Benchmarking research performance of the IITs using *Web of Science* and *Scopus* bibliometric databases

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Although engineering education at the tertiary level in India is now more than 150 years old, it was only since independence that the IITs have been set up as institutions of national importance with an emphasis on postgraduate education and research. In this communication, we benchmark the recent research performance of the IITs in academic research in the area of engineering science and technology in the country against that of similarly placed institutions in the world using bibliometric indicators from the *Web of Science* and *Scopus* databases.

Keywords: Bibliometrics, benchmarking, engineering education, research evaluation.

THE four engineering colleges set up at Roorkee (1847), Shibpur (1856), Guindy (1794) and Poona (1854) could arguably be called the first four engineering colleges in the country[1]. The express purpose was to train the engineers needed for the civil and other engineering activities of the day[2]. The Indian Institute of Science (IISc), Bangalore which was founded in 1908, and the Banaras Hindu University (BHU), Varanasi which was founded in 1916 gave a boost to postgraduate education and research in engineering science and technology. After independence, the opportunities for postgraduate engineering and research were significantly enhanced by the setting up of the Indian Institutes of Technology (IITs; from 5 initially to 16 currently) as institutes of national importance. Among the technological institutes in the country, the IITs turn out the major chunk of Ph Ds in engineering and also the largest share of scientific articles every year. To ensure that the performance is of world-class quality, it would be necessary to implement research assessment exercises based on the best practices used today in evaluative bibliometrics and benchmark it against similarly placed institutions in the world.

Recently, efforts have been made to benchmark the quality and quantity of research using bibliometric indicators[3,4]. In this communication, we use such tools to review the current performance of IITs in academic research in the area of engineering science and technology in the country.

The IITs were the first engineering schools to be established as institutes of national importance through acts of parliament. One can say that from the point of view of providing broad-based education, they were modelled on the Massachusetts Institute of Technology, USA and this was indeed the spirit in which they were set up. But over the years, the operationalization of the IIT system began to imitate that of the Ecole Polytechniques of France. Admission is through a procedure based on a very highly selective entrance examination at a national level, which requires students to augment their regular school classes with intensive coaching classes.

Initially, five IITs were established at Kharagpur (1951), Bombay (1958), Madras (1959), Kanpur (1960) and Delhi (1961). A sixth IIT was established in 1995 at Guwahati only after a gap of three decades. The Engineering College at Roorkee was first made a University and then became the seventh IIT (2001). In 2008, four more IITs were established at Patna, Jodhpur, Hyderabad and Gandhinagar, and the following year, four more were added at Ropar, Bhubaneswar, Mandi and Indore. The Institute of Technology at BHU has now been recognized as the 16th IIT.

The Essential Science Indicators (ESI), from the *Web of Knowledge* a Thomson-Reuters product, lists all the IITs as a single entity and this is of comparable size to the leading higher technological institutes in the world. We can therefore use the data from ESI to benchmark how scientific research in the field of engineering in India from these premier institutes compares with other leading institutions in engineering. The second-order indicator[5] ($X = C^2/P = iC$) is used here, where C is the total citations to the papers P published in Thomson Reuters-indexed engineering journals by the various institutions, and impact $i = C/P$ is used as a proxy for quality. These institutions are chosen out of a pool of 1291 institutions ranked by total citation count in this field. Table 1 is based on this exergy indicator[5] and is arguably the best indicator for research performance, taking into account quality and quantity. MIT heads this list and the IITs take the 14th place. The Chinese Academy of Sciences ranks first on count of papers (11,383) and citations (69,400). On impact ($i = C/P$), Harvard University leads this select list of 20 with 13.35 citations/paper, whereas the IITs have 5.49 citations/paper. On count of papers, which can be taken to be a reasonable proxy for quantity of output, the IITs come second to The Chinese Academy of Sciences. However, on quality of research, assuming that the impact i (ratio of citations to papers) is a good proxy for this, the IITs rank at the bottom of this list of 20, just below The Chinese Academy of Sciences.

While in the sixties, and even as late as in the eighties, the IITs were considered as better destinations for scientific research when compared to the Singapore institutions in this list, namely the National University of Singapore (NUS) and the Nanyang Technological University (NTU), these now clearly have a commanding lead over the IITs.

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Table 1. Performance ranked by exergy of the top institutions in engineering, 2002–2012 (1 January 2002–31 December 2012)

Rank	Institution	Papers *P*	Citations *C*	Citations per paper *i*	*X* = *iC*
1	MIT	5,243	56,102	10.70	600311.73
2	STANFORD UNIV	3,817	45,540	11.93	543330.26
3	UNIV CALIF BERKELEY	4,912	49,541	10.09	499656.08
4	UNIV ILLINOIS	6,170	54,632	8.85	483736.70
5	CHINESE ACAD SCI	11,383	69,400	6.10	423118.69
6	NATL UNIV SINGAPORE	5,773	43,888	7.60	333649.15
7	UNIV MICHIGAN	5,201	41,613	8.00	332944.00
8	GEORGIA INST TECHNOL	5,918	44,063	7.45	328075.02
9	NANYANG TECHNOL UNIV	7,006	47,835	6.83	326603.94
10	UNIV CALIF LOS ANGELES	2,840	29,949	10.55	315824.86
11	CALTECH	1,811	23,618	13.04	308012.11
12	UNIV LONDON IMPERIAL COLL SCI TECHNOL & MED	4,416	36,171	8.19	296272.93
13	ECOLE POLYTECH FED LAUSANNE	3,091	29,696	9.61	285296.80
14	INDIAN INST TECHNOL	9,453	51,856	5.49	284464.69
15	CITY UNIV HONG KONG	4,258	33,840	7.95	268939.78
16	PRINCETON UNIV	1,751	21,583	12.33	266034.20
17	CNRS	4,511	34,503	7.65	263900.91
18	HARVARD UNIV	1,469	19,616	13.35	261938.36
19	PENN STATE UNIV	4,031	32,454	8.05	261290.53
20	UNIV MINNESOTA	2,920	26,547	9.09	241350.41

Source: Essential Science Indicators from Thomson Reuters.

Table 2. Comparison of performance trajectories using *iCX* representation of the IITs and NUS and NTU from 1981 to 2011

Windows	One-year publications window	1980	1985	1990	1995	2000	2005	2010
	One-year citations window	1981	1986	1991	1996	2001	2006	2011
NUS and NTU	Publications from one-year window	115	502	865	2323	4594	6990	9229
	Citations from one-year window	27	219	491	1333	3733	9911	23569
	i based on moving windows	0.23	0.44	0.57	0.57	0.81	1.42	2.55
	X based on moving windows	6.3	95.5	278.7	764.9	3033.4	14052.6	60190.5
IITs	Publications from one-year window	1157	1299	1302	1907	2117	3893	6008
	Citations from one-year window	438	496	476	756	1349	4203	8661
	i based on moving windows	0.38	0.38	0.37	0.40	0.64	1.08	1.44
	X based on moving windows	165.8	189.4	174.0	299.7	859.6	4537.7	12485.5

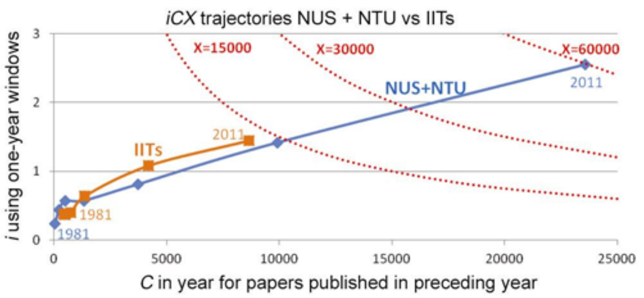

Figure 1. Data from Table 2 are used to track the performance trajectories of the IITs and compare it with NUS and NTU taken together, from 1981 to 2011 using the *iCX* representation[6].

We can easily visualize this using what are called *iCX* trajectories[6]. Table 2 compares the performance trajectories of the IITs with that of NUS and NTU taken together from 1981 to 2011 using the iCX representation[6]. Again, *Web of Science* (*WoS*) data are used and the database was accessed on 26 April 2013. To keep the numbers manageable (*WoS* allows citation reports to be generated only if the number of items is less than 10,000), a one-year publications window is taken to obtain the papers published *P* during that year and a one-year citations window immediately following that year is used to compute the citations *C*. The impact *i* is computed as the ratio *C*/*P*, and a two-dimensional representation of *i* and *C* allows the performance trajectory to be tracked. This is visually displayed in Figure 1. Figure 2 shows that sometime around 1987–1988, NUS and NTU taken together begin to outperform all the IITs taken together.

Datasets from the 2013 release of Scimago Institutions Rankings (SIR) (http://www.scimagoir.com/) are now available and allow us to see how the performance of NUS and NTU can be compared with that of IISc and the IITs.

The SIR reports are arguably the most comprehensive and systematic ranking of worldwide research institutions.

Table 3. Comparison of research performance of NUS and NTU with that of IISc and the leading IITs appearing in SIR 2013

Organization	Q = O	NI	Q1	Exc	q^2	$X = qQq$
National University of Singapore	28,848	1.59	60.79	20.08	4.16	119,938.85
Nanyang Technological University	22,185	1.5	48.90	19.76	3.33	73,805.89
Indian Institute of Science	9,111	1.05	54.25	12.27	2.44	22,221.51
Indian Institute of Technology, Kharagpur	7,665	1.04	45.62	11.78	1.93	14,816.90
Indian Institute of Technology, Delhi	6,629	1.03	41.30	12.45	1.78	11,799.68
Indian Institute of Technology, Madras	6,252	0.93	46.42	11.14	1.85	11,573.71
Indian Institute of Technology, Bombay	5,822	1.12	47.97	11.99	2.12	12,369.41
Indian Institute of Technology, Kanpur	5,075	0.99	50.86	10.87	2.10	10,658.27
Indian Institute of Technology, Roorkee	4,277	1.01	37.20	13.03	1.64	7,031.46
Indian Institute of Technology, Guwahati	2,626	0.98	43.11	11.69	1.77	4,639.72

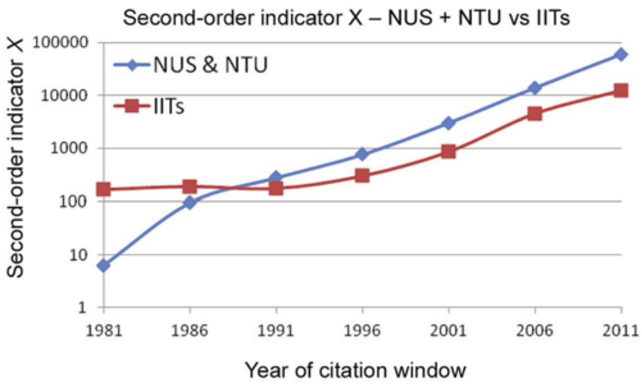

Figure 2. Sometime around 1988–1989, NUS and NTU taken together begin to outperform all the IITs taken together.

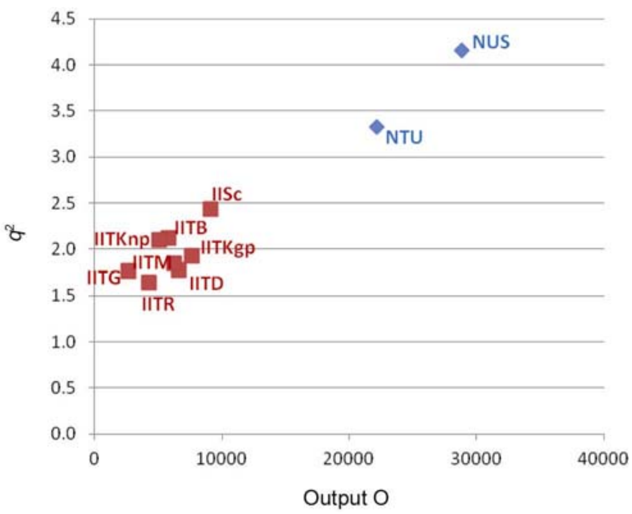

Figure 3. Graphical comparison of research performance of NUS and NTU with that of IISc and the leading IITs appearing in SIR 2013.

The global SIR 2013 which was published in July takes into account those organizations from any country, with at least 100 documents published in the last year of the five-year period, i.e. 2007–2011, as collected in the *Scopus* database. The bibliometric analysis is based on many indicators addressing issues like scientific impact, thematic specialization, output size and international collaboration networks of the institutions.

Of the many indicators that SIR 2013 used, one can be identified with the size or quantity attribute and another three with quality attributes. Thus, the *O* (or output) indicator is based on the total number of documents published in scholarly journals indexed in *Scopus* and is a measure of the quantity or size of the publication output of an institution. The three factors which are proxies in various ways of the quality of output are:

1. The NI (or normalized impact) compares the average scientific impact of the institution with the world average (taken as 1). Thus a score of 0.8 implies a 20% below average performance, while a score of 1.3 means the institution is cited 30% above average.
2. The *Q*1 (or high-quality publications), which is the ratio of publications that the institution publishes in what the SCImago team takes as the most influential scholarly journals of the world; those ranked in the first quartile (25%) in their categories as ordered by SCImago Journal Rank. Since this is reported as a percentage, the ratio (*Q*1/25) is again another normalized proxy for quality of publication, with a value of 1 taken as the world average.
3. The ER (or excellence rate) which indicates the percentage of an institution's scientific output that is included into the set formed by 10% of the most cited papers in their respective scientific fields, and serves as a measure of the high-quality output of research institutions. Again, the ratio ER/10, allows one to normalize this proxy so that the world average becomes 1.

It is possible to combine these three quality proxies into a single one. We propose for this purpose, the q proxy, where q^2 is defined as $((NI)^2 + (Q1/25)^2 + (ER/10)^2)/3$. This has the simplicity that it is a composite quality indicator with a value of 1 describing the world norm. Thus in this analysis we have simplified the SIR 2013 data to a quantity term (Q = O) and quality term (q). From this, we define that a single composite term, $X = q^2Q$, is that term

Table 4. Comparison of research profiles of the IITs with NTU from 2003 to 2013

Rank	Field	Papers	Cites	*i*	*X*	%*X*
ESI as of 1 May 2013 to cover the period 1 January 2003–28 February 2013						
IITs						
1	CHEMISTRY	8,271	93,005	11.24	1,045,376	48.01
2	ENGINEERING	9,137	48,339	5.29	255,713	11.74
3	PHYSICS	5,379	36,723	6.83	250,818	11.52
4	MATERIALS SCIENCE	5,554	34,129	6.14	209,552	9.62
5	BIOLOGY & BIOCHEMISTRY	1,238	14,559	11.76	171,214	7.86
6	ENVIRONMENT/ECOLOGY	858	9,879	11.51	113,707	5.22
7	GEOSCIENCES	1,416	9,544	6.74	64,327	2.95
9	AGRICULTURAL SCIENCES	447	3,176	7.11	22,581	1.04
8	COMPUTER SCIENCE	1,598	5,351	3.35	17,926	0.82
11	CLINICAL MEDICINE	311	2,203	7.08	15,597	0.72
10	MATHEMATICS	883	2,507	2.84	7,120	0.33
12	SOCIAL SCIENCES, GENERAL	175	769	4.39	3,376	0.16
	ALL FIELDS*	36,369	268,539	7.38	2,177,308	100.00
NTU						
1	CHEMISTRY	3,576	44,502	12.44	553,605	32.59
2	MATERIALS SCIENCE	2,927	29,849	10.2	304,460	17.92
3	ENGINEERING	6,643	43,927	6.61	290,357	17.09
4	PHYSICS	4,144	33,724	8.14	274,513	16.16
5	BIOLOGY & BIOCHEMISTRY	778	8,746	11.24	98,305	5.79
6	ENVIRONMENT/ECOLOGY	319	3,729	11.69	43,592	2.57
7	MICROBIOLOGY	223	3,035	13.61	41,306	2.43
8	CLINICAL MEDICINE	580	3,797	6.55	24,870	1.46
9	COMPUTER SCIENCE	1,904	6,764	3.55	24,012	1.41
10	ECONOMICS & BUSINESS	427	2,754	6.45	17,763	1.05
11	PLANT & ANIMAL SCIENCE	137	1,544	11.27	17,401	1.02
12	SOCIAL SCIENCES, GENERAL	820	2,631	3.21	8,446	0.50
	ALL FIELDS*	24,031	195,373	8.13	1,698,631	100.00

*Total for all fields taken together.

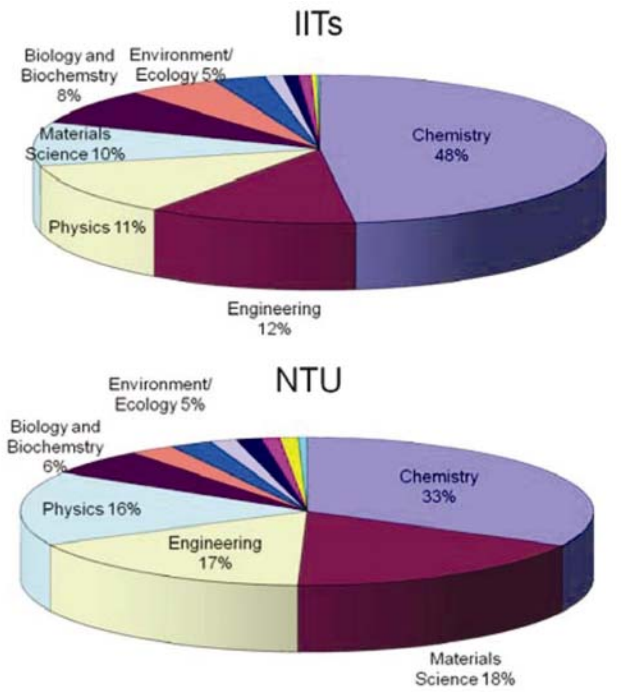

Figure 4. Comparison of research profiles of the IITs with NTU from 2003 to 2013.

that serves as the best proxy for total performance in the research context.

In the present exercise, we have prepared a league table comparing NUS and NTU with IISc and the leading IITs (Table 3). The graphical comparison is shown in Figure 3. NUS and NTU are at least five times more active than the IISc or IITs.

ESI allows us to compare the research profile of all the IITs taken together with that of NTU. The latest update of ESI of 1 May 2013 covers the 10-year plus two-month period, i.e. 1 January 2003–28 February 2013. We use these data to compare the profiles of scientific research of all the IITs taken together with those of NTU during this period. Table 4 shows the bibliometric data and the profiles are drawn based on the shares of the second-order indicator as shown in Figure 4.

We see from Figure 4 that although the IITs and NTU are technological institutes of the highest calibre, the hard-core engineering research (12% of total in the former and 17% in the latter using the second-order indicator as the measure of performance) is very small compared to that in the basic sciences.

Although India made a good beginning after independence, its research efforts in engineering have not kept pace with that of the more developed countries in the world. This is dramatically borne out by the trajectories shown in Figures 2 and 3. Huge investments in just two instititutions in Singapore, NUS and NTU have taken them far ahead of all the IITs put together.

Indian universities rarely turn up in world university rankings such as Quacquarelli Symonds (QS), Times Higher Education (THE) and the Shanghai Jiao Tong ARWU. Even when they do, the best from India are invariably the five oldest IITs which take their turn as if in a game of musical chairs in the various league tables. Very much more has to be done for India to be able to claim that its higher technological institutes can rank with the best in the world.

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Metrological performance evaluation of force standard machines using intercomparison as a measure at National Physical Laboratory, India

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National Physical Laboratory, India has been maintaining the standards of force from 1 N to 3 MN. There are various force machines of capacities ranging from 50 N to 3 MN. A new 1 MN force standard machine has been established to provide better traceability up to 1 MN. In order to establish the validity of metrological capabilities of the existing 50 kN dead weight force machine (BMC 0.003% at $k = 2$), it has been compared to 1 MN force standard machine having force realization between 1 and 100 kN using dead weights (best measurement capability (BMC) 0.002% at $k = 2$) and 10 kN–1 MN with 10 kN incremental using lever multiplication (BMC 0.009% at $k = 2$) through the precision force transducers of relative repeatability 0.005%. The intercomparison has been used to evaluate the normalized error (*En* value) and it has been found within the permissible limit during the whole range of the 50 kN dead weight force machine.

Keywords: Force standard machine, intercomparison, metrological performance, normalized error.

NATIONAL Physical Laboratory, India (NPLI) has been the custodian of maintaining and dissemination of national standards at the apex level in the country. The force and hardness standard group of NPLI has the responsibility to maintain and disseminate the standards of force, torque and hardness. The group has various force machines of different capacities from 50 N to 3 MN (ref. 1). For realization of force with utmost precision at the apex level, the 50 kN dead weight force machine and the newly established 1 MN force standard machines have been employed. The former was developed by More House Corporation, USA, according to the instructions of NPLI and has been used for about a decade (Figure 1); it has been already discussed elsewhere. The expanded uncertainty associated with the force applied is 0.003% ($k = 2$) (ref. 2).

Figure 1. The 50 kN dead weight force machine.

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