Excellence and diversity mapping of research in IISc, IITs, NUS and NTU

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A three-dimensional evaluation approach is used to decompose the research performance of the two leading research clusters from India and Singapore into three components – size, excellence, and balance or evenness. Data are retrieved from the Excellence Mapping web application. The NUS + NTU cluster from Singapore outperforms the IISc + 7IITs cluster from India on all three counts.

Keywords: Balance, bibliometrics, excellence, research evaluation, size.

A benchmarking exercise on the research performance of the Indian Institutes of Technology (IITs) using Web of Science (WoS) and *Scopus* bibliometric databases revealed that India's research efforts in engineering have not kept pace with those of more developed countries in the world[1]. Indeed huge investments in just two institutions in Singapore, the National University of Singapore (NUS) and the Nanyang Technological University (NTU) have taken them far ahead of all the IITs put together where once, not long ago, they were significantly behind[1]. From the sixties to the eighties, IITs were considered as better destinations for scientific research compared to premier Singapore institutions, namely NUS and NTU. By the late eighties, i.e. sometime around 1987–88, NUS and NTU together began to outperform all the IITs taken together[1]. India has a nominal gross domestic product (GDP) that is 6.6 times that of Singapore (https://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal)), and one would expect that the premier grouping of Indian research universities would outperform that from Singapore.

In this communication, we revisit the comparison using a three-dimensional framework in terms of size, excellence and diversity of the research base of the premier institutes in India and Singapore. For this, we choose to represent India through the cluster comprising the Indian Institute of Science (IISc) and the seven IITs at Kharagpur, Kanpur, Delhi, Chennai, Mumbai, Roorkee and Guwahati (which we collectively call IISc + 7IITs). Singapore is again represented by NUS + NTU cluster. At this level of aggregation, we breakdown scholarly performance into three components – size, excellence and balance or evenness. A web application now available in the public domain permits us to visualize scientific excellence worldwide in several subject areas using this paradigm.

The latest and fourth release of the web application (http://www.excellencemapping.net/#/view/measure/top10/calculation/a_ohne_kovariable/field/materials-science/significant/false/org/) based on articles during the five-year publication window 2008–12 visualizes scientific excellence worldwide in 22 major subject areas[2–4]. These subject areas are covered by Scopus data as collected for the SCImago Institutions Ranking (http://www.scimagoir.com/). Only those institutions (universities or research-focused) that have published at least 500 articles, reviews and conference papers in each subject area within the publication period are covered. Also, only subject categories where globally at least 50 institutions are found meeting this criteria are included in the web application. The full counting method was used to attribute papers from the Scopus database to institutions: if an institution appears in the affiliation field of a paper, it is fully attributed to this institution (with a weight of 1). We find that IISc and the seven IITs, as well as NUS and NTU are prominent in the excellence mapping list from India and Singapore. Table 1 shows the number of units of assessment (an institution in a specific subject area which has published more than 500 papers in the respective area

Table 1. The number of units of assessment which have published more than 500 papers in their respective areas during 2008–2012 from the IISC + 7IITS and NUS + NTU groups

Subject area	IISc + 7IITS	NUS + NTU
Agricultural and biological sciences	0	1
Arts and humanities	0	1
Biochemistry, genetics and molecular biology	2	2
Business, management and accounting	0	2
Chemical engineering	6	2
Chemistry	8	2
Computer science	8	2
Earth and planetary sciences	1	0
Energy	1	2
Engineering	8	2
Environmental science	1	2
Health professions	0	0
Immunology and microbiology	0	1
Materials science	8	2
Mathematics	6	2
Medicine	1	2
Neuroscience	0	1
Nursing	0	0
Pharmacology, toxicology and pharmaceutics	0	1
Physics and astronomy	8	2
Psychology	0	0
Social sciences	0	2
Total	58	31
Nominal GDP in USD trillions*	2.05	0.31

*https://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal).

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during 2008–2012 counts as a unit of assessment) from the IISC + 7IITs and NUS + NTU groups. Also shown in Table 1 are the International Monetary Fund's nominal GDPs of the two countries (https://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal)). We see that in ten areas, the IISc + 7IITs cluster has no significant presence. In five areas, all eight institutes have contributed significantly at this level of excellence. NUS and NTU are absent in five areas, but are found together in 13 areas.

We carry out a two-stage assessment to derive the necessary performance indicators. In the first stage, we take any unit of assessment, say an institution in a specific subject area. During the publication window (2008–2012), it will have published a total number of papers or articles, P, and received a total number of citations, C. Then $C \cdot P$ can be taken as the indicator or proxy measure for the size of the unit and C is the total impact of its published research respectively[5]. From the web application[2–4], we can find the associated best paper rate (BPR). This is the proportion of publications from an institution which belongs to 10% of most cited publications in their respective subject area and publication year. We can then use the indicator i = BPR/10 to be a measure of quality. BPR corresponds to PP (top 10%) used in the Leiden Ranking and the excellence rate used in the SCImago Institutions Ranking[6]. The excellence rate is a field-normalized size-independent indicator which serves as a measure of the high quality output of research institutions[2–4]. A single-valued composite outcome indicator for the research performance of each unit of assessment can be computed as the second-order indicator[7] called the exergy term from the quantity (size) and quality (excellence) indicators, $x = i^2P$.

In the second stage we examine the variance in performance of the units within a larger aggregation. Within an area, we will find several institutions that have P and i varying considerably. Thus, the size-dependent proxy for research performance may vary by orders of magnitude. Similarly, when we take within an institution, a subject-wise cross-section, P, i and x vary considerably. There is therefore a large variation in performance. This issue of diversity has been addressed in a recent study[8] which argues that structural diversity – the diversity of disciplines, institutions and support mechanisms is needed as 'it is a property of a "strong" research base that not only produces great research today, but also has the capacity to address new challenges flexibly and responsively tomorrow. It is distinct from the contribution made by social diversity – the diversity of gender, nationality and ethnicity – to productivity, innovation and social cohesion.' Here, we argue that in a system or set of j categories or sources (that is, institutions within a discipline or area, or disciplines or areas within an institution), if x_j is the exergy of each source of a total of S sources, then we can have a measure of consistency or evenness of distribution η defined as follows[7]

$$X = \sum x_j,$$

$$E = \sum x_j^2,$$

$$x = X/S,$$

and

$$\eta = X^2/(SE).$$

We now need a measure that combines performance as measured by x_j and X with diversity[8]. The Stirling approach to diversity[9] adopted in the above-mentioned study[8], combines three basic properties: 'variety', 'balance' and 'disparity'. In our case, S is the measure of variety as it is the number of categories into which system elements (institutions in an area, or areas within an institution) are apportioned. For example, we have eight institutions in IISc + 7IITs that have published more than 500 papers during 2008–2012 in engineering. NUS has published more than 500 papers during the same period in 18 subject areas. Everything else being equal, the greater is the variety, greater is the diversity[8]. In the present case, we interpret balance as a function of the variation of x_j elements across categories. It performs the same role as statistical variance. We find that η as defined above is a natural candidate for measuring this, and $\eta = 1$ is the ideal condition when all elements perform at the same level. Again, all else being equal, the more even the balance, greater is the diversity[8].

We propose a framework score (F)[10–11], which combines the number of elements in a system S, the total exergy X within the system (institutions within an area or areas within an institution) and the balance as the product $F = \eta X$. We shall use this framework score F along with the exergy X and the number of papers P to see how the IISc + 7IITs group compares with the NUS + NTU group.

Table 1 is based on a fine-grained classification involving 22 subject areas. A simpler picture emerges if we use a broad, all-encompassing classification like that of the research excellence framework (REF) used for assessing the quality of research in UK higher education institutions. REF uses broader groupings under four panels: physical sciences and engineering, biological sciences

Table 2. The number of units of assessment arranged using the research excellence framework (REF) classification

REF 2014 panels	IISc + 7IITS	NUS + NTU
Biological sciences and medicine	3	8
Physical sciences and engineering	55	18
Social sciences	0	4
Arts and humanities	0	1
Total	58	31
Balance (excellence mapping)	0.38	0.77
Balance (REF)	0.28	0.59

and medicine; social sciences; and arts and humanities. Table 2 shows the result. Ninety-five per cent of the research presence in IISc + 7IITs is in physical sciences and engineering, while the corresponding figure for NUS + NTU is 58%. We also see from the last two rows of Table 2 that while IISc + 7IITs have low structural diversity, this is much higher for NUS + NTU. We reiterate the argument for structural diversity[8] as mentioned earlier in the text[8].

Table 3 shows the papers published by the IISc + 7IITs and NUS + NTU clusters. The NUS + NTU cluster delivers considerably more than the IISc + 7IITs cluster, confirming earlier findings[1]. What is true for the size of output (95,414 papers to 76,847 papers) is also true when one compares the quality of output in terms of BPR. The NUS + NTU cluster average BPR is 20.5 (maximum 28.4; minimum 14.3), while the IISc + 7IITs has an average of 11.0 (maximum 17.0; minimum 5.6). Considering a BPR of 10.0 as a global norm (i.e. 10% of the output will be among 10% of the globally highly cited papers), all the NUS + NTU units of assessment perform at considerably higher levels, while the IISc + 7IITs units span

Table 3. Papers published by the IISc + 7IITs and NUS + NTU clusters

Subject area	IISc + 7IITs	NUS + NTU
Agricultural and biological sciences	0	1,545
Arts and humanities	0	714
Biochemistry, genetics and molecular biology	1,741	6,923
Business, management and accounting	0	1,417
Chemical engineering	4,030	4,037
Chemistry	8,928	7,230
Computer science	10,523	13,468
Earth and planetary sciences	583	0
Energy	713	1,610
Engineering	19,485	17,559
Environmental science	593	1,741
Health professions	0	0
Immunology and microbiology	0	766
Materials science	12,335	10,155
Mathematics	4,674	5,495
Medicine	647	7,126
Neuroscience	0	821
Nursing	0	0
Pharmacology, toxicology and pharmaceutics	0	861
Physics and astronomy	12,595	10,420
Psychology	0	0
Social sciences	0	3,526
Total	76,847	95,414
Nominal GDP in USD trillions*	2.05	0.31

*https://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal).

Table 4. X-scores for the IISc + 7IITs and NUS + NTU clusters

Subject area	IISc + 7IITs	NUS + NTU
Agricultural and biological sciences	0	4,678
Arts and humanities	0	2,288
Biochemistry, genetics and molecular biology	797	27,448
Business, management and accounting	0	5,959
Chemical engineering	3,916	20,073
Chemistry	8,020	42,312
Computer science	15,351	48,603
Earth and planetary sciences	1078	0
Energy	2,012	11,005
Engineering	41,996	91,543
Environmental science	692	7,832
Health professions	0	0
Immunology and microbiology	0	1,937
Materials science	12,851	58,394
Mathematics	5,423	13,008
Medicine	1,197	38,268
Neuroscience	0	1,897
Nursing	0	0
Pharmacology, toxicology and pharmaceutics	0	4,129
Physics and astronomy	13,921	37,846
Psychology	0	0
Social sciences	0	9,409
Total	107,253	426,630

Table 5. *F*-scores for the IISc + 7IITs and NUS + NTU clusters

Subject area	IISc + 7IITs	NUS + NTU
Agricultural and biological sciences	0	4,678
Arts and humanities	0	2,288
Biochemistry, genetics and molecular biology	792	23,304
Business, management and accounting	0	4,321
Chemical engineering	3,642	19,932
Chemistry	5,523	42,275
Computer science	12,491	48,270
Earth and planetary sciences	1,078	0
Energy	2,012	10,313
Engineering	36,017	91,482
Environmental science	692	7,735
Health professions	0	0
Immunology and microbiology	0	1,937
Materials science	9,228	57,051
Mathematics	5,174	12,828
Medicine	1,197	29,476
Neuroscience	0	1,897
Nursing	0	0
Pharmacology, toxicology and pharmaceutics	0	4,129
Physics and astronomy	11,820	37,747
Psychology	0	0
Social sciences	0	8,782
Total	89,667	408,444

Table 6. Estimates for the balance (evenness or consistency) as measured by $\eta = F/X$ in the two clusters arranged into the broader REF categories

Research excellence framework 2014 panels	IISc + 7IITs	NUS + NTU
Biological sciences and medicine	1.00	0.83
Physical sciences and engineering	0.83	0.99
Social sciences	–	0.85
Arts and humanities	–	1.00
Total	0.84	0.96

the global average. This is reflected in the X-scores and F-scores (Tables 4 and 5). The NUS + NTU cluster is four times more effective than the IISc + 7IITs cluster at the level of the second-order indicators[10,11].

Finally, we can give a broad estimate for the balance (evenness or consistency) as measured by $\eta = F/X$ in the two clusters arranged into the boarder REF categories, as shown in Table 6. We see that the NUS + NTU cluster has a slight edge over the IISc + 7IITs cluster.

In conclusion, we decompose the research performance of the IISc + 7IITs and NUS + NTU clusters into three components – size, excellence and balance or evenness. Data are retrieved from the excellence mapping web application. The NUS + NTU cluster outperforms the IISc + 7IITs cluster on all three counts. The research base in the former is larger, it produces work which is uniformly of higher quality and is structurally more diverse.

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ACKNOWLEDGEMENTS. I thank the creators of the web applications, Lutz Bornmann, Division for Science and Innovation Studies, Administrative Headquarters of the Max Planck Society, Munich, Germany; Rüdiger Mutz (Professorship for Social Psychology and Research on Higher Education, ETH Zurich/MUG, Switzerland); Moritz Stefaner (Truth and Beauty Operator); and Felix de Moya Anegón, CSIC/CCHS/IPP, SCImago Group (Spain), Communication and Information Science Faculty, University of Granada, Spain for making the applications available in the public domain. I also thank Lutz Bornmann for useful discussions.

Received 19 February 2016; accepted 30 August 2016

doi: 10.18520/cs/v112/i05/1012-1015

ABCD matrix formalism to determine nonlinear refraction coefficient by Z-scan technique

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In this study, we revisit the popular method of measuring the nonlinear susceptibility of a material through Z-scan technique, introduced in 1990 by Sheik-Bahae and co-workers through a simple ray optics defined by the ABCD matrix formulation. The work therefore looks at the Z-scan measurement curves analysed through ray propagation in the medium and analysed through an aperture. The transmittance of a sample in the Z-scan technique is measured through a finite aperture in the far field, as the sample is scanned along the propagation direction (Z) of a focussed Gaussian beam. The sign and magnitude of nonlinear refractive index are easily deduced from the transmittance curve (Z-scan) using the theoretical model based on ABCD matrix formalism.

Keywords: ABCD ray matrix, linear optics, nonlinear optics, Z-scan technique.

ABCD matrix formalism is an efficient and widely used tool to describe the propagation of a beam through arbitrary optical systems. ABCD matrices for free propagation and for many optical components (lens, mirror, etc.) are known[1,2] and extensively used in commercial ray tracing softwares like ZEMAX, Code-V, etc. for design and analysis of complex optical systems. These matrices are also useful to determine the characteristics of paraxial optical systems, such as their effective focal length and the position of their six cardinal points. They are used to characterize the width and the wavefront curvature of an optical gaussian beam after its propagation through different optical components. The present work attempts to use the ABCD matrix formulation to describe the Z-scan technique to determine the nonlinear response of a material. There are several methods to measure nonlinear refraction including nonlinear interferometry[3,4], degenerate four-wave mixing[5], degenerate three-wave mixing[6], ellipse rotation[7], and beam distortion measurements[8] and Z-scan[9,10]. The first three methods are potentially sensitive techniques, but these require relatively complex experimental apparatus, whereas Z-scan is a simple technique to study nonlinear refraction and nonlinear absorption. It has been shown that nonlinear refraction and its sign can be obtained from a simple linear relationship between the

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