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

Robert J.W. Tijssen*, Thed N. Van Leeuwen and Erik van Wijk
Center for Science and Technology Studies (CWTS)
Leiden University
PO Box 905
2300 AX Leiden
The Netherlands

*Corresponding author (tijssen@cwts.leidenuniv.nl)

Abstract

Surprisingly, there is still no comparative information as to which universities are among 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

Forthcoming in the journal *Research Evaluation* (March/April, 2009)

1 Introduction

While 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, university rankings and league tables are now a prominent feature of the public information, where measurement issues and cross-national comparisons are becoming increasingly important within research evaluation frameworks (Dill and Soo, 2005; Marginson and Van der Wende, 2007; Williams and Van Dyke, 2007). A global knowledge market is emerging and we are witnessing 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 to students.

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 performance measures. Given the ongoing globalization of industrial R&D, and associated worldwide markets for university–industry research partnering, this information gap deserves more attention in the inter¬national benchmarking of university research performances. This paper presents the first results of an empirical study to help fill this gap. 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 these measurements for international comparisons and rankings of universities?

The structure of this paper is as follows: the next section introduces and discusses relevant measurement issues to address those research questions; the third section describes our analytical framework and metrics; we present the main findings in the fourth section, and conclude with an extensive general discussion and suggest some methodological recommendations.

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 performance 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 interorganizational comparability (e.g. Usher and Savino, 2007), but also on related statistical issues such as the choice of appropriate statistical models and performance measures (e.g. Goldstein and Speigelhalter, 1996). Is there sufficient common ground for reliable and systematic comparisons of university–industry research cooperation across a diversity of universities? And, if so, how can one strike a trade-off between the uniqueness of each university and cross-university comparability?

With regards to the first issue (data availability), there are 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 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, 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 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), performance rankings and benchmarking exercises are basically meant to reduce the complexity within a system of metrics; preferably into a single performance indicator or a single number. The crucial observation is that these comparisons 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 possible differences between universities

and their local R&D circumstances. Adopting the right context and analytical framework is an issue, especially with regards to international standards and benchmarks that should be implemented.
Industrially relevant research activities can be classified along three main dimensions according to the university's organizational characteristics:

- 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 private sector 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 multi-disciplinary bibliographic database of worldwide research literature. The WoS covers 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. WoS-indexed journals are primarily in English-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 and humanities fields). 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-authors and the geographical location of those research 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). University-industry co-publications (UICs) have author affiliate addresses referring to at least one university and one organization assigned to the private sector.[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 or both.[5]
An estimated 7% of all WoS-indexed research publications can be classified as UICs, totaling some 60,000 publications per year worldwide (NOWT, 2008).7 As such, they represent a very extensive multidisciplinary source of empirical data that is amenable to large-scale systemic quantitative
analysis of university–industry research interaction and cooperation, both at the country level and at institutional levels (e.g. Tijssen, 2004; Tijssen and Van Leeuwen, 2005; Sun et al, 2007). UIC-based statistical information provide a proxy measure of

university research-based contributions to national or global ‘science-innovation ecosystems’.[6]

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 universities, especially the very large multinational enterprise active within the biopharmaceutical, ICT and chemical sectors (Tijssen, 2004; 2009);
- 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, 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 those capturing the geographical closeness between universities and their 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, a 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 2002–2006.8 We assume this sample is sufficiently large and diverse to represent all large and medium-large research universities worldwide. The global reach covers 36 countries, where the United States ac-counts for 109 universities, followed by Germany (34), United Kingdom (24), Canada (17), China (16), Japan (15), Italy (12) and France, Netherlands and Spain (11).9 The vast majority of these universities are included in the top 500 universities of the 2007 edition of Shanghai Jiao Tong’s Academic Ranking of World Universities.10

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 represent 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, but also a large number of 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 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 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 that 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 multi-disciplinary profiles.

The geographical dimension of UIC patterns is further illustrated in Figure 1, showing the UIC performance of all 350 universities categorized by three major geopolitical regions in terms of R&D competition: Europe, Asia and USA, complemented by the group of universities located elsewhere. The con-figuration clearly shows the dominance of the USA in the middle section of the distribution, especially in terms of

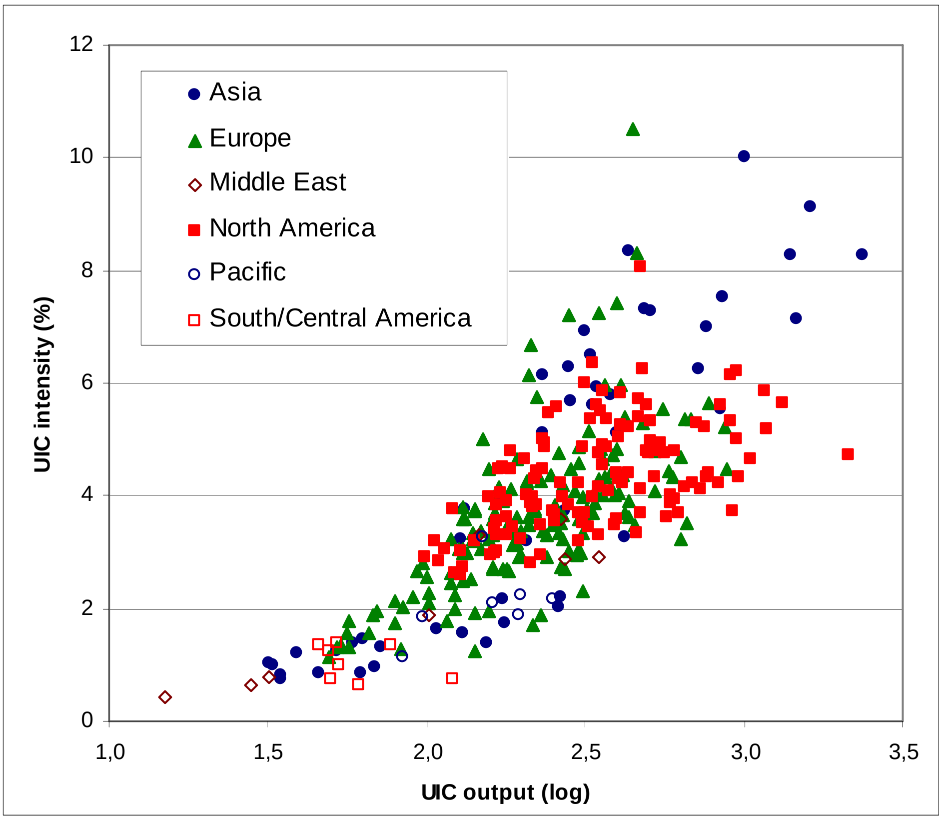
UIC magnitude, but also reveals the absence of the USA in the upper percentiles of the UIC intensity distribution which is dominated by Asian universities.

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 1. 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).

4.2 UIC rankings

Which universities have become major suppliers of industry-relevant knowledge and skills for research-intensive technology companies? As far as their 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 4. 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 4. 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; the US and Japanese universities generate shares of 80% or more partners from within their own countries whereas the other universities have shares of 60% or less. The large fractions of domestic partners in the case of the US and Japanese universities relates to the size and nature of the science-innovation systems, which characterized by many opportunities to interact with home country R&D-intensive companies that their need to perform cutting-edge R&D and/or acquire state-of-the-art university research inputs. The USA, Japan and Korea all have several large R&D-intensive science-dependent industries on their soil (mainly technology companies and bio-pharmaceutical companies). Japan has several large private sector research organizations funded by (joint) industry.

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 a high share, which is most likely a result of UICs involving Korea's large electronics companies in Korea.

Inasmuch as the university's total volume of research is clearly a determining factor of UIC quantities, controlling for it will enable better comparisons of universities regardless of size. The results are displayed in Table 5. Although a Dutch university is now at the top of this league table, most of the top 10 universities are Japanese. Part of this bias towards Japan is explained by the fact that Japanese universities publish fewer research papers in areas that are not of industrial relevance (the US universities publish many more WoS-indexed research papers in the social sciences and the humanities). This list is also determined by the presence of large corporate R&D-units and private sector research institutes at relatively close 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 5 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 the propensity for 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 6 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 based 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 350 selected 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. As such, these universities are also likely to represent major actors in both national and international 'science-innovation ecosystems'.

Table 6. 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 university rankings. Our bibliometric evidence reveals significant differences between universities, particularly in terms of their industrially relevant research fields (Tables 2 and 3), differences that need to be addressed by restricting rankings and comparisons to subsets of similar universities in terms of size and research specialization. As a consequence the cross-country cross-university comparisons presented in previous tables are not an appropriate approach for benchmarking and ranking of universities according to UIC characteristics. The key analytical question then is how to classify universities into clusters with sufficiently large measures of internal homogeneity.

The solution lies in adopting a 'multi-dimensional' perspective, where universities are grouped according to different UIC performance indicators and context variables , thus enabling various classifications and rankings of universities rather than a single one. But which characteristics should be selected, and how? As the number added to the scoreboard increases, its analytical power tends to decrease (Tijssen, 2004). Trade-offs between both properties will have to guide the design of UIC scoreboards. These contextualized 'intelligent' scoreboards should be application-oriented rather than data-oriented. In the case of UIC benchmarking approaches, the scoreboards should only include universities of a similar size and active within comparable R&D environments. Proper 'counterpart' comparisons should comprise of as many as possible significant performance variables, especially related to the organizational characteristics mentioned above: geographical embeddedness (local and/or foreign UIC orientation) and differentiation profile (degree of research specialization and/or a breakdown by fields of science). Table 7 presents a list of these variables and

Pearson correlation coefficients with both UIC indicators. We find a 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 as prime criterion 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 are comparatively strong.

Table 7. 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).

Table 8 displays a disciplinary breakdown for the top 10 universities listed in Table 5. It reveals an UIC profile of Eindhoven University of Technology with a relatively large UIC intensity in the broad field of Electrical engineering and a low intensity in Basic life sciences. Clearly, UIC scoreboards of this university should focus on similar-type universities. We selected the top 10 ‘lookalike’ universities according to the similarity in distribution of the shares of UICs across in the five broad fields, in addition to each university’s share of domestic UIC partners across all fields of science.[11]

Table 9 presents these 10 universities sharing a strong emphasis on UICs in Chemistry and chemical engineering (Chem.) and Physics and materials science

(Phys.). These results reveal three European universities as prime candidates for benchmarking: Delft University of Technology, Chalmers University of Technology, and the Swedish Royal Institute of Technology. The Tokyo Institute of Technology differs significantly given its extremely strong focus on UICs with domestic partners. The list is completed by no fewer than six Chinese universities, which exhibit much lower UIC levels that are likely to increase significantly in the future given the growth rates of the Chinese R&D system.

Table 8. 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).

Table 9. 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 10 presents the 'dynamic' version of the scoreboard in Table 9, focusing on changes that occurred over the last decade. The findings indicate that Eindhoven University of Technology is outperforming the prime benchmark universities in terms of its increase of UICs as well as the increase of UICs with foreign partners. It is 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 very higher growth rates across the board, but these increases started from much lower base lines and are therefore hardly comparable to Eindhoven University of Technology. The rise of the Chinese universities is a telltale sign of catching-up processes within the science systems of major emerging economies, where UIC-intensive universities are likely to become major players within local and regional science-innovation systems.

Table 10. UIC scoreboard for *Eindhoven University of Technology*
(% change in UIC characteristics between 1997-2001 and 2002-2006)

	UIC output*		Domestic UICs**		Foreign UICs***	
University	Chem.	Phys.	Chem.	Phys.	Chem.	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 pro¬cesses, national accountability, but 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 data, and the reliability, validity, applicability and generalizability of the measurements. 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.

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.[12] According to these principles, published in 2006, rankings and league tables should at the very least be specific and clear with regard to their objective(s) and (main) target groups. They should comply as much as possible with 16 standards of good practice, which are grouped into four classes:

- Purposes and goals;

- Design and weighting of indicators;
- Data collection and processing;
- Presentation of results.

Adopting the Berlin framework allows us to scrutinize strengths and weaknesses of the current UIC ranking approach presented in this paper. While being transparent in data collection, the choice of indicators as well as 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 ability to link UIC outputs to relevant inputs (funding or human resources within industry-relevant fields of science). Hence, the UIC-based indicators presented is this study, designed primarily to identify and explore similarities and differences between HEIs, are not appropriate for other (evaluative) purposes.

Nonetheless, the two UIC rankings ('UIC magnitude' and 'UIC intensity') presented in this paper offer information with the potential to complement other university rankings, especially the CWTS 'Leiden Ranking' and the Shanghai Jiao Tong's Academic Ranking of World Universities both focusing on research performance. The Shanghai Ranking constitutes a 'catch all' holistic ranking that comprises 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 rankings are less appropriate 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. 'One-size-fits-all' league tables 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 an entry point to assemble a relativelt homogenous cluster of comparable universities according to some distinctive background characteristic or performance variable. Each 'peer group' will then define its own unique framework for benchmarking with context-dependent performance indicators and a breakdown by relevant fields of science. The disciplinary profile of universities will have to be one of the main considerations when designing these UIC profiles of university performance. Also, 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 and UICs in industrially relevant fields. Only in the truly science-based sectors (such as biotechnology, pharmaceuticals and semi-conductors) and their related fields of science (medical and life sciences, physics and materials science) may one expect to find satisfactory degrees of statistical robustness and validity.

Whether or not UICs qualify as a key proxy measure of collaborative performance hinges critically on the degree to which the UIC model gives legitimate insight into those collaborative relationships. First, UIC outputs are also influenced by many other factors, not least the available resources, ability and willingness to publish about successful cooperation in the open scientific literature. As such, UICs 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 in a peer-reviewed journal. Secondly, one may safely assume that UIC-active universities are attractive research partners for firms. UICs represent preferential attachments of science-intensive industries for certain universities as sources of research-based knowledge. Thirdly, 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 UIC rankings, or prominent within UIC scoreboards, 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.

5.2 General conclusions and recommendations

Returning to the prime analytical question underlying this paper (Which universities are major suppliers of research services to industry?), the results presented in this paper suggest that UIC data enable meaningful comparisons for ranking and benchmarking objectives. The empirical results and statistics presented in this paper identify universities that seem to be outperforming others beyond any doubt. However, these findings should be seen as a first approximation and treated with due caution. UIC data obscure economic, managerial and organizational factors underlying cooperation mechanisms and knowledge interaction processes. The scoreboards also introduce their own specific analytical problems, especially how to select the appropriate sets of benchmark universities and the choice of performance indicators. 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 university board rooms.

In conclusion, UIC data are certainly a very helpful source of evidence-based quantitative information, but 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.[13] They should not become a statistical tool that induces over-reliance on what are still non-validated proxy data and obviates the need for good judgment. 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 of 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 further 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 more easily 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.

Acknowledgement
The authors are grateful for Martijn Visser's valuable research assistance.

Endnotes

1. "Universities" are taken to mean all higher education institutions, irrespective of their name and status within their country of location.
2. The significant part of industry spending will related to applied research with a short- or medium-term commercialisation focus. Publishable results of applied research are usually not disseminated in the peer-reviewed international journal litera-ture, but are issued as (confidential) reports, blueprints, patents, or other document types.
3. The WoS-indexed publications are attributed to organizations by CWTS based on information extracted from the author af-filiate 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 ad-dresses 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 were extracted 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 term and concept 'science-innovation ecosystem' is broadly defined as 'an interactive and dynamic structure of intra and inter-organizational processes, connections and relationships between actors and entities involved in the creation, storage, transfer, translation and utilization of science-based knowledge, skills, ideas and facilities within an institutional and physical environment (partially) devoted to producing, improving and exploiting science-based technologies and associated technological innovations'.
7. 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, 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>).
8. See Calero-Medina et al (2008) for more details about the collection of large universities from which this sample was drawn.
9. The distribution of the 350 selected universities across coun-tries (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.

10. The nine exceptions are: Huazhong Univ. Sci. & Technol. (China); Univ. Aix Marseille 2 (France), Univ. Patras (Greece); Univ. Zagreb (Croatia); Univ. Bari (Italy); Kyung-pook Natl. Univ. (South Korea); Univ. Pais Vasco (Spain); Univ. Ankara and Hacettepe Univ. Ankara (Turkey).
11. 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.
12. 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.
13. A single UIC index, incorporating several proxy measures of university–industry cooperation, may be designed to provide helpful summary information, but will tend to suffer from lack of transparency and arbitrariness in the composition of indictors. Index values can be highly sensitive to the choice of indicators and measurement parameters.

References

Calero-Medina, C, C López-Illescas, M S Visser and H F Moed 2008. Important factors when interpreting bibliometric rankings of world universities: an example from oncology. Research Evaluation, 17(1), March, 71–81.

Dill, D and M Soo 2005. Academic quality, league tables, and public policy: a cross-national analysis of university ranking systems. Higher Education, 49, 495–533.

Goldstein, H and D Speigelhalter 1996. League tables and their limitations, statistical issues in comparisons of institutional performance. Journal of the Royal Statistical Society, Series A, 159, 385–443.

Katz, J S and B R Martin 1997. What is research collaboration? Research Policy, 26, 1–18.

Kivinen, O and J Hedman 2008. World-wide university rankings: a Scandinavian approach, Scientometrics, 74, 391–408.

Mansfield E and J Lee 1996. The modern university: contributor to industrial innovation and recipient of industrial R&D support. Research Policy, 25, 1047–1058.

Marginson, S and M van der Wende 2007. To rank or to be ranked: the impact of global rankings in higher education. Journal of Studies in International Education, 11, 306–329.

NOWT, Netherlands Observatory of Science and Technology 2008. Science and Technology Indicators Report 2008. The Hague: Report by NOWT for Netherlands Ministry of Education, Culture and Science.

Pratt, A D 1977. A measure of class concentration in bibliometrics. Journal of the American Society for Information Science, 28, 285–292.

Sun, Y, M Negaishi and M Nisizawa 2007. Co-authorship linkages between universities and industry in Japan. Research Evaluation, 16(4), December, 299–309.

Tijssen, R J W 2004. Measuring and evaluating science-technology interactions: towards international statistics. In Handbook of Quantitative Science and Technology Research: The use of publication and patent statistics in studies on S&T Systems, eds. H Moed, W Glänzel and U Schmoch, pp. 695–716. Dordrecht: Kluwer Academic Publishers.

Tijssen, R J W 2006. Universities and industrially relevant science: Towards measurement models and indicators of entrepreneurial orientation. Research Policy, 35, 1569–1585.

Tijssen, R J W 2009. How globalized is corporate pharmaceutical research? An analysis of Europe’s multinational companies. Technology Analysis and Strategic Management (forthcoming).
Tijssen, R J W and T N van Leeuwen 2005. Measuring impacts of academic science on industrial research: a citation-based approach. Scientometrics, 66, 55–69.
Usher, A and M Savino 2007. A global survey of university ranking and league tables. Higher Education in Europe, 32, 5–15.
Williams, R and N van Dyke 2007. Measuring the international standing of universities with an application to Australian uni-versities. Higher Education, 53, 819–841.
Van Raan, A F J 2005. Fatal attraction: conceptual and methodological problems in the ranking of universities by bibliometric methods. Scientometrics, 62, 133–143.
Van Raan, A F J, H F Moed and T N van Leeuwen 2007. Scoping study on the use of bibliometric analysis to measure the quality of research in UK higher education institutions. Bristol: Higher Education Council for England, CWTS report to HEFCE.