Study of the socio-economic impact of CERN HL-LHC and FCC-HH

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REPORT
The Value of Human Capital Formation at CERN
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Disclaimer: This report has been prepared as a contribution to the FCC study (DCC-GOV-CC-0004, EDMS 1390795) in the frame of the Collaboration Agreement between the University of Milan and CERN (KE3044/ATS). The findings, interpretations and conclusions presented in this document are entirely those of the authors and should not be attributed in any manner to CERN or other institutions. Any errors remain those of the authors.
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List of Abbreviations

CERN  European Organisation for Nuclear Research
ECR   Early Career Researcher
HEP   High Energy Physics
LHC   Large Hadron Collider
HL-LHC High Luminosity Large Hadron Collider
NACE  National Association of Colleges and Employers
RI    Research Infrastructure
Executive Summary

This report summarises the results of the impacts of training that Early Career Researchers (ECR) experience during their activity in CERN’s LHC/HL-LHC programme. The report focuses on demonstrating the robustness of the findings by validating them using additional information such as the experience gained with an initial survey in the frame of the CERN Alumni Network\(^1\), a survey carried out with the leaders of those teams in CERN projects that form the frame for the training activities, salary surveys in the domain of physics and salary databases.

The findings lead to the following conclusions:

- An experience-based learning process at Research Infrastructure is instrumental in creating skills that are needed by economy.
- The study confirmed both quantitatively and qualitatively the impact of training in a CERN accelerator project in the form of a 5\% to 13\% salary premium for ECRs, depending on the level of higher education and technology field.
- The salary premium for ECRs involved in CERN projects is much higher in case of additionally acquired competencies - beyond the project technical domain - such as data analysis and software development skills for physicists and engineers.

\(^1\) [http://alumni.cern](http://alumni.cern), The CERN Alumni Network helps its members stay connected with the organization.
1. Introduction

CERN is an attractive environment for graduate and doctoral students, postdoctoral fellows and also for trainees. As reported by (1), the intake of these Early Career Researchers (ECRs) for the Large Hadron Collider (LHC) experiments during the period 1993-2025 amounts to approximately 36'800. This figure comprises around 19'400 master and doctoral students and 17'400 postdoctoral researchers (not including participants in limited duration training courses). In these studies the value of training has not been assessed for trainees and professionals of cooperating companies who also participate in the CERN programme for limited time periods, typically from 6 to 12 months. Beyond scientific, engineering and development activities, these ECRs draft a significant number of scientific products (e.g. papers, posters, presentations) (2).

For ECRs, having the opportunity to spend a period in a such vibrant and stimulating environment means developing new technologies, getting practically experiences with new technologies, having direct access to unique data, interacting with people from different cultures and knowledge domains, participating to meetings ranging from technical to managerial levels, actively contribute to conferences and workshops with established professional and renowned scientists. Such unique experience allows them to develop and improve skills and competences which are needed in almost all workplaces, also outside research [ (3), (4), (5)] from a certain professional level onwards. Studies report that skills learned in research laboratories are highly valued both in the academic and non-academic field\(^2\). CERN is a Research Infrastructure (RI) that builds and enhances the human capital\(^1\) of ECRs, thus contributing to an increase of personnel qualifications in the job market. This effect is measurable via higher average lifetime salaries and better job opportunities (2).

The benefit related to the human capital accumulation can be measured in terms of the expected incremental lifelong salary earned, over the entire career, by an ECR who has spent part of his/her educational period at CERN compared with a ‘peer’, who has not benefitted from such experience (hereafter, the without-project scenario). This incremental lifelong salary is the ‘premium’ earned over the entire career compared with the without-the-project scenario. Conceptually, two effects contribute to the salary premium. First, the premium reflects the marginal salary increase, gained by a former student who has spent time in the RI relative to the salary which he/she would have earned without such experience. Second, after the working experience in the RI, ECRs have an increases chance of being hired in labour markets or positions with higher average wages (e.g. the financial sector or a managerial position).

The expected present value of human capital accumulation benefits, \(E(H)\), can be defined as the sum of the expected increasing earnings, \(E(E_{it})\), gained by the RI ECRs and commonly indexed by \(i\), from the moment (at time \(\varphi\)) they leave the RIs (2).

\[
E(H) = \sum_{i=1}^{I} \sum_{t=\varphi}^{T} s_t \cdot E(E_{it}).
\]

where \(s_t\) is the discount factor \((1/(1 + Social\ Discount\ Rate)^t)\) at year \(t\). Directly assessing the effect produced by CERN would require tracking the careers of cohorts of students over a long time period, comparing salary information of people who are trained in the RI with those who lack such experience.

\(^2\) See for instance [ (16), (8), (18)]

\(^1\) By using the OECD definition, the human capital can be defined as “the knowledge and skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic wellbeing” [ (14) p. 29].
(2). However, this approach is not yet feasible due to the novelty of the study and the lack of an established long-term salary tracking framework. Therefore, the study depends on surveys, the experience of long-term ECR supervisors and existing, non-RI specific salary databases.

2. Aim of this report

Several studies [(3), (8) and (9)] have already quantitatively and qualitatively reported on the positive effects of CERN concerning the creation of human capital. The results are briefly described in Section 3 below. The objective of this report is to show the robustness of the results of these studies and to refine the level of the salary premium. The strategy adopted for this purpose has been threefold:

1. Gathering ‘fresh opinions’ from the recently created CERN Alumni Network accounting currently for more than 3'100 members and including students who have carried out their research at CERN. A previous survey (1) has been used as a basis for this investigation. The results are reported in Section 4.

2. Launching a consultation of the team leaders involved in CERN projects in order to assess from a different perspective the impacts on the career of students they have been supervising. The results are reported in Section 5.

3. Gathering information on the salary expectations of ECRs in the labour market using secondary data sources such as salary databases and existing surveys from funding agencies. A literature review on previous studies dealing with returns on education (e.g. doctorate vs. master degree) across different sectors has also been carried out. The results are reported in Section 6. A set of Annexes with results of surveys and a list of references complete the report.

3. Measuring the human capital benefit at CERN: previous estimates

A first quantitative estimation of the ‘salary premium’ arising from a training experience at CERN has been presented in (1) as part of the assessment of the socio-economic impacts of the LHC programme. Consistent with the literature on marginal returns to education (e.g. (6)), the benefit arising from the ECR experience at the LHC has been estimated by (1) as the present value of the LHC-related incremental salary earned over the entire work career. This effect does not correspond to the entire cumulative future salary of former ECRs, but it is a lower-bound estimation of the CERN premium effect on future earnings.

(1) considered five types of ECRs: CERN doctoral students, CERN technical students, CERN fellows, users under 30 years and users between 30 and 35 years4. In order to confirm the robustness of the economic benefit for each of these types of ECRs, a survey5 with about 400 current and former LHC students6 from more than 50 countries was carried out to elicit the expectations of two samples. Each respondent answered questions on a number of individual characteristics, his/her perception of the skills acquired at the LHC. Students provided information on the expected salaries and former students provided information on their current salaries. The research design assumed that former ECRs have

4 The sources of data are the yearly reports of CERN Personnel statistics from 1995 until 2013. Future incoming student flows have been extrapolated from past trends and checked with CERN. For more details, see (1).
5 The survey was performed between May and October 2014 and in March 2015 through an on-line questionnaire and direct interviews at CERN. The details of the survey, including the questionnaire, are available in (15).
6 This strategy reflected the need to have a control group of non-LHC peers, actually the current students at LHC experiments not yet employed.
acquired first-hand information of job market opportunities and could compare their expectations with those of their peers. It is found that the two samples’ averages for the premium effect are coherent. The average salary premium declared by the respondents who are already employed was approximately 9%. This percentage premium has been applied to the average annual salary at different experience levels, retrieved from the Payscale database\(^7\). In particular, salaries have been classified by experience level (entry, mid-career, experienced and late career) for different jobs in the USA and grouped in four broad sectors: industry, research centres, academia, and others (the latter including, for instance, finance, computing and the civil service). The distribution of the number of CERN students across these broad sectors has been retrieved based on earlier work by (3)\(^8\) and other sources. An additional small premium of between 2–3% has been applied because of the composition effect of job opportunities across occupations\(^10\). The resulting combined premium of 11.8% has been assigned to an average student over an active career period spanning 40 years. This implies that the cohort of students entering the job market in 2025 will perceive the benefit of the premium up to 2065. This premium has been found to be in a comparable range of the returns related to higher education in general which is reported in the literature\(^11\). The resulting expected value of the corresponding benefits has been found to repay 41% of the total LHC social cost and it is the largest single contributor on the benefit side.

A more detailed statistical analysis of the survey data used by Florio, Forte and Sirtori (2016) for their estimation was carried out by (7) with the objective to study the key determinant of incremental salary expectations. By using the same set of information, three main findings have been drawn from the analysis.

1. It can be confirmed that **there is no statistical difference in end-career expectations between current students and former students** who are employed and provide actual salary information.

2. **The core drivers of the expectations are the duration of activity in the LHC/HL-LHC programme and the type of skills acquired.** Hence, the perceived professional premium is not attributed to a purely reputational effect associated with the mere fact of having been selected for training at CERN, but it increases proportionally to the time spent on research in that context. Respondents were able to indicate on a five-point scale which were the most important skills acquired: the salary premium increases according to the perceived importance of technical skills. This result clearly points to learning-by-practical-experience as a driver for future professional opportunities. The **correlation between the two drivers is statistically significant.**

3. According to the convergent perception of respondents, either current or former students at CERN, there exists a **professional premium** arising from sustained practical learning in the RI. This premium is estimated to be **in the range of 5% to 12% over the entire career** compared to peers not having had the opportunity to be involved in the LHC/HL-LHC programme. Hence (7) confirms (3) with a multivariate analysis.

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\(^8\) (3)

\(^9\) With regard to CERN technical students, it was assumed that only 10% will go either to research centres or academia and 45% to industry and others. With regard to the other students, it was assumed destinations in research and academia for 60% and 20% respectively. Interviews with experts (including ‘head hunters’ who regularly monitor CERN students) confirmed this distribution.

\(^10\) See (3) for details on the job effect component of the human capital formation benefit.

\(^11\) For a review of more than 50 years of empirical research, see (17).
The findings of recent studies reporting qualitatively on the positive effects of CERN on the human capital formation of ECRs are highlighted in the following table.

Table 1: CERN human capital effects: evidence from qualitative studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Description</th>
</tr>
</thead>
</table>
| (3)   | A survey with students involved at CERN’s Large Electron–Positron Collider (LEP) Delphi experiment was performed in two phases (1996 and 1999). 671 students provided information about their first employment after they obtained their degrees with an accurate as a possible job description. Most of these students chose not to remain at CERN. They acknowledged that their activity in the LEP project has played a major role in their professional career. They reported that the private sector was specifically interested in specific skills acquired during this experience, such as:  
  o the ability to work effectively in large and diverse teams,  
  o the drive and motivation to solve complex problems,  
  o the exposure to cutting edge technologies in the electronics and computing domain,  
  o being familiar with software techniques related to handling large quantities of data and to perform sophisticated modelling. |
| (8)   | This study reports findings from a survey of early stage researchers in high energy physics. The objective of the survey was to record attitudes and interests, including career outlook, for those employed in non-academic fields after training in high-energy physics. A total of 1’112 responses were collected, around 750 from graduate students or postdocs, 57% US citizens, and the remainder from a number of other countries. Around 30% of the respondents were at CERN, 40% in universities, and the remainder in other laboratories. Two thirds wanted to pursue an academic career despite fears that funding for their field would decline. For those in a non-academic career, “many of the skills learned in HEP are seen as valuable skills”. The study provides also two examples of students previously working at CERN and then moved in other sectors to better explain how a learning process in RIs is instrumental in creating skills needed outside the basic research field. |
| (9)   | This study reports on a recent survey conducted by the CERN Alumni Network. The first version of online questionnaire was created in 2016 and was addressed only to former LHC experiments members. 282 responses were collected by September 2016. The questionnaire asked about the reason for leaving CERN, the current job position, the satisfaction with the current employment, the level of satisfaction with the period spent at CERN and the potential influence of CERN on their current position. Building on this pilot survey, a second version of the questionnaire was prepared to target both current and past members of the LHC programme and other CERN experiments. It included more detailed questions. 2’692 responses (specifically 97% respondents are from LHC and 3% from other CERN experiments) were collected by September 2017. The survey revealed that around one-third of... |

respondents (28%) moved from High Energy Physics (HEP) to other sectors of work. Out of these people (757 respondents), the majority currently works in the private sector (58%), specifically in ICT, engineering, consulting and other domains, where they hold key positions, such as management, directorate and executive level positions (around 140 in total). These people declared to have acquired a variety of skills at CERN which are considered to be important in their current job, specifically related to software technologies, working in an international group, data analysis, logical thinking and communication. The more they have spent time at CERN, the higher is their satisfaction with the current position and the larger and diversified are the skills they have acquired.

4. Survey to Alumni community

As mentioned above, the survey carried out by study (1) was extended to the CERN Alumni community in order to update and extend the previous sample. As in the first phase, the survey targeted both current researchers at CERN and former ones, now employed in different jobs and sectors. The survey was officially announced during the “CERN Alumni first collision event” held on February 2nd and 3rd, 2018. The link to the online questionnaire was announced on the Alumni platform by the University of Milan (Italy) and supported by the Alumni team (specifically by Laure Esteveny, Head of Alumni Relations at CERN). From March to May 2018, 54 new responses were collected. The average age of the respondents is higher than in the previous survey (34 years with respect to 31) and it includes respondents belonging to the highest salary category (84% in the new sample, 74% in previous one) with no respondents in the lowest two categories of salary expectations14. The average duration of stay at CERN, i.e. of the ‘learning’ experience in high-energy physics, is 43 months, which mirrors the average of 44 months in the previous sample.15 This new sample was added to the previous one (384 respondents) and the results were re-calculated16,17. The results of the original analysis were confirmed.

Following the methodological approach adopted in (7), the ‘salary premium’ was estimated by looking at the marginal effects18 of the working experience at CERN proxied by the variable duration of stay19 on the end-career salary expectations.

Results on the marginal effect can be interpreted as follows: one additional month of training spent at CERN increases the probability of declaring an expected salary in the highest category (>60 000 EUR) and reduces the probability of expecting a low salary (less than 60 000 EUR) by 0.292 percentage points.

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14The percentage of respondents in the two lowest categories of salary expectations in the previous sample was 10%.
15There is a slightly difference of 7 months in the length of stay between former researchers: 59 months in the previous sample and 52 months in the new one. The percentage of physicists is lower in the new sample (60% against 85% in the old sample) and, similarly, the level of education (the percentage of PhD holders is 47% in the new sample, while it was 71% in the old sample). However, these differences disappear when the two samples are merged. In the total sample of 438 entries (384 collected questionnaires in the previous survey plus the new 54 entries) the percentage of physicists is 84% and the percentage of PhD holders is 69%.
16For the re-calculation, model 5 reported in (7) was used.
17For the sake of a better interpretation of results, the Principal Component Analysis was avoided. The variable ‘Technical skills’ was obtained as a categorical variable either as a dummy variable (i.e. taking on the values 0/1) or as an ordered index (the higher the value, the higher the perception that respondents have improved their technical skills). Robustness checks were performed for any specification of this variable.
18The marginal effect is the probability of the salary expectation change per year of research carried out at CERN.
19Respondents were asked to indicate the overall number of months spent at CERN.
Considering an average stay of 45 months at CERN (24 months for students and 59 months for former CERN students which are currently employees), we found that the **CERN salary premium effect** for researchers belonging to the highest category is, on average, **13%** (17% or post-doctoral researchers, **7% for master level students**). This result is line with the findings reported by (7) and confirms that the estimates of the salary premium are sufficiently accurate for future CBA studies of a post-LHC particle-collider research infrastructure.

The average yearly salary level expected by respondents over the entire career amounts to EUR 49 265 (entry salary level), 75 617 (mid-career salary level) and 95 679 (experienced or senior salary level), expressed in 2018 currency value. By using the premium effects estimated on the basis of this survey’s results and the estimations reported by (7), a range of average salary premium earned by a person who was trained in the LHC/HL-LHC programme over an active work of 40 years is shown in Table 2 with and without applying a social discount rate$^{20}$.

**Table 2: Salary premium, absolute estimations**

<table>
<thead>
<tr>
<th>Salary premium effect</th>
<th>Source</th>
<th>Not discounted CERN salary premium (EUR)</th>
<th>Discounted salary CERN premium (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13%</td>
<td>Survey Alumni (2018)</td>
<td>Over 40 years: 428 240 Per year: 10 706</td>
<td>Over 40 years: 233 017 Per year: 5 825</td>
</tr>
<tr>
<td>12%</td>
<td>(7)</td>
<td>Over 40 years: 395 299 Per year: 9 882</td>
<td>Over 40 years: 215 093 Per year: 5 377</td>
</tr>
<tr>
<td>5%</td>
<td>(7)</td>
<td>Over 40 years: 164 708 Per year: 4 118</td>
<td>Over 40 years: 89 622 Per year: 2 241</td>
</tr>
<tr>
<td>9%</td>
<td>Average of results reported by (7)</td>
<td>Over 40 years: 280 003 Per year: 7 000</td>
<td>Over 40 years: 152 358 Per year: 3 809</td>
</tr>
</tbody>
</table>

5. **Survey to Team Leaders**

A survey of CERN ‘team leaders’ was launched in order to double check the findings highlighted in Section 3 as well as to assess the career of former CERN students from a different perspective. Team leaders are senior scientists, usually at universities or other research institution, who supervise the work of doctoral students and hence are be able to compare the career outcome of different students in their group, including those not having spent time at CERN or in other RIs. The survey was carried out from March to May 2018. 332 team leaders responded, a response rate of about 29% of the potential target, mostly from the Atlas and CMS experiments (Figure 1.e in Annex B). Out of the supervised doctoral students, 38% spent one year or more at CERN, 25% instead stayed at their university or went elsewhere for a research period. The remainder spent a shorter period of time at CERN (Figure 1.a in

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$^{20}$ Values have been discounted by using a discount rate of 3% as recommended by the European Commission’s CBA Guide.
Amongst others, financial constraints are cited by some team leaders as the main reason of limitation in the duration of stay.

For the majority of the respondents, the period at CERN is rated “very important” for students because of “working in an international environment”, the “possibility to work with world class scientists and engineers”, “deepening the knowledge and competences in the domain of work” (Figure 1.b). In comparison with students not benefitting from experience at CERN, the most important effect perceived by the team leaders in terms of skills acquired is the “ability to develop, maintain and use networks of collaborations” as well as “technical and communication skills” (Figure 1.c in Annex B).

Team leaders were asked to comment on the findings of (7) about the salary premium (Figure 1.d in Annex B). 85% of the respondents confirm the findings reported in (7) on the salary premium for ECRs having spent a research period at CERN. Specifically, half of the team leaders (54%) found the range reasonable and one third (31%) would have expected a greater impact. Only 3% would have expected a lower impact. 12% have stated that they did not possess sufficient information to be able to judge the impact of the stay at CERN on the salary levels of their former students. This points to a consensus agreement about the “salary premium” level since team leaders know different cohorts of students and also students not spending time at CERN over a significantly large period of time.

For a further analysis, we looked at the potential association between the CERN experiments (Alice, Atlas, CMS, LHCb and other experiments) and two specific questions. The first one, reported in the table below, was about the team leaders’ opinion concerning the salary premium (between 5% and 12%) estimated by (1). We were particularly interested in verifying whether the opinions of the team leaders on the estimated salary premium are independent of the CERN experiment.

To test this hypothesis of independence, we performed a Chi-squared tests. For both, Pearson and likelihood ratio tests, the p-value suggests to refuse the null hypothesis of independence, pointing to an association between type of experiments and team leaders’ opinion on salary premium. Cramer’s V is 0.154. This can be probably better visualized by considering the percentage values (Table 3 below).

**Table 3 – Association between CERN experiments and salary premium**

<table>
<thead>
<tr>
<th>CERN Experiment</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALICE</td>
<td>5</td>
<td>1</td>
<td>30</td>
<td>13</td>
<td>49</td>
</tr>
<tr>
<td>ATLAS</td>
<td>20</td>
<td>5</td>
<td>63</td>
<td>37</td>
<td>125</td>
</tr>
<tr>
<td>CMS</td>
<td>6</td>
<td>1</td>
<td>32</td>
<td>36</td>
<td>75</td>
</tr>
<tr>
<td>LHCb</td>
<td>3</td>
<td>0</td>
<td>15</td>
<td>4</td>
<td>22</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
<td>0</td>
<td>28</td>
<td>8</td>
<td>39</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>37</td>
<td>7</td>
<td>168</td>
<td>98</td>
<td>310</td>
</tr>
</tbody>
</table>
Based on their experience of supervising students, team leaders found the estimated salary premium as reasonable, and this is true also across different experiments (although with different shares), with the exception of CMS, where the majority of team leaders would have expected a higher impact. On average, 12% of the team leaders declared to have no knowledge of the job market (answer 1).

Another interesting association is between the CERN experiment and the number of doctoral students spending a training period at CERN. Team leaders were asked whether they expected the number of PhD students going to CERN from their institution to increase, decrease or remain stable.

To verify whether these expectations depend on the CERN experiment, again we tested the hypothesis of independence via Chi-squared tests; for both, Pearson and likelihood ratio tests, there is no sufficient evidence to refuse the hypothesis of independence, so there does not seem to be an association between the experiment and the number of doctoral students going to CERN from the team leaders’ institute. Cramer’s V is 0.132. Table 4 below shows the percentage values. Irrespective of the CERN experiment, the majority of team leaders thinks that the number of doctoral students coming to CERN will remain stable.

Table 4 – Correlation between CERN experiments and salary premium
In the table, replies indicate that team leaders think this number will: 1 = “Significantly decrease”; 2 = “Slightly decrease”, 3 = “Remain stable”; 4 = “Slightly increase”; 5 = “Significantly increase”. Incomplete answers were dropped, leading to a total number of respondents of 304 for this question.

<table>
<thead>
<tr>
<th>CERN Experiment</th>
<th>A.5 In the next 5-10yrs the # of doctoral stud going to CERN from your inst will</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALICE</td>
<td></td>
<td>2.04</td>
<td>6.12</td>
<td>51.02</td>
<td>28.57</td>
<td>12.24</td>
<td>100.00</td>
</tr>
<tr>
<td>ATLAS</td>
<td></td>
<td>0.83</td>
<td>16.53</td>
<td>56.20</td>
<td>22.31</td>
<td>4.13</td>
<td>100.00</td>
</tr>
<tr>
<td>CMS</td>
<td></td>
<td>4.11</td>
<td>5.48</td>
<td>63.01</td>
<td>16.44</td>
<td>10.96</td>
<td>100.00</td>
</tr>
<tr>
<td>LHCb</td>
<td></td>
<td>4.55</td>
<td>4.55</td>
<td>59.09</td>
<td>18.18</td>
<td>13.64</td>
<td>100.00</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>0.00</td>
<td>17.95</td>
<td>48.72</td>
<td>20.51</td>
<td>12.82</td>
<td>100.00</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1.97</td>
<td>11.51</td>
<td>56.25</td>
<td>21.38</td>
<td>8.88</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Pearson chi²(16) = 21.2594  Pr = 0.169

Note: Pearson chi²(16) = 21.2594; Pr = 0.169; likelihood-ratio chi²(16) = 22.7080; Pr = 0.122; Cramér’s V = 0.1322
6. Statistical analysis on salary expectations with secondary data

The findings from the data presented above (see Table 5 below for an overview) have been compared to the returns to non-specific higher education that secondary data sources indicate.

**Table 5: CERN human capital premium: results from primary data**

<table>
<thead>
<tr>
<th>Reference</th>
<th>Estimated Salary Premium</th>
<th>Data Source</th>
<th>Year of the survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>9 - 12%</td>
<td>Survey with 384 CERN current and former students and additional estimation</td>
<td>2014 - 2015</td>
</tr>
<tr>
<td>(7)</td>
<td>5 - 12%</td>
<td>Survey with 384 CERN current and former students</td>
<td>2014 - 2015</td>
</tr>
<tr>
<td>See Section 4 above</td>
<td>9 - 13%</td>
<td>Survey with the 384 original and 54 newly collected questionnaires from the CERN Alumni community</td>
<td>2018</td>
</tr>
<tr>
<td>See Section 5 above and Annex B for details</td>
<td>5 - 12%</td>
<td>Survey with 322 Team Leaders</td>
<td>2018</td>
</tr>
</tbody>
</table>

The extra salary earned due to an increase in years of education acts as a proxy for the estimation of the so-called “return to human capital” (10). The effect of a research period at CERN in terms of salary premium can be compared with the effect of general doctoral studies at universities elsewhere. The idea is to compare the salary premium resulting from a year of experience at CERN to the salary premium of a year of doctoral study elsewhere. Obtaining a doctorate degree allows students to acquire skills that are relevant in their career, such as understanding and analyzing a large amount of information, managing complex projects, preparing concise written documents, working under-pressure and moving deadlines.

In order to estimate these returns, information was collected on the salary differences between people with a master’s degree and those with a doctoral degree (see Table 6 below for an overview). The average gross annual salaries associated with different labour markets can be derived from national and international statistics. For instance, (11) (12) (13) report the results of a salary survey in the field of physics. As Table 6 shows, starting salaries for persons with a doctorate in physics (classes 2013-2014) have a median between 25 and 75 percentiles of USD 71,000 per year\(^{21}\). The equivalent salary after one year for those with a master’s degree was USD 53,000 (in the period 2012-2014)\(^{22}\). Although the samples are small, the reported data would imply a “premium” of around USD 18,000 (34%) at the

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\(^{21}\) USD 99,000 permanent full-time jobs in the private sector – 31% of respondents; USD 66,000 for those working in government positions - 14% of respondents; 46,000 for those working in academia – 52% of respondents. 

\(^{22}\) USD 65,000 in the private sector – 53% of respondents; USD 41,000 in the academia – 19% of respondents. 
starting level in the US. Assuming that the average number of years needed to earn a doctoral degree is four years\textsuperscript{23} – a single year of doctoral study corresponds to a salary premium of USD 4,500 (34%/4 = 8.4\%) which is consistent with the additional expected LHC salary premium estimated by the student, alumni and team leader surveys. Hence, if the doctorate degree premium in physics is USD 18'000, the cumulate effect of doctoral studies plus one year of research at CERN would be roughly (4+1)18,000/4 = USD 22.500. Lower returns for doctoral studies are found by the NACE (National Association of Colleges and Employers) salary survey\textsuperscript{24} in other scientific sectors. However, these figures are not based on the 25 and 75 percentiles and refer to base salaries only, hence they do not include bonuses, commissions, fringe benefits or over time rates. Data are obtained by surveying NACE employer members from August 2016 to November 2016 for a total of 243 people (25.3\% response rate). Results show a total doctoral study premium of 24\% in math and science, 28\% in engineering and 37\% in computer science. A single year of doctoral studies would correspond to a premium of 5.9\%, 7.0\% and 9.2\% respectively. These percentages are again comparable with the potential CERN premium found from the primary data collection, which further increases the doctoral degree premium. However, the premium of doctoral studies is lower than the premium of doctoral studies carried out in the LHC/HL-LHC programme at CERN.

In continental Europe and for natural sciences in general, the doctorate premium tends to be lower, but exact data do not exist. The premium is reported to be in the 20\%\textsuperscript{25} range. The average yearly salary for a general master’s degree is EUR 47\‘200 per year. For doctoral degrees, it is on average EUR 55\‘266 per year. The doctoral degree premium in Europe is 4.3\%, which is significantly lower than the one estimated than the doctoral programme premium of created by the LHC/HL-LHC programme at CERN, estimated by (7).

A different way to approach the discussion on the salary premium for ECRs and the comparison between primary and secondary data is to consider the salary difference in terms of the skill set acquired during the period spent at the LHC/HL-LHC programme. A detailed survey of the economic value of specific skills remains yet to be carried out. Some initial indications exist, however. According to the Payscale survey data\textsuperscript{26}, a physicist with data analysis skills has an average salary of USD 93\‘140, while the average salary for a research position in physics is USD 89\‘000 and USD 75\‘000 for a physicist with generic skills. The total yearly salary premium for a physicist with specific skills is in the range of 5.5\% to 26.7\% compared to a physicist with generic skills (see Table 7 below). Based on these differences, the skills acquired by persons who spend a research period at CERN can therefore be considered for an additional salary premium with respect to persons who have not carried out a significant period of practical research and development during their studies.

\textsuperscript{23} An examination of different PhD courses respectively in Europe and USA suggested an average length of around 4 years.
\textsuperscript{26} https://www.payscale.com/research/US/Job=Physicist/Skill accessed on March 7, 2018
Table 6: Salary premium for a doctorate degree in STEM: an overview from secondary data sources

<table>
<thead>
<tr>
<th>a) Reference</th>
<th>b) Description of data</th>
<th>c) Year</th>
<th>d) Statistics</th>
<th>e) Field of Science</th>
<th>f) Salary for a person with doctoral degree</th>
<th>g) Salary for a person with Master degree</th>
<th>h) Total Salary Premium</th>
<th>i) Total Premium (%)</th>
<th>j) 1 year Salary Premium</th>
<th>k) 1 year Salary Premium (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doctorate: [12] American Physical Society Statistical Research Center</td>
<td>Doctorate: US - Data are based on respondents holding potentially permanent positions in the private sector (158) and in universities and 4-year colleges (36) and on postdocs in government labs (65) and in universities and UARIs (291);</td>
<td>Doctorate: 2013 &amp; 2014</td>
<td>Median (USD)</td>
<td>Physics</td>
<td>66,000 (government, 14%) 48,000 (university, 52%) 99,000 (private sector, 31%)</td>
<td>41,000 (university, 53%) 65,000 (private sector, 19%)</td>
<td>18,000</td>
<td>34%</td>
<td>4,500</td>
<td>8.5%</td>
</tr>
<tr>
<td>NACE (National Association of Colleges and Employers) Salary Survey</td>
<td>US - NACE members (243 respondents)</td>
<td>2017</td>
<td>Average (USD)</td>
<td>Computer Science</td>
<td>110,841 81,039 29,802</td>
<td>37% 7,451 9.2%</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Engineering</td>
<td>95,973 75,053 20,920</td>
<td>28% 5,230 7.0%</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Math &amp; Science</td>
<td>86,713 70,061 16,652</td>
<td>24% 4,163 5.9%</td>
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<td></td>
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</tr>
<tr>
<td><a href="https://www.academics.com/science/salaries_who_earns_what_in_research_and_development_53193.html">https://www.academics.com/science/salaries_who_earns_what_in_research_and_development_53193.html</a> and <a href="https://www.academics.com/science/what_chemists_earn_37951.html">https://www.academics.com/science/what_chemists_earn_37951.html</a></td>
<td>Salary comparison conducted by Personal Markt based on an evaluation of 15,857 datasets</td>
<td>2013</td>
<td>Average (EUR)</td>
<td>General scientific subject</td>
<td>55,300 48,000 7,300</td>
<td>15% 1,825 3.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Natural Science</td>
<td>55,266 47,200 8,066</td>
<td>17% 2,017 4.3%</td>
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<tr>
<td></td>
<td>Chemistry</td>
<td>63,000 57,000 6,000</td>
<td>11% 1,500 2.6%</td>
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</tbody>
</table>

Table 7: Average salary for a physicist in the US by skills

<table>
<thead>
<tr>
<th>AVERAGE PHYSICIST</th>
<th>Average Salary USD</th>
<th>Total Premium compared to the average physicist</th>
<th>Total Premium compared to a physicist with generic skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research physicist</td>
<td>89,000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>General physicist</td>
<td>75,000</td>
<td>-15.7%</td>
<td>24.2%</td>
</tr>
<tr>
<td>Physicist with data analysis skills</td>
<td>93,140</td>
<td>4.7%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Physicist with engineering skills</td>
<td>79,096</td>
<td>-11.1%</td>
<td>26.7%</td>
</tr>
<tr>
<td>Physicist with research analysis skills</td>
<td>95,000</td>
<td>6.7%</td>
<td>16.3%</td>
</tr>
<tr>
<td>Physicist with systems engineering skills</td>
<td>87,203</td>
<td>-2.0%</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors based on Payscale 2018
7. Conclusions

The education programme at CERN generates human capital with significantly higher qualifications that translate into a salary premium with respect to persons who do not carry out such additional studies and who enter the labour market immediately after their bachelor’s or master’s degree or doctoral studies. The salary premium effect is either direct, valuing the additional skills and experience or indirect, if the person enters a position that is characterized by a higher salary because it includes managerial or leadership tasks.

Based on a range of statistical models, we have estimated that performing research and acquiring skills at CERN (particularly at LHC/HL-LHC programme and experiments) leads to a salary premium effects which varies between 5% and 13% more than the normal return to education in the relevant fields. For example, if the average PhD premium in natural science in Europe (as from Table 6 above) is 4.3%, the cumulated effect of the PhD premium and the CERN premium would be in the range of 9.3% (4.3% + 5%) and 17.3% (4.3% + 13%). The total lifetime salary premium varies depending on the obtained academic degree and the total duration of the stay at CERN.

These findings - reported by previous studies [(1) and (7)] - have been confirmed by the new evidence collected for the purpose of this report with complementary methods (student and alumni community surveys, feedback from team leaders and secondary salary information from national and international salary databases).

Since the employers value the additional degree, skills and experience, training at CERN generates a measurable socio-economic added value.

Acknowledgments

A special thank goes to Johannes Gutleber (secretary of the FCC study, member of the host-state concertation structure, CERN Accelerator and Technology Sector Directorate Office) for his continuous suggestions on the design and implementation of activities which have allowed to the findings presented in this report and for the reviews of the report. We also thank many people for the helpful discussion which have indirectly contributed to this report, including: J. Butler (CERN, CMS), T. Camporesi (CERN, CMS), A. Charkiewicz (CERN, CMS), J. Closier (CERN, LHCb), A. Cook (CERN, Human Resources Department), C. D’Ambrosio (CERN, LHCb), F. Dittus (CERN, Atlas), E. Elsen (CERN, Director for Research and Computing), L. Esteveny (CERN, Alumni network), F. Giffoni (CSIL and University of Milan), N. Grub (CERN, LHCb), M. Kasemann (CERN, CMS), G. Passaleva (CERN, LHCb), A. Talesca (CERN, Alice). Last, but not least we thank all the survey’s respondents.
8. ANNEXES

A. Evidence from survey of team leaders

Figure 1 – A statistical overview of survey data

Q.1 Out of the doctoral students in your Group (100%), what is the share of those:

- Spending a practical research period (not less than 1 year) at CERN: 38%
- Spending a practical research period (some months) at CERN: 37%
- Spending a practical research period not at CERN but anyway outside the university (e.g. at another research centre, company or laboratory): 10%
- Staying at University (no practical research period elsewhere): 15%
- a) Deepening the knowledge and competences in the domain of interest: 8%
- b) Developing new professional skills: 20%
- Working in an international environment: 30%
- Possibility to work with world class scientists and engineers: 40%
- World undisputed prestige of CERN: 50%
- Not important: 10%
- Fairly important: 20%
- Slightly important: 30%
- Important: 40%
- Very important: 50%

Q.2 How do you rate the importance of the following considerations in the attractiveness for doctoral students to spend a research period at CERN? Please, provide a rate from 1 (= Not important) to 5 (= Very important) to each of the following items by keeping in mind that they are not mutually exclusive.
Q.3 As compared to doctoral students of your group NOT spending a research period at CERN, in your opinion to what extent the experience at CERN improved the following skills? Please, provide a rate from 1 (= not at all) to 5 (=a very great extent) to each of the following items by keeping in mind that they are not mutually exclusive.

Q.4 In a recent survey, current and former students at LHC and experiments (some of them now employed outside HEP) put a price tag on their learning experience: a ‘salary premium’ ranging from 5% to 12% compared with what they would have expected for their career without such an experience at CERN. Please, provide your opinion by selecting one of the following options.

c) 

Q.5 Do you think that in the next 5-10 years the number of doctoral students from your institute going to CERN for a research period will:

c)
Survey response rate by experiments

Source: Own elaborations of survey data
B. References


