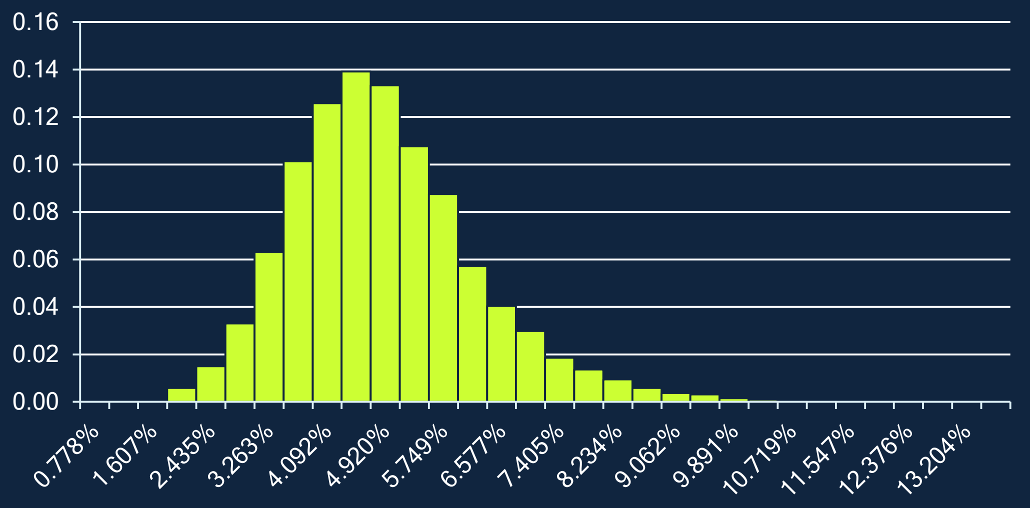
TOTAL MEASURED BENEFITS OF LHC

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



SUMMING UP

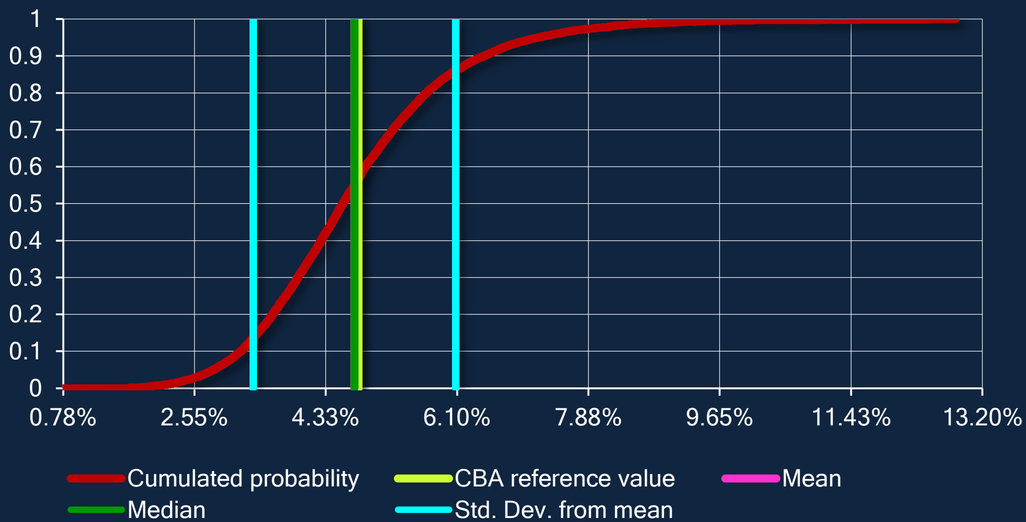
PROBABILITY DENSITY FUNCTION



PROBABILITY DISTRIBUTION OF THE LHC ECONOMIC INTERNAL RATE OF RETURN

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

CUMULATIVE DISTRIBUTION FUNCTION



ESTIMATED PARAMETERS OF DISTRIBUTION

Mean	4.7139%
Median	4.5544%
Standard deviation	1.37%
Minimum	0.778%
Maximun	13.204%

ESTIMATED PROBABILITIES

Pr. ERR ≤ Social discount rate	0.074

CONCLUSION

Our CBA model uses the standard ingredients of CBA: social discount rate, marginal costs, willingness to pay, with an extension to the social value of discovery of the concept of existence value, risk analysis.

The application to the LHC allows to conclude that setting at zero any quasi-option value of unknown applications of the discoveries, there is 92% probability that the NPV over 30 years (1993-2025) is positive.

The Monte Carlo error with 10,000 random extractions is around 2% (3σ).

We have shown how a social CBA probabilistic model can be applied to evaluate a large scale research infrastructure, based on empirically feasible methods. The unpredictable benefits of science (if any) are not included in our analysis: they will remain as an extra bonus for future generations, donated to them by current taxpayers.

Further research

- Testing the model by other case studies, in different science fields
- Larger sampling for the WTP for pure discovery (existence value)
- In depth study of technological spillovers (externality)
- Refinement of the risk analysis (matrix of correlations across stochastic variables)

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Thank you

comments are welcome