Specialization Patterns in the Global Field of Nobel Laureates in Physiology/Medicine, Physics and Chemistry.

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Abstract
This paper examines the distribution of Nobel laureates in Physiology/Medicine, Physics, and Chemistry across countries and research organizations. We provide basic information about where future laureates receive their education and/or conduct their research, then present heatmaps depicting organizational specializations in the field. In addition, we identify the *organizational ultra-elite* in science: universities and research institutes that show continuously above-average numbers of future laureates, typically in one career phase. Furthermore, we identify those universities and research institutes that underwent considerable growth (or decline) in their capabilities for highly innovative research. Also, we compare country-specific profiles with those at the organizational level. Our findings are interpreted in the light of findings from comparative-historical studies.

Introduction
Following the seminal publication by Zuckerman (1977), the Nobel Prizes in Physiology/ Medicine, Physics, and Chemistry have attracted considerable attention from quantitative studies of science, especially with regard to achievement age (Jones & Weinberg, 2011; Redelmeier & Naylor, 2016), the time lag between prize-winning work and awarding of the prize (; Becattini, Chatterjee, Fortunato, Pan, & Parolo, 2014; Fortunato, 2014), and the distribution of other science awards and collaboration networks in the years before and after their awarding (Chan, Gleeson, & Torgler, 2014; Chan, Önder, & Torgler, 2015). Several studies examined Nobel laureates from a bibliometric point of view, including spillover effects for the citations of laureates' publications unrelated to the Nobel Prize (Mazloumian, Eom, Helbing, Lozano, & Fortunato, 2011), and differences in citation patterns between landmark papers featuring theory, methods, experiments or inventions (Heinze, Heidler, Heiberger, & Riebling, 2013; Zhou, Xing, Liu, & Xing, 2014). Cross-national comparisons have found that Nobel Prizes "can be used to validate bibliometric indicators" (Rodríguez-Navarro, 2011).

More recently, analyses of the population of Nobel laureates have focused on the rise of North America as a global center of science and technology, its subsequent hegemony (Heinze, Pithan, & Jappe, 2019) and how national institutional contexts have shaped the capabilities of universities and research organizations to achieve scientific breakthroughs (Heinze, Pithan, & Heyden, 2019). These studies found that North America, in particular the United States, replaced Germany as global scientific center by the 1920s, that its hegemony was consolidated in the 1970s, and that although its leadership has come under pressure since the 2000s, a new global powerhouse is not in sight. Furthermore, it was shown that national contexts exerting weak institutional control are associated with organizational capabilities to achieve scientific breakthroughs. More specifically, countries with weak institutional control (United States, United Kingdom) have produced many more Nobel laureates, controlled by population size and by GDP per capita, than those exerting strong control (France, Germany).

However, much less attention has been paid to the distribution of laureates across universities and research institutes (Schlagberger, Bornmann, & Bauer, 2016). There is no comprehensive map of the organizational field in which future laureates were educated, conducted their prize-winning research, and worked when awarded the prestigious prize. Furthermore, rankings that include Nobel laureates, such as the "Academic Ranking of World Universities" (commonly known as Shanghai Ranking), do not consider where future Nobel laureates were educated or conducted their prize-winning research, but focus solely on information at the time when the Nobel Prize was awarded.

Data and Method

This paper examines the distribution of Nobel laureates in Physiology/Medicine, Physics, and Chemistry across national and organizational boundaries. We distinguish three career stages: (1) the university where future Nobel laureates received their highest academic degree (HD), (2) the university or research organization where they performed their prize-winning research (PWR), and (3) the university or research organization where they were employed at the time of the award (NP). Our analysis builds on an existing dataset (Heinze, Pithan, & Heyden, 2019; Heinze, Pithan, & Jappe, 2019) that is currently updated. Thus, we will present results for the time period 1901-2020 (120 years) at the ISSI Conference. The primary data source was the Nobel Foundation's website (www.nobelprize.org), enriched by data from secondary sources, such as the American Institute of Physics, American National Biography, Encyclopedia Britannica, Howard Hughes Medical Institute, National Academy of Sciences, Notable Names Database, and Royal Society.

First, we provide basic descriptive information about both the laureate population and the Top-50 universities and research organizations (Tab. 1). *Second*, we present heatmaps based on calculations of the specialization index RESP (see below). This index is calculated using the *Activity Index* (Narin, Carpenter, & Woolf, 1987; Piro et al., 2017), that captures the extent to which certain entities are specialized in certain activities (Formula 1). AI values lower 1.0 indicate a negative specialization (below-average scores), AI values greater 1.0 a positive specialization (above-average). A verbal expression of the AI, applied to Nobel laureates, is given in Formula 2.

Formula 1: General formula of the Activity Index (AI)

$$AI_{ij} \coloneqq \frac{N_{ij}/\sum_i N_{ij}}{\sum_j N_{ij}/\sum_{ij} N_{ij}}$$

Formula 2: Specific AI applied to career phases of Nobel laureates

$$AI_{ij} := \frac{\text{Nobel laureates of University i in career phase j/Nobel laureates of University i}}{\text{All Nobel laureates in career phase j/All Nobel laureates}}$$

The AI's value range of $[0.0, +\infty]$ lacks an upper limit. Available indexes that are symmetrical both above and below the expected value include for example the *Revealed Symmetric Comparative Advantage (RSCA)* to capture country-specific technical specialization (Laursen, 2000, 2015). Furthermore, the *Relative Specialization Index (RSI*) has been used to map profiles of Scandinavian universities (Piro et al., 2011; 2017; 2014). Interpreting RSCA and RSI is easier than the AI due to their symmetrical value range of $[-1.0, +1.0]$: values lower 0.0 indicate negative specialization; values greater 0.0 indicate positive specialization.

We use a modified version of the RSCA/RSI index that was introduced by Grupp (1994, 1998). Its value range is $[-100.0, +100.0]$ with an expected value of zero (Formula 3). This index, which we call RESP (for "Index of Relative Specialization") is different from RSCA/ RSI in that it is based on the *hyperbolic tangent.* Consequently, its curve is steeper and reaches the upper limits of its value range more quickly than RSCA/RSIHence, RESP-based heatmaps are richer in contrast, and present more visibly specialization profiles. For further details, see Heinze, Tunger, Fuchs, Jappe, and Eberhardt (2019).

Formula 3: Relative Specialization (RESP)

$$\text{RESP} := 100\ \frac{\text{AI}^2 - 1}{\text{AI}^2 + 1}$$

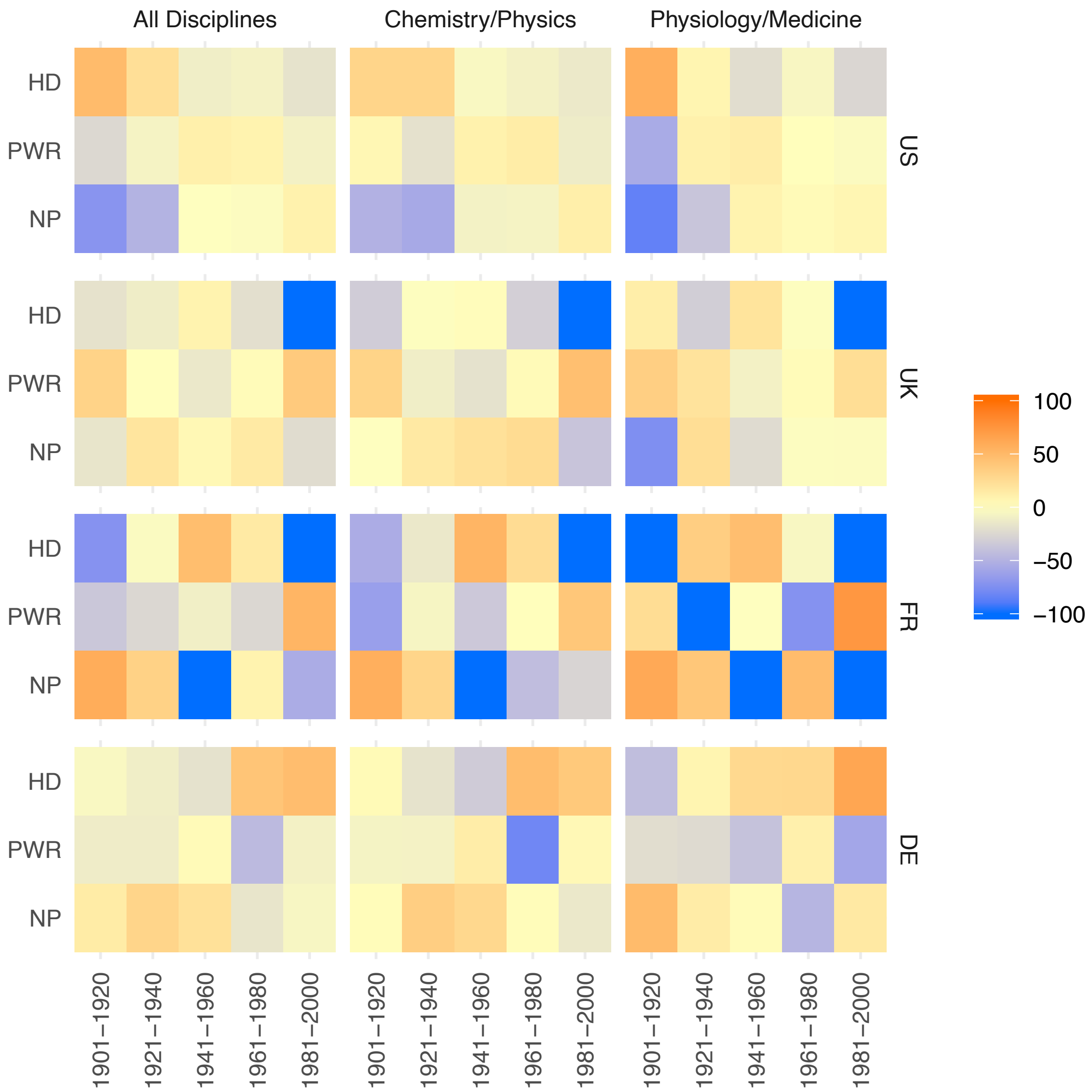
Note: The subindices i and j of the AI are omitted for the sake of simplicity.

Results

The organizational field of the three scientific Nobel Prizes in all three career phases (HD, PWR, NP) contains 1521 career events and 334 organizations from 100 years (1901-2000), the latter including universities, public research institutes, and private research laboratories. The four countries with most career events (1182 or 78%) and most organizational entities (227 or 68%) are (in descending order): United States (694 career events & 115 organizations), United Kingdom (235 career events & 40 organizations), Germany (176 career events & 50 organizations), and France (77 career events & 21 organizations). We calculated RESP values based on all countries in the database (n=30), using 20-year periods. Figure 1 displays the results for the four countries mentioned above.

Apart from the fact that there seems to be no clear career pattern for France, three results are noteworthy. *First*, the United States shows a decreasing specialization in educating future laureates (HD): compared to other countries, the United States increasingly relies on foreign-born and foreign-educated scientists. This result corroborates findings from Stephan and Levin (2001). At the same time, it becomes more specialized in the later career phases (PWR, NP), indicating its growing attractiveness over the 20th century as work environment for future laureates (see also Heinze, Pithan, & Heyden, 2019). These developments are especially pronounced in the medical sciences. *Second*, Germany has almost the opposite specialization to that of the United States: it shows an increasing specialization in the education of future laureates (HD), whereas its attractiveness as work environment for later career phases has decreased in the second half of the 20th century. *Third*, the United Kingdom shows stability in the two later career phases: its specialization in PWR and NP is straight for the entire 20th century.

Figure 1. Career specialization profile of countries with Nobel laureates



The first and second results are in line with comparative-historical evidence that highlights the declining hegemony of German universities in the early 20th century, coupled with an upswing of research universities in the United States (Ben-David, 1960, 1971). Ben-David explains this development both with regard to internal organizational features in North-American universities that were more conducive to the growth of new research fields (compared to those in Germany), and the more pronounced level of decentralized competition in the American university system, particularly between public and private universities (compared to exclusively public higher education in Germany). Also, the first and third results are in line with comparative-historical evidence suggesting that national contexts in United States and the United Kingdom exerted weak institutional control on universities and research organizations, and thus facilitated highly innovative research capabilities in the 20th century (Hollingsworth, 2004, 2006), a finding that is reflected also in data on institutional context in the 21st century (Pruvot & Estermann, 2017).

We turn now to the organizational level. Given the results above, it is certainly not astonishing that the first ten universities in the global Top-50 list are from the United States (8) and the United Kingdom (2). Equally important, however, appears the considerable variation among the Top-50 with regard to their representation in the three career phases (Table 1). Therefore, we probed organizational specializations in Nobel laureates' careers. For this purpose, we calculated RESP values for all organizations in the database (n=334), using 20-year periods. Figures 2 and 3 display results for the Top-20. We also checked robustness by calculating RESP values for those organizations with more than two career events and for those with more than ten career events. Overall, specialization patterns were very robust. Therefore, we focus here on results for all organizations in the database. In our view, the following results are noteworthy.

First, there is some stability in single career phases over time, most notably in the education of future Nobel laureates (HD). Here, in at least four (out of five) consecutive periods, the following universities show a constant positive specialization over the 20th century: Cambridge, Harvard, Columbia, Berkeley, MIT, and Göttingen. Among those with a stable positive specialization in later career phases are in at least four (out of five) consecutive periods: Rockefeller (PWR, NP), Bell Labs (PWR), Caltech (NP), and London (NP). Clearly, constant positive specializations in either of PWR and/or NP career phases require considerable resources to building and maintaining capabilities for highly innovative research. Borrowing a term coined by Zuckerman (1977), it is fair to call those universities and research institutes among the Top-20 list with constant positive specializations in either of the three career phases the *organizational ultra-elite* in global science. To be sure, this ultra-elite constitutes a very thin layer. Note that the Rockefeller Institute (later: Rockefeller University) stands out as the single entity with double status as organizational ultra-elite (for a historical account see Hollingsworth, 2004).

Table 1. Global Top-50 Institutions with regard to Nobel Prize winners, 1901-2000

	Country	HD	PWR	NP	Total	Rank
University of Cambridge, Cambridge	UK	42	33	14	89	1
Harvard University, Cambridge	US	39	22	26	87	2
Columbia University, New York	US	21	19	8	48	3
University of California, Berkeley	US	19	14	10	43	4
California Institute of Technology, Pasadena	US	12	9	14	35	5
Massachusetts Institute of Technology, Cambridge	US	14	9	10	33	6
Rockefeller University, New York	US	1	14	15	30	7
Stanford University, Palo Alto	US	6	9	14	29	8
University of Oxford, Oxford	UK	12	7	9	28	9
University of Chicago, Chicago	US	15	7	6	28	9
Princeton University, Princeton	US	11	7	9	27	11
Cornell University, Ithaka	US	8	10	8	26	12
University of London, London	UK	5	6	12	23	13
Russian Academy of Sciences, Moscow	RU	6	8	8	22	14
Humboldt University, Berlin	DE	8	5	6	19	15
University of Goettingen, Goettingen	DE	11	3	5	19	15
University of Munich, Munich	DE	9	4	5	18	17
Bell Laboratories, Murray Hill	US	0	13	4	17	18
Washington University, St. Louis	US	3	10	4	17	18
University of Copenhagen, Copenhagen	DK	6	6	4	16	20
Karolinska Institute, Stockholm	SE	6	4	5	15	21
MRC Laboratory of Molecular Biology, Cambridge	UK	1	6	7	14	22
Yale University, New Haven	US	8	3	3	14	22
Johns Hopkins University, Baltimore	US	8	4	2	14	22
Swiss Federal Institute of Technology, Zurich	CH	5	5	3	13	25
Institut Pasteur, Paris	FR	1	5	6	12	26
Uppsala University, Uppsala	SE	3	4	5	12	26
University of Illinois, Urbana-Champaign	US	6	4	2	12	26
Technical University, Munich	DE	5	4	2	11	29
University of Tokyo, Tokyo	JP	6	4	1	11	29
University of Heidelberg, Heidelberg	DE	3	1	6	10	31
University of Zurich, Zurich	CH	3	3	4	10	31
University of Wisconsin, Madison	US	5	2	3	10	31
University Pierre and Marie Curie, Paris	FR	6	1	3	10	31
University of Vienna, Vienna	AT	3	5	2	10	31
University of Pennsylvania, Philadelphia	US	5	3	2	10	31
Imperial College, London	UK	3	2	4	9	37
University of California, San Francisco	US	0	6	3	9	37
University of Washington, Seattle	US	2	4	3	9	37
University of Toronto, Toronto	CA	3	3	3	9	37
University of Strasbourg, Strasbourg	FR	4	3	2	9	37
IBM Zurich Research Laboratory, Zurich	CH	0	4	4	8	42
National Institutes of Health (NIH), Bethesda	US	0	4	4	8	42
University of Texas Southwestern Medical Center, Dallas	US	1	3	4	8	42
University of California, Los Angeles	US	2	2	4	8	42
University of Kiel, Kiel	DE	2	3	3	8	42
Kyoto University, Kyoto	JP	2	4	2	8	42
University of Freiburg, Freiburg	DE	2	4	2	8	42
University of Edinburgh, Edinburgh	UK	3	3	2	8	42
Nagoya University, Nagoya	JP	5	3	0	8	42

Note: HD=highest degree, PWR=prize-winning research, NP=award of Nobel Prize. Column "Total" sums up HD, PWR and NP.

Figure 2. Career specialization of Top-10 universities and research organizations

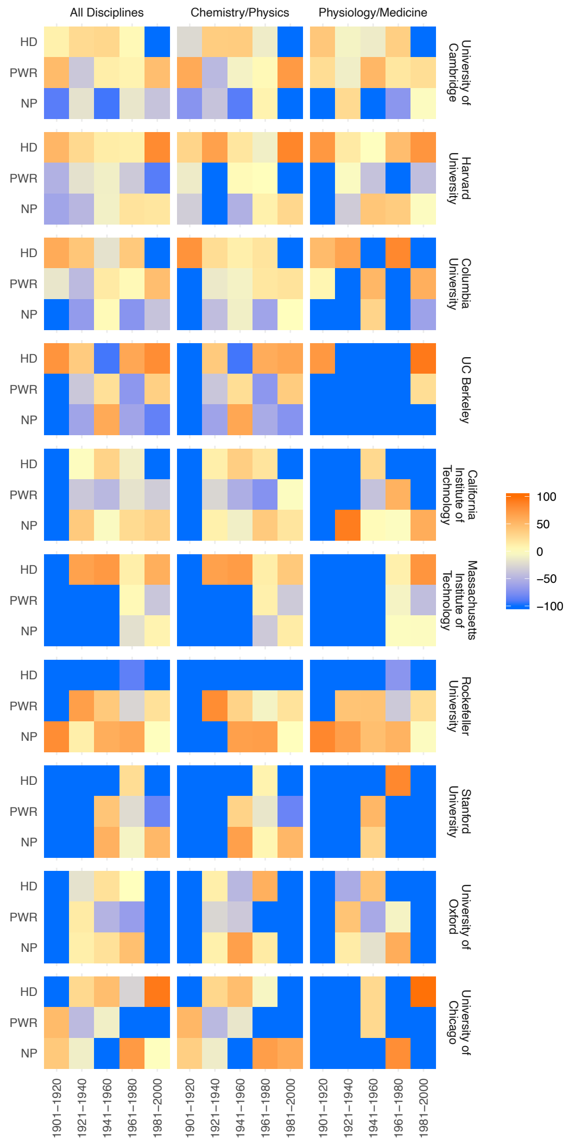
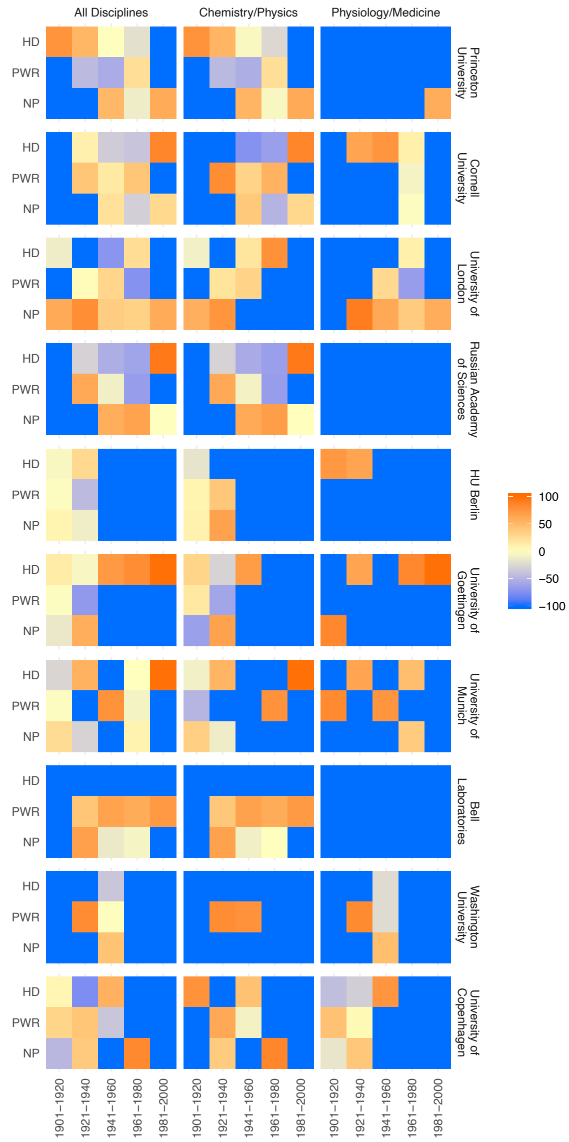


Figure 3. Career specialization of Top-11-20 universities and research organizations



Second, there is no single university or research organization with positive specializations in all three career phases in one (or more) 20-year period(s). More specifically, every university has at least one 20-year period, where no laureate either made his highest academic degree (HD), performed its price-winning research (PWR), or was employed at the time of the award (NP). However, we find examples that come close to that: MIT (1961-2000), Cambridge and Munich (1961-80), Columbia and Oxford (1941-60), HU Berlin and Göttingen (1901-20). Note that above-average scores in the PWR and NP career phases indicate capabilities for highly innovative research at an extremely high level. In addition, consider that some universities underwent a considerable change of their respective capabilities. For example, compare the first (1901-20) and fifth period (1981-2000) for two of the above-mentioned universities: HU Berlin (decrease) and MIT (increase). Also, most often several decades lie between HD and NP, so both HD and PWR observations are concentrated before 1980.

Third, few universities have changed their profile in a given career phase in one particular direction. Among those with growing specialization (over at least four consecutive periods) are Cambridge and Columbia (both PWR); conversely, among those with a decreasing specialization are Princeton (HD) and Copenhagen (PWR). This suggests that in Cambridge and Columbia, some intra-organizational process of building-up capabilities to conduct highly innovative research took place, whereas in Princeton and Copenhagen we assume that some process of downscaling of such capabilities occurred. How such processes unfolded and why is beyond the scope of this paper, but could be examined from a historical perspective.

In the light of the above-mentioned country-specific specializations, we probed whether such profiles are reflected on the organizational level. Our analysis shows that this is not the case. *First*, there is no single university or research organization that roughly matches all three national specializations over time. Rather, we find some examples where specializations in one career phase (and sometimes two) are similar. Three examples: 1) Cambridge mirrors the UK specialization both in HD (decreasing) and PWR (stable positive); 2) Princeton reflects the US specialization both in HD (decreasing) and NP (increasing), and 3) Göttingen develops a profile similar to that of Germany both in HD (increasing) and in NP (decreasing). *Second*, there are several universities that show specializations quite different from the national level. Two examples: 1) Cambridge is less specialized in the third career phase (NP) than the United Kingdom in general. Although it has educated an above-average number of future Nobel laureates and provided them with attractive working conditions, Cambridge retains them less often than the UK as a whole. 2) Similarly, although Columbia follows the (increasing) specialization of the United States in the first two career phases (HD, PWR), it has a weaker profile in the third phase (NP) compared to the United States as a whole.

Discussion

Taken together, our results suggest that analyzing the organizational field of the Nobel Prize yields several important insights that complement those obtained from conducting cross-country comparisons. Interestingly, national specialization profiles cannot be directly found on the organizational level. If universities and research institutes mirror national profiles, they do so with regard to selected career phases. However, the overall scientific growth (or decline) of countries can be seen in the profiles of particular universities and research institutes, as examples in Figures 2 and 3 illustrate for the United States and Germany. Perhaps the most important finding is the *organizational ultra-elite*, a group of (mostly private) universities and research institutes that show continuously above-average contributions in the education and employment of future laureates.

In the future, these results can be analyzed further. Besides the RESP values for countries and for particular institutions, the interaction of both can be explored, i.e. how RESP values change in the context of world-wide versus country-wide consideration. Also, for most ultra-elite institutions information about resources are available online. The link between RESP values and resource values could expose more information about how to characterize ultra-elite institutions further. Finally, we used descriptive statistic for presenting the RESP values here. Of course, RESP values can be statistically analyzed, too.

Notes

All graphs can be found and used under the CC-BY-NC-ND-4.0 international license at https://fachprofile.uni-wuppertal.de/conferences/issi2021.html.

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