HOW MUCH DOES A COLLIDER COST?

And is it worth it?

A COST-BENEFIT ANALYSIS OF THE LHC

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UNIVERSITÀ DEGLI STUDI DI MILANO

LAL Orsay, March 27, 2016

INFN Istituto Nazionale di Fisica Nucleare

WHAT IS COST-BENEFIT ANALYSIS (CBA) ALL ABOUT?

Jules Dupuit (1801-1866)

"De la mésure de l'utilité des travaux publics"
(*Annales des Ponts ets Chaussées, 1844*)

What is the benefit produced by a bridge on which no toll is levied?

WHY CBA?
WHAT IS IT GOOD FOR?

What is the benefit of this bridge?

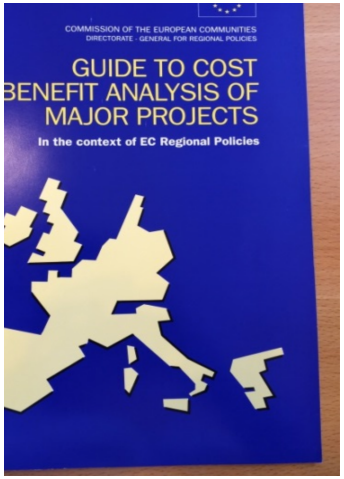
- **Benefits may be quite diverse**:
  -someone is willing to pay a ticket in order to dive from the bridge
  -someone else is willing to pay in order to take a picture of it

- The decision to build the bridge may well depend on other considerations (political, social, cultural, etc.)
  AND THIS IS
  AS IT SHOULD BE!

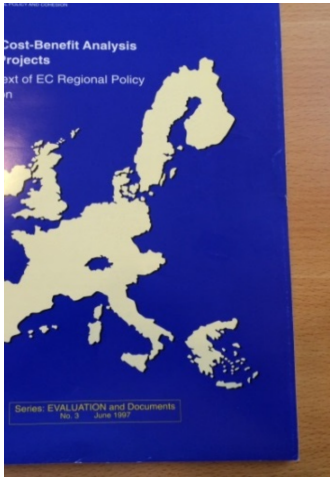
THE USES OF CBA

The european commission

1994: 1st edition, 28 pages

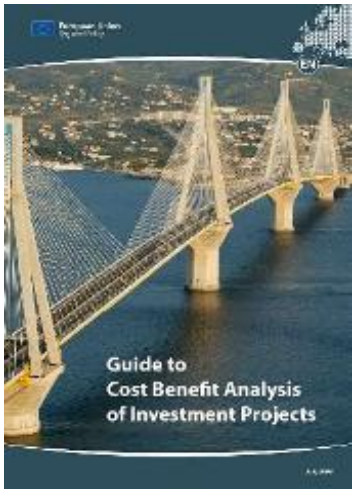


1997: 2nd edition, 84 pages



2002: 4th edition, 133 pages

2008: 4th edition, 257 pages



Scientific Director:
Massimo Florio

2014: 5th edition, 364 pages

Coordinator of the Academic review panel:
Massimo Florio

- CBA routinely used as assessment tool:
  mandatory for EU grants when total cost beyond 50 M€
- Performed following a standardized methodology (5 editions of the EC CBA Guide)

THE BENEFITS OF BIG SCIENCE PROJECTS?

Battelle
The Business of Innovation

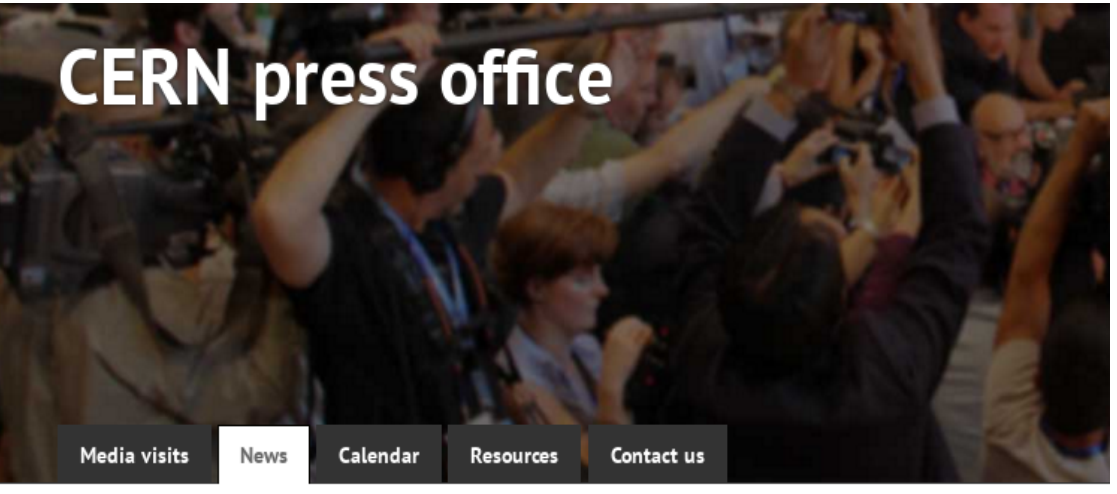
$3.8B Investment in Human Genome Project Drove $796B in Economic Impact Creating 310,000 Jobs and Launching the Genomic Revolution

The Washington Post

A 1 to 140 'return' from the Human Genome Project?

THE FUNDING OF BIG SCIENCE PROJECTS

LHC



Updates | Press releases

EIB lends € 300 million for CERN's major collider

18 Dec 2002

Geneva, 18 December 2002. The European Investment Bank (EIB) is lending EUR 300 million to fin final phase of construction of the Large Hadron Collider (LHC) at CERN[1], the European Organizatior Research. The EIB loan will also help to finance the instrumentation to record and analyse the high-e particle collisions at the LHC. A loan to enable construction of this major project was foreseen by CEF governing Council when it approved the LHC in 1996.

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SCIENTIFIC AMERICAN™

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THE SCIENCES

The Supercollider That Never Was

The Texas-based high-energy accelerator would have easily found the Higgs and been capable of searching for still more evidence of new physics

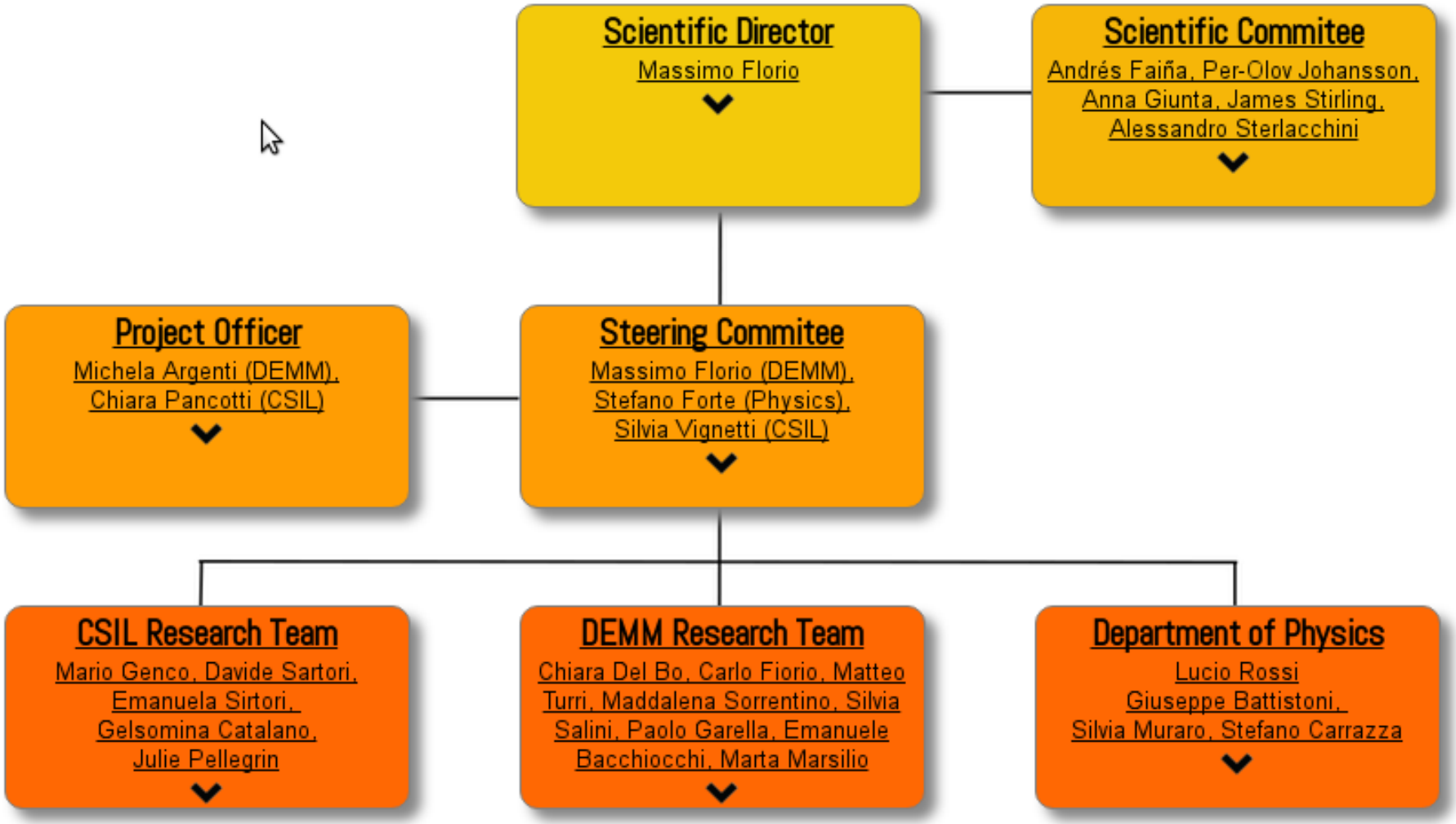
By David Appell on October 15, 2013

THE EIBURS PROJECT

- The European Investment Bank – Institute issued a call for proposals on its University Research Sponsorship program
- Our team presented a proposal and won a competitive grant

www.eiburs.unimi.it

THE TEAM


Scientific Director
Massimo Florio
Scientific Commitee
Andrés Faiña, Per-Olov Johansson, Anna Giunta, James Stirling, Alessandro Sterlacchini
Project Officer
Michela Argenti (DEMM), Chiara Pancotti (CSIL)
Steering Commitee
Massimo Florio (DEMM), Stefano Forte (Physics), Silvia Vignetti (CSIL)
CSIL Research Team
Mario Genco, Davide Sartori, Emanuela Sirtori, Gelsomina Catalano, Julie Pellegrin
DEMM Research Team
Chiara Del Bo, Carlo Fiorio, Matteo Turri, Maddalena Sorrentino, Silvia Salini, Paolo Garella, Emanuele Bacchiocchi, Marta Marsilio
Department of Physics
Lucio Rossi
Giuseppe Battistoni, Silvia Muraro, Stefano Carrazza

GOALS AND DELIVERABLES

THE MODEL (Florio, Sirtori, 2015)

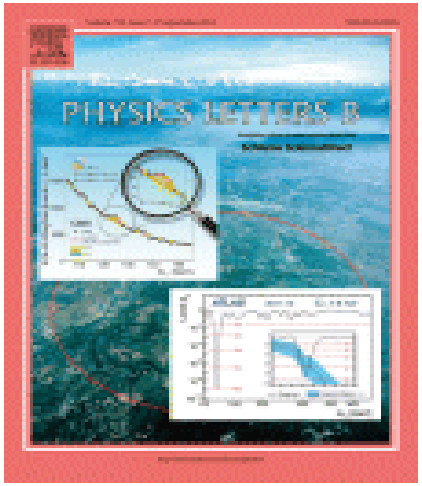
NET PRESENT VALUE:

$$\mathrm{NPV} = \sum_i \frac{B^u_{t_i} - C_{t_i}}{(1+r)^{t_i}} + B^{nu}$$

- The **net** value is the difference between benefits and costs
- Costs (C_{t_i}) and user benefits ($B^u_{t_i}$) are defined at times t_i and must be converted to a **present** value using a discount rate r
- The model is a classification of the benefits which in turns involves (a) a classification of beneficiaries, and (b) an understanding of the non-use benefits
- We argue that the model is of general applicability for any research infrastructure
- The model is tested by applying it to the LHC

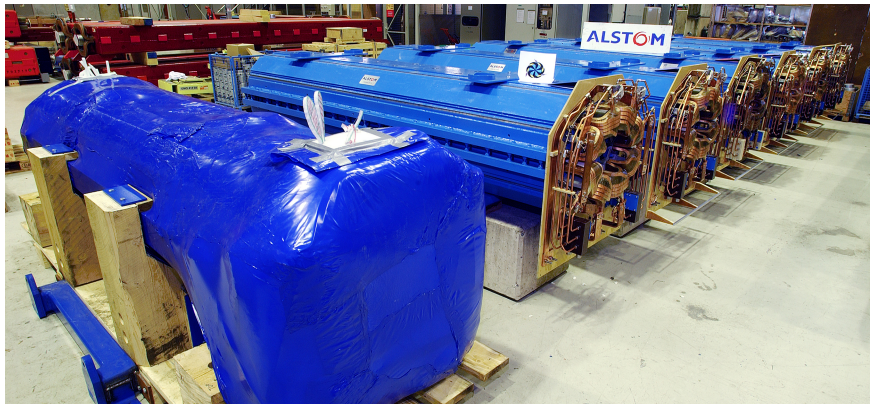
THE USE BENEFITS
AND THEIR USERS

Knowledge output (publications):
scientists



Human capital formation:
students and postdocs

Technological spillovers:
firms



Cultural benefits:
visitors & outreach

NON USE BENEFITS

QUASI OPTION VALUE:

the value of future (=option) possible (=quasi) discoveries

unpredictable, in fundamental science: assumed zero

EXISTENCE VALUE:

the value attached to the existence of something, even if useless

estimated using standard methods of environmental economics

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

- Information acquired thanks to co-operation of CERN admin, directorate, and experiments (access to procurement, fellow database, etc)
- All variables for which information is incomplete assigned a probability distribution and final distribution of costs and benefits obtained through a Monte Carlo

COSTS

A (very) difficult accounting problem:

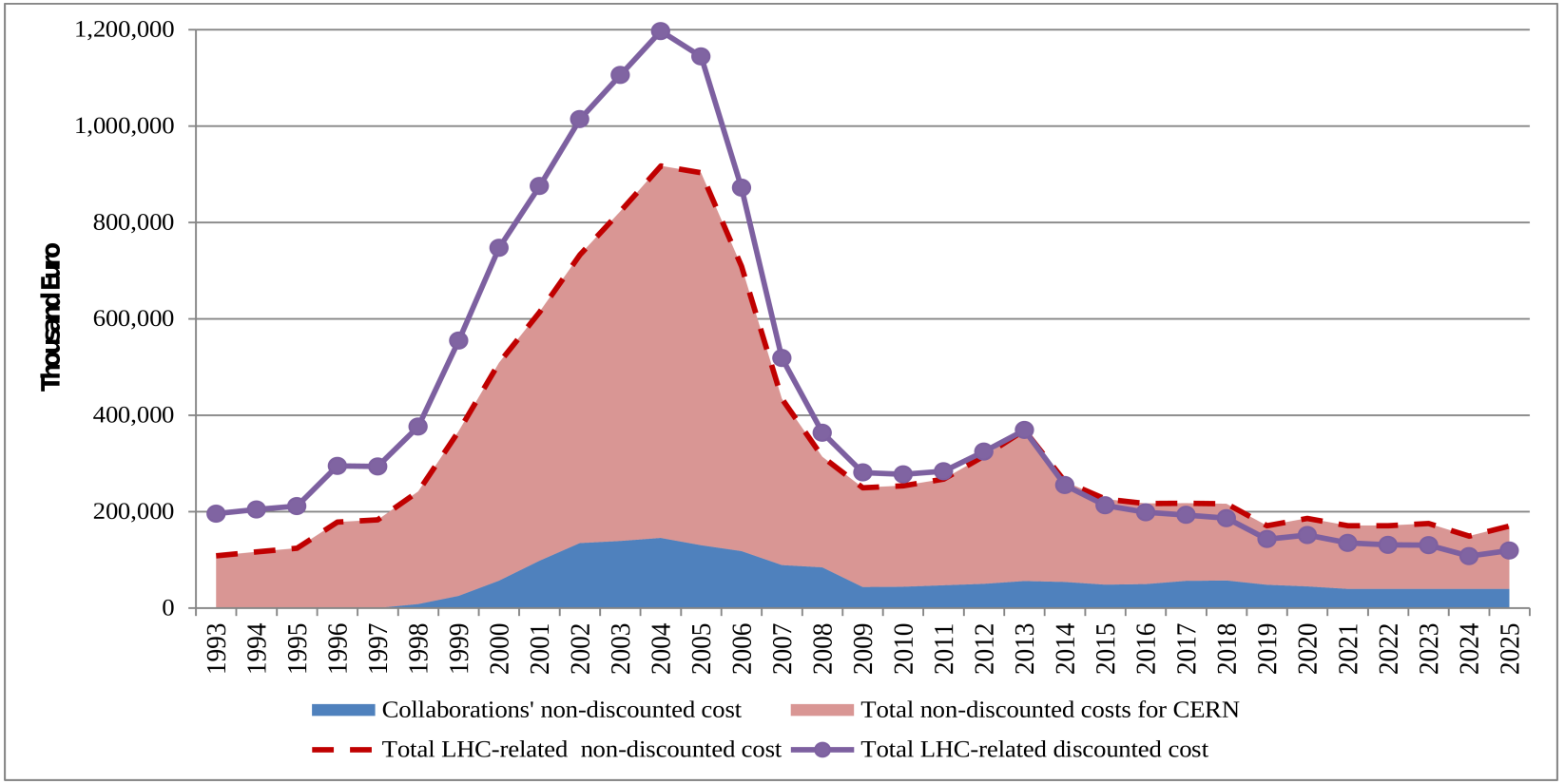
- Long time span & need to forecast future costs
- Costs born both by CERN and by users (experiments, funding agencies)
- Many contributions in-kind
- Need to apportion costs between LHC and the rest of the lab

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
LEP	0%
LHC	100%
LHC injectors	100%
LHC injectors upgrade	100%
LHC upgrade	100%
Low and medium energy	0%
Medical applications	0%
PS complex	50%
R&D	50%
R&D CLIC	0%
SPS complex	67%
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%

COSTS
time profile

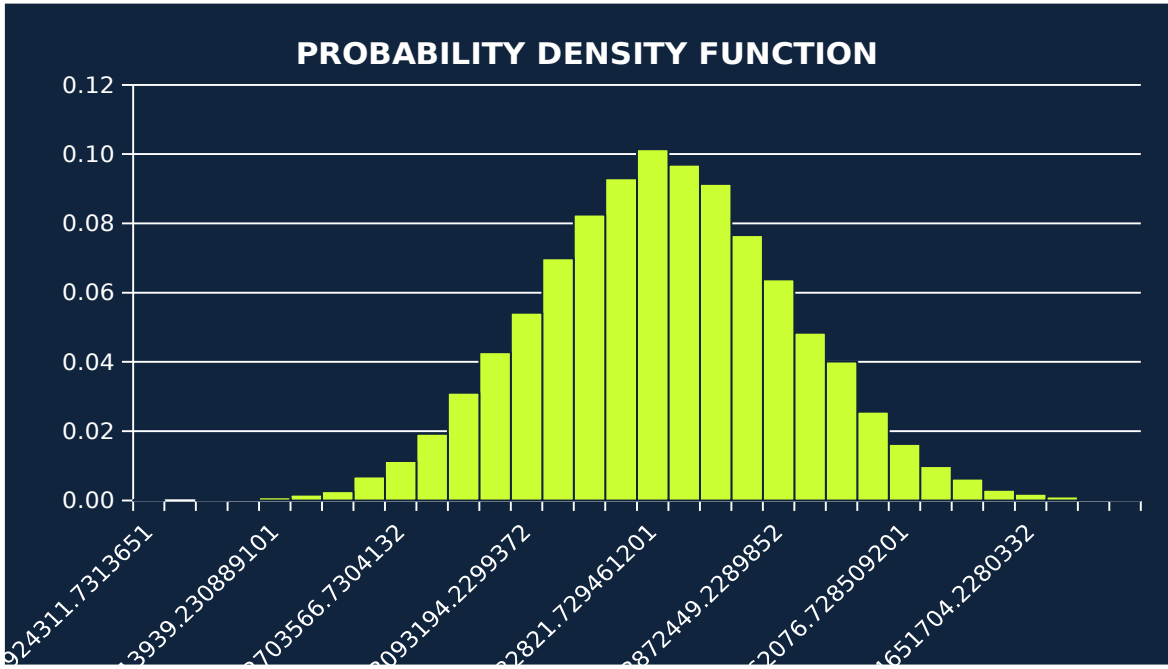


COSTS

final results

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

Present value in kEuro



ESTIMATING BENEFITS

the fallacy of the hole in the ground

- If you pay someone for digging a hole in the ground, the benefit of having created a new job is cancelled by the cost
- And don't forget the cost of fixing the leg of those who fall into the hole

Benefits should be determined as incremental
failure to do so will lead to meaningless (and typically unrealistic) results

Our guiding principles:

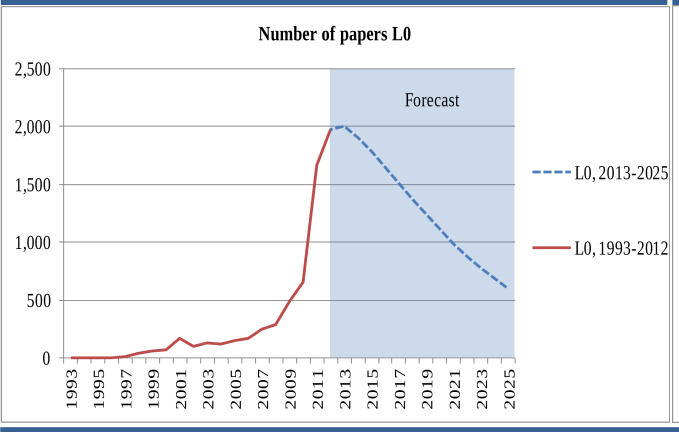
- results must be quantitative: if something cannot be estimated, set it to zero
- always determine the gain compared to a counterfactual

USE-BENEFITS: KNOWLEDGE OUTPUT

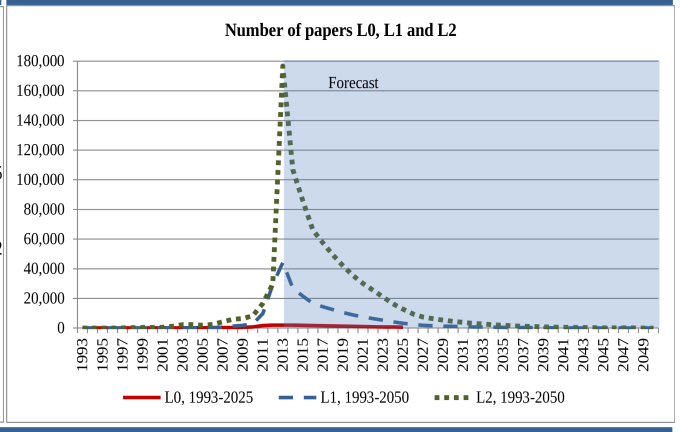
- For publications by CERN users (L0), costs and benefits exactly cancel
- The benefit consists of publications (L1) which cite L0 papers, those which cite the latter (L2) and so on
- Publication flows are forecast based on models tested on similar contexts (LEP experiments)
- The value of a publication is measured as the value of time a scientist spends on it (estimated)

USE-BENEFITS: KNOWLEDGE OUTPUT

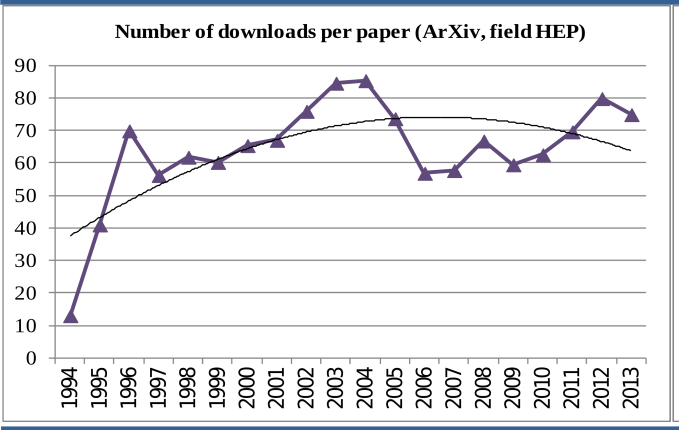
PAPERS PRODUCED BY LHC USERS (L0)

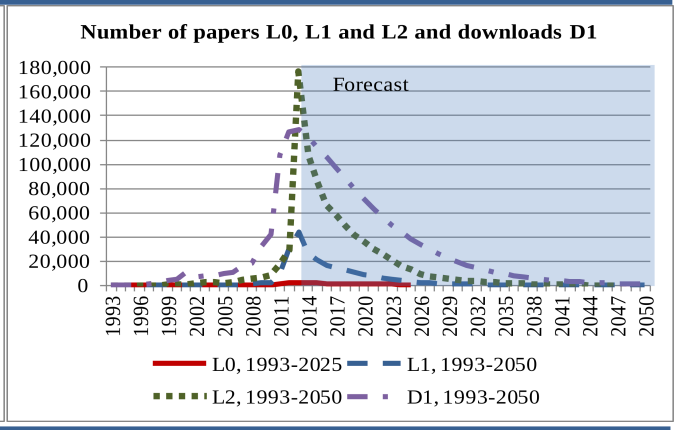


PAPERS PRODUCED BY NON-LHC USERS (L1 & L2)

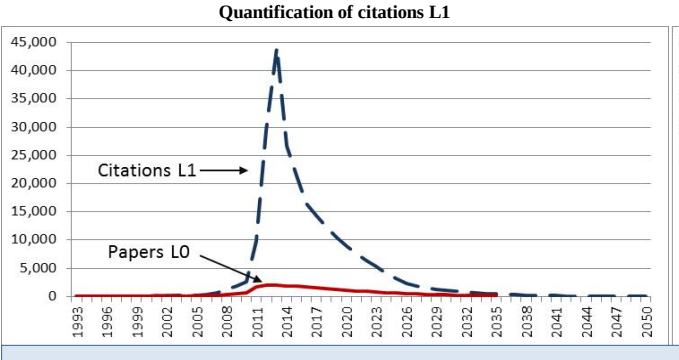


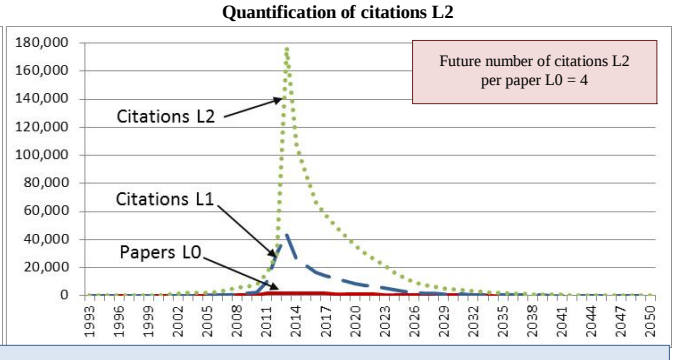
DOWNLOADS OF LHC PAPERS (D1)





TRACKING THE KNOWLEDGE OUTPUTS





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

VALUATION

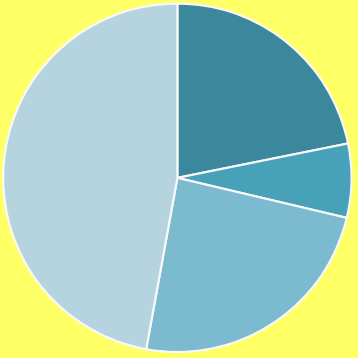
Unit economic value of papers L1

	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



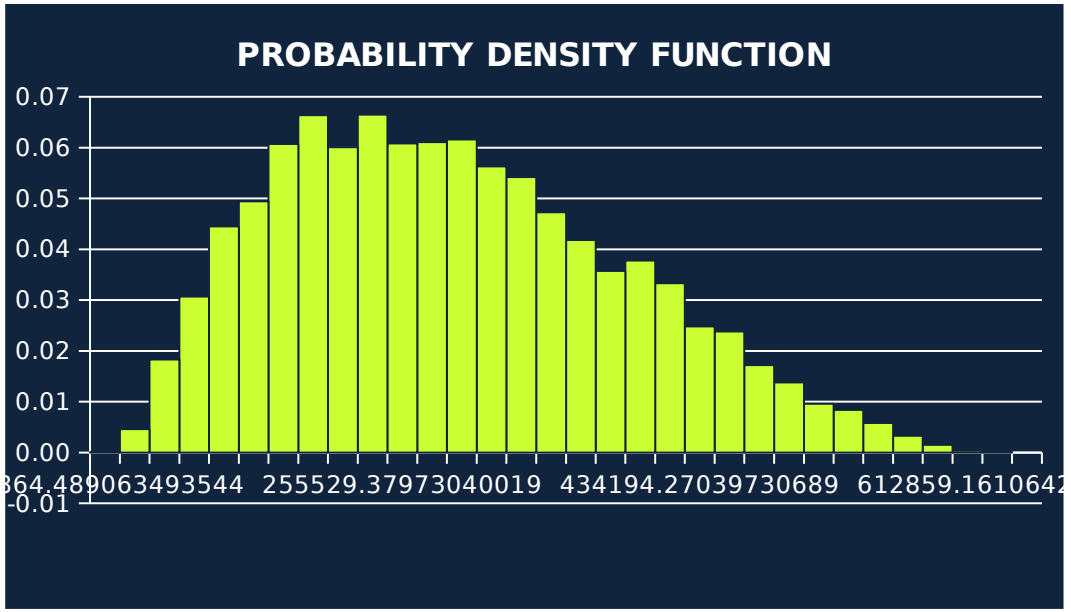
million EUR

Total present value of knowledge output benefit **277**

USE-BENEFITS: KNOWLEDGE OUTPUT

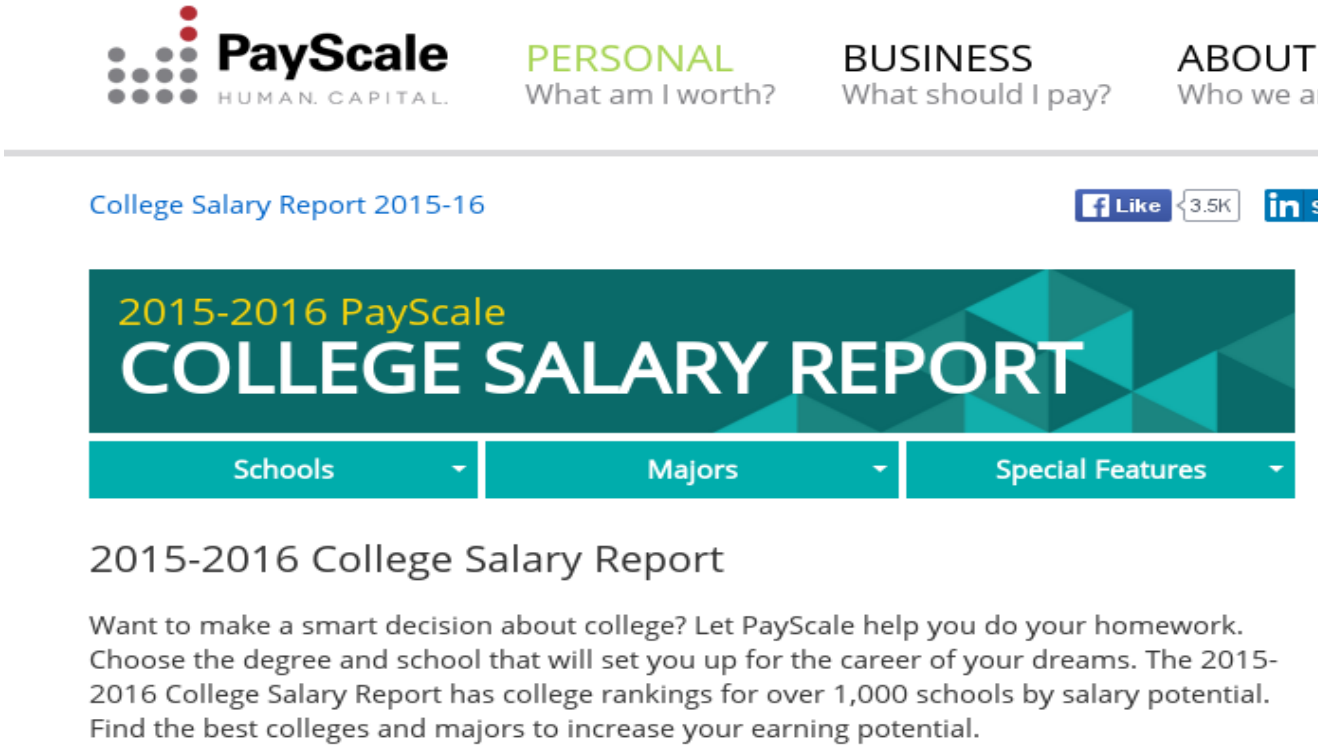
ESTIMATED PARAMETERS OF DISTRIBUTION	
Mean	277,051
Median	266,578
Standard deviation	102,768
Minimum	76,864
Maximun	612,859

Present value in KEuro



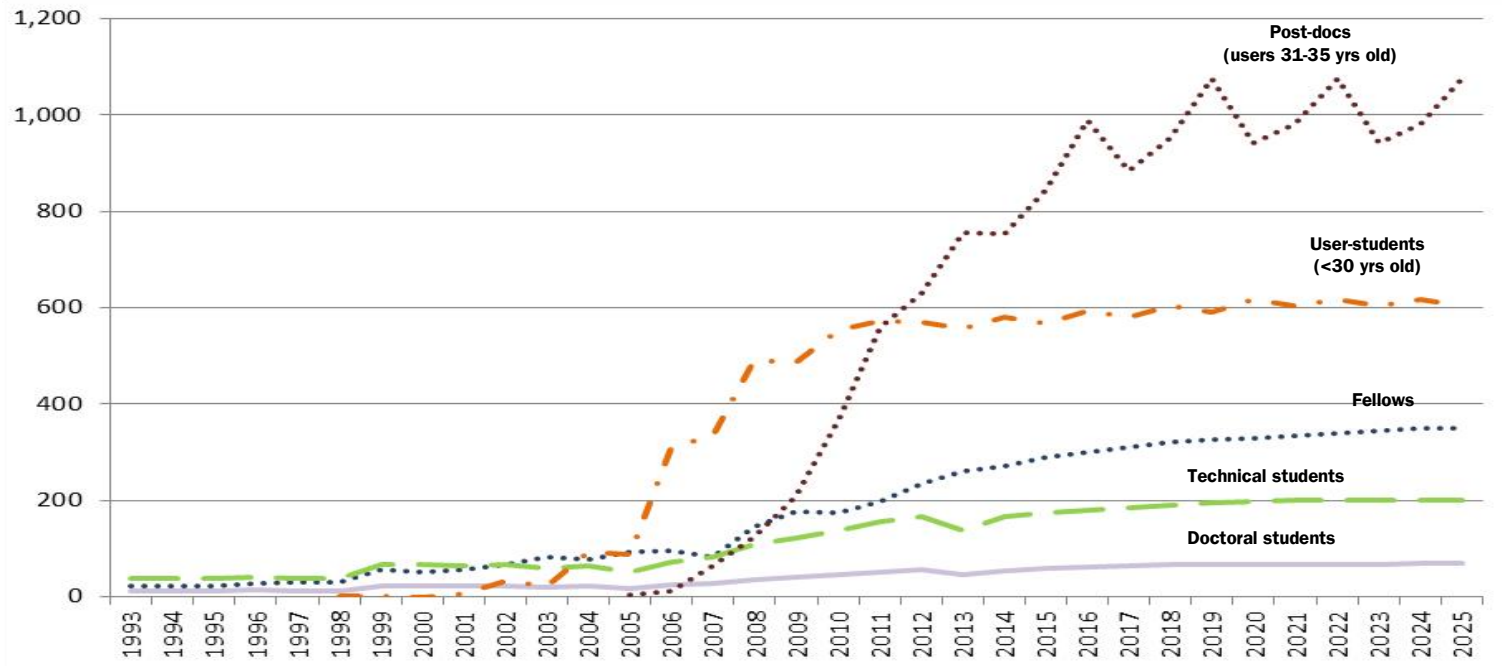
USE-BENEFITS: HUMAN CAPITAL

- The benefit due to human capital formation can be measured as the increase in salary for someone who benefitted from training at CERN
- This applies both to those who stay in academia and to those who go to industry
- Comparable to the benefit of going to a top university, as usually done to justify the high cost! Can be estimated with similar methods



USE-BENEFITS: HUMAN CAPITAL

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

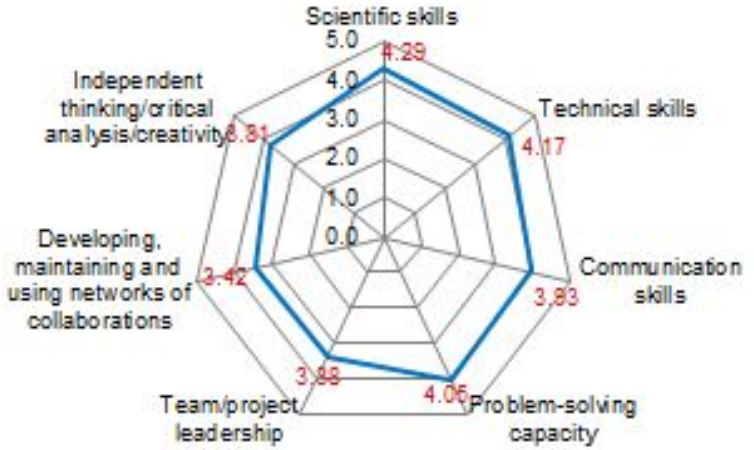
Main assumptions: - Future number of beneficiaries; - Number of users-students and post-docs among users (assumed based on their age group); - Incoming number of user-students and post docs

ASSUMED DISTRIBUTION OF FORMER LHC STUDENTS BY PROFESSIONAL SECTOR

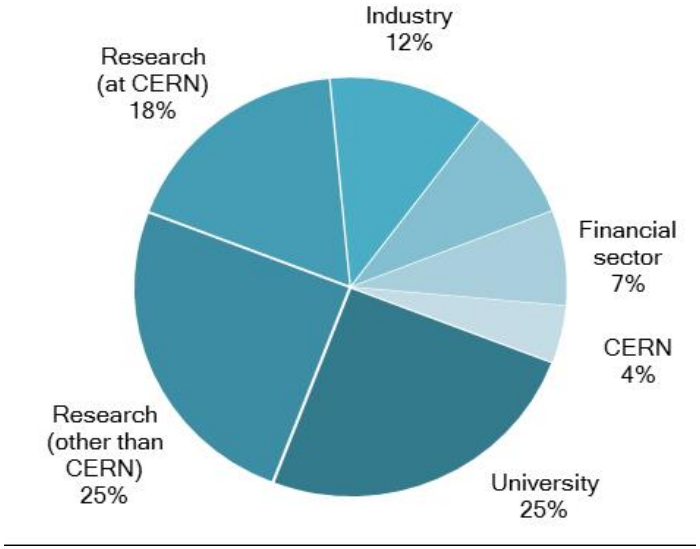
Sector	CERN fellows	CERN technical students	CERN doctoral students	User-students and post-docs
Industry	20%	45%	20%	20%
Others (computing, finance, public administration, …)	20%	45%	20%	20%
Research centres	30%	5%	30%	30%
Academia	30%	5%	30%	30%
TOTAL	**100%**	**100%**	**100%**	**100%**

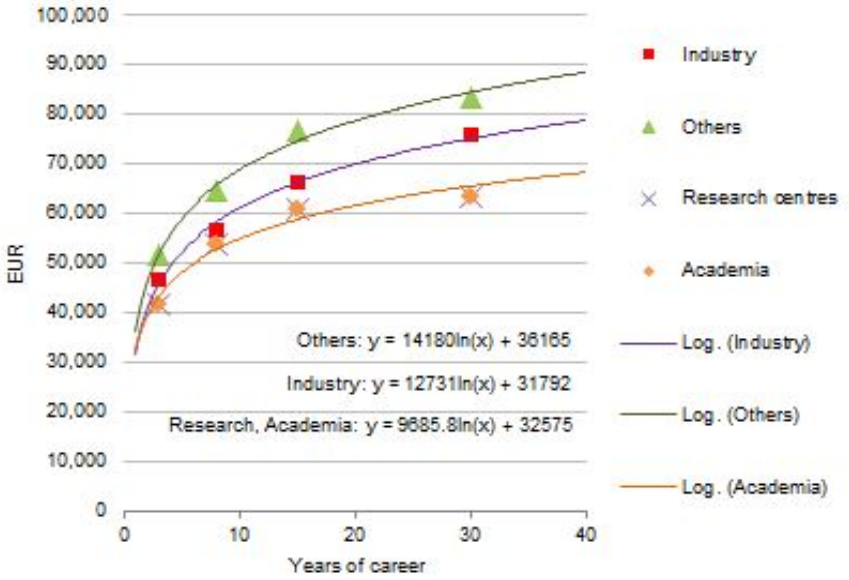
USE-BENEFITS: HUMAN CAPITAL

Combine information on perceived or known effects on skills and salaries...



...with known distribution of occupational outcomes and salary flows in time

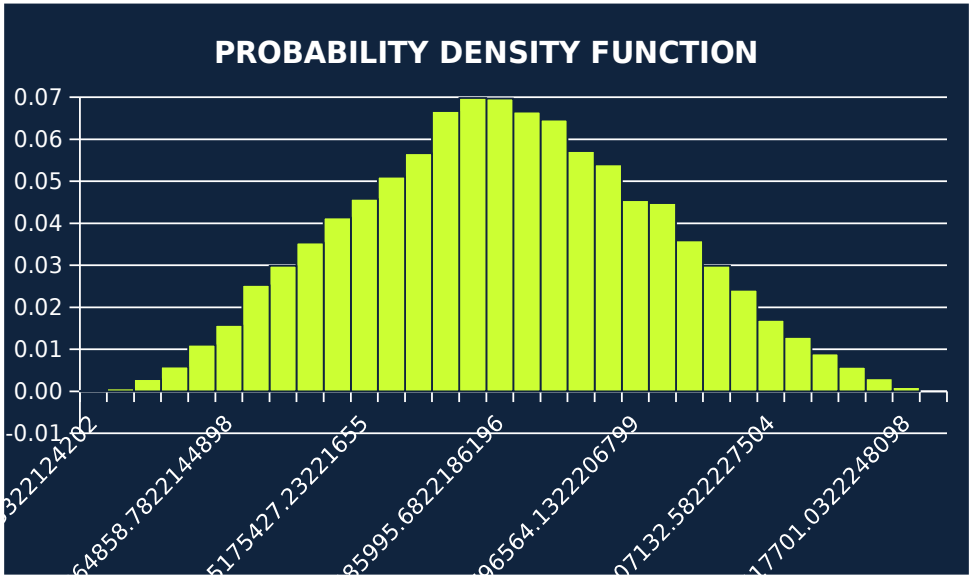




USE-BENEFITS: HUMAN CAPITAL

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

Present value in kEuro



USE-BENEFITS: TECHNOLOGICAL SPILLOVERS

Two main classes of benefits:

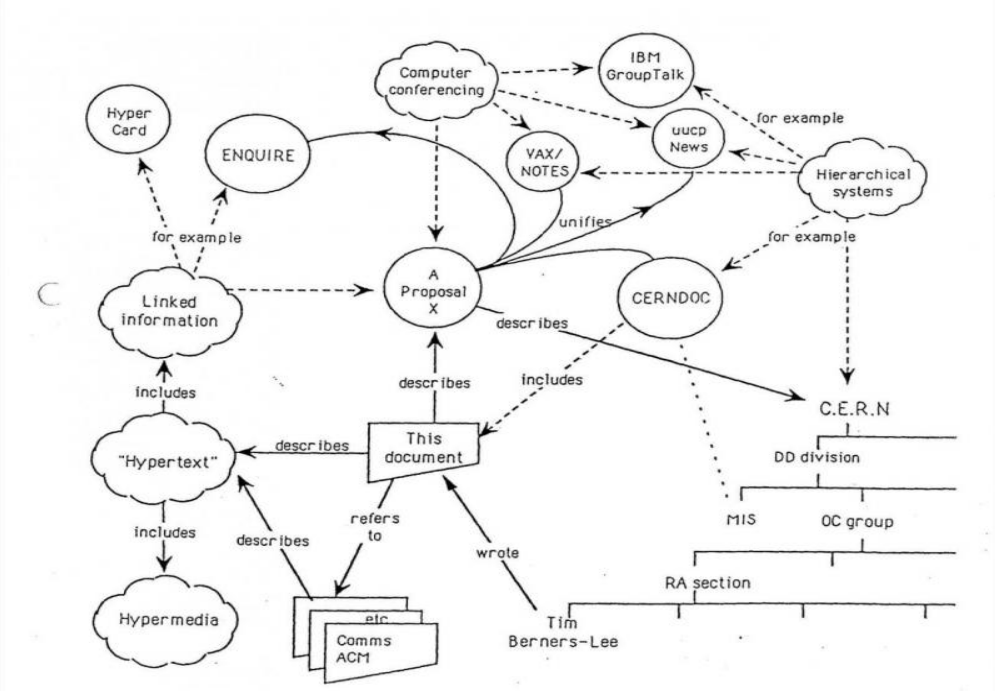
- Acquisition of know-how by suppliers

☞ can be estimated using procurement data

- Technological results and products made freely available

☞ can be estimated knowing usage data &
comparing to the price of similar commercial products

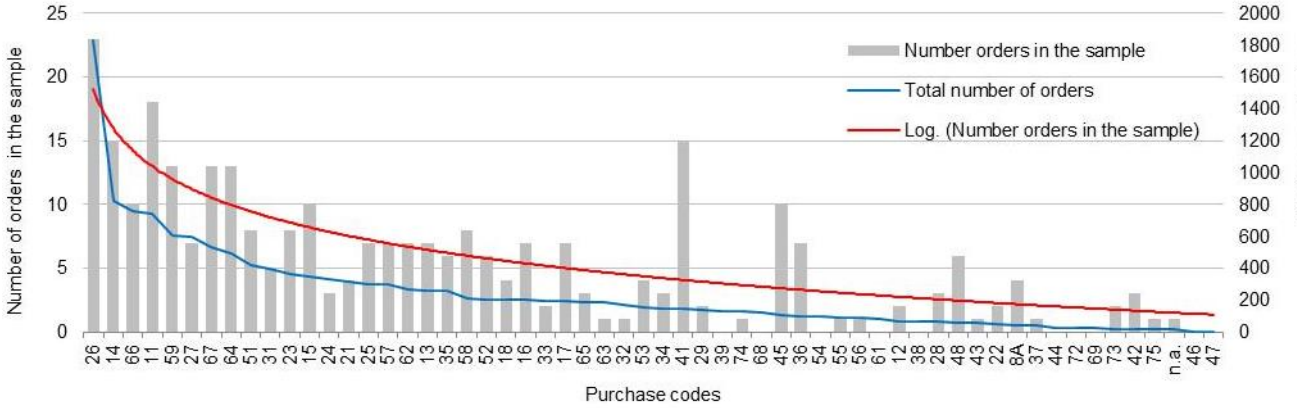
(no, we did not include the World Wide Web)



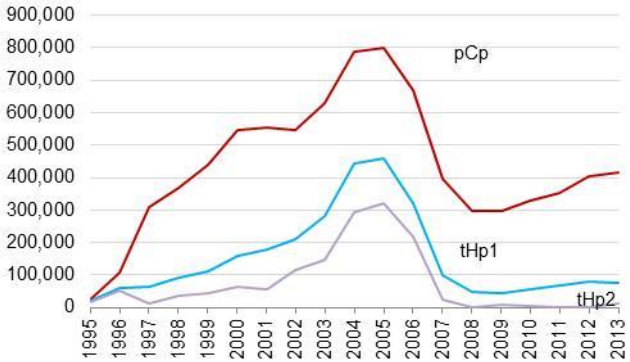
USE-BENEFITS: TECHNOLOGICAL SPILLOVERS

Studying CERN procurement....

Orders by purchase code

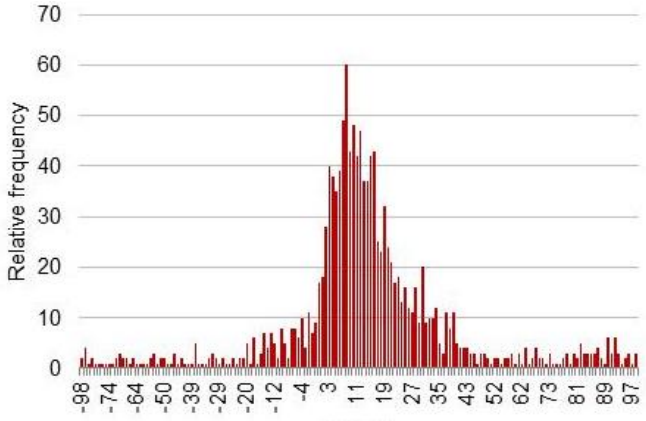


Procurement: total & hi-tech



...and matching it to earning data for similar companies...

Distribution of EBITDA matched to CERN codes



...with incremental turnover determined from interviews (BUT: stay tuned for more!)

USE-BENEFITS: TECHNOLOGICAL SPILLOVERS

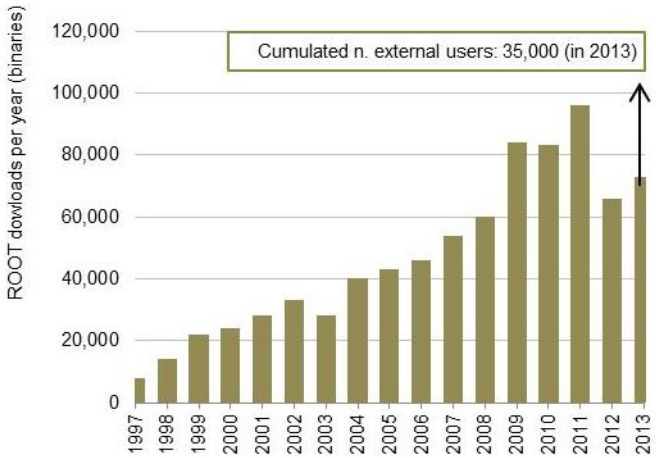
FREELY AVAILABLE SOFTWARE

ROOT: Multivariate analysis tool, available since 1997

About 25000 users outside physics in 2013, mostly in finance

Savings determined from licence price of Oracle Advance Analytics (comparable commercial product)

ROOT download data



GEANT4: Simulation software, available since 1999

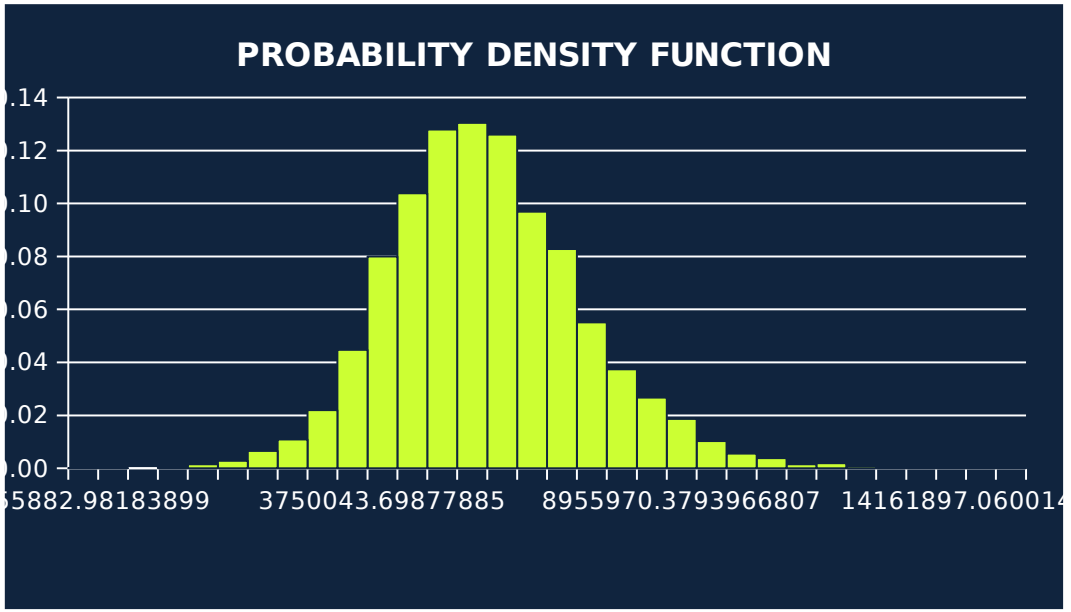
About fifty research centers, space agencies and firms routinely using it (not including a large number of hospotals using it for medical applications)

Saving determined from development costs incurred by CERN

USE-BENEFITS: TECHNOLOGICAL SPILLOVERS

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

Present value in kEuro



USE-BENEFITS: CULTURAL BENEFITS

- Science labs receive a large number of visitors

  benefits can be estimated as in the tourism industry
  (even when, like at CERN, no ticket purchase is required)

- The general public also profits from traveling exhibitions, media coverage, website visits

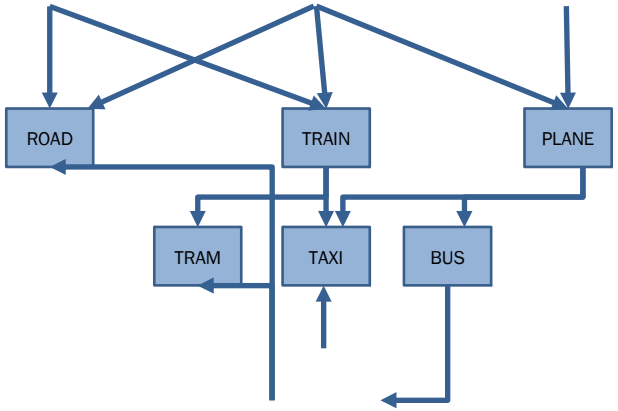
- Volunteers participate in distributed computing projects

  benefits can be estimated based on time spent

USE-BENEFITS: CULTURAL BENEFITS

TRAVEL ZONES CONSIDERED

VALUATION THROUGH THE TRAVEL COST METHOD

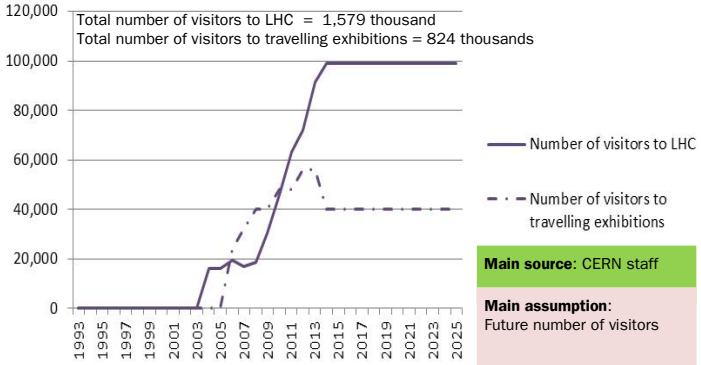


Main assumption:
- % of visitors by mode of transport
- Travel cost by zone

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

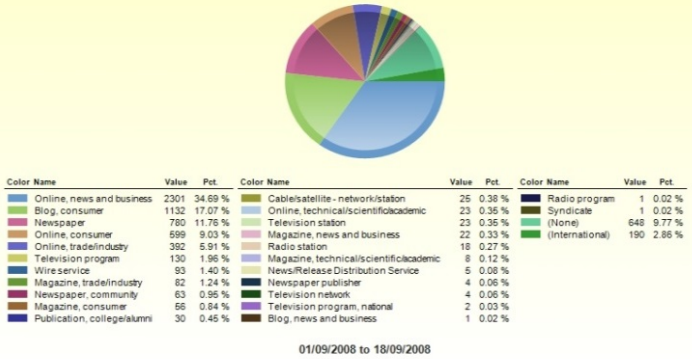
BENEFITS TO PERSONAL VISITORS: QUANTIFICATION OF VISITORS



Main source: CERN staff

Main assumption:
Future number of visitors

MASS MEDIA BENEFITS: NEWS BY MEDIA CHART



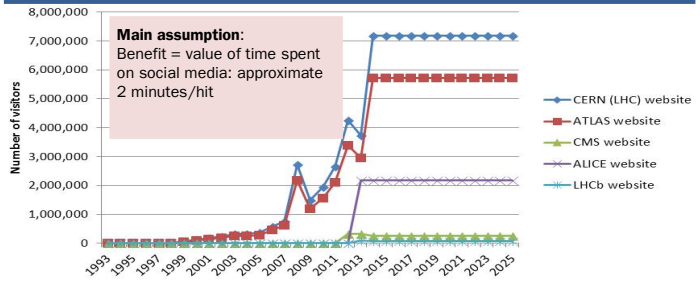
Color	Name	Value	Pct.
	Online, news and business	2301	34.69 %
	Blog, consumer	1132	17.07 %
	Newspaper	780	11.76 %
	Online, consumer	599	9.03 %
	Online, trade/industry	392	5.91 %
	Television program	130	1.96 %
	Wire service	93	1.40 %
	Magazine, trade/industry	82	1.24 %
	Newspaper, community	63	0.95 %
	Magazine, consumer	56	0.84 %
	Publication, college/alumni	30	0.45 %

Color	Name	Value	Pct.
	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 %

Color	Name	Value	Pct.
	Radio program	1	0.02 %
	Syndicate	1	0.02 %
	(None)	648	9.77 %
	(International)	190	2.86 %

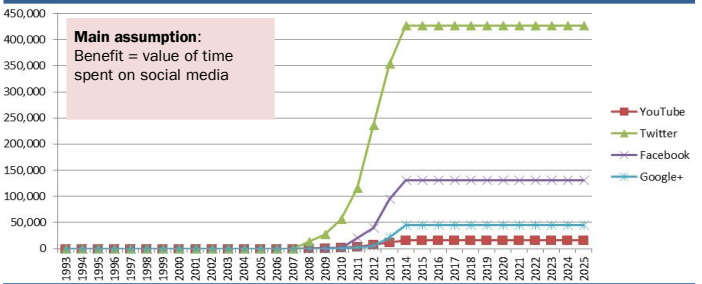
01/09/2008 to 18/09/2008

BENEFIT FOR WEBSITE VISITORS



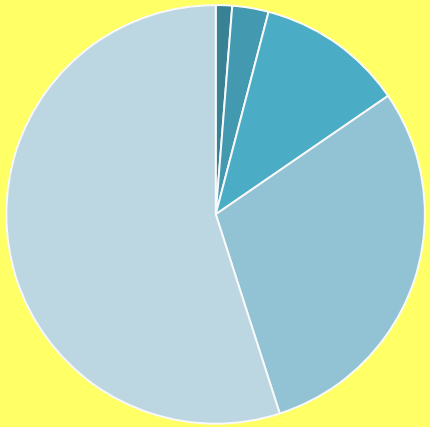
	Estimated n. visitors until 2025
CERN (LHC) website	211,924,673
ATLAS website	168,746,259
CMS website	7,190,918
ALICE website	56,514,575

BENEFIT FOR SOCIAL MEDIA USERS



	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

OUR PRELIMINARY RESULTS



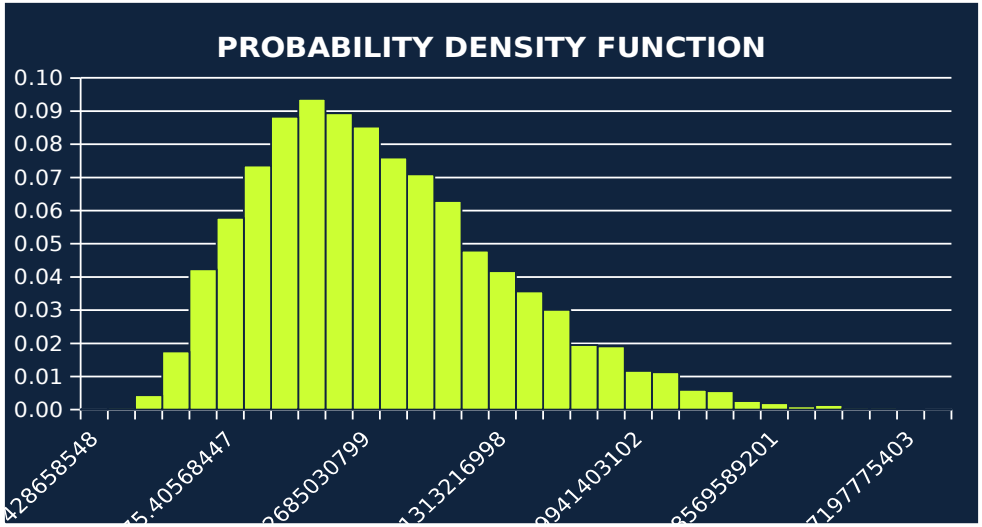
- social media users
- volunteer computing
- website visitors
- mass media on general public
- personal visitors

Total present value of cultural effects **2,099.8** **million EUR**

USE-BENEFITS: CULTURAL BENEFITS

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

Present value in kEuro



NON-USE BENEFITS: THE EXISTENCE VALUE

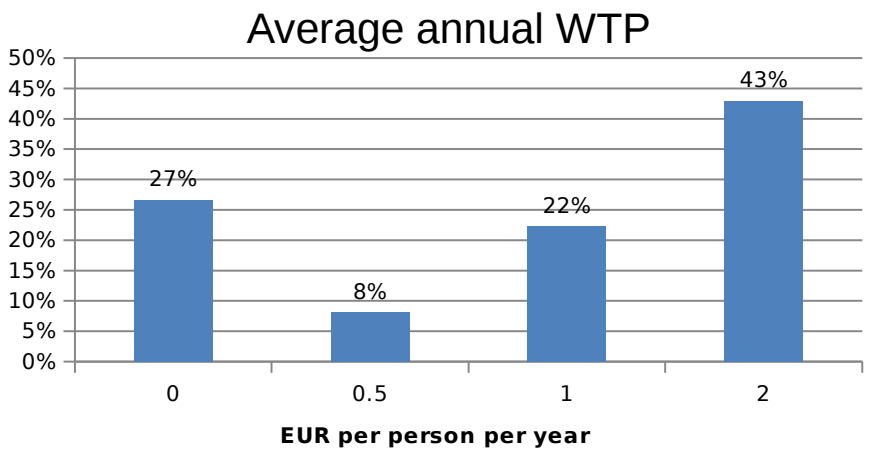
- The value of non-use benefits can be assessed by contingent valuation: essentially by estimating the willingness to pay of the taxpayer based on a survey
- Protocols for performing contingent valuation surveys have been developed, and used in the quantitative assessment of damage
  e.g. in the Exxon Valdez oil spill

What is the value of this whale?

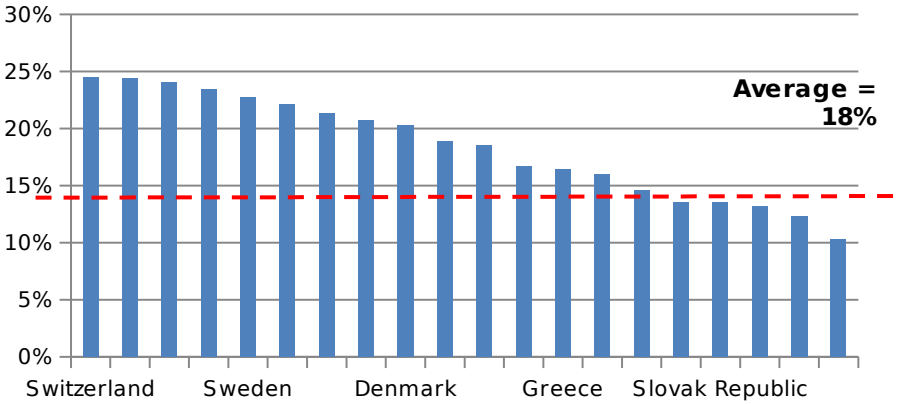
NON-USE BENEFITS: THE EXISTENCE VALUE

Survey to 1027 students in Italy, Spain, France, UK, consistent with NOAA protocol

WTP determined



Share of adult population with tertiary education

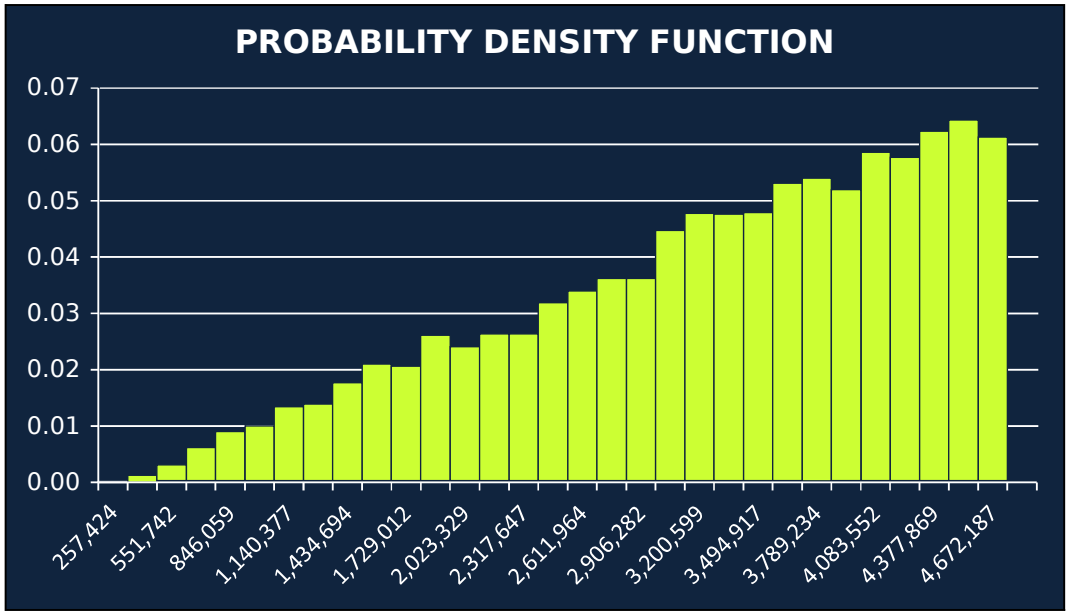


This WTP assumed to apply (stochastically) to people with tertiary from CERN member states + fraction of non-member population based om CERN visits

NON-USE BENEFITS: THE EXISTENCE VALUE

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

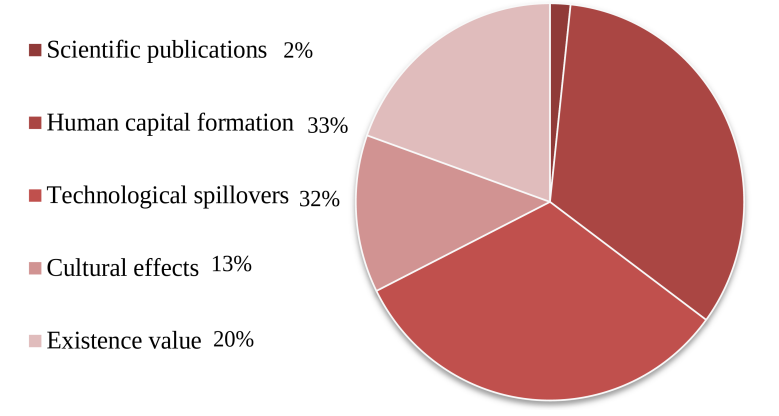
Present value in kEuro



SUMMARY: COSTS AND BENEFITS

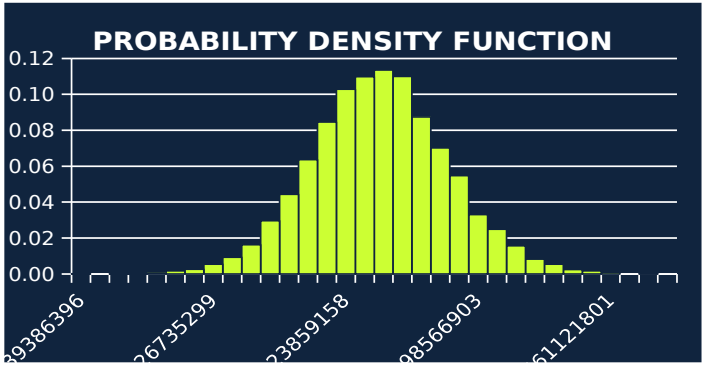
(MEURO)

• **COSTS**:		13.5	± 0.4
• **USE BENEFITS**:	knowledge formation	0.3	± 0.1
	human capital	5.5	± 0.3
	technological spillovers	5.3	± 1.7
	cultural	2.1	± 0.5
• **NON-USE BENEFITS**:	existence value	3.2	± 1.0



- Human capital, technological spillovers, cultural+existence value each give about 33% of benefits (publications negligible)
- Uncertainty largest on tech. spillovers
- Mean cost/benefit ratio (30 years) 1.2 with about one sigma significance; rate of return 4.7%
- More than 90% chance of positive NPV

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



CONCLUSIONS & OUTLOOK

THE MODEL

- The LHC case study shows that the model is viable
- One more (much easier) case study has been performed (CNAO)
- More are under way and will be needed for full validation & widespread adoption

THE LHC CASE STUDY

- More detailed studies using econometric methods required to reduce the dominant uncertainty: technological spillovers
- Contingent valuation can be improved and deepend by studying correlations

STAY TUNED!

HL-LCC & FCC STUDIES

- MOU with CERN to extend these studies and perfrom CBA for future facilities
- Plenary presentation by M. Florio at the forthcoming FCC week in Rome

Particle accelerators are the cathedrals of the XX century

(A. Weniberg, in coining the term “Big Science”)

How do we estimate the benefit of a cathedral?