Cost-benefit analysis of the High Luminosity LHC and economic impact on technological suppliers of CERN

(preliminary results)

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with

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SOCIO-ECONOMIC IMPACT
OF LHC TO 2025 AND BEYOND
Project Leadership
Developing and Maintaining Collaborations
Critical Analysis
Communication Skills
Problem-solving Capacity
Technical Skills
Scientific Skills
SKILLS
Human capital (H)
Technological spillovers
1'400 Firms
>30 Countries
14'400 Orders
Tech spillovers (T)
14'400 Orders
Superconductors & Magnets
Materials
Vacuum Components
Cryogenics
Power Cables and Conductors
Measurement and regulation
Refrigeration Equipment
Precision machinery
Electronic
500
1000
1500
INNOVATION
(1995-2008)
56% Off-the-shelf
44 % high-tech
Students 53%
(19400)
Post-docs 47%
(17400)
Students & Post-docs
(1993-2025)
LHC preprints & publications
(1993-2025)
808'000
P2: Publications by external scientists citing P1
228'000
P1: Publications by external scientists citing P0
23'000
P0: LHC related publications by CERN staff and collaborators
P0
P1
P2
Publications (S)
Public good value (EXV)
Cultural Effects (C)
3'000'000
Visitors to CERN
1'000'000
Visitors to travelling exhibitions
17'000'0
social media users
446'000'000
How much taxpayers contribute?
415 Million taxpayers
21 Member Countries
2 € pro per Person
€
LHC IMPACT (1993-2025)
Scientists (preprints & publications): 2%
Firms (technological spilovers): 32%
Students and post-docs (human capital): 33%
General public (cultural effects): 12%
Taxpayers (science as public good): 21%
References:
fcc.web.cern.ch

Outline

- Part I: social costs and benefits of HL-LHC
- Social CBA of research infrastructures
- Application to HL-LHC: methods and scenarios
- Benefits & costs
- Results
- Next Steps
- Part II: economic impact on suppliers of technology
- Approach 1, accounting data
- Approach 2,survey data
- Aproach 3, case studies
- Conclusion

Introduction to social CBA of research infrastructures


EN

Horizon 2020

Work Programme 2018-2020

4. European research infrastructures (including e-Infrastructures)

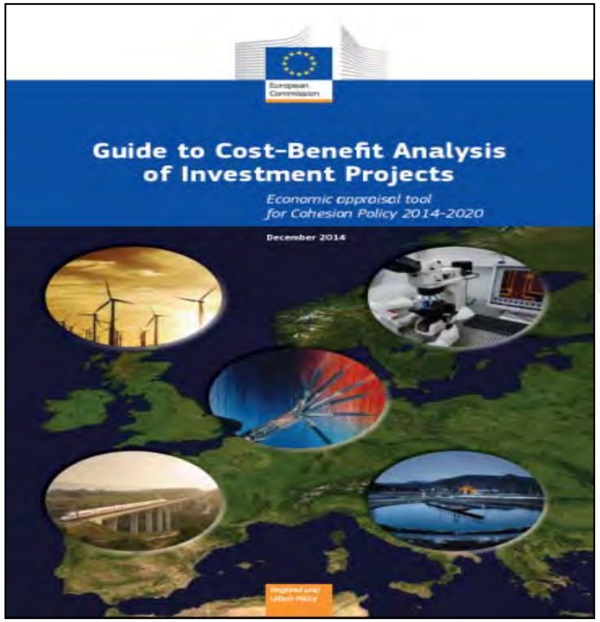
Important notice on the Horizon 2020 Work Programme

This Work Programme covers 2018, 2019 and 2020. The parts that relate to 2019 and 2020 are provided at this stage on an indicative basis. Such Work Programme parts will be decided during 2018 and/or 2019.

(European Commission Decision C(2017)7124 of 27 October 2017)

"(…) *The ESFRI roadmap, updated periodically, identifies the needs of the European scientific community in terms of research infrastructures* (…) *Societal and economic benefits of the infrastructure should be analysed to carry out a Cost-benefit analysis"*

[H2020 Work Programme 2018/20]



CBA Guide: European Commission (2014). "*Guide to Cost-Benefit Analysis of Investment projects*". DG Regional and Urban Policy.

- **CBA needed** for funding major projects under the EU Structural Funds;
- **Reference guide** for evaluation of RI under H2020 program [EC Decision C(2017)7124]

Social CBA of RI

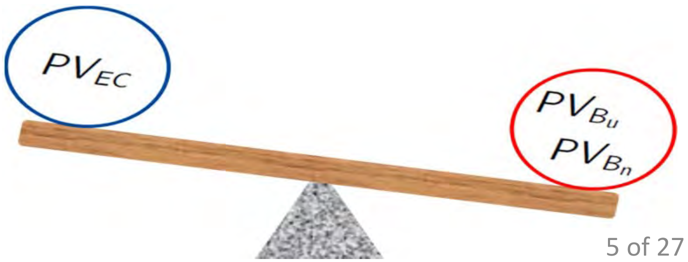
Methodology in a nutshell

$$\mathbb{E}\,(NPV_{RI}) = \mathbb{E}\,[\,\underbrace{(PV_{B_u} - PV_{EC})}_{NPV_u} + PV_{B_n}\,]$$

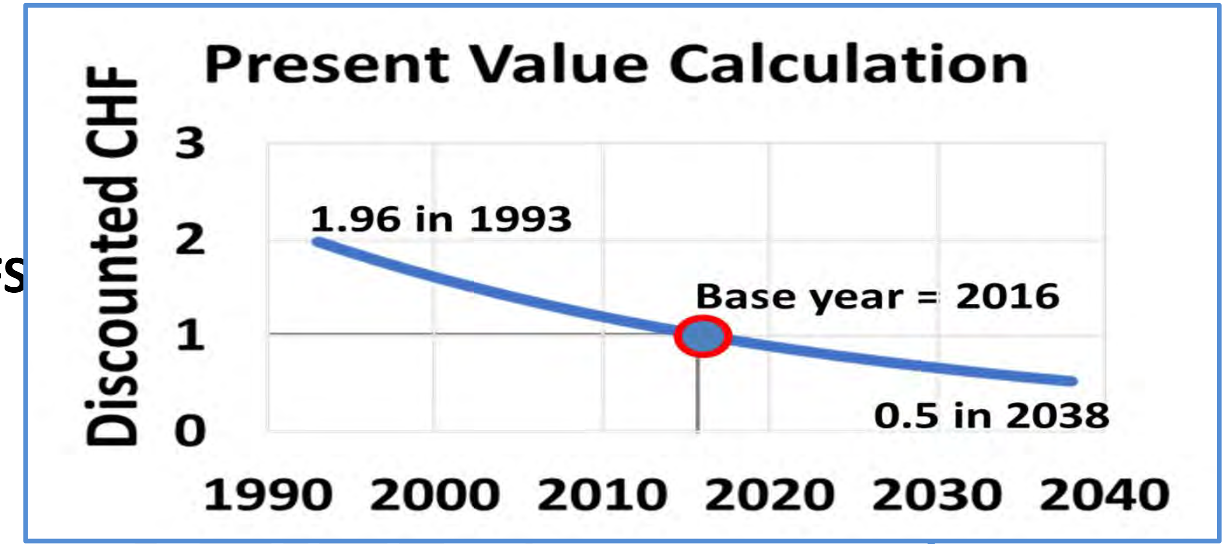
- NPV_{RI}: Net Present Value (NPV) of a RI
- $NPV_u = PV_{B_u} - PV_{EC}$: benefits for users of the R
- $PV_{B_n} \approx EVX$: benefits for non–users $\approx$ "public good value" of scientific discovery
- PV_{EC}: economic costs (i.e. operating, inv. costs and externalities, if any)
- PV_{B_u}: benefits of stakeholders

$\Longrightarrow$ RI passes CBA if:

$$\mathbb{E}\,(NPV_{RI}) > 0$$



CBA of HL-LHC
Methodology & assumptions



- **HL-LHC preferred to the counterfactual CFS**
- **if:**

$$NPV_{HL\text{-}LHC} > NPV_{CFS}$$

- **Difference due to HL-LHC**:

$$\Delta NPV = NPV_{HL\text{-}LHC} - NPV_{CFS}$$

- Base year: 2016 (i.e. discounting and inflation adjustments)
- Discount rate: 3% (EC - CBA Guide).
- Present value:

$$\boxed{PV = \sum_t \frac{1}{(1+0.03)^t}}$$

with t = -23 (1993), …, 0 (2016), 22 (2038)

CBA of HL-LHC
Methodology & assumptions

- Horizon: 1993-2038 for cost and most benefits (but up to 2080 for certain benefits).
- Other issues:
  - 1993-14: baseline scenario (HL-LHC) corresponds to LHC (CBA by FFS).
  - 1993-25: operating LHC "under normal consolidation" corresponds to FFS's CBA of LHC.
  - In both scenarios undiscounted figures for 1993-14 are the same as those in FFS.
  - Scientific personnel cost: removed to avoid double-counting benefits.
  - Inflation adjustment: using CPI for CH only over the 1993-16 period.
  - Inflation and exchange rates after 2016: no attempt to model or forecast them.
  - Warning: FFS used 2013 as base year, discounted values are numerically different


Contents lists available at ScienceDirect

Technological Forecasting & Social Change

ELSEVIER

Forecasting the socio-economic impact of the Large Hadron Collider: A cost–benefit analysis to 2025 and beyond

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CBA of particle accelerators: benefits

$$Benefits = \underbrace{(S + H + T + C)}_{PV_{B_u}} + \underbrace{EXV}_{PV_{B_n}}$$

Scientists (S): 1993-2063

- Preprints & publications

Students & post-docs (H): 1993-2063

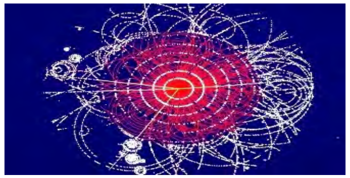
- Human capital formation

Firms (T) : 1993-2038

- Technological spillovers and open access software

General public (C): 1993-2038

- Cultural effects of outreach

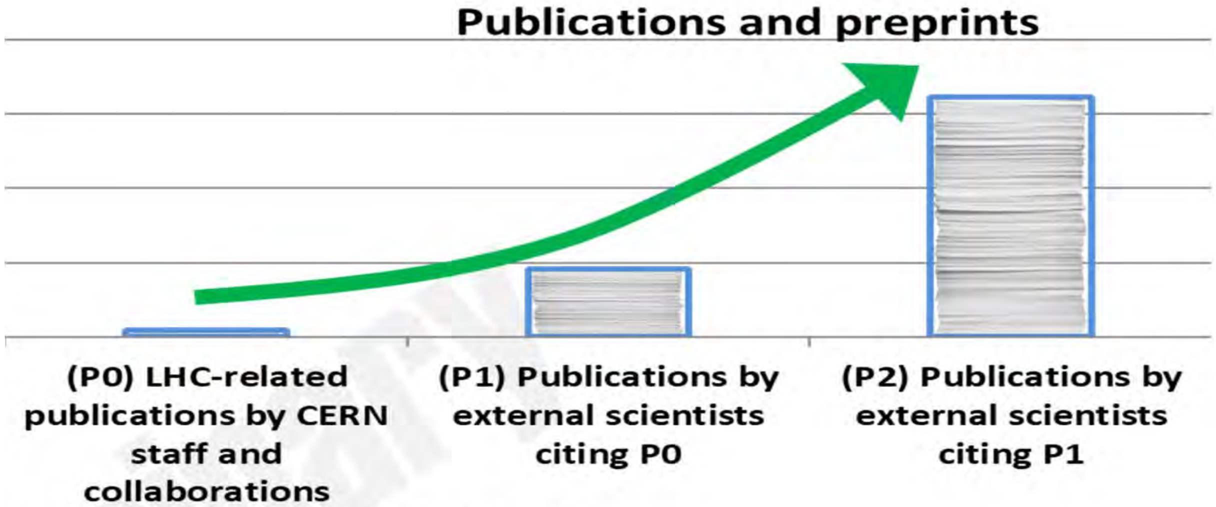


Taxpayers (EXV): 1993-2038

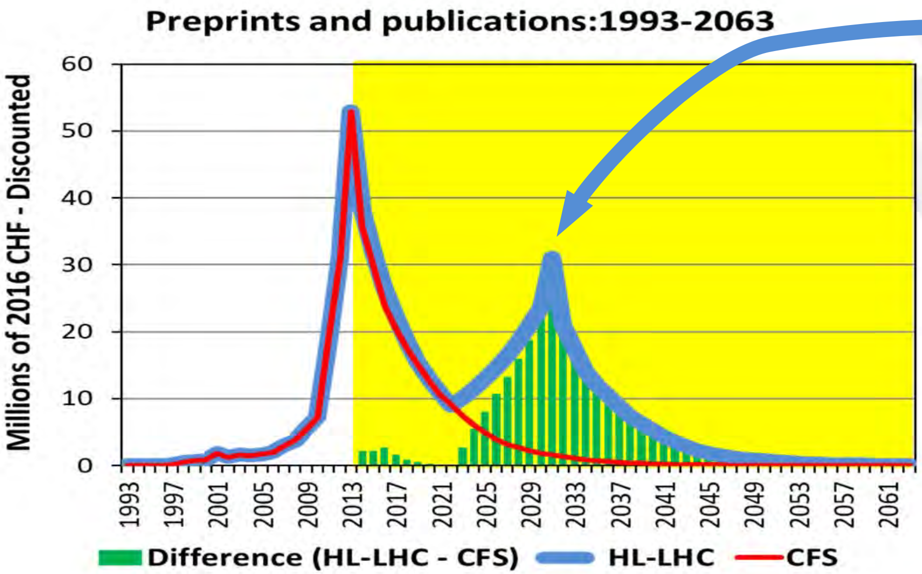
- Existence value: science as a public good

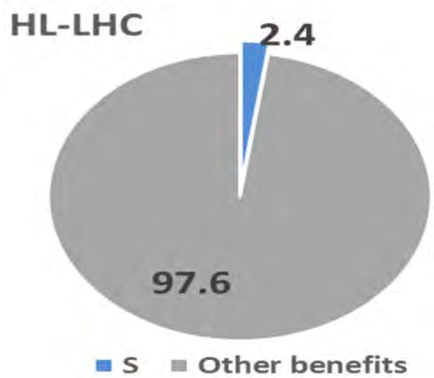
Scientists (S) - Preprints & publications (PP: 1993-2063)

- (P0) HL-LHC (or LHC) PP by CERN staff and collaborations (Value = cost prod.)
- (**P1**) PP by external scientists citing P0
- (P2) PP by external scientists citing P1 (value = 0)

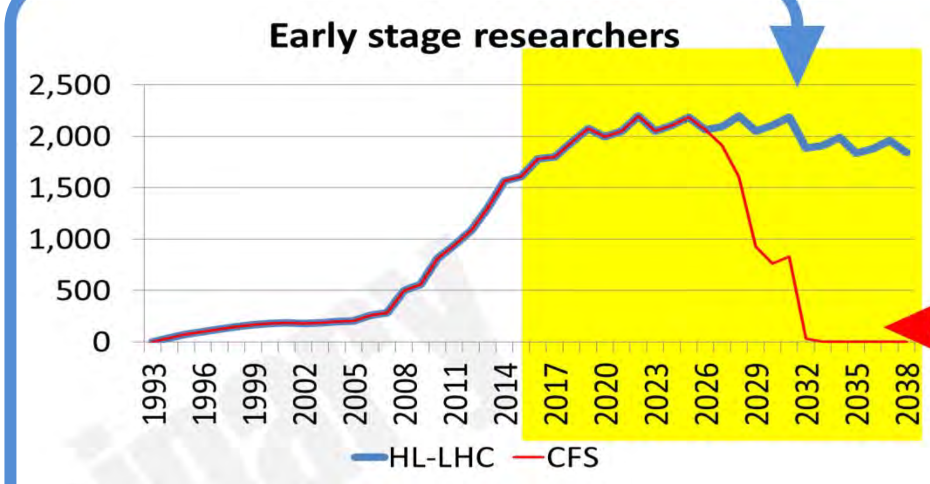


- **P1** benefits extend to 2036.
- HL-LHC: new peak in 2031
- i.e. new experiments and new physics?

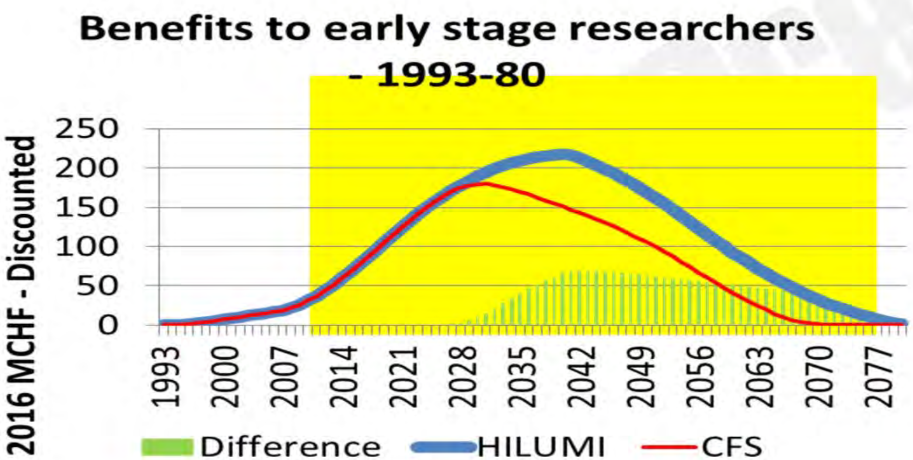


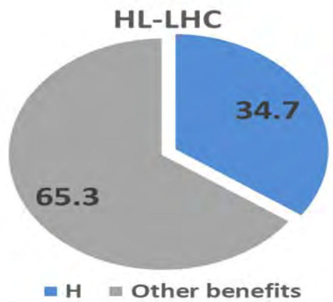


Early stage researchers (H) - Human capital effects (1993-2080)

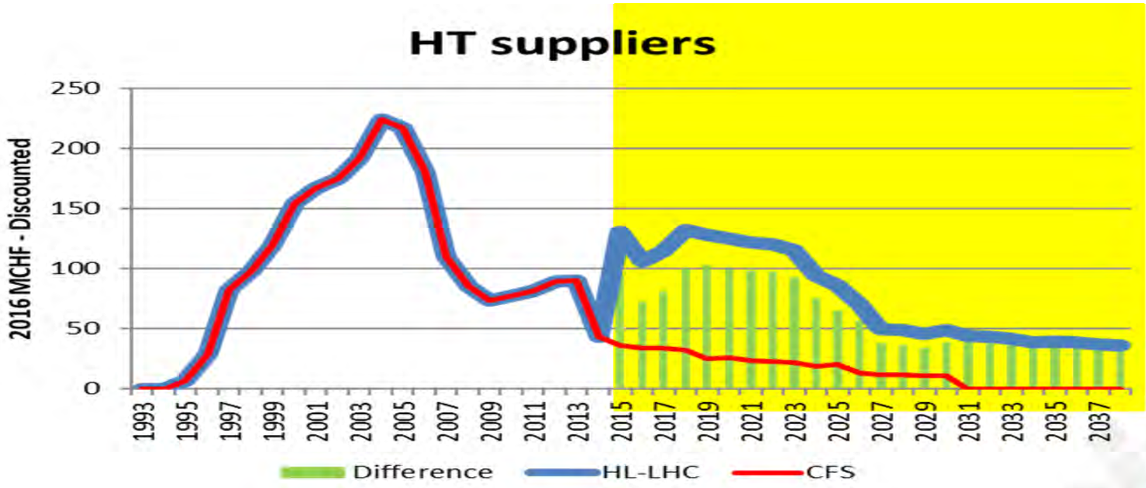


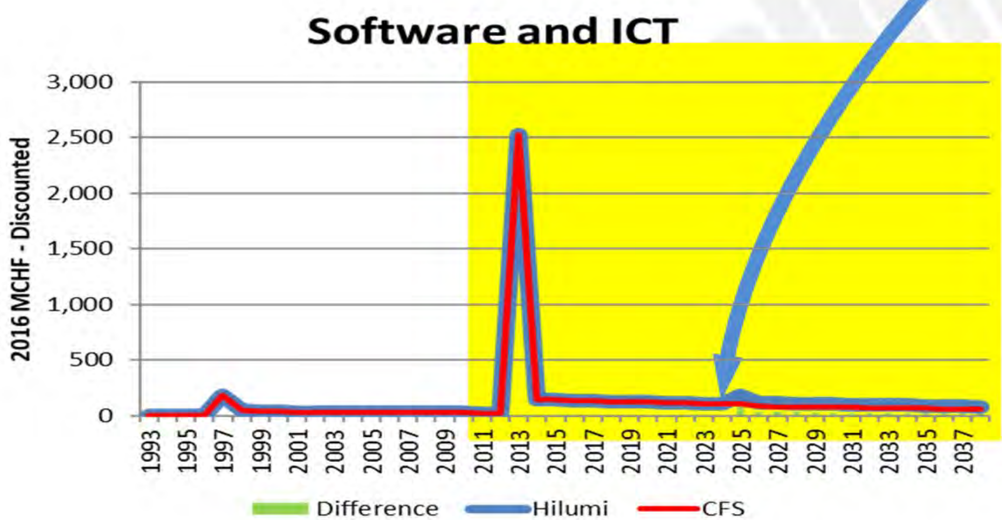
- HL-LHC: by 2025 no. ESR = full capacity
- CFS: without a major technological improvement, CERN loses attractivity for ESR





Technological spillovers & software (T) – Firms (1993-2038)





- Tech spillovers proportional to costs
- Share of HT procurement for HL-LHC greater than for CFS

- HL-LHC requires a substantial revision of current software to manage an increased experimental data flow
- HL-LHC: new peak in 2025 similar to Root in 1997 in FFS.
- <u>Very conservative assumption</u>: new codes?

"The High-Luminosity LHC (…) is planned to come online in around 2026. By this time, the total computing capacity required by the experiments is expected to be 50-100 times greater than today, with data storage needs expected to be in the order of exabytes"

Source: https://home.cern/about/updates

Cultural Effects (C) – General public (1993-2038)

Visitors to CERN, experiments & travelling exhibitions

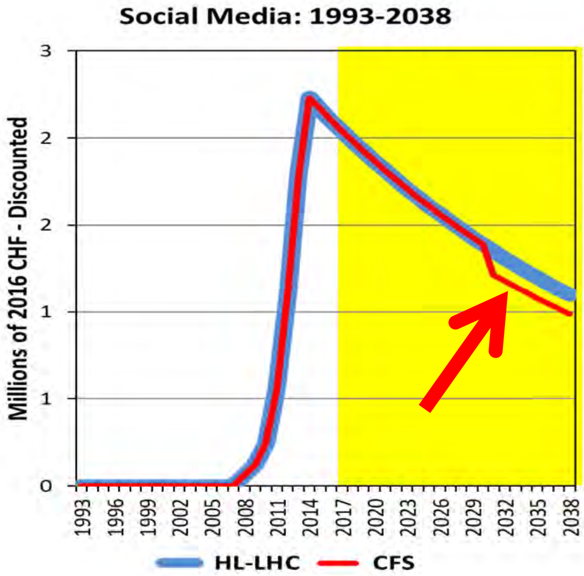
Social media users

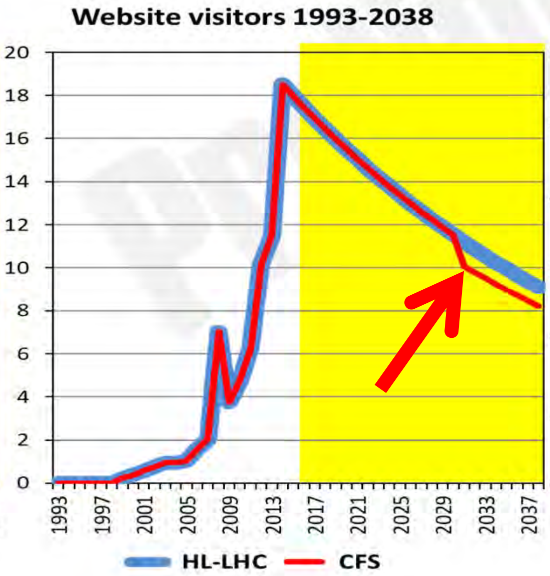
Website visitors & mass media on general public

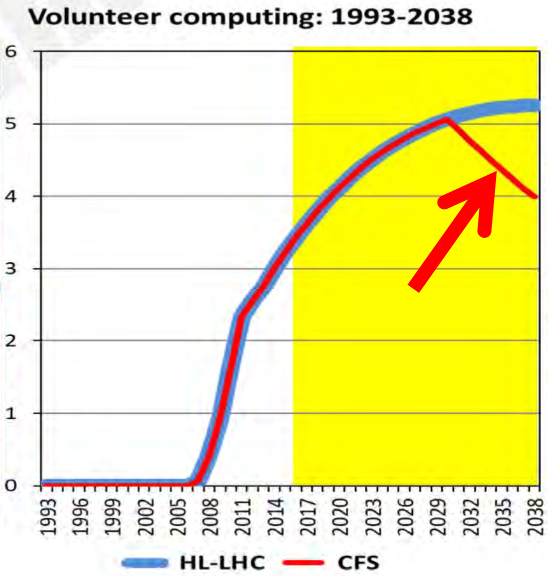
Volunteer computing

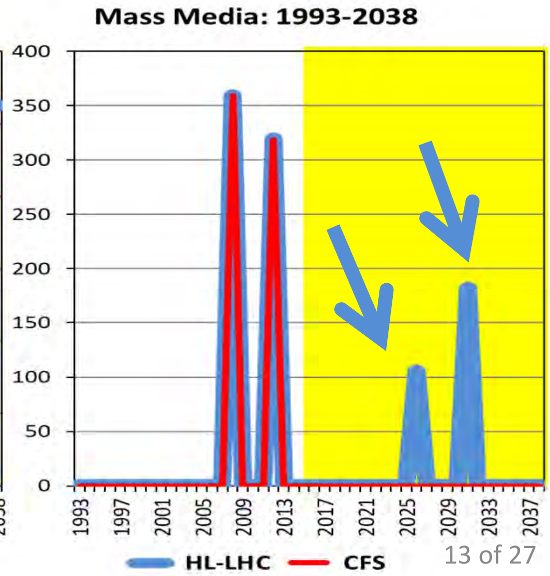
Cultural Effects (C) – General public (1993-2038)

- Personal visitors: increase during long shut down 4 for HL-LHC and increase after 2030 for CFS
- Website visitors and social media users: benefits decreases by 5% after 2030 for CFS.
- Volunteer computing: benefit decreases after 2030 for CFS

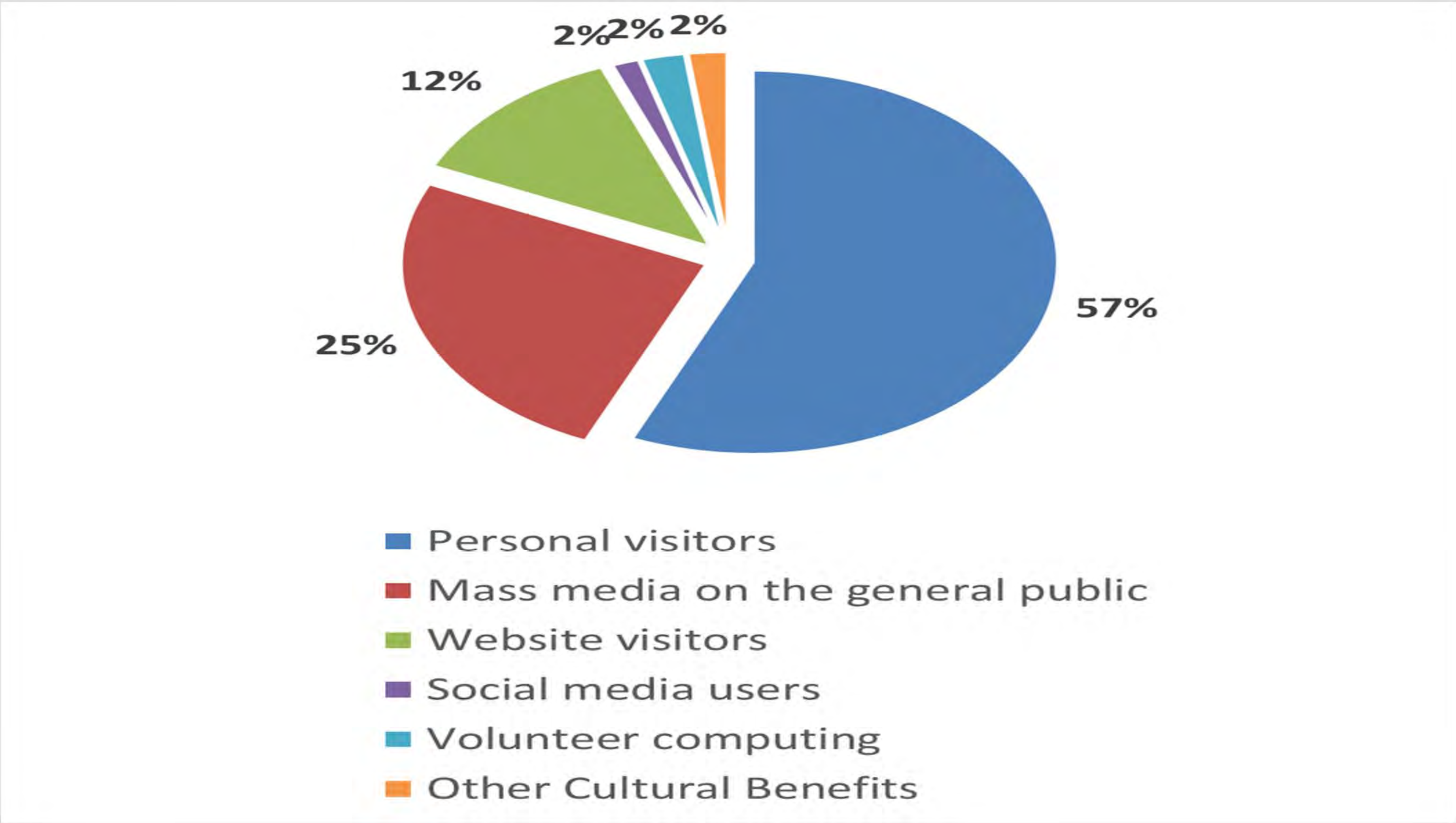








Cultural Effects (C) – General public (1993-2038)



Existence value (EVX) – Scientific knowledge as public good

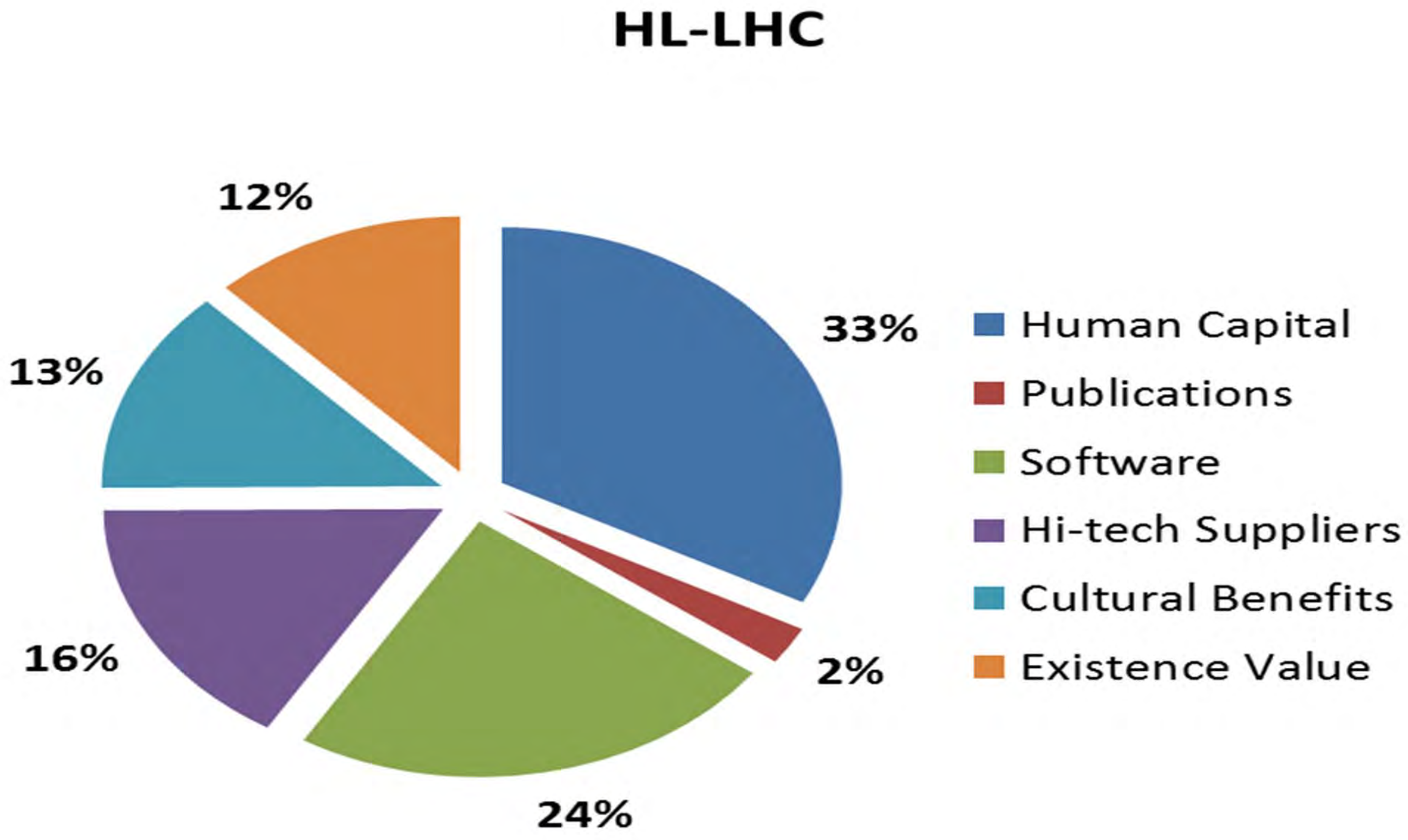
"*A resource or a service might be valued even if it is not consumed. Such values are referred to as non-use values (…) this should be reflected in the cost-benefit analysis (…) among these are existence values*" (Johansson and Kriström, 2015, pp. 24–25).

In 2016 the per capita contribution of the 415M taxpayers in Member States for CERN related discovery : was around 2.3 EUR each per year.

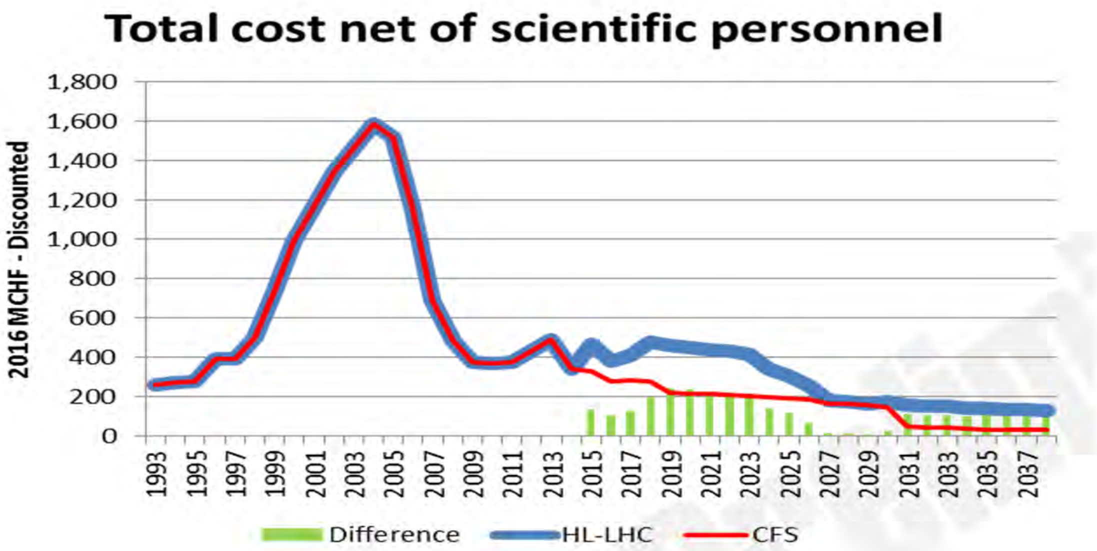
- Culture, science, environment are public goods and as such have an existence value reflected in the willingness to pay for them
- Median Annual per-capita WTP for the Royal theatre in Copenhagen: EUR 8 (DKK 60) [Hansen, 1997. J Cult. Ec., 21(1):1-28.

- WTP for LHC: contingent valuation experiment (FFS 2016).

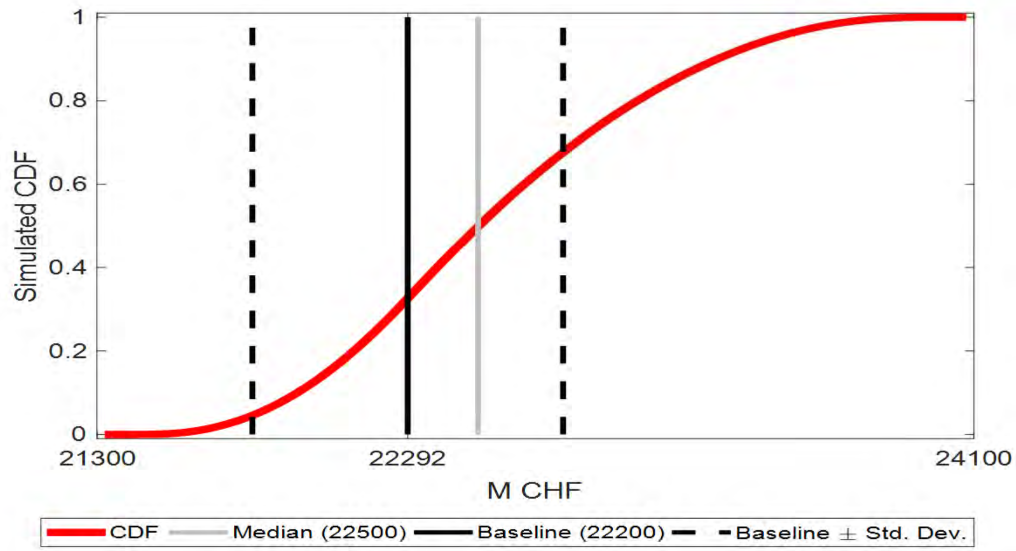
Benefits: share of total



Total Costs



(*a*) Total cost 1993-38

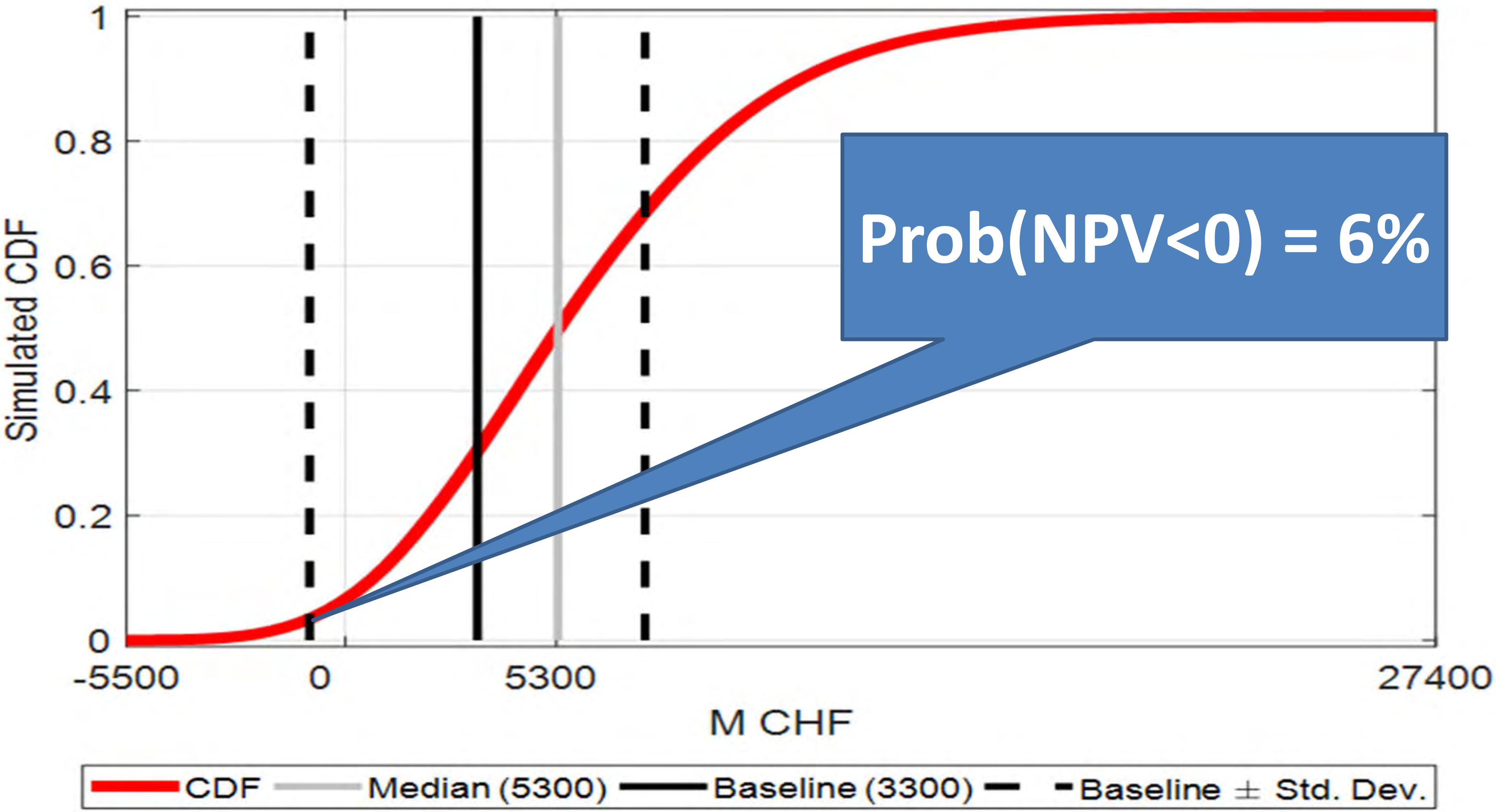


(*b*) Monte Carlo cumulative distribution function for HL-LHC

Cost-benefit analysis

Cost Benefit Analysis			
Discounted MCHF 2016	HL-LHC		%
Total cost	22292		
Total Benefit	25608		
Human Capital	8379		33%
Publications	613		2%
Technological Spillovers	10187		40%
- Software	6029		24%
- Hi-tech Suppliers	4158		16%
Cultural Benefits	3319		13%
Existence Value	3110		12%
NPV	3316		
B/C ratio	1.15		

HL-LHC Net present value: 1993-2080



Evaluating the economic impact of procurement on CERN supply chain

Three approaches

Accounting data (from the Orbis Database)

Castelnovo, Florio, Forte, Rossi Sirtori (2017)
WP DEMM

Surveys

Florio, Giffoni, Giunta, Sirtori (2017)
WP Cento Rossi-Doria

- Schmied (1975)
- Bianchi-Streit et al (1984)
- Autio et al. (2003)
- Autio (2004)

Case Studies

CSIL - Centre for Industrial Studies (2018)

- Aberg and Bengston (2015)
- OECD (2014)
- Arenius and Boisot (2011)

Approach 1

- **Aim**

To assess the existence of a positive long-term effect on LHC suppliers' R&D, innovativeness, productivity and economic performance (revenues and profitability).

- **Distinguishing features of the study**

The effects on the value chain and the suppliers of large RI have never been quantitatively evaluated by any econometric study: we are the first to perform an empirical analysis based on firms' balance-sheet data.

Data

- CERN-LHC Procurement Database 1995-2008:

Includes around 12.000 orders >10.000 CHF commissioned to almost 1300 LHC suppliers belonging to 35 different States

- Our sample:

Exploiting the Orbis Database, we were able to build a sample of more than 350 LHC suppliers for which financial data are available over the years 1991-2014, for a total of >5800 observations

Data

- Classification of activity codes according to their technological intensity based on CERN experts' assessment of a sample of 300 LHC orders > 10,000 CHF[1].

Lo-Tech	Hi-Tech
(1) very likely to be "off-the-shelf" orders with low technological intensity	(3) mostly "off-the-shelf" but usually high-tech and requiring some careful specification
(2) "off-the-shelf" orders with an average technological intensity	(4) high-tech orders with a moderate to high specification activity intensity to customize products for LHC
	(5) products at the frontiers of technology with an intensive customization work and co-design involving CERN staff.

[1] Details in: Florio, M., S. Forte and E. Sirtori (2016). "Forecasting the socio-economic impact of the Large Hadron Collider: A cost–benefit analysis to 2025 and beyond." *Technological Forecasting and Social Change*, 112, 38–53.

Methods

- Empirical approach: compare the before/after event values of the outcome variable for each firm

- This approach is similar to a difference-in-difference panel because we do not have just 1 before/after time, but 12 such different times, each involving different firms.

Empirical Model

1. $\Delta\left(\frac{IA}{empl}\right)_{it} = \beta CERN_{it} + Size'_{it}\gamma_1 + \theta_1\Delta GDP_{ct} + \theta_2\Delta CPI_{ct} + \sigma_s + \delta_t + \rho_c + \delta_t\rho_c + u_{it}$
2. $\Delta patents_{it} = \beta CERN_{it} + Size'_{it}\gamma_1 + \gamma_2\Delta\left(\frac{IA}{TA}\right)_{it} + \theta_1\Delta GDP_{ct} + \sigma_s + \sigma_t + \rho_c + u_{it}$
3. $\Delta\left(\frac{sales}{empl}\right)_{it} = \beta CERN_{it} + Size'_{it}\gamma_1 + \gamma_2\Delta\left(\frac{IA}{empl}\right)_{it} + \gamma_3\Delta\left(\frac{patents}{empl}\right)_{it} + \theta_1\Delta GDP_{ct} + \theta_2\Delta CPI_{ct} + \sigma_s + \delta_t + \rho_c + \delta_t\rho_c + u_{it}$
4. $\Delta Performance^{j}_{it} = \beta CERN_{it} + Size'_{it}\gamma_1 + \theta_1\Delta GDP_{ct} + \theta_2\Delta CPI_{ct} + \sigma_s + \delta_t + \rho_c + \delta_t\rho_c + u_{it}$
   where the subscript *j* identifies the three different measures of performance that we use: *j*=EBIT, Operating Revenue and EBIT margin.

These regressions are estimated on-by-one and also as a simultaneous system of equations

Findings

- We found evidence of a positive and statistically significant correlation between LHC procurement and supplier R&D effort, innovation capacity, productivity and economic performance (revenues, profits and profit margins)

- These results are driven by high-tech suppliers

⇒ A learning process leading to product and process innovation ultimately boosted the performance of high-tech firms only.

Approach 2: Survey

- To all CERN suppliers which received at least 1 order > 10,000 CHF between 1995 and 2015
- 5 languages on-line survey
- Multiple-choice questions, 5 point Likert scale *(strongly disagree, ..., strongly agree)*

Population	**Sample** (as of end April 2017)
4,204 suppliers from 47 countries	538 (**13%**) suppliers from 31 countries
33,414 orders	6,679 (**20%**) orders
4,318 Million CHF of expenditure	732 (**17%**) Million CHF of expenditure

Motivation and Research Hypotheses

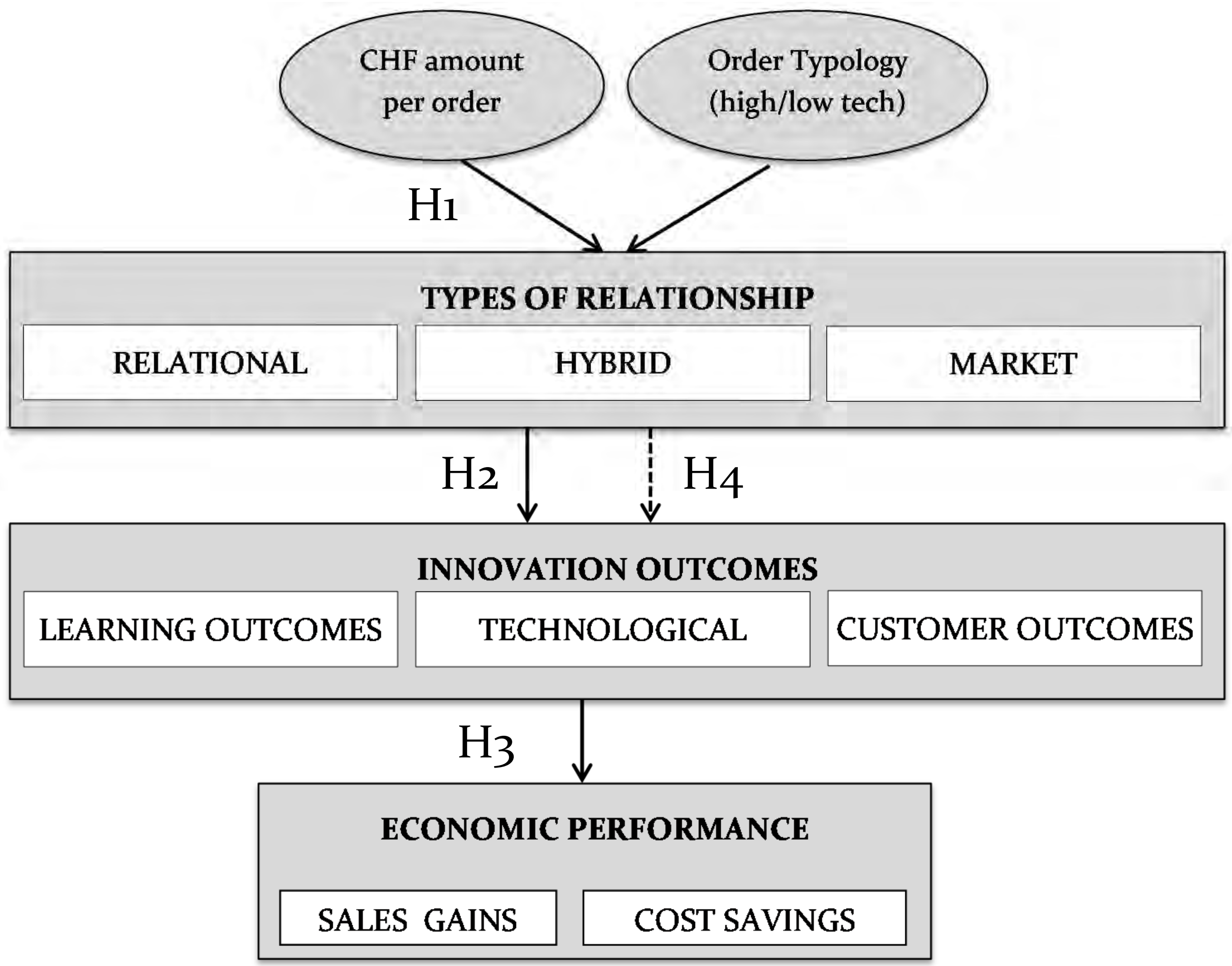
Does CERN stimulate innovation and economic performance of firms through its procurement activity? In what way?

H1: the technological level and the volume of orders shape the relationship between CERN and its suppliers

H2: more structured types of relationships positively influence CERN suppliers' innovation outcomes

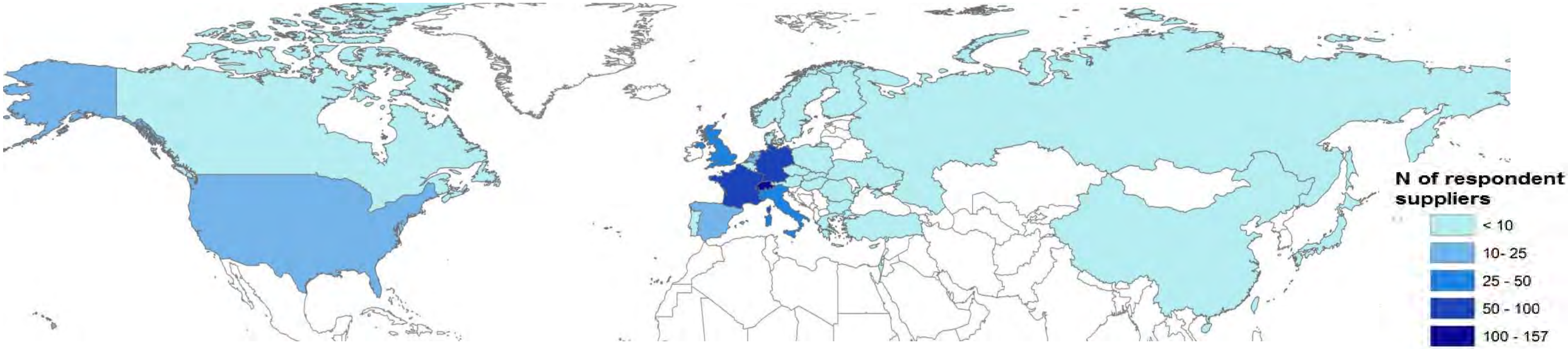
H3: innovation outcomes of CERN supplier firms are expected to positively impact on their economic performance

Conceptual model

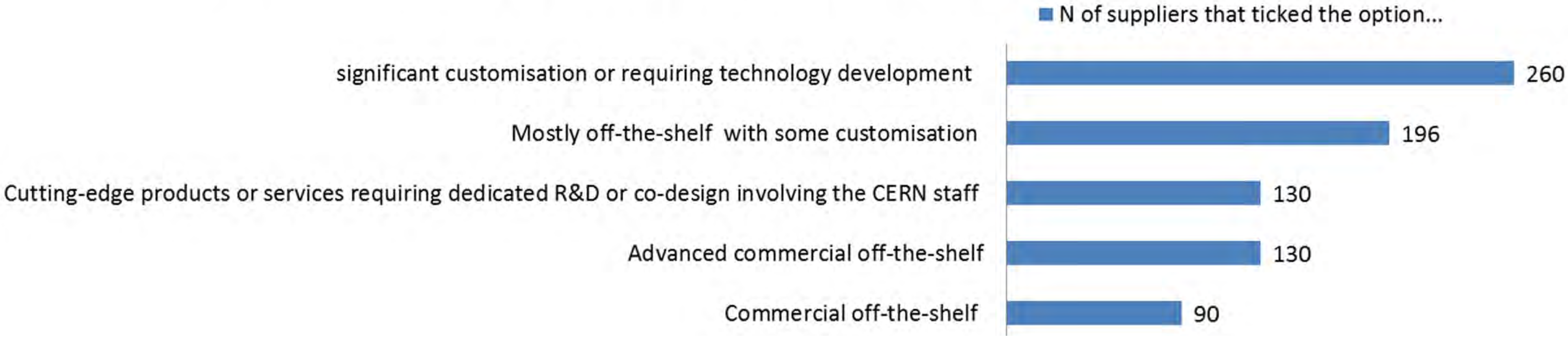


Control Variables
Size
Sector
Age
Experience as supplier of science centers
Country

Sample



What was the **INNOVATION LEVEL OF PRODUCTS AND SERVICES** supplied to CERN? (Tick at most 2 options)



Methodology of analysis

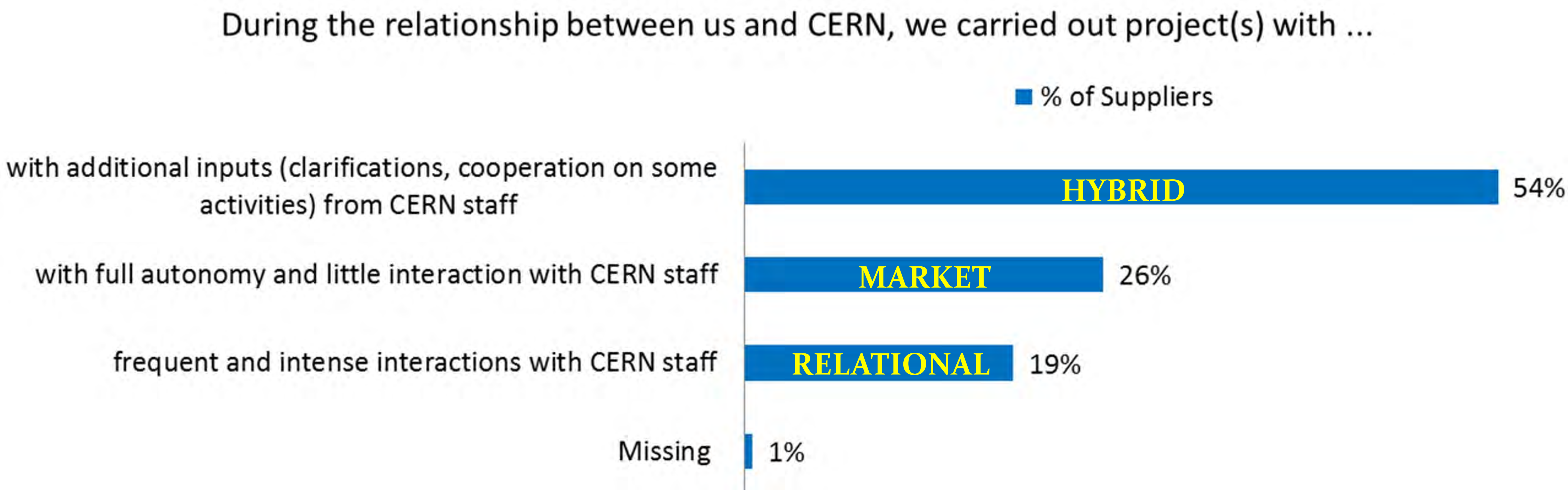
Bayesian Network Analysis (BNA):

- **Conditional probability distributions** to find multiple relationships and dependences among variables
- **Hierarchical arrangement** of variables via a directed acyclic graph
- **Causal mechanisms** are revealed
- Find **unexpected relationships** between variables

\+ **Econometric analysis** to test the robustness of results

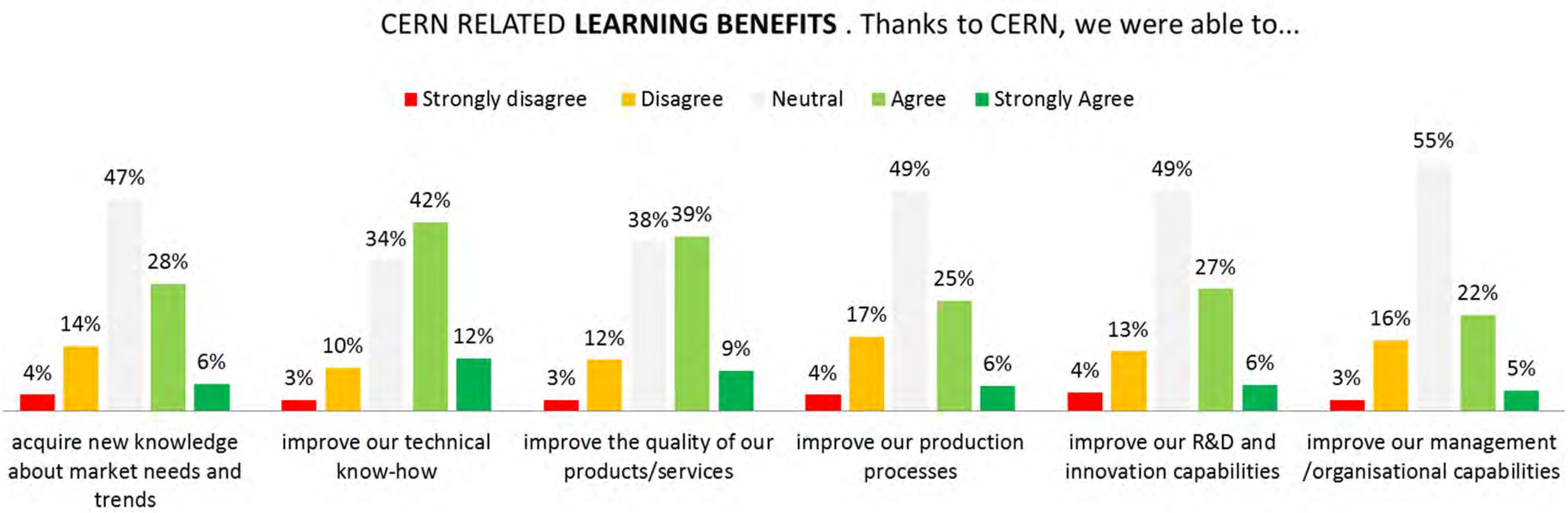
Testing H1: CERN-supplier relationship

H1: the technological level and the volume of orders shape the relationship between CERN and its suppliers



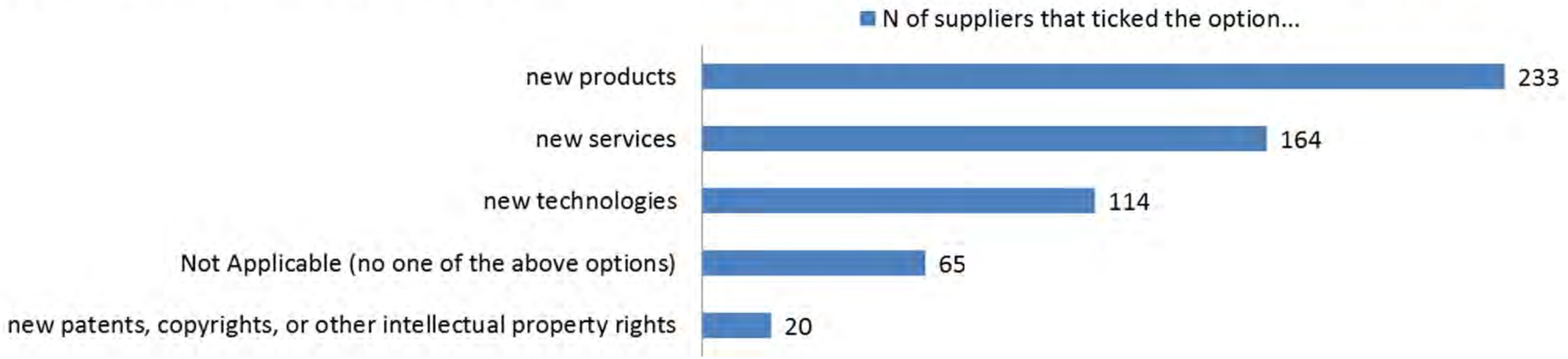
Testing H2: innovation outcomes

H2: more structured types of relationships positively influence CERN suppliers' innovation outcomes

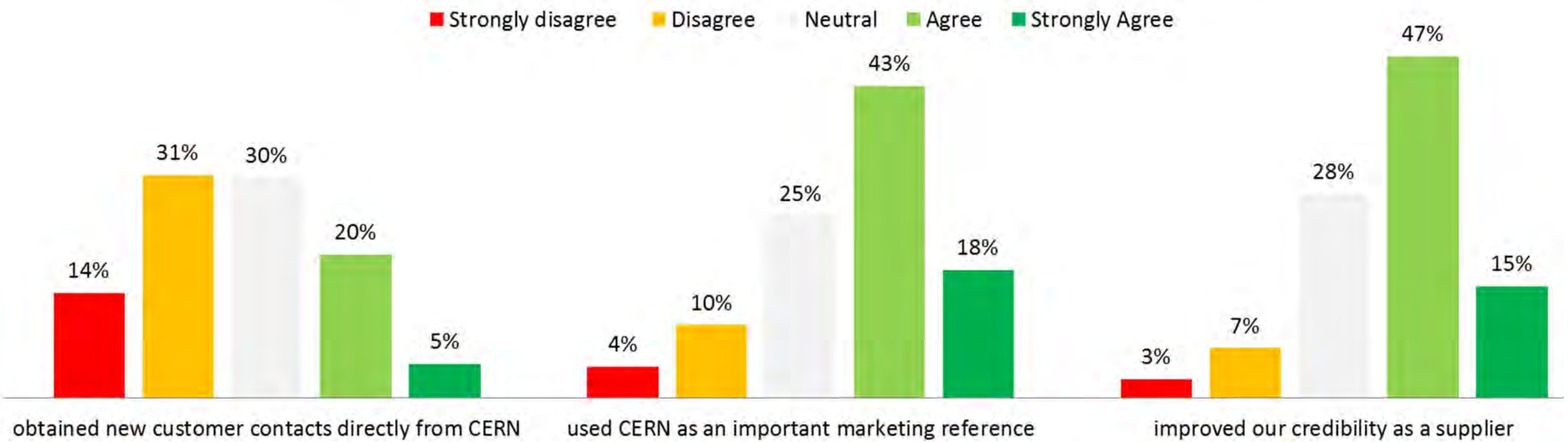


Testing H2: innovation outcomes *(cont.)*

As a results of new knowledge acquired and improvements, we were able to develop **TECHNOLOGICAL OUTCOMES**. Specifically ...

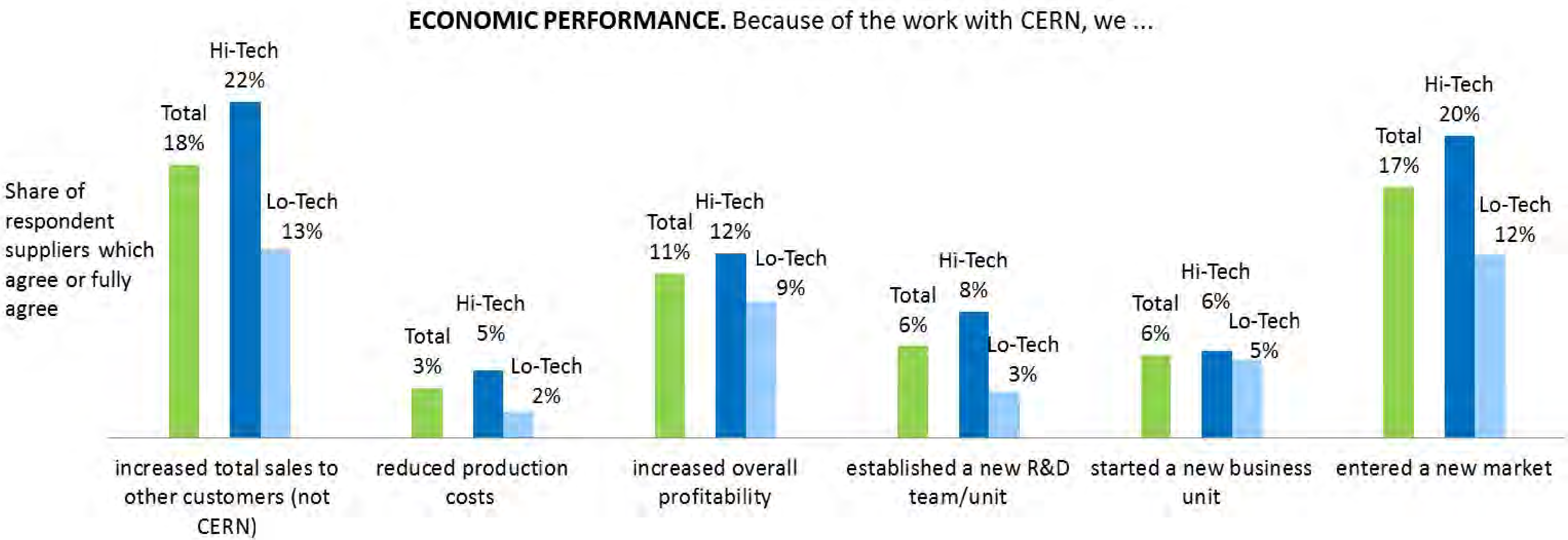


CERN RELATED **CUSTOMER BENEFITS**. Because of the relationship with CERN, we...

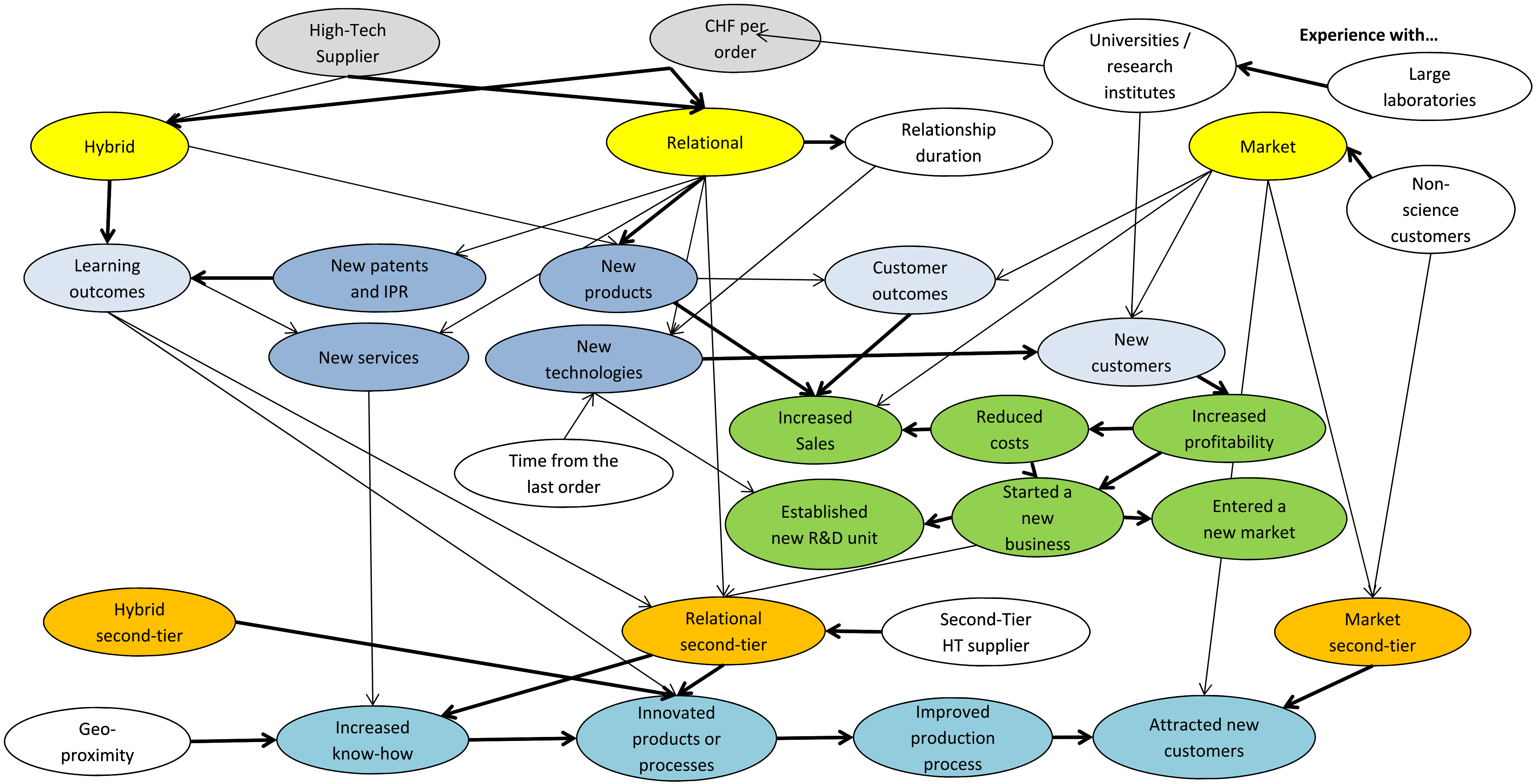


Testing H3: economic performance

H3: innovation outcomes in CERN supplier firms are expected to positively impact on their economic performance



Results – Bayesian Network



Approach 3: Case Studies

Work in progress…

Evaluation of CERN impact using the Ansoff matrix

Markets	Existing	Modified	New
New	**Market development (New clients)**	**Market extension through partial diversification**	**Diversification**
Expanded	**Market expansion through remerchandising**	**Market expansion through improved product**	**Partial diversification through new product line**
Existing	**Market penetration through advantage over competitors**	**Product extension through added value**	**Replacement through new product development**

Technology Innovation Level

Conclusions

- This study provides empirical evidence about the **various types of benefits** accruing to companies involved in a procurement relationship with CERN:
  - Technological benefits
  - Learning benefits
  - Market benefits

  Economic performance

- **Key mechanisms** which explain the type and size of benefits enjoyed are:
  - The way how CERN interacts with its suppliers
  - The type and volume of orders

Thank you!

Work in progress… Stay tuned!

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