A quantitative approach to world university rankings

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ABSTRACT

World university rankings are lists of higher education institutions ordered using a combination of indicators. Some rankings rely mainly on research indicators, while others place a great deal of emphasis on opinion based surveys. Up to now, there has been no ranking measuring the quality of the learning environment as well as research without relying on surveys and university data submissions. Here it is shown that a ranking measuring the quality of education and training of students as well as the prestige of the faculty and the quality of their research could be constructed based solely on verifiable data and robust indicators. It is found that, in addition to research performance, the quality of an institution's alumni significantly affects its ranking. The results of this study will be of interest to students, academics, university administrators, and government officials from around the world.

INTRODUCTION

In recent years, there has been an increasing interest in world university rankings. The Academic Ranking of World Universities[1], first published in 2003, was the first attempt at a global ranking. Despite not using subjective indicators, the ranking has the following drawbacks: 1) It is weighted toward institutions whose faculty or alumni have won Nobel Prizes and Fields Medals, but ignores other major awards, medals, and prizes in the same as well as other academic disciplines. 2) It relies mainly on research indicators, without properly assessing the quality of education and training of students. 3) Published papers are given the same weight regardless of the journals in which they were published. Except for publications in *Nature* and *Science*, papers published in prestigious journals such as *Proceedings of the National Academy of Sciences of the USA* are given the same weight as papers published in any other scientific journal listed in the ISI

[1] http://www.shanghairanking.com

Web of Science database[2]. 4) Publications in arts and humanities are not counted. 5) Perhaps the biggest drawback is the Highly-Cited indicator. A university could boost its ranking by offering part-time contracts to highly-cited researchers in exchange of adding the institution's name as a second affiliation on the 2011 list of ISI's highly-cited researchers[3]. Another ranking, now called the QS World University Rankings[4], has been published since 2004. One of its shortcomings is its reliance on reputational indicators for half of its analysis. Another shortcoming is the faculty to student ratio indicator, where the number of faculty could be inflated by including academic-related and non-teaching staff, resulting in the indicator failing to reflect the quality of teaching. A third ranking, the Times Higher Education World University Rankings[5], has been released since 2010. As with the QS ranking, its main drawback is that it relies heavily on surveys, which make up about one third of its analysis. Roughly another third is made up of data submitted by universities, which could be manipulated in order to move up in the ranking. In this study, degree-granting institutions of higher education are ranked according to eight objective and robust indicators, which are explained in detail below. The full list of the world's top 1000 institutions can be found at the website of the Center for World University Rankings[6].

METHODOLOGY

Publications: In this study**,** Journals are classified into three types: Science, Social Sciences, and Humanities. For the first two, the list of journals is obtained from Thomson Reuters' Journal Citation Reports (*JCR*) website[7]. World-Class Universities should be judged not on the total number of publications in these journals, but rather on the number of publications in the top-tier journals in the *JCR* database. For a given Subject Category SC_i, journals are sorted according to the product Π of their Eigenfactor and Article Influence Score, from largest to smallest. A list L_i of journals with non-zero Π can then be obtained. If N_i is the total number of articles in L_i listed in the most recent edition of *JCR*, the journals chosen for this indicator are the ones with the highest Π in L_i and containing between them $0.25N_i$ articles

[2] http://www.webofknowledge.com
[3] http://www.highlycited.com
[4] http://www.topuniversities.com
[5] http://www.timeshighereducation.co.uk/world-university-rankings
[6] http://www.cwur.org
[7] http://admin-apps.webofknowledge.com/JCR/JCR

in total. Repeating this algorithm for all Subject Categories in *JCR* we obtain a combined list $J_{Sci\text{-}Soc}$ of the top journals in Science and Social Sciences. It is worth mentioning that the theory behind the Eigenfactor (which measures a journal's total importance to the scientific community) and the Article Influence Score (which measures the average influence, per article, of the papers in a journal) is that a citation from a high-quality journal counts more than a citation from a lesser quality journal. In addition, unlike the Impact Factor, self-citations are excluded. For Humanities, the list of journals is obtained from the European Reference Index for the Humanities (*ERIH*)[8]. Humanities journals are classified as *NAT*ional journals and *INT*ernational journals. *INT* is itself divided into two subcategories: *INT*2 and *INT*1 - the latter being the most prestigious category. Let J_{INT1} be the set of all journals listed under the *INT*1 category. Using the Science Citation Index Expanded, Social Sciences Citation Index, and Arts & Humanities Citation Index from the Web of Science's website, institutions are sorted by the number of "Article" publications in journals $J_{Sci\text{-}Soc}$ and J_{INT1} during the last 10 full years.

Influence: For this indicator, an Influential Journal is defined as having $\Pi \geq min\ \Pi$ (*Nature*, *Science*, *Proceedings of the National Academy of Sciences of the USA*). For a given Influential Journal, an institution's partial score is simply the number of "Article" publications in the last 10 full years in that journal multiplied by the journal's Π. Repeating this algorithm for all Influential Journals, the institution's total score is the sum of its partial scores. Degree-granting institutions of higher education can then be sorted according to their total scores.

Citations: If Y is the current year then, for each Subject Category in the Web of Science classification, the most cited "Article" publications are counted between the years $Y - 2$ and $Y - 11$ in the Science Citation Index Expanded, Social Sciences Citation Index, and Arts & Humanities Citation Index. The cutoff for the number of highly-cited papers in a given classification is proportional to the total number of "Article" publications in that classification. The cutoffs are chosen in such a way that their sum equals 5000. By considering all Subject Categories, institutions are sorted according to the total number of the highly-cited publications.

[8] https://dbh.nsd.uib.no/publiseringskanaler/erih/searchForm

Broad Impact: The *h*-index is a number intended to measure both the productivity and the impact of published work[9]. If *Y* is the current year then the *h*-index for institutions is calculated by considering "Article" publications between the years $Y - 2$ and $Y - 11$ in the Science Citation Index Expanded, Social Sciences Citation Index, and Arts & Humanities Citation Index. Degree-granting institutions of higher education can then be sorted according to their *h*-indices.

Patents: The World Intellectual Property Organization (WIPO)[10], an agency of the United Nations dedicated to the use of intellectual property, administers the Patent Cooperation Treaty (PCT). By filing one international patent application under the PCT, applicants can simultaneously seek protection for an invention in most countries throughout the world. If *Y* is the current year, PCT patents published between years $Y - 2$ and $Y - 11$ are collected. In the case of joint patents, or multi-campus institutions filing patents under a single university system, patents are assigned according to the first inventor's affiliation. Institutions can then be ranked based on the average number of PCT patents filed per year.

Quality of Faculty: This indicator measures the weighted number of faculty members of an institution who have won, in addition to the Nobel Prize and the Nobel Memorial Prize in Economic Sciences, the following awards, medals, and prizes covering virtually all academic disciplines: Abel Prize, Balzan Prize, Breakthrough Prize, Charles Stark Draper Prize, Crafoord Prize, Dan David Prize, Fields Medal, Gruber Prize, Holberg International Memorial Prize, Japan Prize, Kavli Prize, Kluge Prize, Kyoto Prize, Millennium Technology Prize, Praemium Imperiale, Pritzker Prize, Queen Elizabeth Prize for Engineering, Shaw Prize, Schock Prize, Templeton Prize, Turing Award, Wolf Prize, and World Food Prize (this list could be modified in the future if necessary). Faculty members are defined here as those who were employed at the institution in question at the time of winning the award, medal, or prize. For each faculty member, r_F points are assigned to his/her institution according to the following formula:

$$r_F = C \cdot \exp\left[-k \cdot ((Y-1) - x)^2\right]$$

[9] Hirsch, J.E., An index to quantify an individual's scientific research output, *Proc. Natl. Acad. Sci. U.S.A.*, **102**: 16569 (2005)
[10] http://www.wipo.int

where Y is the current year and x is the year when an award/prize/medal was made to the faculty member. The constant C is set to 1 except in very rare cases where a faculty member holds more than one full-time position (in which case, C is equal to the reciprocal of the number of institutions). The positive constant k is chosen so that $r_F = 0.01$ when $(Y - 1) - x = 99$ and $C = 1$. This gives $k = 99^{-2}\ln(100)$. If a faculty member receives more than one award/prize/medal, the maximum points he/she can contribute to his/her institution will be 1. Let p_F be the sum of all the r_F points of an institution. Degree-granting institutions can then be sorted based on the total points p_F.

Alumni Employment: This indicator measures the weighted average number (per year) of an institution's alumni who have held CEO positions since 2011 at the world's top 2000 public companies relative to the institution's size. The top companies are those listed on the Forbes Global 2000 list[11]. An alumnus is defined as a student who graduated with a Bachelor, Master, or Doctorate degree (or their equivalents). If more than one degree was obtained from a given institution, the institution is considered only once. In very rare cases where an alumnus is a CEO of more than one company, his/her educational institution will be considered only once. The weighting factor is similar to the quantity $(1/C)\cdot r_F$ above with x being the year the Forbes list is published. If an institution has a yearly weighted average of q CEO alumni, it will be assigned points according to the formula

$$p_E = \frac{q}{\sqrt{n+N}}$$

where n is the current number of students enrolled at the institution (which can be obtained from national agencies) and N is a positive damping factor which will be described later (it ensures that small fluctuations in the number of CEOs from year to year for institutions with a very small student body don't have a significant effect). The ratio p_E measures the performance of the training programs of universities, based on the professional future of their alumni.

Quality of Education: This indicator measures the weighted number of an institution's alumni who have won major awards, medals, and prizes relative to the institution's size. Here, alumni are defined as students

[11] http://www.forbes.com/global2000

who obtained Bachelor, Master, or Doctoral degrees (or their equivalents) and won awards, medals, and prizes listed under "Quality of Faculty". For each alumnus, r_A points are assigned to his/her institution according to the following formula:

$$r_A = \exp\left[-k \cdot ((Y-1)-x)^2\right]$$

where Y is the current year, x is the year when the degree was awarded, and $k = 99^{-2}\ln(100)$ as in the "Quality of Faculty" indicator. If an alumnus obtains more than one degree from an institution, the institution will be considered only once and the date of the last degree will be used for x. Let s_A be the sum of all the r_A points of an institution. As in the previous indicator, each university is assigned points according to:

$$p_A = \frac{s_A}{\sqrt{n+N}}.$$

This ratio measures the quality of education of an institution based on the academic future of its alumni.

Aggregation and Scoring: World-class universities should have a significant number of publications in top-tier journals. The institutions considered for ranking were the top 1000 performing institutions in the publications indicator. The average number of students at these 1000 universities is N (the damping factor introduced earlier in this article). A quadratic model is used throughout, with indicator raw scores s_k (scaled so that the maximum value equals 10) replaced by $t_k = s_k^2$, ensuring that fluctuations from year to year don't have a significant effect, while at the same time rewarding institutions with very high raw scores. Raw data are then converted to z-scores and then to percentiles. For publications in reputable journals, influential research, citations, broad impact, and patents, the weighting factor for each indicator is 1. For the three other indicators, the weighting factor assigned to each is 5. Thus, research contributes 50% of the overall score of an institution, while teaching and training of students the other 50%. An institution's pre-final score S_{pf} is given by

$$S_{pf} = \frac{1}{20}\sum_{k=1}^{8} w_k(.99P_k + .01t_k)$$

where P_k is the institution's percentile score on indicator k, and w_k is the weighting factor for the corresponding indicator. The small contribution from t_k is added to increase differentiation between

institutions at the very top of the rankings. Pre-final scores are then scaled to the top performing institution to arrive at final scores.