Benchmarking university-industry research cooperation worldwide: performance measurements and indicators based on co-authorship data for the world's largest universities

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Abstract

World rankings of universities have become an established research management tool and have taken centre stage in many evaluations of university systems. Surprisingly, there is still no comparative information as to which universities are the world's major providers of research-based information and services to the business sector in general, and science-dependent industry in particular. This paper presents the first results of statistical analyses to help fill this information gap.

Our case study of university-industry research cooperation patterns deals with the world's 350 largest research universities. The statistical data were derived from university-industry co-authored research publications (UICs) that were published during the years 2002-2006 and jointly authored by university researchers and staff employed by business enterprises. The results reveal a host of organizational variables that are likely to determine a university's UIC performance. The various UIC rankings highlight measurement issues and reveal significant differences depending on which UIC indicator is selected for comparison.

We conclude that these UICs offer an interesting new source of empirical data for domestic and international comparisons of research universities but, pending further validation studies, university-level UIC statistics should preferably be used only within non-evaluative multidimensional benchmarking frameworks rather than for university league tables.

Keywords

Worldwide university rankings, research-intensive universities, university-industry research cooperation, research performance indicators, validity

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1 Introduction

As universities become increasingly relevant to societies and knowledge-based economies, the demand for comparative information on the current performance universities tends to increase.[1] As a result, national university rankings and international league tables are now a prominent feature of the public information across a wide range of performance indicators, were cross-national comparisons and measurement issues are becoming increasingly important (Dill and Soo, 2005; Marginson and Van der Wende, 2007; Williams and Van Dyke, 2007). A global knowledge market is emerging and we are now also witnessing is an increasingly fierce competition among universities to be among the best in their region or worldwide. Transparent and objective metrics are increasingly used as elements for internal debate and strategic exploration within research management, where national and international top performers, and their best practices, provide standards against which performance can be measured, compared and evaluated. Despite differences in vantage points and inconsistencies in the measurement methodologies, there is often a surprising level of agreement as to which universities are the best in terms of providing educational services.

However, there is no comparative information – especially at the international level - as to which universities are considered the "best" providers of research services to the business sector. There is no widely acceptable and globally available set of measures. Given the on-going globalization of industrial R&D, and associated worldwide markets for university-industry research partnering, this information gap deserves more attention in the international benchmarking of university research performances. This paper presents the first results of a study to help fill this gap in university performance statistics. The guiding questions are: can quantitative statistics derived from university-industry research publications be used as a performance indicator? If so, which measurement parameters should be taken into account? And how valid and useful are the measurements for international comparisons and rankings of universities?

The structure of this paper is as follows: section 2 introduces and discussed relevant measurement issues to address those research questions; section 3 describes our analytical framework and metrics; we present the main findings in section 4, and concludes in section 5 with an extensive general discussion and methodological recommendations.

2 Measurement issues

The measurement and evaluation of university research characteristics has always been a controversial issue, especially with respect to effectiveness of quality assurance systems, and performance-driven research funding systems. A large part of the heated controversy with respect to institutional performance rankings arises from the lack of (generally accepted) systematic information and lack of inter-organizational comparability (e.g. Usher and Savino, 2007), but also on related statistical issues such as the choice of appropriate statistical models and performance measures and (e.g. Goldstein and Speigelhalter, 1996). Is there sufficient common ground for reliable and systematic comparisons of UIC performances across a diversity of universities? And, if so, how can one strike a trade-off between the uniqueness of each university and UIC comparability?

[1] "Universities" are taken to mean all higher education institutions, irrespective of their name and status within their country of location.

With regards to the first issue (data availability) there no comparative statistics among universities. There is no university-level information in the public domain on recruitment of graduates by the business sector, or which universities are particularly valued by industry by industry for research inputs or research-related services, nor do we know the sums of money for contract research done by universities for the business sector. For lack of better, this information gap can be remedied, up to a certain degree, by examining the institutional origins of joint research publications that are co-produced by R&D staff from public sector research organizations and their partners employed by business companies and other private sector organizations. The majority of these group-authored publications relate either to biopharmaceutical research, clinical trials or other strategic basic research, all focusing on longer term perspectives for business applications and commercialization.[2]

With regards to the second measurement issue (statistical models) the crucial observation is that comparisons and rankings are meaningless if the heterogeneity among the universities exceeds a certain threshold where the differences become larger than the similarities. There's little to be gained from including universities devoted entirely to education and training. Nor is it wise to compare large comprehensive research universities with specialized universities in for example medicine, or in engineering and technology. Clearly, measurement methodologies should take into account the local R&D circumstances. So, adopting the right context and analytical framework is issue, especially against international standards and benchmarks should UIC performances be measured and compared.

Industrially relevant research activities can be characterized along three main dimensions according to the university's organizational characteristics and disciplinary scope:

- External attractiveness, i.e. the capacity to attract resources from the private sector (funding, human resources, partners, tools, facilities and equipment);
- Geographical embeddedness, i.e. the geographical distribution of those resources, contacts and partnerships;
- Research specialization profile, i.e. the distribution of university-industry interactions across fields of science and areas of technology.

Each of these characteristics can be captured by empirical information extracted from research publications in the open scientific literature. Research articles are probably the most relevant output of academic science, and constitute primary data for developing performance metrics and "bottom-up" indicators of knowledge production characteristics within major research-oriented universities.

3 Data source and performance indicators

The statistical ("bibliometric") data on university research publications was extracted from the *Web of Science,* an international multidisciplinary bibliographic data base of worldwide research literature. The WoS is one of the key sources are research articles in some 14 000 international peer-reviewed scientific and technical journals. Each journal is attributed to one or more WoS-defined Journal Categories, representing a subfield of science that CWTS aggregrated into (broad) fields of science. This source provides a comprehensive coverage of international "main stream" science presented in these research journals. These are primarily in English-

[2] The significant part of industry spending will related to applied research with a short-term or medium term commercialisation focus. Publishable results of applied research are usually not disseminated in the peer-reviewed international journal literature, but are issued as (confidential) reports, blue prints, patents, or other document types.

language journals and biased towards presented the findings of basic "academic" research. The coverage of the research literature is reasonable to (very) good in the case of the industrially relevant fields of science (but limited in the case of the social and behavioral sciences, and very limited for arts & humanities fields). The WoS is an excellent source of empirical and quantifiable data on basic research cooperation in the form of co-authored publications, albeit limited to those successful research activities that eventually emerged as publications in the peer-reviewed open literature. WoS-based data is one of the main sources to rank universities by various output-related aspects of their research performance and has been applied in several exploratory studies in recent years, as well as being subject of academic debate (e.g. Van Raan, 2005; Calero-Medina et al., 2008; Kivinen and Hedman, 2008).

The bibliographic record of each publication contains information on the author addresses and their institutional affiliations, which enables us to identify the institutional sector of co-authoring partners and the geographical location of those partners.[3] The information on the institutional affiliations was cleaned and harmonized where the names of the main organizations were standardized and organizations classified according to their main institutional sector such as: universities, public sector research institutes, and business enterprises and other private sector organizations (the private sector). Publications in which the author addresses include affiliations refer to at least one university and one private sector organization where classified as *university-industry co-publications* (UICs).[4] The private sector organizations listed in these UICs are split into two broad geographical classes: 'domestic' (private sector partners based in the same country as the university) or 'foreign'. Depending on the locations of the pairs of organizations mentioned in the author addresses, a publication can be attributed to either class of both.[5]

Bibliometric analyses of these links between university science and industrial R&D represents an analytical window to gauge the scale and intensity of university-industry research interaction and cooperation, both at the country level and at institutional levels (e.g. Hicks and Hamilton, 1999; Tijssen, 2004; Tijssen and Van Leeuwen, 2005; Sun et al., 2007). UIC-based statistical information will capture empirical information about university propensities for research cooperation with industry, thus providing us with a proxy measure of their role as knowledge supplier in innovation systems, or from a broader perspective, their role in international 'science-innovation ecosystems'.

An estimated 7% of all WoS-indexed research publications can be classified as UICs, totaling some 60 000 publications per year worldwide (NOWT, 2008).[6] As such, they

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3 The WoS-indexed publications are attributed to organizations by CWTS, based on information extracted from the author affiliate addresses within each publication. The results of this attribution process have not been verified by the respective organizations. The publication output may miss publications, or include erroneous attributions, thus creating an incomplete presentation of the actual output.

4 CWTS applies computerized routines to scan the information on the affiliate addresses of authors listed in the WoS records in order to identify those research papers that originate from private sector organizations. Information on the affiliate addresses is cleaned and standardized. These routines focus on for-profit private enterprises in manufacturing sectors and services sectors, including contract research organizations and company-owned research institutes. It excludes "hybrid" university-industry organizations and for-profit medical practices (and other organizations in the medical and health care sectors). The university-industry co-publications are drawn from CWTS' Corporate Research Papers database (edition January 2008), an integral part of the CWTS WoS database, which includes the large majority of publications with an author affiliate address referring to business sector organizations.

5 Each UIC is counted only once in the computation of the total number of UICs per university.

6 The share refers to the total number of UICs within the WoS-indexed publication output of 2005-2006 of the 17 countries worldwide (Australia, Austria, Belgium, Canada, Denmark, Finland, France,

represent a very extensive multidisciplinary source of empirical data that is amenable to large-scale systemic quantitative analysis. However, co-publication data have their drawbacks and caveats (Katz and Martin, 1997), in this particular case:

- the majority of the business enterprises represented in UICs will be large science-dependent companies with sufficient human and financial resources to conduct basic research and/or to engage in research cooperation with HEIs, especially the very large multinational enterprise active within the biopharmaceutical, ICT and chemical sectors (Tijssen, 2004; 2008);
- UIC output is mainly driven by academic incentive systems to publish interesting findings in the open scientific literature and therefore more representative of university research efforts than industrial research;
- UICs are a subset of all publications reporting on research that was (partially) funded by industry (the share of this subset within the total number of industry-funded research publications is unknown);
- not all co-authors of a research article will be full contributors (or "phantom" co-authors with no direct input whatsoever), nor will all collaborating researchers become co-authors;
- In a minority of cases the UICs reflect the multiple affiliations of a single author rather than institutional cooperation.

Despite these limitations, UIC outputs provide a unique source of information for developing aggregate-level proxy measures of the magnitude and intensity of university-industry research cooperation. The next section will elaborate on several UIC-relevant characteristics of large research universities, including the issue of geographical closeness between universities and partner companies.

4 Results of UIC analyses

4.1 Description of world's 350 largest research universities

National university systems differ in terms of governance systems, funding systems, and socio-economic framework conditions. Even within a country large degree of heterogeneity can be found between universities in terms of size, quality, research specialization profiles, management structures and societal missions. Convincing statistical analyses will have to take country-level and institutional-level heterogeneities into account. This UIC study deals with a large sample of research universities across the globe, more precisely: the world's 350 largest research universities in terms of publication output in *Web of Science*-indexed journals and their publication output during the years 2002-2006.[7] We assume this sample is sufficiently large and divers to represent all large and medium-large research universities worldwide. The global reach covers 36 countries, where the United States accounts for 109 universities, followed by Germany (34), United Kingdom (24), Canada (17), China (16), Japan (15), Italy (12) and France, Netherlands and Spain (11).[8] The vast majority of these universities are included in the top 500

Germany, Great Britain, Ireland, Japan, Netherlands, Norway, South Korea, Sweden, Switzerland, USA). This set was used for benchmarking the UIC performance of the Netherlands for *2008 Science and Technology Indicators Report* issued by the Dutch government (NOWT, 2008; www.nowt.nl).

[7] See Calero-Medina et al. (2008) for more details about the collection of large universities from which this sample was drawn.

[8] The distribution of the 350 selected universities across countries (ISO codes) is as follows: US: 109, DE: 34, UK: 24, CA: 17, CN: 16, JP: 15, IT: 12, ES: 11, FR: 11, NL: 11, SE: 9, AU: 8, KR: 8, BE: 7, CH: 7, BR: 5, IL: 5, TW: 5, DK: 4, EL: 3, FI: 3, NO: 3, TR: 3, AT: 2, NZ: 2, PL: 2, PT: 2, SG: 2, AR: 1, CL: 1, CZ: 1, HR: 1, IE: 1, IN: 1, MX: 1, RU: 1, SA: 1, SI: 1.

universities of the 2007 edition of Shanghai Jiao Tong's *Academic Ranking of World Universities*.[9]

Tables 1 and 2 introduce summary bibliometric statistics of these universities and a list of the fields in which most of their UICs are concentrated. The findings show an average *UIC intensity* of 3.8, i.e. UICs account for an average 3.8% of their total publication output. The majority of their UICs are within four broad fields: Clinical medicine, Physics and materials science, Biomedical sciences, and Basic life sciences. The other fields within the natural, life, medical and engineering sciences, and mathematics (11 fields in total) account for a further 13%. The social sciences, arts and humanities cover the remaining 2%.

Table 1. World's top 350 most frequently publishing research universities; summary statistics of publication output and citation impact (2002-2006)

	Average	Std. Dev.	Maximum	Minimum
Total publication output (across all fields)	9 499	5 770	54 431	2 813
Share of UICs (UIC intensity)	3.8%	1.6%	10.5%	0.4%
Share of international co-publications*	32.8%	10.4%	56.2%	12.2%
Share of national co-publications**	40.3%	11.0%	79.5%	10.8%
Field-normalized citation impact score***	1.21	0.33	2.43	0.43

Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).
* Publications with two or more different countries in the author address information.
** Publications from a single country with two or more different main organizations.
*** World average impact score equals 1.

Table 2. Top 10 industrially relevant fields of science
(% distribution of UICs across fields of science, 2002-2006)

Broad field*	Distribution of UICs across fields	WoS coverage of research literature**
Clinical medicine and biomedical sciences	34%	82%
Physics and materials science	15%	84%
Basic life sciences	11%	93%
Chemistry and chemical engineering	10%	88%
Electrical engineering and telecommunication	5%	53%
Computer sciences	4%	43%
Earth sciences and technology	2%	74%
Biological sciences	2%	82%
Agriculture and food science	2%	75%

Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).
* Broad fields are based on CWTS aggregates of WoS defined *Journal Categories*.
** Share of WoS indexed publications within the reference list of WoS indexed publications (source: Van Raan et al., 2007).

The sample of 350 universities includes many specialized universities of technology or medicine, as well as comprehensive universities covering a much larger range of scientific disciplines. Table 3 outlines the extent of this disciplinary variation according to their research specialization profiles within the fields of industrial relevance. The medical sciences are by far the most important area; almost 200

[9] The nine exceptions are: Huazhong Univ. Sci. & Technol. (China); Univ. Aix Marseille 2 (France), Univ. Patras (Greece); Univ. Zagreb (Croatia); Univ. Bari (Italy); Kyungpook Natl. Univ. (South Korea); Univ. Pais Vasco (Spain); Univ. Ankara. (Turkey) and Hacettepe Univ. Ankara (Turkey).

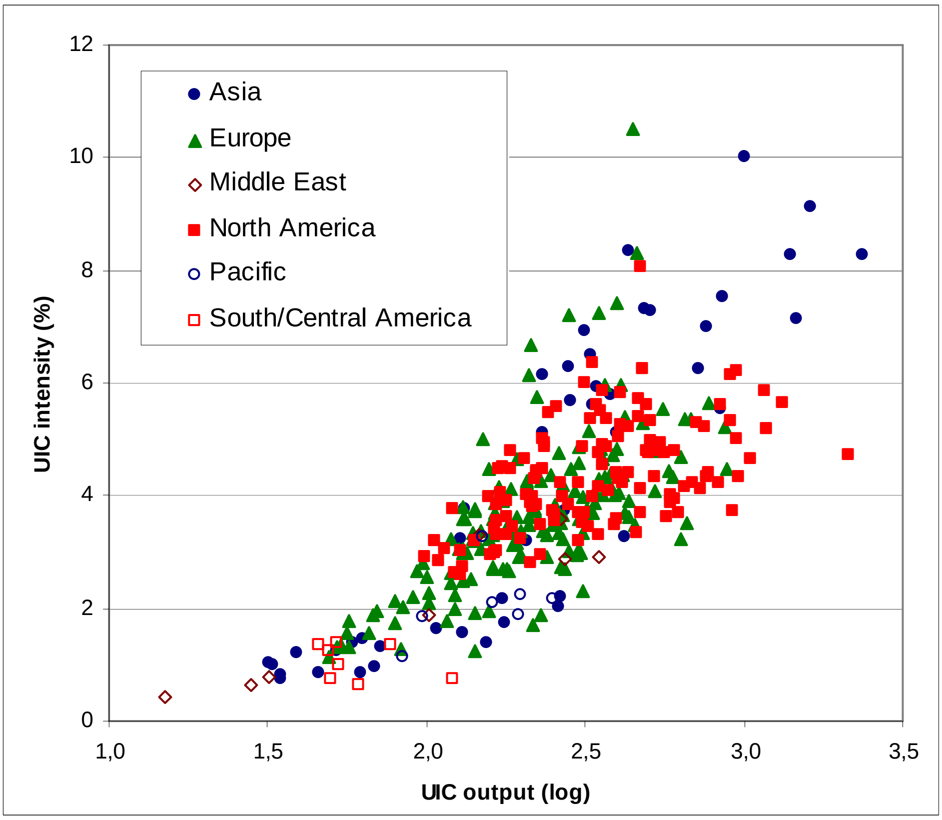
universities produce 50% of more of their UICs in Clinical medicine and biomedical sciences. In contrast only, 12 universities have a similarly strong focus on Physics and materials science, and only 3 in Chemistry and chemical engineering. All and all, we find some 50 "medical universities" show a major emphasis on UIC activity in the medical and life sciences; another 50 can be described as "universities of engineering and technology" focus on their UIC in the natural sciences and engineering. The remaining 250 universities are comprehensive research-intensive universities with broad multidisciplinary profiles.

Table 3. Quartile distribution of 350 universities by disciplinary breakdown of UICs (as a % of all UICs, 2002-2006)

Broad field	Share in a university's total UIC output 0-24%	25-50%	51-74%	75-100%
Clinical medicine and biomedical sciences	79	84	146	41
Physics and materials science	251	87	12	
Chemistry and chemical engineering	306	41	3	
Electrical engineering and telecommunication	325	25		
Basic life sciences	342	8		

Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).

Figure 4. Geographical distribution of the world's top 350 universities by UIC magnitude and UIC intensity (2002-2006)



Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).

The geographical dimension of UIC patterns is further illustrated in Figure 4, showing the UIC performance of all 350 universities categorized by three major geo-political regions in terms of R&D competition: Europe, Asia and USA, complemented by the group of universities located elsewhere (Other). The configuration clearly shows the dominance of the USA in the middle section of the distribution, especially in terms of

UIC magnitude, but also reveals the absence of the US in the upper percentiles of the UIC intensity distribution which is dominated by Asian universities.

4.2 UIC rankings

Which of universities have become major suppliers of industrial relevant knowledge and skills for research-intensive technology companies? As far as the output of UIC publications is concerned, one would expect the world's largest research universities, with the largest quantities of research publications, to populate the top of the ranking, which is what happens in Table 5. Some 80% of these UIC-active universities are either US or Japanese. However, even among the top 10 giants we find significant differences in terms of the share of UICs within the total publication output; the share of *Tokyo Institute of Technology* (10%) is twice as high as the top ranking US universities (5-6%). Evidently, some universities are more inclined to produce UICs than others of a comparable size.

Table 5. University ranking by UIC output

Top 25 most highly ranked universities according to quantity of university-industry research cooperation (UIC output frequencies, 2002-2006)*

	University	Country	UIC output	UIC intensity	% of domestic industry partners
1	Univ. Tokyo	Japan	2 353	8	91
2	Harvard Univ.	USA	2 127	5	87
3	Osaka Univ.	Japan	1 631	9	93
4	Kyoto Univ.	Japan	1 473	7	89
5	Tohoku Univ.	Japan	1 401	8	93
6	Univ. Calif. - Los Angeles	USA	1 325	6	91
7	Johns Hopkins Univ.	USA	1 175	5	87
8	Stanford Univ.	USA	1 161	6	86
9	Univ. Washington Seattle	USA	1 045	5	87
10	Tokyo Inst. Technol.	Japan	1 006	10	96
11	Univ. Michigan Ann Arbor	USA	961	4	85
12	Columbia Univ.	USA	945	5	92
13	Univ. Calif. - San Francisco	USA	945	6	88
14	Univ. Toronto	Canada	924	4	39
15	Univ. Calif. - San Diego	USA	911	5	85
16	MIT	USA	907	6	78
17	Univ. Cambridge	United Kingdom	889	4	61
18	Imperial Coll. London	United Kingdom	872	5	53
19	Hokkaido Univ.	Japan	863	8	95
20	Seoul Natl. Univ.	Korea	850	6	86
21	Duke Univ.	USA	844	6	86
22	Univ. Penn	USA	837	4	86
23	Kobenhagen Univ.	Denmark	774	6	60
24	Cornell Univ.	USA	773	4	86
25	Nagoya Univ.	Japan	761	7	95

Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).

* Frequency data computed through 'integer' counting of UICs, where each publication with one or more author affiliate addresses listing a private sector organization is counted only once.

The presence of local science-dependent industry is also clearly reflected in the share of domestic partners within the UICs, where the US and Japanese universities generate shares of 80% or more partners from within their own countries while the other universities have shares of 60% of less. The extremely large fractions of domestic partners in the case of the US and Japanese universities relates to the size of the national research and innovation systems (i.e. more opportunities to interact with home country partners) and/or the drive for competitive advantages among the domestic R&D-intensive companies (i.e. the need to perform cutting edge R&D and/or acquire state of the art university research inputs). The US, Japan and Korea all have several large R&D-intensive science-dependent industries (mainly technology companies and bio-pharmaceutical companies) and their main R&D sites on their soil. Clearly the national R&D environment can have a huge impact on a university's UIC behavior this creating a division between "parochial" UIC-oriented universities and their "cosmopolitan" counterparts with a much large share of private sector partners from abroad.

The other countries are more internationally oriented in their research partnerships owing to their relative small numbers of science-dependent R&D-intensive companies. For example, in relative terms, the *University of Cambridge* produces double the amount of UICs with foreign companies compared to *University of Tokyo*. The one exception is *Seoul National University* with quite high share, which is most likely a result of UICs that involve the large electronics companies in Korea.

Since the university's total volume of research is clearly a determining factor in the number of UICs, controlling for it will enable a better ranking of universities regardless of size. The results are displayed in Table 6. Although a Dutch university is now at the top in this league table, most of the top 10 universities are now Japanese. Part of this bias towards Japan is explained by the fact that Japanese universities publish less research papers in areas that are not of industrial relevance (the US universities publish much more WoS-indexed research papers in the social science and the humanities). Nonetheless, this list is again heavily determined by the presence of large R&D-intensive science-dependent industries and probably at relatively close geographical proximity. For example, the campus of *Eindhoven University of Technology* is a few kilometers away from the central R&D labs of *Philips*, one of the world's largest R&D-intensive electronics companies.

Table 6 University ranking by UIC Intensity
Top 10 most highly ranked universities according to their fraction of university-industry research cooperation (% UICs within total publication output, 2002-2006)

	University	Country	UIC intensity	% domestic industry in UICs
1	Eindhoven Univ. Technol.	Netherlands	11	71
2	Tokyo Inst. Technol.	Japan	10	96
3	Osaka Univ.	Japan	9	91
4	Keio Univ.	Japan	8	95
5	Delft Univ. Technol.	Netherlands	8	75
6	Tohoku Univ.	Japan	8	94
7	Univ. Tokyo	Japan	8	91
8	Indiana Univ. Purdue Univ. Indianapolis	USA	8	92
9	Hokkaido Univ.	Japan	8	95
10	Tech. Univ. Denmark	Denmark	7	73

Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).

Having established the major impact of home country science-based industry on university-industry research cooperation, which of the 350 universities show the largest numbers of domestic UICs and hence a preference for ties with local industry? Table 7 provides some answers. The top 10 universities are clearly strongly focused on joint research with the domestic private sector. From a global industrial perspective it would be tempting to label these universities as local universities in view of their research cooperation relationships with local or domestic industries.

However, a closer look at number of the countries where their private sector co-publication partners are located reveals a global outreach. Even the most domestically oriented university, *George Washington University* in Washington DC, still lists a total of 15 different countries. Not surprisingly, the bottom 10 universities show a larger geographical dispersion in terms of the numbers of different countries where private sector partners are located. But interestingly, the differences between the top 10 and bottom 10 are relatively small; it appears that all these 350 largest research universities attract significant numbers of industrial partners across a wide range of countries. They are all, to varying degrees, global players in the world's science base. These universities are also likely to represent major actors in both national and international 'innovation-oriented industrial ecosystems' (Coombs and Georghiou, 2002).

Table 7. Top 10 and bottom 10 ranked universities according to domestic university-industry research cooperation
(% domestic industry in UICs, 2002-2006)

	University	Country	% domestic industry in UICs	Countries of industry partners
1	George Washington Univ.	USA	98	15
2	Kyushu Univ.	Japan	97	17
3	Chiba Univ.	Japan	97	12
4	Univ. S. Florida	USA	96	15
5	Tokyo Inst. Technol.	Japan	96	21
6	Keio Univ.	Japan	95	12
7	Hokkaido Univ.	Japan	95	21
8	Univ. Tsukuba	Japan	95	14
9	Kyungpook Natl. Univ.	Korea	95	8
10	Univ. Utah	USA	95	24
341	Univ. Fed. Minas Gerais	Brazil	11	11
342	Australian Natl. Univ.	Australia	10	28
343	Univ. Queensland	Australia	9	30
344	Med. Univ. Wien	Austria	8	25
345	Univ. Krakow	Poland	7	18
346	Univ. Adelaide	Australia	7	27
347	Univ. Wien	Austria	4	22
348	Warsaw Univ.	Poland	3	16
349	Istanbul Univ.	Turkey	0	16
350	Univ. Natl. Autonom. Mexico	Mexico	0	20

Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).

4.3 UIC benchmarking

Benchmarking different universities according to pre-specified performance criteria is at the core of the current craze of university rankings. The crucial observation is that these rankings are meaningless if the heterogeneity of the universities exceeds a certain threshold where the differences become larger than the similarities. Obviously there's no point in comparing research universities with medical schools devoted entirely to education and training. Nor is it wise to compare large classical research universities with specialized universities specialized in a single disciplines such as medicine. So clearly, cross-country cross-university cross-field comparisons, like those presented in previous tables, are not an appropriate approach for ranking universities according to UIC characteristics. Our bibliometric evidence reveals significant differences between universities which need to be addressed by restricting the comparisons to field-dependent scoreboards with a subset of similar universities in terms of size and specialization. The key analytical question then is how to classify universities into groups with a sufficiently large measure of internal homogeneity.

The solution lies in adopting a "multidimensional" perspective, where the different UIC performance characteristics of universities are grouped in a scoreboard, thus enabling various classifications of universities rather than a single ranking. But which variables should be selected, and how? As the number of variables added to the scoreboard increases, the analytical power tends to decrease. Trade-offs between both properties will have to guide the design of the scoreboard. Clearly "intelligent" scoreboards should be application oriented rather than data oriented (Tijssen, 2004). In the case of UIC benchmarking approaches, the scoreboards should are designed to compare counterpart universities of a similar size and active within comparable R&D environments.

Table 8. Pearson correlation coefficients between UIC-based indicators and background variables

Background variables	UIC output	UIC intensity
Overall research performance		
Total publication output	.839 *	.235**
Citation impact score	.447 **	.438 **
% International co-publications	-.117 *	-.077
% Domestic co-publications	.195 **	.146 **
Disciplinary profile		
Research specialization index (Pratt score for total publication output)	.060	.193 **
Total publication output in fields of industrial relevance	.786 **	.254 **
% Publication output in Medical and health sciences	.096	.080
% Publication output in Physics and materials science	-.025	-.044
% Publication output in Chemistry and chemical engineering	-.195 **	-.169 **
% Publication output in Electrical engineering and telecommunication	.017	.169 **
% Publication output in Basic life sciences	.175 **	.132 *
UIC profile		
% of UICs listing a domestic private partner	.409 **	.609 **
Number of partner countries listed in UICs	.503 **	.247 **
UIC specialization index (Pratt score for UIC output)	.029	.134 *
% UICs in Medical and health sciences	.094	.067
% UICs in Physics and materials science	-.03	.032
% UICs in Chemistry and chemical engineering	-.196 **	-.165 **
% UICs in Electrical engineering and telecommunication	.003	.162 **
% UICs in Basic life sciences	.155 **	.105 *

* Statistical significance at 0.05 level (2-tailed), ** Statistical significance at 0.01 level (2-tailed). Computations done with SPSS software version 14.0 (SPSS Inc. Chicago, IL, USA).
Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).

Proper "like with like" comparisons should also include as many as possible significant variables related to the two main organizational characteristics mentioned in section 3: geographical embeddedness (local and/or foreign UIC orientation) and differentiation profile (degree of research specialization and/or a breakdown by fields of science). Table 8 presents a list of these background variables and the Pearson correlation coefficients with both UIC indicators. We find significant positive statistical relationship between UIC intensity and the total publication output of a university, suggesting scale effects. Furthermore, the "scientific quality" of a university, in terms of citation impact in the international research literature, also seems to have a positive effect on UIC intensity, as suggested by earlier empirical studies of industry-university cooperation (e.g. Mansfield and Lee, 1996).

The research specialization index, based on the Pratt's measure of concentration (Pratt, 1977), is applied to the distribution of research publication output across all fields of science, where the social and behavioral sciences, and fields of the arts and humanities, are excluded in view of their lack of relevance for industry (see Table 2). The results show that a university's home country attractiveness, as measured by share of domestic private partners in UICs, is by far the most discriminating variable in the UIC profiles and hence should be used to select comparator universities. It is also clear that UIC rankings need to account for disciplinary profiles of universities. UIC intensity rankings per field of science will provide a better picture of where universities a comparatively strong in UIC. Table 9 displays a disciplinary breakdown for the top 10 universities listed in Table 6.

Table 9 UIC Intensities per broad field of science for the world's Top 10 UIC-intensive universities
% UICs within the publication output, 2002-2006

	All fields	Electr. Eng.	Phys.	Chem.	Med. sci	Life sci.
Eindhoven Univ. Technol.	11	26	15	14	10	5
Tokyo Inst. Technol.	10	19	14	13	15	17
Osaka Univ.	9	20	13	10	17	10
Keio Univ.	8	23	15	10	13	8
Delft Univ. Technol.	8	17	11	13	16	7
Tohoku Univ.	8	22	14	10	11	7
Univ. Tokyo	8	24	13	13	14	10
Indiana Univ. Purdue	8	24	15	8	12	11
Hokkaido Univ.	8	14	11	14	11	7
Tech. Univ. Denmark	7	13	9	13	12	8

Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).

This overview reveals that the UIC profile of *Eindhoven University of Technology* is extreme in its relatively large UIC intensity in Electrical engineering and low intensity in the Basic life sciences. A more appropriate UIC scoreboard of this university should focus on similar type universities. We selected the top 10 "lookalike" universities according to (a) similar distributions of the share of UICs across in these five broad fields, and (b) each university's share of domestic UIC partners across all fields of science[10].

Table 10 presents an abridged version of this UIC scoreboard with seven UIC indicators. These 10 universities share a strong emphasis on UICs in Chemistry and Chemical Engineering (Chem.) and Physics and Materials Science (Phys.). These results suggest that the three European universities are prime benchmark candidates in terms of profile similarity: *Delft University of Technology*, *Chalmers University of Technology* and the *Swedish Royal Institute of Technology*. The *Tokyo Institute of Technology* differs in terms of its extremely strong focus on UICs with domestic partners. The list is completed by no less than six Chinese universities, which exhibit much lower UIC levels (which are very likely to significantly increase in the years to come given the growth of the Chinese R&D system).

The dynamic version of the scoreboard is presented in Table 11 focusing on the changes that occurred over the last 10 years. The findings indicate that *Eindhoven University of Technology* is outperforming the four prime benchmark universities in terms of increase of UICs, and the increase of UICs with foreign partners. It is

10 The Pearson correlations between the disciplinary profiles of these 10 universities and the profile of the Eindhoven Univ. Technol. range from r=0.92 to 0.96.

surpassed by *Tokyo Institute of Technology* in terms of the increase of UICs with research partners from domestic private sector. Four of the six Chinese universities show even higher growth rates across the board, but these catching up processes started from much lower base lines and are therefore hardly comparable to *Eindhoven University of Technology*.

Table 10. UIC benchmark universities for *Eindhoven University of Technology*
(Top 10 ranked universities according to UIC-profile similarity, 2002-2006)

University (country code)	Total publ. output	UIC intensity	% domestic UICs	% output in Chem.	% output in Phys.	% of all UICs in Chem.	% of all UICs in Phys.
Eindhoven Univ. Technol. (NL)	5 012	11	71	36	37	29	29
Tokyo Inst. Technol. (JP)	12 230	10	96	31	45	39	56
Delft Univ. Technol. (NL)	6 740	8	75	20	30	27	38
Chalmers Univ. Technol. (SE)	4 865	7	70	26	38	29	54
Royal Inst. Technol. (SE)	5 924	7	65	25	44	30	57
Tsing Hua Univ. (CN)	15 224	2	46	24	39	27	52
Nankai Univ. (CN)	4 817	1	42	48	35	62	40
Lanzhou Univ. (CN)	3 600	1	62	39	31	53	33
Univ. Sci. & Techn. China (CN)	8 339	1	45	32	49	39	58
Nanjing Univ. (CN)	8 683	1	47	30	37	39	48
Jilin Univ. (CN)	5 414	1	57	51	35	61	42

Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).

Table 11. UIC scoreboard for *Eindhoven University of Technology*
(% change in UIC characteristics between 1997-2001 and 2002-2006)

University	UIC output* Chem.	UIC output* Phys.	Domestic UICs** Chem.	Domestic UICs** Phys.	Foreign UICs*** Chem.	Foreign UICs*** Phys.
Eindhoven Univ. Technol.	137	109	108	105	166	188
Tokyo Inst. Technol.	56	69	181	146	-11	98
Delft Univ. Technol.	64	26	44	49	126	-5
Chalmers Univ. Technol.	39	28	57	-2	-18	32
Royal Inst. Technol.	58	14	83	20	46	-16
Tsing Hua Univ.	197	240	307	461	150	65
Nankai Univ.	65	43	211	-43	21	250
Lanzhou Univ.	425	#	633	##	500	1 500
Univ. Sci. & Tech. China	336	700	650	3500	1 300	219
Nanjing Univ.	144	124	180	600	133	100
Jilin Univ.	-13	36	-9	150	-57	-9

Source: Thomson Reuters/CWTS *Web of Science* database (edition July 2008).
* % change in numbers of UICs
** % change of UIC partners from domestic private sector
*** % change of UIC partners from foreign private sector
# Increase from 0 to 8 UICs
Increase from 0 to 8 occurrences

5 How to use UIC data for performance measures

5.1 Complying to international standards of good practice

University research performance rankings have not only become part of managerial frameworks for comparative intelligence, quality assurance processes, national accountability, they have also gained prominence as powerful PR and marketing tools in the higher education sector worldwide. University rankings and performance league tables have given an impetus to national and international competitive pressures and exert an impact on science policy objectives and institutional goals. Given their gravity as management tools, the underlying ranking methodologies and measurements should be as error-free, objective and impartial as possible. It is therefore crucial that developers and producers of these tools should be held accountable for the quality in their own data collection, methodology, and dissemination. Any new measurement model, metrics or performance indicator, should therefore be carefully scrutinized as to (potential) biases in the input data, and the reliability, validity, applicability and generalizability of the measurements.

To tackle these issues, we need methodological guidelines. *The Berlin Principles on Ranking of Higher Education Institutions* provides us with a set of principles of quality and good practice in HEI rankings.[11] According to these principles, published in 2006, rankings and league tables should comply as much as possible with 16 standards of good practice, which are grouped into four classes: (a) purposes and goals, (b) design and weighting of indicators, (c) data collection and processing, and (d) presentation of results. Adopting the Berlin framework allows us to scrutinize the strengths and weaknesses of the UIC ranking approach presented in this paper. UIC performance must be measured against determinants and criteria that are closely aligned to accepted notions of what conducting industrially relevant research means, and what UICs actually represent. While being transparent in data collection, the choice of indicators, and the calculation of the performance scores, the approach in its current stage of development falls short in lack of clarity with regard to validity of UICs as an internationally comparative measure of institutional strengths, and its inability to link UIC outputs to relevant inputs (funding or human resources within industrial relevant fields of science). Hence, the UIC-based indicators presented is this study, which were designed to identify and explore similarities and differences between HEIs, are not be adequate for other (evaluative) purposes.

5.2 Tailored "analytical" benchmarking

Rankings are analytical tools to reduce the complexity within a system of metrics into to a single performance indicator or a single number. As such, the two UIC rankings ('UIC magnitude' and 'UIC intensity') presented in this paper may offer information that can be used to complement other university rankings, especially the *CWTS Ranking* and the Shanghai Jiao Tong's *Academic Ranking of World Universities* with their focus on research performance. The latter however constitutes a "catch all" holistic ranking that comprises of a wide range of performance variables but disregards crucial background information on universities, an essential precondition for providing analytical context and a proper platform for benchmarking. Such holistic rankings are useless for in-depth analytical purposes where one needs to focus on specific measurable achievements such as university-industry co-publications that reflect knowledge co-production and knowledge flows to industry. But clearly a "one-

[11] These principles were drafted by the *International Ranking Expert Group* (www.ireg-observatory.org), founded in 2004 by the *UNESCO European Centre for Higher Education* in Bucharest and the *Institute for Higher Education Policy* in Washington, DC.

size-fits-all" league table will not be appropriate given the variety of universities and different UIC-related institutional missions. To avoid unjustified comparisons one should opt for tailored "analytical" benchmarking, where one or more target universities act as a entry point to assemble a small set of benchmark universities according to some distinctive background characteristic or performance variable. Each class will then define its own unique framework for benchmarking with its context-dependent set of variables and a breakdown by relevant fields of science.

Clearly, the disciplinary profile of universities will have to be one of the main considerations when designing a UIC-based assessment of university performance. The magnitude and intensity of university-industry cooperation varies significantly by scientific discipline and industrial sector, as do the numbers of co-publications. UIC-based analysis is therefore only valid and acceptable in those cases where universities produce sufficiently large numbers of publications in industrially relevant fields and where a significant share of those publications are co-authored with researchers employed by business enterprises. Only in the truly science-based sectors (like biotechnology, pharmaceuticals and semi-conductors) and their related fields of science (medical and life sciences, physics and materials science), one may expect to find a satisfactory degree of validity. Moreover, medical universities are incomparable to universities of technology. Likewise, there's no point in comparing or benchmarking universities that only co-publish with industry in those fields of research (say, social sciences) where this kind of joint activity is rare and therefore not representative of university-industry research cooperation.

5.3 General conclusions and recommendations

Some may want to stress the significance of university research capabilities and achievements against the backdrop of knowledge-based economies and national systems of innovation, others may prefer a broader perspective of knowledge-based societies and universities focus on suppliers of public knowledge in general. Either way, few will dispute that any research-intensive university that aspires to play a leading role in science should be judged on their track record. We may surmise that UICs qualify as a key proxy measure of past performance with regard to university-industry research linkages. The validity of this assumption hinges critically on the degree to which the UIC-model gives legitimate insight into the actual collaborative relationships. Obviously, UIC production is also influenced by many other factors, not in the least the available resources, ability, willingness to publishing about successful cooperation in the open scientific literature.

We may safely assume that UIC-active and UIC-intensive universities are attractive research partners for firms. It also seems reasonable to assume that UICs reflect the attractiveness of specific universities as sources of research-based knowledge for science-intensive industries. Still, in many ways UICs represent a very special tip of the iceberg, i.e. these joint publications reflect effective and fruitful research that not only produced valuable results worth disseminating to a wider international public, but also inspired collaborating partners to invest time and money to jointly draft a high-quality research article for publication a peer-reviewed journal. Given the levels of investment and sophisticated infrastructures that are required for research staff to produce UICs on a regular basis, one may also expect a bias towards well-staffed and well-funded universities with academic incentive systems in place that promote the production of these research articles. This is not a necessarily a detrimental bias because companies tend to favor exactly this kind of high-quality research partner for basic research. Hence, the universities at the top of the UIC rankings reflect not only achievements in terms of the magnitude of university-industry cooperation, but also the presence of an academic environment conductive to producing significant quantities of internationally high-quality research publications. Business sector partners will only engage in longer-term joint research if they are sufficiently confident about the research capabilities of their academic partners and the potential utilization value of their outputs. UIC statistics therefore should also partially reflect the (cost) effectiveness of universities in meeting quality specifications imposed by those partners.

Returning to the prime analytical question underlying this paper (“which universities are major suppliers of research services to industry”?), the first results suggest that UIC data enable meaningful comparisons between selected universities and the creation of analytical scoreboards according to relevant metrics and performance indicators. These research performance scoreboards introduce their own specific analytical problems, especially how to select variables and weigh of the scores on the different variables to generate indices (e.g. Tijssen, 2003). However, UIC statistics are not yet fit for duty as indices or composite measures within evaluative settings, let alone authoritative world rankings of universities providing insufficient evidence in terms of accuracy and comprehensiveness. One needs to single out those key determinants of research performance that appeal to the scientists and scholars themselves, thus making comparisons and findings more acceptable at working floor levels. Broad support for key indicators within scoreboards should also lend credibility to rankings outside the university board rooms.

In conclusion, UIC data are certainly a very helpful source of evidence-based quantitative information, it should not become a statistical tool that induces over-reliance on what are still non-validated proxy data and obviates the need for good sense of judgment. The empirical results and statistics presented in this paper should therefore be seen as a first approximation and treated with due caution. In the absence of large scale systematic validation studies, one can only assume that UICs are sufficiently valid comparative meso-level indicators of university-industry research cooperation - as long as they are applied within to similar types of research universities. UICs are not an appropriate measure for disparate universities, or for comparing fundamentally different national R&D systems. Also, UIC statistics obscure the economic, managerial and organizational factors underlying cooperation mechanisms and knowledge interaction processes. Pending validation studies, UIC-based performance rankings and scoreboards provide at best crude estimates about the general attractiveness of universities as knowledge suppliers to industry, but no conclusive evidence about the magnitude or nature university-industry research interactions, nor the effectiveness and impacts of university policies and programmes to initiate or foster research partnerships with private sector partners. In order to assure the credibility of this UIC approach and associated rankings, thorough verification of all UICs is needed to establish their scope for detailed comparisons. Such audited and verifiable data are also easier accepted by universities and relevant (funding) authorities. Other information sources (statistical or otherwise) should be consulted to address validation issues. These sources of comparative information, such as contract research income from industry and the numbers of joint research projects, could also be used to develop multi-proxy scoreboards. Corresponding multi-dimensional rankings will then allow for better systematic assessments of UIC-performance while taking university-specific differences into account.

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