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Important factors when interpreting bibliometric rankings of world universities: an example from oncology

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This paper presents bibliometric characteristics of the 386 most frequently publishing world universities and of a (partly overlapping) set of 529 European universities. Rather than presenting a ranking itself, it presents a statistical analysis of ranking data, focusing on more *general* patterns. It compares US universities with European institutions; countries with a strong concentration of academic research activities among universities with nations showing a more even distribution; a ranking of universities based on indicators calculated for all research fields combined with one compiled for a single field (oncology); general with specialised universities; and rankings based on a single indicator with maps combining social network analysis and a series of indicators. It highlights important factors that should be taken into account in the interpretation of rankings of research universities based on bibliometric indicators. Moreover, it illustrates policy-relevant research questions that may be addressed in secondary analyses of ranking data. In this way, this paper aims at contributing to a public information system on research universities.

MORE AND MORE ATTEMPTS are made to identify top research universities from a global perspective as internationalization and globalization in academic research and teaching proceeds, Universities are more and more competing for research funds, research students and researchers in the global research area. Their reputation as research universities is a crucial factor in such a competitive system. Therefore, members of the international scientific community, officials responsible for institutional, national and supra-national science policies, and the wider public need 'objective', 'reliable' information about the research performance of universities.

Comparative analyses of the performance of universities at a *national* level, focusing on particular research fields or disciplines, have been carried out for many years. For instance, in 1995 the US National Research Council (NRC), the working arm of the National Academy of Science and the National Academy of Engineering, published a report presenting a quality rating of PhD programs at 274 US institutions in 41 fields, based on surveys sent to faculty (Goldberger *et al*, 1995). The NRC report also presented bibliometric indicators based

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The data for the study presented in this paper are partly based on the ASSIST project (Analysis and Studies and Statistics & Indicators on Science and Technology), funded by the European Commission Sixth Framework Programme of Research, Technology and Development. This paper is a slightly modified version of a paper by the same authors entitled 'Important factors to be considered in the interpretation of bibliometric rankings of world universities' published in the Proceedings of the Third Meeting of the International Ranking Expert Group (IREG-3), October 28–31 2007, Shanghai Jiao Tong University, Shanghai, China. The research carried out by Carmen López-Illescas is funded by a grant of the Ministry of Science and Education of Spain for the training of university teachers.

on publication and citation data extracted from the ISI Citation Indexes, but these indicators were not used by the NRC for ranking purposes. Diamond and Graham (2000) further analysed the NRC data and concluded that “reputational ratings showed a strong positive correlation with citation densities”, in the sense that the institutions appearing in the top of the former tended to be highly ranking on the latter as well. However, younger and smaller “challenging” institutions tended to have higher positions in the citation impact rankings than in the reputational rankings.

A recent phenomenon is the compilation of rankings of universities from a *supra-national* or *global* perspective. For instance, the European Commission published in the recent European Science Indicators Reports listings of European universities presenting their bibliometric scores. Global rankings of universities were published by the Jiao Tong University in Shanghai (SJTU, 2007) and by the *Times Higher Education Supplement* (THES, 2007). The SJTU rankings were to a large extent based upon bibliometric indicators, and partly upon counts of prizes and awards. In compiling the THES rankings, expert opinions collected from surveys constituted the most important indicator, while bibliometric indicators played a less important role. For a thorough review of these two rankings, the reader is referred to Van Raan (2005).

This paper presents bibliometric characteristics of the 386 most frequently publishing world universities and of a (partly overlapping) set of 529 European universities. Rather than showing a ranking itself, it presents a statistical analysis of ranking data, focusing on more *general* patterns in the data. It compares US universities with European institutions; countries with a strong concentration of academic research activities among universities with nations showing a more even distribution; a ranking of universities based on indicators calculated for all research fields combined with one compiled for a single field; general with specialised universities; and rankings based on a single indicator with maps combining social network analysis and a series of indicators. It highlights important factors that should be taken into account in the interpretation of rankings of research universities based on bibliometric indicators. Moreover, it illustrates policy-relevant research questions that may be addressed in secondary analyses of ranking data. In this way, this paper aims at contributing to a public information system on universities, particularly research universities, useful in research management and policy at the institutional and (supra-)national level, and for the wider public.

The paper provides a series of bibliometric indicators of the research performance of universities, derived from the *Web of Science* (*WoS*), published by *Thomson Scientific*. Research universities produce knowledge, contribute to the advancement of scientific-scholarly knowledge. These contributions are normally embodied in research articles, published in the open, serial literature and subjected to criticism of colleagues. A base assumption underlying a bibliometric approach is that one can learn about scientific activity and performance by analyzing the scientific literature (e.g. Garfield, 1964, 1979; Narin, 1976). In this paper three bibliometric indicators play a key role, measuring article production, disciplinary specialisation, and citation impact, respectively. A brief description of the methodology applied in this paper is given.

A first research question is: *How does the citation impact of European universities relate to that of their US counterparts?* A basic notion underlying the analyses presented under the heading ‘Comparison of European and US universities’ holds that the bibliometric outcomes of an individual university can only be interpreted properly when one takes into account the structure of the national academic system in which it is embedded, and the particular role of the university therein. The next sections distinguish two models for distributing ‘top’ research among a nation’s universities: a *concentration model* in which a limited number of big research universities carries out research at a top level in a wide range of disciplines, and *a distributed model*, in which top research is more evenly distributed among universities, and a strong link between teaching and research is maintained. In the USA the concentration model is dominant, whereas in Europe many countries tend to show a more distributed model, although substantial differences exist among European countries.

These differences in the degree of concentration of a country’s academic research activities among its universities are further analysed. In the set of European countries, the statistical relationship between a country’s degree of concentration within the academic system and its overall performance measured in terms of citation impact is examined. The research question addressed is: *Do European countries in which academic research activities are concentrated in a limited number of universities perform better than nations in which research is more evenly distributed among its academic institutions?*

Rankings of world universities are normally based on indicators for an institution as a whole, combining all fields in which it is active. Universities tend to be active in a range of scientific-scholarly *research fields*, but their performance may vary from one field to another. This variability is invisible in an overall indicator such as the total number of published articles, or the normalised citation impact calculated for a university’s total publication output. The next section addresses the following question: *To what extent does a ranking of universities based on their bibliometric scores in a particular research field differ from that based on an overall indicator calculated for all fields combined?* As an example, the field of oncology is analysed.

The distinction between *general and specialised* universities is highlighted, even though it is difficult to draw a sharp borderline between the two. An index is proposed to measure the degree of disciplinary specialisation in a university's research activities, applying a classification of published articles into 15 disciplines. A research question addressed is: *How does the performance of general universities statistically relate to that of specialised universities?* The section compares the citation impact of the two types of academic institutions, both at the level of an institution as a whole and at the level of individual disciplines.

Rankings are in a sense one-dimensional, as entities are ordered by descending score on one particular statistic, even if it is a compound measure based on a weighted series of indicators. Rankings disregard how the performance of one entity depends upon that of others. The next section deals with the question: *What are the potentialities of using social network analysis to display collaboration networks among universities?* It presents preliminary outcomes of an analysis of the top 100 world universities in terms of number of published articles.

Finally, the conclusion indicates lines of future research, and proposes further steps towards the creation of a reliable information system of world universities, and its use in thorough empirical analyses of policy relevant issues.

General methodology

Assignment of articles to universities; accuracy

For European universities the Membership Directory of the European University Association was used as a starting point. Since this list did not include all European universities, it was expanded during the project. The data collection process aimed at defining the article output of European universities publishing at least 500 papers during the time period 1997–2004. For non-European universities the process identified the articles of the *200* most frequently publishing universities. Articles were assigned to universities on the basis of the information on the institutional affiliations of authors, included in the corporate address field. Two rounds were carried out.

In a *first* round, papers were selected with the name of a university (and its major departments) mentioned *explicitly* in the address. Name variations were taken into account. For instance, *Ruprecht Karls University* is a name variant of the *University of Heidelberg, TUM* of the *Technical University München;* and *Université Paris 06 of Université Pierre et Marie Curie*. For European universities, this round took into account all variations occurring five or more times. For non-European universities this threshold was set to 25.

In a *second* round, additional papers were selected from affiliated teaching hospitals on the basis of an author analysis. This round added to a particular university's article output selected in the first round papers from affiliated hospitals, published by authors who did *not explicitly* mention this university's name in their institutional affiliation, but who showed strong collaboration links with that university, as its name appeared in the address lists of at least half of their papers. In this way, for instance, a part of the papers containing the address *Addenbrookes Hospital* was assigned to *University Cambridge*, and a part of the papers with the address *Hospital La Pitié Salpetrière to University of Paris VI*, and another part to *University of Paris V*.

Since the de-duplication and counting process of European universities took into account only name variants occurring five or more times, an overall accuracy rate for this group of universities is estimated to be about 95%. It is somewhat higher for universities with a large number of published articles than it is for universities with smaller publication volumes. For non-European universities it is around 90%. It is important to note that the data were *not* verified by representatives of institutions.

Universities analysed in this paper

This paper analyses two sets of universities. The *first and most important one* is the set of universities that published more than 5,000 articles in *WoS* journals during 1997–2004, or on average more than 625 papers per year during this time period. It contained 386 universities, and is denoted as the *global* or *world* set, containing *world universities*. In view of the collaboration among institutions, resulting in co-publications by scientists from two or more institutions, it would be more precise to state that the universities contributed at least one author to more than 625 papers per year. Technically, this number is denoted as an *integer* count. A *second* set of universities analysed in this paper is a set of 529 *European* universities publishing at least 500 articles during 1997–2004, or on average 65 articles per year. There is an overlap between the European and the global set: 172 European universities are included in both sets.

Indicators calculated

The indicators calculated in this paper are summarized in Table 1. The first indicator, denoted as *article output*, is defined as the number of articles published during a particular time period in journals processed for the *WoS*. Article types included in the counts are *full articles*, *letters* and *reviews*. Other types, such as *editorials*, *discussion papers* and *meeting abstracts*, are not included.

A *disciplinary specialisation index* for a particular university is based on Pratt's Index, calculated for a university's distribution of normalised publication activity across 15 disciplines. These disciplines are listed in Table 2. Pratt's Index ranges between 0 (no specialisation at all) and 1 (extremely strong specialisation). For further details on this index the

Table 1. Four bibliometric indicators calculated in this paper

Indicator	What it measures	Technical description
Article output	Scale of scientific activity (number of active scientists) *and* article productivity (number of articles per active scientist)	The number of research articles published in about 7,500 journals processed for the *WOS*
Disciplinary specialisation index	Are activities more or less evenly distributed among disciplines (as in general universities) or concentrated (as for instance in medical, agricultural or technical universities)?	Pratt Index: ranges between 0 (no specialisation at all) and 1 (extremely strong specialisation); assessed relative to the world distribution
Normalised citation impact (also denoted as citation impact per paper)	Intellectual influence; prominence of research groups in their fields; their authoritativeness; visibility	Average number of citations per article published by a university, relative to the world citation average in the subfields in which it is active
Collaboration strength	The extent to which two universities collaborate as expressed in co-authorship	Number of co-publications between two universities, divided by the square root of the product of the number of papers published by each

reader is referred to Moed (2006), Bookstein and Yitzhaki (1999) and Egghe and Rousseau (1990).

Normalised citation impact is defined as the average number of citations per article published from a university, relative to the world citation average in the subfields in which it is active. It is also denoted below as 'citation impact' or 'impact per paper'. A value of 1.0 indicates a citation impact equal to the world citation average. Details can be found in Moed *et al*, 1995) or in Van Raan (1996).

Comparison of European and US universities[1]

Figure 1 relates to the 386 universities publishing more than 5,000 papers during the time period 1997–2004. The horizontal axis gives the average number of articles published per year during this time period, and the vertical axis their normalized citation impact. Universities are categorized into three broad geographical regions: USA, Europe and all other countries.

Figure 1 shows that US universities are highly overrepresented in the top of the ranking based on normalised citation impact, and to a lesser extent, on the number of published articles per year. In fact, in the group of the 25 universities with the highest citation impact, all universities are from the USA, and in the group of 76 universities with a citation impact above 1.5, 67 (88%) are located in the USA. Among the top 25 institutions with the highest number of published articles per year, 20 (80%) are from the USA.

In the set of 386 world universities, 172 are located in Europe, and 122 in the USA. Table 3 gives for each geographical region the mean and quartiles of the distribution of normalised citation impact among universities. Table 3 shows that US universities tend to have a higher normalised citation impact than European academic institutions: 1.55 versus 1.11. The 75th percentile of the distribution for Europe is lower than the 25th percentile for the USA. The third column shows that the 172 European universities account for around 72% of the total European university output. The 122 US universities published about 83% of the total US university output. This percentage is higher than the 72% obtained for Europe, and indicates that there is a stronger concentration of published articles among US universities than there is among European institutions, in agreement with earlier analyses published by Matia *et al* (2005).

In order to further characterize differences among European and US universities, an institution's citation impact was analysed *per discipline*, using a classification of research articles into 15 disciplines, listed in Table 2. More detailed information can be obtained from Moed (2005: 189). For each institution the number of disciplines was determined in which it was 'world leader', i.e. ranked among the

Table 2. Pearson correlation coefficients between a university's normalised citation impact in a discipline and its publication activity index in that discipline

Acronym	Discipline	No. univs	Pearson's R
APC	Applied physics and chemistry	270	–0.02
BIOL-HU	Biological sciences primarily related to humans	310	+0.24*
BIOL-AP	Biological sciences primarily related to animals and plants	194	–0.18
CHEM	Chemistry	301	–0.03
CLM	Clinical medicine	320	+0.23*
ECON	Economics	23	–0.05
ENG	Engineering	227	–0.03
GEO	Geosciences	147	+0.15
H&A	Humanities and arts	40	+0.12
MATH	Mathematics	75	–0.11
MOLB	Molecular biology and biochemistry	270	+0.41*
SOC-MED	Other social sciences primarily related to medicine and health	81	+0.01
SOC	Other social sciences	70	–0.20
PHYS	Physics and astronomy	290	+0.17*
PSY	Psychology and psychiatry	101	–0.07

Note: * significant at p = 0.01

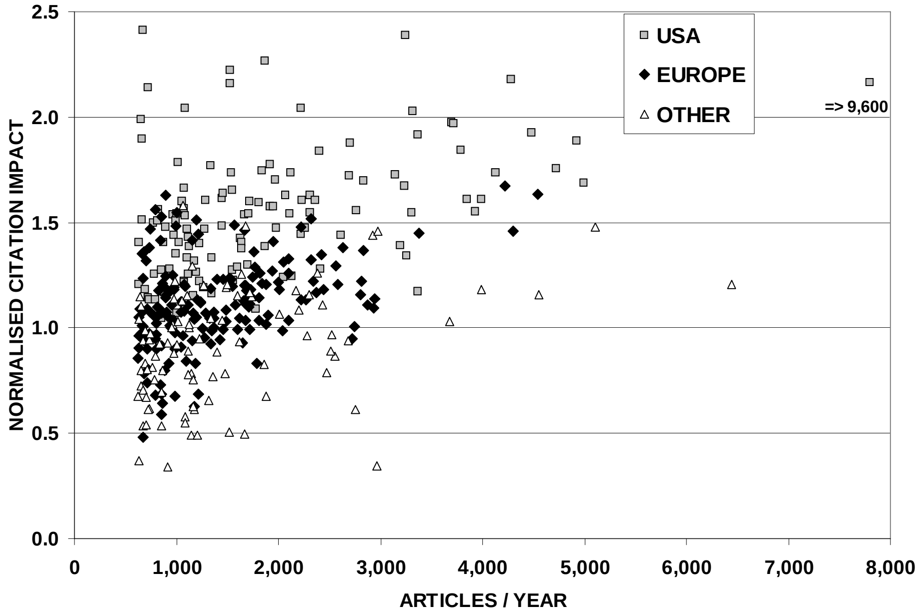

Figure 1. Number of published articles per year and normalised citation impact for 386 world universities

top 10 or top 25% according to the normalized citation impact in the set of 386 world universities. For each geographical region, the number and percentage of universities was determined that was world leader in at least one discipline, and for these institutions the average number of such 'top' disciplines per university was computed. These indicators were calculated for all universities in the set, and also for the 'very best' universities in their region, i.e. being among top 25% in their region on the basis of their overall normalised citation impact.

The results are presented in Table 4. The upper half of this table presents the outcomes when the concept of 'world leader' in a discipline is defined as being among the *top 10%* among all 386 world universities in that discipline. In the lower half, the criterion for being world leader is somewhat relaxed, and defined as belonging to the *top 25%* in a discipline. A key finding is that *all* the very best European universities are among the 25% best in the world in at least one discipline, and 65% of them even in the top 10% in a field, but that the number of disciplines in which they are world leader is on average substantially lower than that for top US universities.

In a recent report, Lambert and Butler (2006) analysed differences among continental European countries, the UK and the USA as regards the structure and research performance of their national academic systems. They mentioned several structural factors that in their view are responsible for what they term as 'mediocrity' of (particularly continental) European universities, including a lack of concentration of funds among institutions. The

Table 3. Distribution of citation impact among European and US universities

Region	No. univs	% papers from univs	Normalised citation impact distribution			
			Mean	P25	P50	P75
Europe	172	72	1.11	0.99	1.10	1.22
USA	122	83	1.55	1.32	1.54	1.72

Notes: Mean, P25, P50, P75: the mean, 25th, 50th (i.e. the median) and 75th percentile of the distribution
% papers from univs: a rough estimate of the percentage of the total university article output from a country/region published by the universities in the set of 386 world universities. Both percentages are rough estimates, as the number of articles published by the *total* collection of universities in Europe or the USA is not exactly known in this study.

Table 4. Analysis of disciplines in which universities are 'world leaders'

Indicator	All universities		Very best 25% universities	
	Europe	USA	Europe	USA
Number of universities	172	122	43	31
Among the world top 10% universities in a discipline				
• No. (%) universities with at least one 'top' discipline	44 (26%)	99 (81%)	29 (67%)	31 (100%)
• Average number of 'top' disciplines per university	1.8	5.1	2.1	9.3
Among the world top 25% universities in a discipline				
• No. (%) universities with at least one 'top' discipline	112 (65%)	119 (98%)	43 (100%)	31 (100%)
• Average number of 'top' disciplines per university	3.2	8.4	5.4	12.3

citation impact analysis presented in this section indeed revealed that the overall citation impact per paper of European universities tends to be lower than that of their US counterparts. One may question whether the term 'mediocre' is appropriate to qualify the position of European universities in the world rankings. But even if one adopts this qualification from Lambert and Butler, it needs emphasising that 'mediocrity' of a university does not necessarily imply that it is mediocre in *all* disciplines.

A country's degree of concentration within the academic research system versus its overall research performance

One of the recommendations made by Lambert and Butler (2006) is to establish more concentration of funding and research activities in a limited number of 'top' universities. The underlying assumption is that more concentration leads to a better performance of the system as a whole, and the high performance of US institutions is a case in point. In order to further analyse the statistical relationship between a country's degree of concentration of research among its universities and its overall research performance, *Pratt's Concentration Index* of published articles among its universities was calculated for each country. This measure ranges between 0 (no concentration, i.e. all universities publish the same number of papers) and 1 (total concentration, all papers are published by one single university).

Figure 2 plots for major *European* countries a country's Pratt's Concentration Index (on the horizontal axis) against the normalized citation impact of the papers published by its universities with at least 500 published articles during 1997–2004 (on the vertical axis). US universities are not included in this analysis, since the study collected for the USA data on a limited number of top institutions only. Countries showing a relatively low Pratt's Index are *the Netherlands, Switzerland, Portugal* and *Hungary*. The *UK*, *Austria* and the *Czech Republic* show the highest value of this concentration index. This figure shows that there is apparently no linear correlation between these two variables. The Pearson correlation coefficient amounts to 0.06 (not significant at $p = 0.01$).

These findings illustrate that the relationship between a country's degree of concentration of academic research activities among its universities and its overall performance is complex. In Europe there is no clear tendency that national academic systems showing more concentration of research activities among its universities, generate — as a whole — a higher citation impact per paper than national systems in which the article output is more evenly distributed among academic institutions. Although this issue needs to be analysed in more detail, this outcome itself may be of interest in the debate about the effectiveness of national research policies aimed at establishing greater concentration of research activities among universities in a national academic system.

Rankings per research field versus rankings for all fields combined

Rankings of world universities are normally based on indicators calculated for an institution as a whole, combining all research fields in which it is active. In order to illustrate how a ranking of universities based on their bibliometric scores in a *particular research field* may differ from that based on indicators for a university *as a whole*, this section presents an analysis of one important medical subfield: *oncology*.

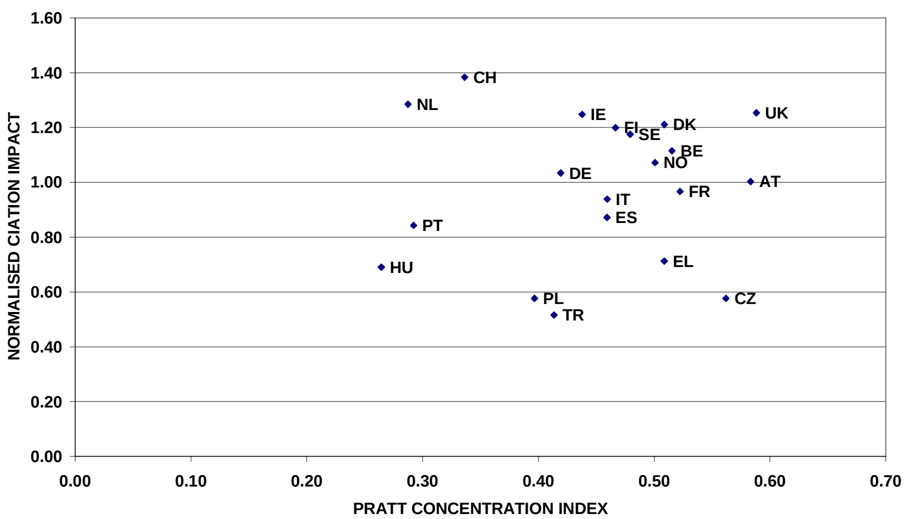

Figure 2. Pratt's Index versus normalised citation impact for major European countries (universities with > 500 papers during 1997–2004)

Key: AT: Austria; BE: Belgium; CH: Switzerland; CZ: Czech Republic; DE: Germany; EL: Greece; ES: Spain; FI: Finland; FR: France; HU: Hungary; IE: Ireland; IT: Italy; NL: Netherlands; NO: Norway; PL: Poland; PT: Portugal; SE: Sweden; TR: Turkey; UK: United Kingdom

The field ‘oncology’ was delimited in the following way. In a *first* step all papers were selected that were published in journals that were included in the *WoS* journal category oncology. This category contains specialist journals in the subfield. But oncologists also publish papers in more general journals or in specialist journals covering other subfields. Therefore, in a *second* step the set of papers in specialist journals was expanded. Oncology-related papers were added that were published in journals not included in the ISI journal category oncology but, for instance, in multidisciplinary journals such as *Science*, *Nature*, in more general medical journals such as the *Lancet* and *New England Journal of Medicine*, and in journals covering other specialties. These are denoted below as *additional* oncology papers.

Oncology-relatedness was measured through citation relationships in the following way. From the total *WoS* database all papers were selected satisfying the following two criteria:

1. At least 10% of documents cited in a paper were published in one of the specialist journals in the *WoS* journal category oncology.
2. These documents were published in journals of which at least 2% of papers satisfied criterion 1.

Merging the papers in the *WoS* journal category oncology and the additional papers into one set, the percentage of papers in journals included in the *WoS* journal category oncology accounted for about 42% of the number in the total set. This percentage was stable over the years. The number of papers in the total set increased from about 39,000 in 1997 to 49,000 in the year 2004. For further details the reader is referred to López-Illescas *et al* (2007).

Table 5 presents a ranking of the top 25 universities based on the *total* number of papers they published — in *all* disciplines — and a ranking according to the number of papers published in the subfield oncology. Data relate to the time period 1997–2004, and to the set of 386 universities publishing at least 5,000 papers during this time period. Table 5 shows that several universities move a significant number of positions up- or downwards in one ranking compared to the other.

Table 6 gives for the total set of 386 top universities the Pearson correlation coefficient between the number of articles a university published in all fields

Table 5. Rankings based on number of papers in all fields combined and in oncology

Rank	All fields combined			Oncology		
	University	Nr publ / year in all fields combined	Rank in oncology	University	Nr publ / year in oncology	Rank in all fields combined
1	Harvard	9,594	2	Univ. Texas - Houston	1,009	68
2	Tokyo	6,445	8	Harvard	981	1
3	Toronto	5,104	4	Johns Hopkins	483	9
4	Univ. Calif - Los Angeles	4,993	10	Toronto	459	3
5	Univ. Washington - Seattle	4,922	9	Karolinska Inst. Stockholm	451	52
6	Univ. Michigan - Ann Arbor	4,720	14	Univ. Calif - San Francisco	415	25
7	Kyoto	4,550	27	Penn.	389	13
8	Cambridge	4,544	120	Tokyo	387	2
9	Johns Hopkins	4,483	3	Univ. Washington - Seattle	366	5
10	Univ. Coll. London	4,301	21	Univ. Calif - Los Angeles	361	4
11	Stanford	4,281	25	Pittsburgh	328	29
12	Oxford	4,223	76	Wien	327	44
13	Penn.	4,134	7	Erasmus Univ. Rotterdam	322	135
14	Osaka	3,991	24	Univ. Michigan - Ann Arbor	312	6
15	Univ. Minnesota - Minneapolis-St Louis	3,987	26	Milano	312	37
16	Univ. Wisconsin - Madison	3,930	49	Duke	285	31
17	Cornell	3,845	31	Ruprecht Karls Univ. Heidelberg	281	65
18	Columbia	3,789	23	Univ. S. Calif.	280	64
19	Univ. Calif -Berkeley	3,722	243	Baylor Coll. Med.	264	109
20	Univ Calif San Diego	3,697	58	Maximilians Univ. Munchen	259	34
21	Tohoku	3,681	72	Univ. Coll. London	257	10
22	Imperial Coll. London	3,377	75	Univ. N Carolina - Chapel Hill	257	39
23	Yale	3,365	43	Columbia	253	18
24	Florida	3,363	111	Osaka	249	14
25	Univ. Calif - San Francisco	3,320	6	Stanford	247	11

Table 6. Comparison rankings based on number of papers in all fields combined and in oncology

Universities	Pearson R	Abs. rank diff.			
		Mean	P25	P50	P75
Top 386	0.71	103	28	76	140

Notes: Abs. rank diff.: absolute number of positions a university moved in one ranking compared to the other
P25, P50, P75: the 25th, 50th (i.e. the median) and 75th percentile of the distribution of the variable abs. rank diff. among universities

combined on the one hand, and the number of published papers in oncology on the other. In addition, it gives the mean, 25th, 50th (median) and 75th percentile of the distribution of the absolute number of positions a university moved in one ranking compared to the other (*abs. rank diff.*) across universities. Table 6 shows that the mean number of positions universities move in one ranking compared to the other amounts to 103; 25% of universities move at most 28 positions, half of universities move at least 76 positions, while another 25% move at least 140 positions.

Table 5 shows that the position of US universities is less dominant in the oncology ranking than it is in the ranking based on publication counts in all fields combined. This is consistent with the finding presented above that European universities do carry out top research in at least some disciplines, but that the number of disciplines in which they are among the top in the world is lower that of US academic institutions. In other words, the top of US universities is broader, and this leads to higher values of bibliometric indicators — especially publication counts — if these are calculated for a university as a whole. The empirical data presented in this section relate to one field only. But if the interpretation of the outcomes is valid, one would expect that they represent a general pattern, and that generally in analyses of research fields or disciplines the position of US universities tends to be less dominant than it is in an overall ranking according to total publication counts in all fields combined.

General versus specialised universities

It is useful to distinguish between *general* and *specialised* universities. General universities cover a wide range of scientific-scholarly disciplines. A typical example is a university that offers courses and carries out research in all domains of science and scholarship. Specialised universities are mainly active in a limited number of disciplines. Often — but definitely not in all cases — their name reveals the disciplines on which they focus. Typical examples are technical, medical, and agricultural universities.

Although general universities show less concentration of research activities among disciplines than specialised universities, they do not necessarily have the same level of activity in all disciplines. They may be more active in some disciplines than in others, and their research profile may reveal a certain specialisation, though not as pronounced as in specialised universities. In practice, it is very difficult to draw a sharp borderline between general universities with a certain specialisation on the one hand, and specialised universities on the other. The transition from the first to the second group is fluent.

This section analyses disciplinary specialisation *within* a university, i.e. the extent to which its research papers are evenly distributed among research disciplines, or whether there are particular disciplines on which a university focuses its research activities. Figure 3 plots, for each of the 386 universities with at least 5,000 papers during 1997–2004, their disciplinary specialisation index measuring the degree of concentration of their published articles among disciplines (on the horizontal axis), against the normalised citation impact of its papers (on the vertical axis). In order to obtain an impression of differences across countries, universities from the Netherlands, Germany, Sweden, UK and USA are indicated by special symbols.

Figure 3 reveals that in the total set of 386 universities there is no simple relationship between these two variables. The line drawn in this figure is the linear regression line. The Pearson and Spearman rank correlation coefficients are –0.06 and –0.10, respectively, and are *not* significant at $p = 0.01$. In this set of 386 world universities, general universities showing a rather even distribution of research papers among disciplines, and specialised universities having their article output concentrated in a limited number of disciplines (regardless of which ones), show statistically similar citation impacts. It must be noted that smaller specialised universities such as the London School of Economics are not included in the analysis, since the number of papers published by this institution does not exceed the threshold of 625 papers per year.

The impact measure plotted in Figure 3 relates to a university's *total* article output in *all* fields combined. More information can be obtained from an analysis by discipline, addressing the question: Do specialised universities in their fields of specialisation perform better than general universities do *in the same fields*? Specialisation is defined here from a disciplinary perspective, in terms of the distribution of a university's research articles among 15 *disciplines*, listed in Table 2.

For each university, the normalised citation impact was calculated for all papers in each of the 15 disciplines separately. In order to correct for large differences in universities' normalised citation impact across countries, a further normalisation of the citation impact indicator was carried out, by calculating per discipline the ratio of the citation impact of a university from a particular country and the mean citation impact across all universities in that

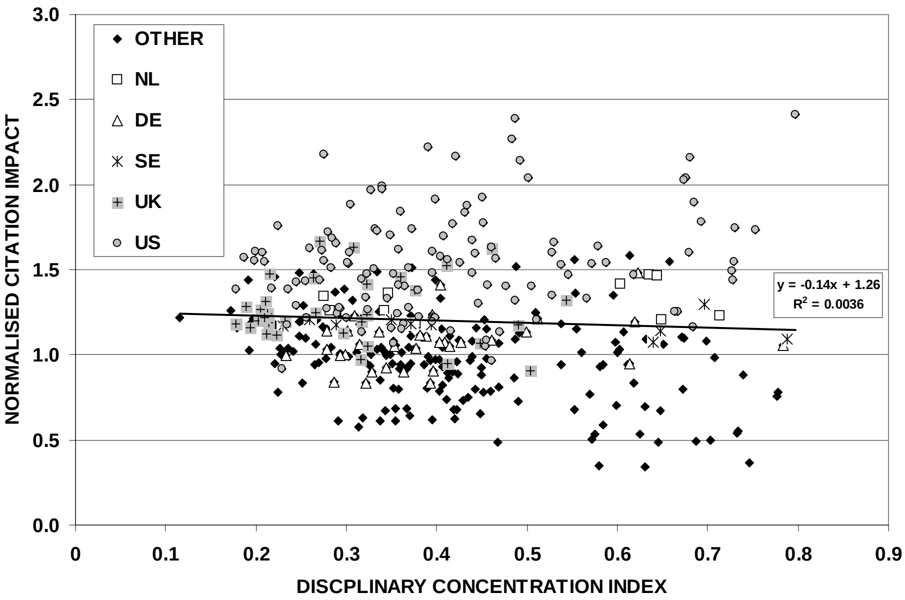

Figure 3. Disciplinary specialisation index versus normalized citation impact for 386 world universities

country. This 'double'-normalised impact indicator was correlated with the publication activity index, expressing the institution's specialisation in a discipline, based upon the distribution of its papers among disciplines compared to the world distribution. Only universities with at least 50 papers in a discipline were included in the correlation analysis for that discipline.

Table 6 presents the outcomes of this analysis. In four disciplines a significant correlation was found between citation impact per paper and degree of specialisation (publication activity index): in biological sciences primarily related to humans, clinical medicine, molecular biology and in physics, with Pearson coefficients of 0.24, 0.23, 0.41 and 0.17, respectively. In all other disciplines the correlations were not significant at $p = 0.01$.

These outcomes await further interpretation. The disciplines in which a significant, positive correlation was found embrace typical 'big science' fields, and perhaps the outcomes show that the concept of 'critical mass' in research activity is more relevant in 'big science' than it is in other domains of science and scholarship. It needs emphasising, however, that this analysis focuses on specialisation *across* rather broadly defined disciplines, and that it does *not* take into account specialisation within a discipline. A more detailed study could further analyse differences across countries and subject of specialisation.

Collaboration networks of universities using social network analysis

In order to analyse the structure of a national academic system and highlight the position of individual universities, maps based on network analysis are particularly useful. Such maps allow one to identify the best research universities in their national or regional environment, based on a *series* of bibliometric and network indicators (Calero-Medina and Moed, 2006). Institutions are not ranked on the basis of one single indicator. Instead, a social network analysis is applied to represent relations between universities based on co-authorship, and to identify patterns of co-publication activity. The novelty of this approach is that one may identify not only the best research universities based on a *series* of bibliometric indicators, but also analyse the way in which universities collaborate, and their position in a global collaboration map.

The institutions were characterised by the following properties:

- The country or geographical region in which the university is located.
- The number of papers published by the university. The size of the circles or triangles representing a university indicates the number of papers it published during the time period considered.
- The field normalized citation impact indicator of a university's publication output. Triangles represent universities that are among the top 25% in terms of the normalised citation impact of the articles it published.

The thickness of a connecting line indicates the strength of the co-publication relationship among a pair of universities. This strength is expressed by Salton's Index, defined as the number of co-publications between two universities, divided by the square root of the product of the number of papers published by each university.

Figure 4 shows the global collaboration network among the top 100 world universities in terms of the number of articles published during 1997–2004. It displays only co-publication links of which the strength exceeds 0.02. Applying this threshold,

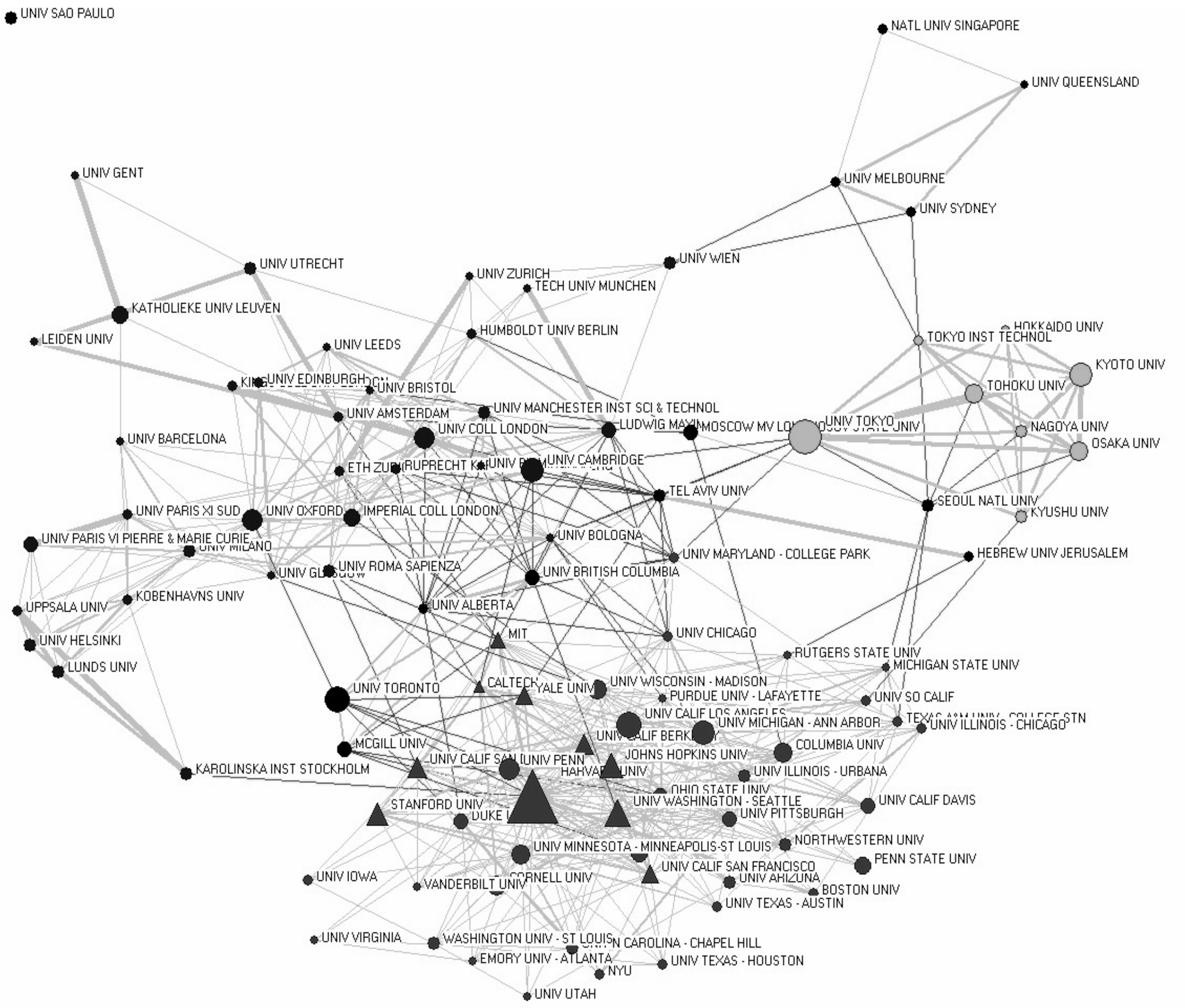

Figure 4. Collaboration network of top 100 world universities

about 12% of the co-publication matrix was taken into account. The map reveals the bridge function of Canadian universities between Europe and the USA, and the central position of the University of Tokyo that shows strong collaboration links with European and North American universities. The collaboration patterns among European universities clearly reflect the importance of national collaboration. This may suggest that the European Research Area is not (yet) as strongly integrated as the research activities carried out in the USA.

In a reasonably easy but still reliable way one generates in just one network map an overall picture of the set of universities (national, regional or worldwide level) based on bibliometric performance measurements. This can be carried out both at an aggregate level of a university as a whole, but also per research field, in order to identify field specific characteristics.

Concluding remarks

More detailed empirical studies should be made of the structure of European, US and other (supra-) national academic systems. A first research topic is the extent to which these systems are structured according to a concentration or a distributed model. Therefore, one should also analyse the performance of other US universities than the 122 studied in this paper, and of academic institutions in other countries. A key question is which of the two is the most appropriate in the various countries, especially which model provides the most optimal conditions for ‘top’ research. This complex, policy-relevant question awaits further study.

A second way to further examine the structure of national academic systems is to produce for a number of countries maps of the type presented as Figure 4 based on social network analysis. Such maps would reveal the positions of individual universities and their relationships within a national academic system. A challenge would be to compare the structures that are obtained for the various countries with one another, to develop a classification system of these network structures, and to characterise countries accordingly. In addition, it would be useful to further characterise the role of individual universities in terms of whether they have an international, national or local orientation.

A practical implication of the findings presented is that it would be appropriate to compile and publish rankings of universities per research field or discipline. In addition, one should consider in rankings

It would be useful to further characterise the role of individual universities in terms of whether they have an international, national or local orientation

based on indicators calculated for all fields combined to add for each university the value of its disciplinary specialisation index, and to indicate for more specialised universities the discipline(s) in which they specialise. This would substantially enhance the information content and utility of the rankings.

The publication data for the universities analysed in this paper were not verified by representatives of the institutions, except in a few cases. A main future task will be to find ways to enable them to verify the data. The bibliometric data used in this study focus on the 'output' side of research. It should be combined with other publicly available, verified or certified information, reflecting aspects of the 'input' side, including per discipline at least the number of students and various categories of research staff, and the amount of public funding. Although these 'input' measures partly reflect 'output' categories such as research quality as well — for instance, 'good' institutions tend to attract more funding than less good ones — their use in statistical analyses is indispensable, and will enrich the comparative analysis of national academic systems.

It is essential that these data are not only available at the level of a university as a whole, but at least also by discipline, in order to relate 'output' to 'input' at the level of disciplines. Therefore, the mismatch that currently exists between disciplinary categorisations at the output and input sides needs to be solved (Luwel, 2004). In this way, a public information system on world research universities can be built, that is not only useful for the general public, but also constitutes a database for further research on research performance and its determinants.

Note

1. This section and the next are partly based upon Visser *et al* (2007).

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