Bibliometric Statistical Properties of the 100 Largest European Research Universities: Prevalent Scaling Rules in the Science System

Anthony F.J. van Raan
Centre for Science and Technology Studies, Leiden University, Wassenaarseweg 52, P.O. Box 9555, 2300 RB Leiden, the Netherlands. E-mail: vanraan@cwts.leidenuniv.nl

The statistical properties of bibliometric indicators related to research performance, field citation density, and journal impact were studied for the 100 largest European research universities. A size-dependent cumulative advantage was found for the impact of universities in terms of total number of citations. In the author's previous work, a similar scaling rule was found at the level of research groups. Therefore, this scaling rule is conjectured to be a prevalent property of the science system. The lower performance universities have a larger size-dependent cumulative advantage for receiving citations than top performance universities. For the lower performance universities, the fraction of noncited publications decreases considerably with size. Generally, the higher the average journal impact of the publications of a university, the lower the number of noncited publications. The average research performance was found not to dilute with size. Evidently, large universities, particularly top performance universities are characterized by being "big and beautiful." They succeed in keeping a high performance over a broad range of activities. This most probably is an indication of their overall attractive scientific and intellectual power. It was also found that particularly for the lower performance universities, the field citation density provides a strong cumulative advantage in citations per publication. The relation between number of citations and field citation density found in this study can be considered as a second basic scaling rule of the science system. Top performance universities publish in journals with significantly higher journal impact as compared to the lower performance universities. A significant decrease of the fraction of self-citations with increasing research performance, average field citation density, and average journal impact was found.

Introduction

In previous articles (van Raan, 2006a, 2006b, 2007), we have presented an empirical approach to the study of the statistical properties of bibliometric indicators of research groups. Now we will focus on a two orders of magnitude larger aggregation level within the science system: the university. The target group consists of the 100 largest European research universities. This set of universities is the result of a study on the scientific strengths of the European Union (EU) and its member states and a ranking exercise based on the results of this study.[1] The different dimensions distinguished are top and lower performance universities, higher and lower field citation densities, and higher and lower journal impact. In particular, the phenomenon of size-dependent (size of a university in terms of number of publications) cumulative advantage[2] of impact (in terms of numbers of citations) is studied for different levels of research performance, field citation density, and journal impact. By taking the number of publications as a measure of size (and not the number of students or staff), the focus here is on internationally successful research-intensive universities—mostly the old, broad-based, classical universities with large medical schools—not the new, large, primarily teaching-oriented universities, such as former polytechnics. For instance, a large majority of the League of European Research Universities (LERU, 2007) is present in the top 30 of these 100 largest European research universities.

Katz (1999) discussed scaling relationships between number of citations and number of publications across research fields and countries. He concluded that the science system is characterized by cumulative advantage, more particularly a

Received April 9, 2007; revised August 17, 2007; accepted September 4, 2007

 • Published online 4 December 2007 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/asi.20761

[1]This "Leiden Ranking" is largely based on our work in a project funded by the European Commission, research DG (the ASSIST project).

[2]By "cumulative advantage," it is meant that the dependent variable (for instance, number of citations of a university, C) increases in a disproportional, nonlinear (in this case: power law) way as a function of the independent variable (for instance, in the present study, the size of a research university, in terms of number of publications, P). Thus, larger universities (in terms of P) do not just receive more citations (as can be expected), but they do so increasingly more advantageously: universities that are twice as large as other universities receive, on average, about 2.5 more citations.

size-dependent "Matthew effect" (Merton, 1968, 1988). As explained in footnote 1, this implies a nonlinear increase of impact with increasing size, demonstrated by the finding that the number of citations as a function of number of publications (in Katz' study for 152 fields of science) exhibits a power law dependence with an exponent larger than 1. In previous articles (van Raan, 2006a, 2006b, 2007), we have demonstrated a size-dependent cumulative advantage of the correlation between number of citations and number of publications also at the level of research groups. In this study, observations are extended to the level of entire universities.

The focus here is on performance-related differences of bibliometric properties of universities. Particularly important are the citation characteristics of the research fields in which a university is active (the field citation densities) and the impact level of the journals used by a university. Seglen (1992, 1994) found a poor correlation between the impact of publications and journal impact at the level of individual publications. However, grouping publications in classes of journal impact yielded a high correlation between publication and journal impact. This grouping is determined by journal impact classes, and not by a "natural" grouping such as research groups and universities. In a previous study, we showed a significant correlation between the average number of citations per publication of research groups, and the average journal impact of these groups. In this study (van Raan, 2006b), we investigate whether this finding also holds at the level of entire universities.

The structure of this study is as follows. Within a set of the 100 largest universities in Europe, we distinguish in our analysis between performance, field citation densities, and journal impact. In the second section, we address several general issues concerning the ranking of universities. In the third section, we discuss the data material of the universities, the application of the method, and the calculation of the indicators. In the fourth section, we analyze the data of the 100 largest European universities in the framework of size-dependent cumulative advantage and classify the results of the analysis in main observations. Our analysis of performance- and field density-related differences of bibliometric properties of universities reveals further interesting results, particularly on the role of journal impact. These observations are discussed in the last part of the fourth section. Finally, in the fifth section we summarize the main outcomes of this study.

About Ranking of Universities

In the last few years, rankings of universities, though controversial, have become increasingly popular. Two rankings widely attracted the attention of policy makers, the scientific world, and the public media: the rankings published by the Jiao Tong University in Shanghai from 2003 (SJTU, 2006), and the rankings published in the *Times Higher Education Supplement* from 2004 (THES, 2006).

Rankings suggest a similar simplicity for the evaluation of scientific performance as in the case of a soccer league. The immediate observation that the well-known U.S. top universities take the lead, reinforces these suggestions. Although things are not so simple and the various methodologies used still have to be discussed thoroughly, the influence of these rankings is striking. Rankings have become unavoidable; they are now part of academic life and they may considerably guide the choice of young scientists and research students. Rankings also strengthen the idea of an academic elite, and institutions use the outcomes of rankings, no matter how large the methodological problems are, in their rivalry with other institutions.

There is an interesting difference between the concepts of reputation and contemporaneous performance. On the one hand, long-time-ago Nobel Prize winners do not relate to the current research quality of a university. On the other hand, the history of a university with "grand old men" does count considerably in reputation. Universities publish in their Web sites honorary lists of Nobel Prize winners (if they have them) and other famous scientists. The historical tradition of scientific strengths of particularly the older, classic universities is a strong asset in their present-day reputation. Thus, a major question is, "What do we want to measure, and how does established reputation relate to contemporaneous performance?" For the moment, we leave this question to further research, but we remark that established reputation is not necessarily the same as "past glory." Often we see that institutions with an established reputation are remarkably strong in maintaining their position. They simply have more power to attract the best people, and this mechanism provides these renowned institutions with a cumulative advantage to reinforce their research performance further.

Judgment by knowledgeable colleague-scientists, known as peer review, is the principal procedure of assessing research performance, notwithstanding its shortcomings and disadvantages. In most cases, peer review is applied on a relatively small scale—from the review of a submitted article or a research proposal by two or three referees, to the review of the record of candidates for a professorship by, say, five experts in the field, or to the assessment of research groups and research programs within a specific discipline by between 5 and 10 peers.

This implies two important things. First, peers can be regarded as experts with respect to the quality of the object. Second, the object to be evaluated has a size that is comparable with the usual working environment of the peer, namely, a research group or a research program appropriate for individual peer judgment. In some rankings, however, scientists have to judge much larger entities, even complete universities, and so the cognitive distance to the object to be evaluated increases considerably. Therefore, it is questionable whether all the individual academics involved in such large-scale surveys can be regarded as knowledgeable experts in all those parts of the evaluated entities that really matter. In such cases, experts will tend to judge on the more general basis of established reputation, instead of their own actual knowledge of recent past performance (van Raan, 2006c).

This awareness of recent past performance, however, is precisely what a peer must have. It is this recognition of recent

DOI: 10.1002/asi

past performance that forms the strength of bibliometric analysis. Bibliometric indicators can be seen as the aggregate of typical peer review. Well-informed colleague-scientists play their role as a member of an "invisible peer review college" by referring in their own work to earlier work of other scientists. Because this happens for all publications of a university in many disciplines, the outcomes of a bibliometric analysis on the level of a university will be statistically very significant.

Bibliometric assessment of research performance is based on one central assumption: scientists, who have to say something important, do publish their findings vigorously in the open, international journal literature. This assumption unavoidably introduces a bibliometrically limited view of a complex reality. Journal articles are not the main carrier of scientific knowledge in all fields. However, the daily practice of scientific research shows that inspired scientists in most cases and particularly in the natural sciences and medical research fields, go for publication in the better and—if possible—the best journals. This is less the case in engineering research, social and behavioral sciences, and certainly for the humanities. Thus, the strength of a university in engineering, in the social and the behavioral sciences, or in the humanities may contribute little—or even hardly—to the position of that university in a ranking based on bibliometric data. Smaller universities, and particularly those with an emphasis on social sciences and humanities, will have a better chance by the peer-review element in the THES ranking as compared to the more bibliometrically oriented Shanghai study. A striking example is the difference in position of the London School of Economics, a top position in the THES ranking and a low position in the Shanghai ranking.

For a detailed discussion of problems related to the ranking of universities we refer to van Raan (2006c). In this article, we take the results of our own Leiden Ranking exercise as described in the next section to study the bibliometric statistical properties of the 100 largest European research universities and to investigate scaling rules in the science system.

Basic Data and Indicators Derived From These Data

We studied the statistics of bibliometric indicators on the basis of all publications covered in the ISI Citation Index (CI covered by the Web of Science; Thomson Scientific, formerly the Institute for Scientific Information [ISI], Philadelphia, PA) of the 100 largest European universities for the period 1997–2004.[3] This material is quite unique. To our knowledge, no such compilations of very accurately collected publication sets on a large scale are used for statistical analysis of the characteristics of indicators at the university level. Obtaining data at the university level is not a trivial matter. The delineation of universities through externally available data such as the address information in the CI database is very problematic. For a thorough discussion of this problem, see Van Raan (2005a, 2006c). As discussed in the previous section, the (CI) publications were collected as part of a large EC study on the scientific strengths of the EU and its member states. For a detailed discussion of methodological and technical issues, we refer to Moed (2006). From a listing of more than 250 European universities, we selected the 100 largest. The period covered is 1997–2004 for both publications and citations received by these publications. In total, the analysis involves the work of many thousands of senior researchers in 100 large universities and covers around 1.5 million publications and 11 million citations (excluding self-citations), about 15% of the worldwide scientific output and impact.

The indicators are calculated on the basis of a total period analysis. This means that publications are counted for the entire period (1997–2004) and citations are counted up to and including 2004 (e.g., for publications from 1997, citations are counted in the period 1997–2004, and for publications from 2004, citations are counted only in 2004). We are currently updating our data system with the 2005 and 2006 publication and citation data.

We apply the Centre for Science and Technology Studies (CWTS, Leiden University) standard bibliometric indicators. Only external citations, i.e., citations corrected for self-citations (if any of the authors of the citing paper is also an author of the cited paper, it is a self-citation), are taken into account. These standard bibliometric indicators include (for a detailed discussion, see Van Raan, 1996, 2004, 2005b):

- Number of publications P in CI-covered journals of a university in the specified period
- Number of citations C received by P during the specified period, without self-citations; including self-citations: Ci, i.e., number of self-citations $Sc = Ci - C$, relative amount of self-citations Sc/Ci
- Average number of citations per publication, without self-citations (CPP)
- Percentage of publications not cited (in the specified period) Pnc
- Journal-based worldwide average impact as an international reference level for a university (JCS, journal citation score, which is our journal impact indicator), without self-citations (on this worldwide scale); in the case of more than one journal we use the average $JCSm$; for the calculation of $JCSm$ the same publication and citation counting procedure, time windows, and article types are used as in the case of CPP
- Field-based[4] worldwide average impact as an international reference level for a university (FCS, field citation score), without self-citations (on this worldwide scale); in the case of more than one field (as almost always) we use the average

[3]We included Israel. We have left out Lomonosov University of Moscow. As far as number of publications concerns, this university is one of the largest in Europe (about 24,000 publications in the covered 8-year period), but the field-normalized impact is so exceptionally low ("crown indicator" $CPP/FCSm$ about 0.3) that it would have a very outlying position in the ranking. The reason for the low crown indicator value is that this university publishes a large amount of publications in (very) low-impact journals resulting in a very high percentage of noncited publications.

[4]We use the definition of fields based on a classification of scientific journals into categories developed by Thomson Scientific. Although this classification is not perfect, it provides a clear and fixed consistent field definition suitable for automated procedures within our data system.

DOI: 10.1002/asi

TABLE 1. Largest 30 European universities.

	University		*P*	*C*	*CPP*	*Pnc*	*CPP/FCSm*
1	UNIV CAMBRIDGE	UK	*36.349*	361.681	9,95	29,1	1,63
2	UNIV COLL LONDON	UK	*34.407*	346.028	10,06	26,9	1,46
3	UNIV OXFORD	UK	*33.780*	355.856	10,53	29,5	1,67
4	IMPERIAL COLL LONDON	UK	*27.017*	222.713	8,24	30,7	1,45
5	LUDWIG MAXIMILIANS UNIV MUNCHEN	DE	*23.519*	177.317	7,54	30,8	1,14
6	UNIV PARIS VI PIERRE & MARIE CURIE	FR	*23.468*	146.483	6,24	32,8	1,09
7	UNIV MILANO	IT	*23.006*	175.181	7,61	30,0	1,11
8	UNIV UTRECHT	NL	*22.668*	189.671	8,37	28,3	1,37
9	KATHOLIEKE UNIV LEUVEN	BE	*22.521*	153.851	6,83	34,9	1,22
10	UNIV MANCHESTER	UK	*22.470*	137.812	6,13	34,4	1,16
11	UNIV WIEN	AT	*21.940*	137.251	6,26	32,9	1,01
12	UNIV ROMA SAPIENZA	IT	*21.778*	119.076	5,47	37,7	0,95
13	TEL AVIV UNIV	IL	*21.447*	112.337	5,24	35,9	0,94
14	UNIV HELSINKI	FI	*21.034*	179.662	8,54	28,5	1,38
15	LUNDS UNIV	SE	*20.631*	157.944	7,66	27,9	1,21
16	KAROLINSKA INST STOCKHOLM	SE	*20.525*	213.629	10,41	23,2	1,30
17	KOBENHAVNS UNIV	DK	*19.555*	153.583	7,85	27,4	1,18
18	UNIV AMSTERDAM	NL	*19.333*	163.417	8,45	28,9	1,35
19	UPPSALA UNIV	SE	*18.998*	140.518	7,40	28,6	1,17
20	RUPRECHT KARLS UNIV HEIDELBERG	DE	*18.735*	155.451	8,30	30,1	1,22
21	ETH ZURICH	CH	*18.611*	148.078	7,96	29,8	1,52
22	KINGS COLL UNIV LONDON	UK	*18.601*	161.460	8,68	28,7	1,32
23	HEBREW UNIV JERUSALEM	IL	*18.389*	127.263	6,92	33,2	1,16
24	UNIV PARIS XI SUD	FR	*18.183*	115.157	6,33	32,8	1,13
25	UNIV EDINBURGH	UK	*17.786*	164.380	9,24	29,7	1,48
26	HUMBOLDT UNIV BERLIN	DE	*17.780*	127.381	7,16	31,6	1,13
27	LEIDEN UNIV	NL	*16.832*	147.821	8,78	26,9	1,26
28	UNIV ZURICH	CH	*16.783*	154.154	9,19	29,2	1,33
29	UNIV BARCELONA	ES	*16.783*	103.628	6,17	32,4	1,03
30	UNIV BRISTOL	UK	*16.387*	119.960	7,32	29,7	1,31

FCSm; for the calculation of *FCSm* the same publication and citation counting procedure, time windows, and article types are used as in the case of *CPP*; we refer in this article to the *FCSm* indicator as the field citation density

- Comparison of the *CPP* of a university with the worldwide average based on *JCSm* as a standard, without self-citations, indicator *CPP/JCSm*
- Comparison of the *CPP* of a university with the world-wide average based on *FCSm* as a standard, without self-citations, indicator *CPP/FCSm*
- Ratio *JCSm/FCSm* is the relative, field-normalized journal impact indicator.

In Table 1, we show as an example the results of our bibliometric analysis for the first 30 universities within the European 100 largest. This table makes clear that our indicator calculations allow an extensive statistical analysis of these indicators for our set of universities. We regard the internationally standardized (field-normalized) impact indicator *CPP/FCSm* as our "crown" indicator. This indicator enables us to observe immediately whether the performance of a university is significantly far below (indicator value <0.5), below (0.5–0.8), around (0.8–1.2), above (1.2–1.5), or far above (>1.5) the international (Western world dominated) impact standard averaged over all fields (van Raan, 2004).

Results and Discussion

Impact Scaling and Research Performance

In our previous study (van Raan 2006a, 2006b, 2007), we showed how a set of research groups is characterized in terms of the correlation between size (the total number of publications P of a specific research group[5]) and the total number of citations C received by a group. Now we calculated the same correlation for all 100 largest European universities. Figure 1 shows that this correlation is described (coefficient of determination of the fitted regression is $R^2 = 0.79$[6]) by a power law:

$$C(P) = 0.36\, P^{1.31}.$$

[5]The number of publications is a measure of size in the statistical context described in this article. It is, however, a proxy for the real size of a research group or a university, for instance in terms of number of staff fulltime equivalents (fte) available for research.

[6]In this study, we are primarily interested in the broad characteristics of the data, particularly concerning cumulative advantage and not in detailed statistical analysis, so we used the statistical analysis procedures provided by Microsoft Excel 2000, which are appropriate for this purpose. However, we also performed an independent second analysis with the special statistical programs for line-fitting (MatLab) designed by Warton, Wright, Falster, and Westoby (2006).

DOI: 10.1002/asi

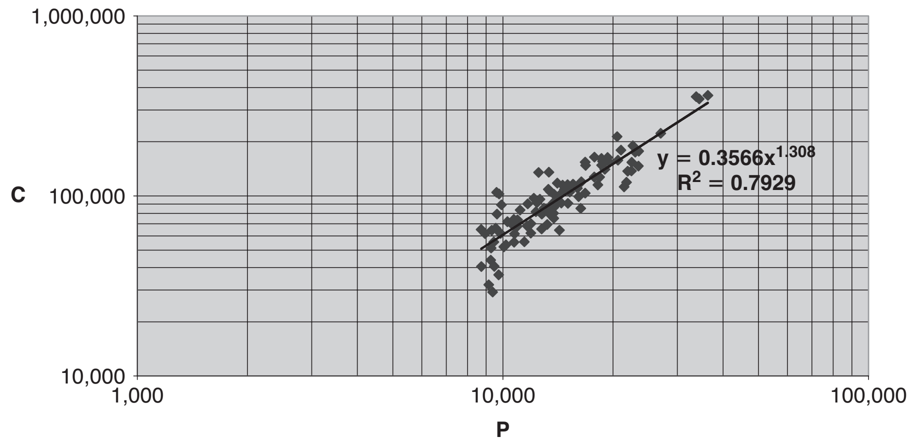

FIG. 1. Correlation of the number of citations (*C*) received per university with the number of publications (*P*) of these universities for all 100 largest European universities.

At the lower side of *P* (and *C*), we observe an interesting phenomenon: there are a few universities that belong, as far as their size concerns, to the 100 largest, but the impact in terms of citations and particularly in terms of the field-normalized impact *CPP/FCSm* deviates considerably from the universities in the same ranking layer, see the Appendix. The power law fit (Figure 1) identifies these outliers better than the nonpower law representation of the data used in Figure 1 (see footnote 6). Moreover, the non-power law fit, particularly a linear fit, covers less adequately a crucial part of the data, namely the universities with the largest size and the highest impact. We tested this finding by an analysis of current work on an extended set of the 200 largest universities. To find out whether the power law relation is caused by a possible outlier position of the top three universities, we provide graphs with and without the top three universities, see the Appendix (Fig. A1). We conclude that the power law relation is not determined by the top three, it is a characteristic of the whole set of universities.

We observe that the size of universities leads to a cumulative advantage (exponent $\alpha = +1.31$) for the number of citations received by these universities. Thus, the Matthew effect also works in at the aggregation level of entire universities. Generally, correlation does not provide a direct insight into causality. For instance, on a worldwide scale a significant negative correlation for countries is found between infant mortality and publication numbers. It is clear that both phenomena will not have a causal relation. It is a third variable, the prosperity of a country that is responsible for the correlation. But in this study causality is clear: Publications are the entities that create citations.

The intriguing question is how the research performance of the universities (measured by *CPP/FCSm*) relates to size dependency. Gradual differentiation between top and lower performance (top/bottom 10%, 25%, and 50% of the *CPP/FCSm* distribution) enables us to study the correlation of *C* with *P* and possible scale effects in more detail. The results are presented in Figure 2, and a summary of all findings in Table 2. The group of highest performance universities (top 10%) does not have a cumulative advantage (i.e., the exponent is not significantly[7] >1). The bottom 10% exponent is heavily determined by the outliers. The broader top 25% shows a slight ($\alpha = +1.16$) and the bottom 25% a stronger cumulative advantage ($\alpha = +1.33$). If we divide the entire set of universities into a top and bottom 50%, we see that both subsets have more or less equal exponents. Thus, the most intriguing finding is that the lowest performance universities have a larger size-dependent cumulative advantage than top performance universities. This phenomenon has already been observed at the level of research groups (van Raan, 2006a, 2006b, 2007). It is fascinating that within the science system this scaling rule covers at least two orders of magnitude in size of entities. Furthermore, the top performance universities are generally the larger ones, i.e., in the right hand side of the correlation function.

TABLE 2. Power law exponent α of the correlation of *C* with *P* for the 100 largest European universities in the indicated modalities.

All 100	1.31
Top 10%	0.94
Bottom 10%	1.43
Top 25%	1.16
Bottom 25%	1.33
Top 50%	1.17
Bottom 50%	1.16

An important feature of research impact is the number of noncited publications. Analyzing the correlation of the fraction (percentage) of noncited publications *Pnc* of the 100 largest European universities with the size (*P*) of a university, we find that the fraction of noncited publications decreases with low significance as a function of size. Thus, as a

[7]To estimate the influence of these noisy data, we randomly removed five universities. We found that the error in the exponent α is about $\pm$ 0.05. Thus, the noisiness of data remains within acceptable limits and does not substantially affect our findings.

DOI: 10.1002/asi

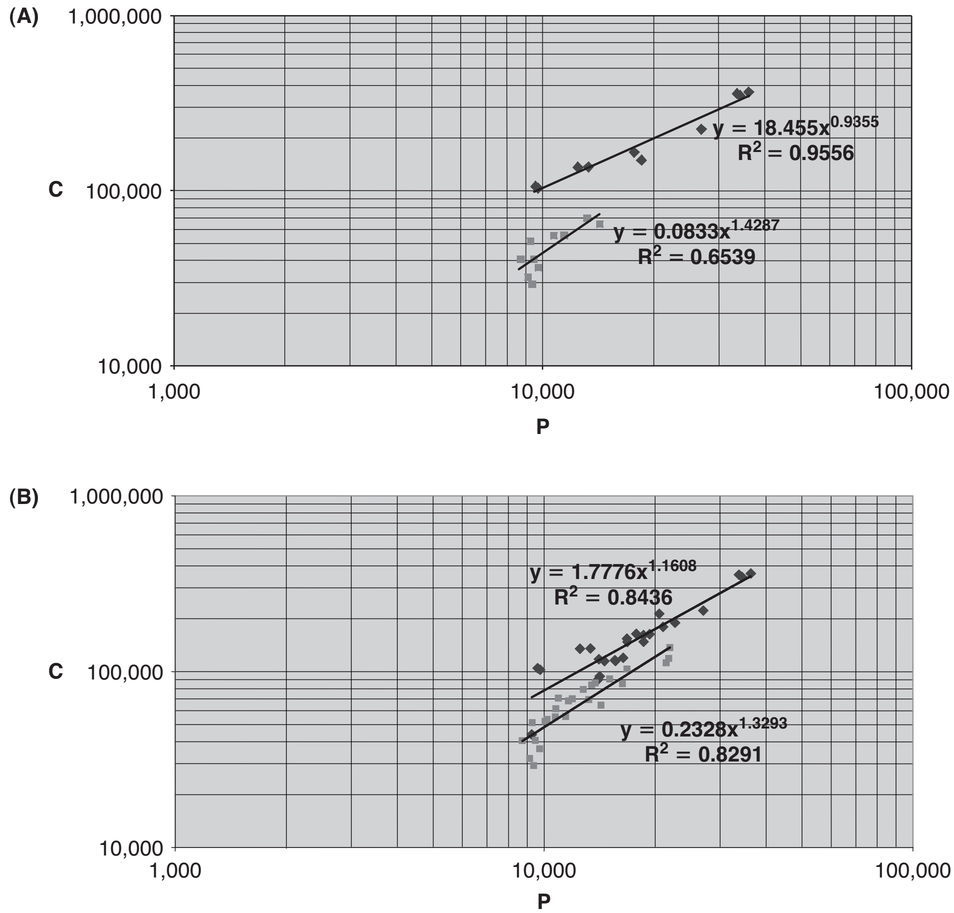

FIG. 2. Correlation of the number of citations (*C*) received per university with the number of publications (*P*) for (A) the top 10% (of *CPP/FCSm*) universities (◆) and the bottom 10% universities (■) within the 100 largest European universities, and (B) the same for the top and bottom 25%.

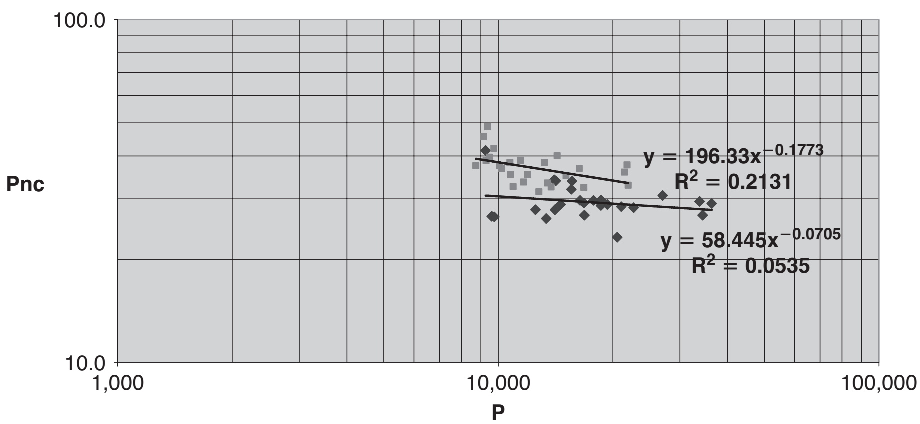

FIG. 3. Correlation of the relative number of not cited publications (*Pnc*) with the number of publications (*P*) for the top 25% (of *CPP/FCSm*) universities (◆), and the bottom 25% universities (■).

further step, we investigated this correlation with a distinction between top and lower performance universities. Figure 3 shows the results for the top and bottom 25% of the *CPP/FCSm* distribution of the 100 largest universities.

The observations suggest that the fraction of noncited publications decreases with size, particularly for the lower performance universities. This phenomenon was also found at the level of research groups (van Raan, 2006a, 2006b, 2007), which means that we identified another scaling rule in the science system covering at least two orders of magnitude. We notice, however, that this scaling rule for noncited publications is less strong at the level of entire universities as compared to groups. Advantage by size works by a mechanism in which the number of noncited publications is diminished. This

DOI: 10.1002/asi

mechanism works at the level of research groups as follows. The greater the number of publications in a group, the more those publications are promoted, which otherwise would have remained uncited. Thus, size reinforces an internal promotion mechanism, namely, initial citation of these stay-behind publications in the more cited publications of the group. Then authors in other groups are stimulated to take notice of these stay-behind publications and eventually decide to cite them. Consequently, the mechanism starts with within-group citation (which is not necessarily the same as self-citation), and subsequently spreads. It is obvious that particularly the lower performance groups will benefit from this mechanism. Top performance groups do not need the internal promotion mechanism to the same extent as low performance groups. This explains, at least in a qualitative sense, why top performance groups show less, or even no cumulative advantage by size. Because an entire university is the sum of a large number of research groups, the above mechanism will also be visible at the university level.

We also investigated the relation between research performance measured by indicator *CPP/FCSm* with size in terms of *P*. We find a very slight positive correlation as shown in Figure 4 for the universities in the top and bottom 25% of the *CPP/FCSm* distribution. This, however, is certainly not a cumulative advantage; the exponent of the correlation is very small, around 0.2. Probably the most interesting aspect of this measurement is that performance does not decrease, not dilute with increasing size.

Impact Scaling, Field Citation Density, and Journal Impact

In Figure 5, we present the correlation of the number of citations with size for those universities among the 100 largest European universities that have high and low field citation densities, i.e., top 25% and bottom 25%, respectively, of the *FCSm* distribution. We observe that the high field density universities hardly have a cumulative advantage (exponent $\alpha = 1.09$). The low field citation density universities on the other hand have a considerably size-dependent cumulative advantage (exponent $\alpha = 1.50$).

In Figure 6, we present a similar correlation for the top and bottom 25% of the *JCSm*, the average journal impact of a university. We see that these results are practically the same as in Figure 5. Given the strong correlation of *JCSm* and *FCSm* at the level of universities, as illustrated in Figure 7,

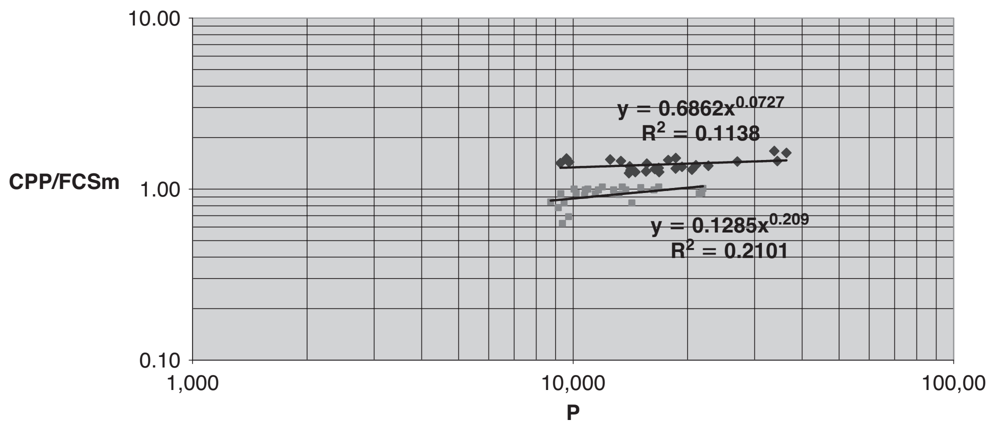

FIG. 4. Correlation of *CPP/FCSm* with the number of publications (*P*) for the top 25% (◆) and the bottom 25% (■) of *CPP/FCSm* distribution of the 100 largest European universities.

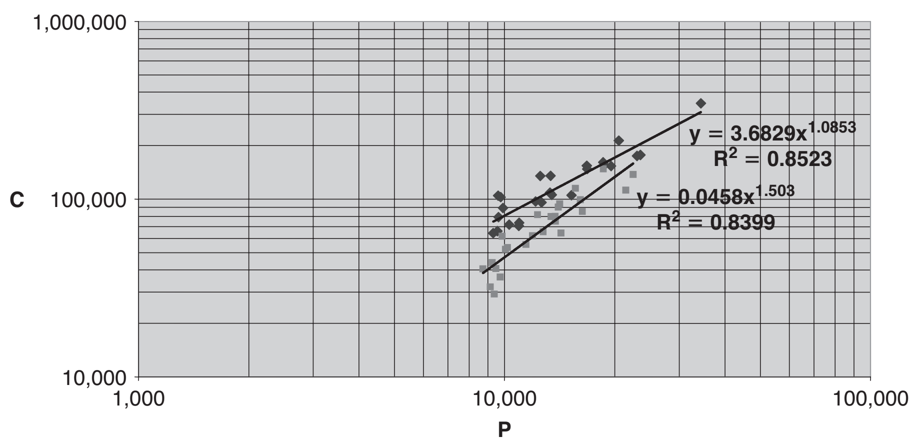

FIG. 5. Correlation of the number of citations (*C*) with the number of publications (*P*) for the universities within the top (◆) and the bottom 25% (■) of the field citation density (*FCSm*) distribution.

DOI: 10.1002/asi

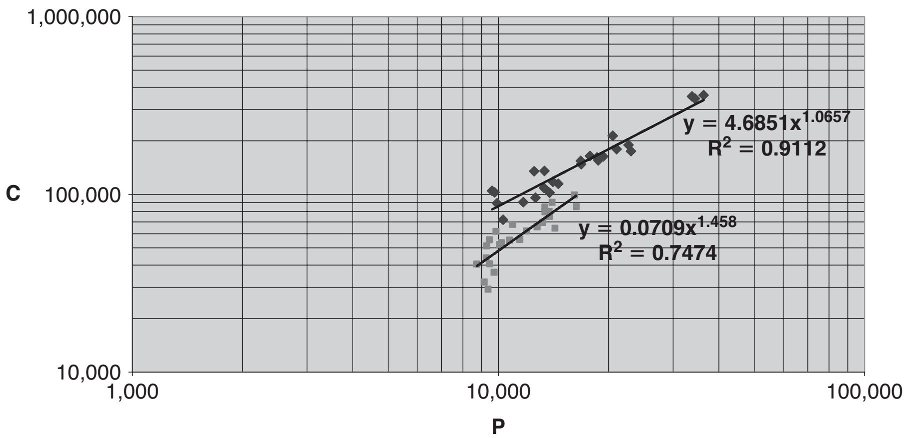

FIG. 6. Correlation of the number of citations (*C*) with the number of publications (*P*) for the universities within the top (◆) and the bottom 25% (■) of the average journal citation impact (*JCSm*) distribution.

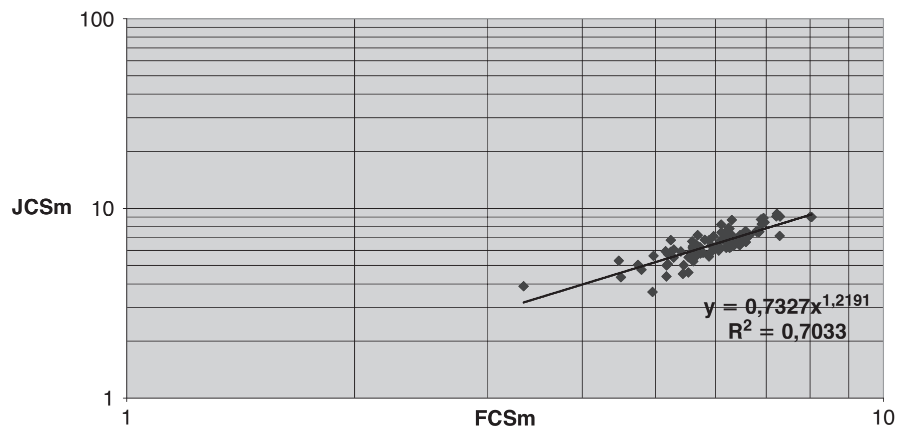

FIG. 7. Correlation of the average journal impact (*JCSm*) with the average field citation density (*FCSm*) for all 100 largest European universities.

this similarity can be expected. We remark, however, that the correlation of *JCSm* and *FCSm* has a power exponent 1.22 which means that the *JCSm* values increase in a nonlinear way (cumulatively) with *FCSm*.

We now investigate the relation between citation impact of a university in terms of average number of citations per publication (*CPP*) on the one hand, and field citation density (*FCSm*) and journal impact (*JCSm*) on the other. Seglen (1994) showed that the citedness of individual publications *CPP* is not significantly affected by journal impact.[8] However, grouping publications in classes of journal impact yielded a high correlation between publication citedness and journal impact. We also found that a natural grouping of publications, such as the work of a research group, leads to a high correlation of *CPP* and *JCSm* (van Raan, 2006b, 2007).

In this study, we find that this is also the case at the aggregation level of entire universities. We find a significant correlation between the average number of citations per publication for the 100 largest European universities (*CPP*) and the field citation density (*FCSm*), as well as the average journal impact of these universities (*JCSm*). We applied again the distinction between top and lower performance universities to find performance-related aspects in the above relation. The results are shown for the correlation of *CPP* with *FCSm* for the top performance universities (top 25% of *CPP/FCSm*) and lower performance universities (bottom 25% of *CPP/FCSm*) universities in Figure 8. The correlation of *CPP* with *JCSm* for the top performance and lower performance universities is shown in Figure 9. We see that these correlations are very significant.

Both the top and lower performance universities have more citations per publication (*CPP*) as a function of field citation density (*FCSm*, Figure 8) as well as of average journal impact (*JCSm*, Figure 9). Clearly, the top universities generally have higher *CPP* values. We find that particularly for the lower performance universities the field citation density provides an exceptionally strong cumulative advantage in citations per publication (*CPP*, exponent $\alpha = 1.97$, which is practically *FCSm*-squared. The correlation of *CPP* with

[8]In Seglen's work, journal impact was defined with the ISI journal impact factor; he did not consider the more sophisticated journal impact indicators such as the *JCSm* used in this study.

DOI: 10.1002/asi

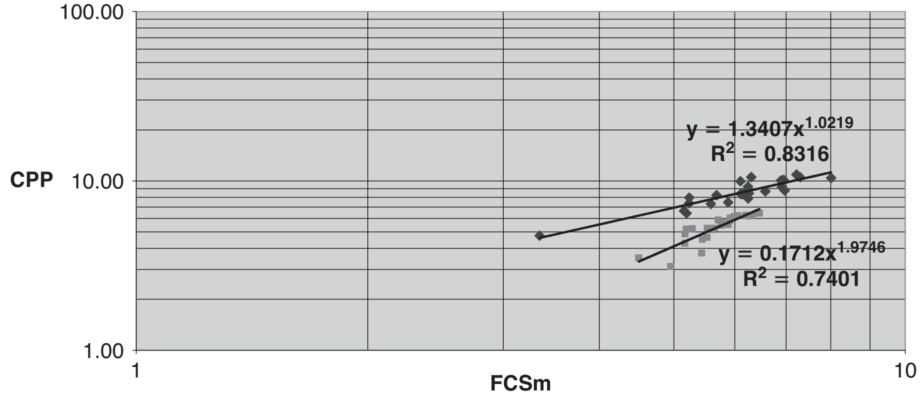

FIG. 8. Correlation of *CPP* with *FCSm* for the top 25% (◆) and the bottom 25% (■) of *CPP/FCSm* distribution of the 100 largest European universities.

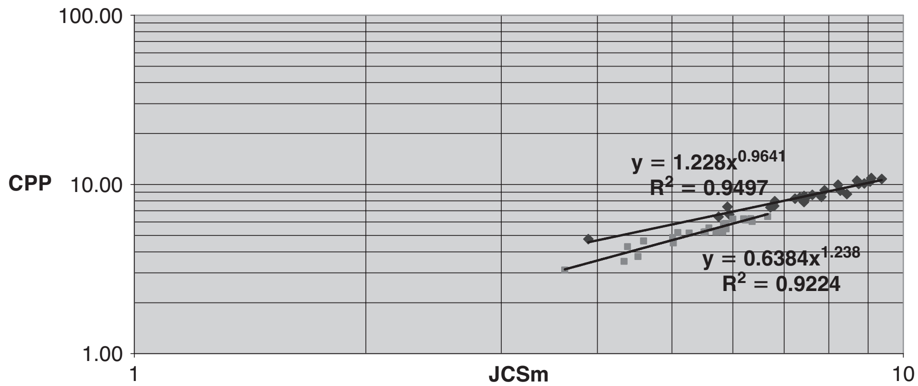

FIG. 9. Correlation of *CPP* with *JCSm* for the top 25% (◆) and the bottom 25% (■) of *CPP/FCSm* distribution of the 100 largest European universities.

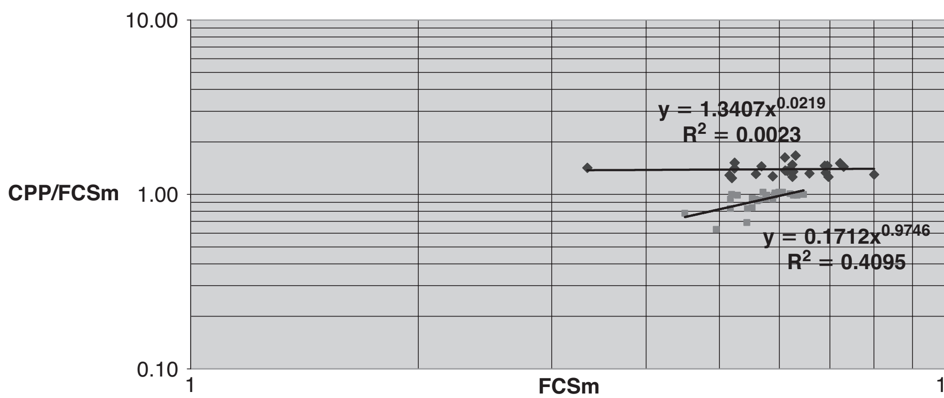

FIG. 10. Correlation of *CPP/FCSm* with *FCSm* for the top 25% (◆) and the bottom 25% (■) of *CPP/FCSm* distribution of the 100 largest European universities.

average journal impact (*JCSm*) shows a less-strong cumulative advantage for the lower performance universities, $\alpha = 1.24$. Most top performance universities publish in journals with significantly higher journal impact as compared to the lower performance universities (see Figure 9). Moreover, the top 25% universities perform in terms of citations per publications (*CPP*) with a factor of about 1.3 better than the bottom 25% universities in journals with the same average impact. An overview of the exponents of the correlation functions is given in Table 3.

We also investigated the correlation of the field-normalized research performance indicator (*CPP/FCSm*) of the 100 largest European universities with field citation density and with journal impact. In Figure 10, we show the correlation of *CPP/FCSm* with *FCSm* for the top performance and lower

TABLE 3. Power law exponent α of the correlation of *CPP* with *FCSm* and with *JCSm* for the 100 largest European universities.

	FCSm	*JCSm*
All	1.37	1.22
Top 25%	1.02	0.96
Bottom 25%	1.97	1.24

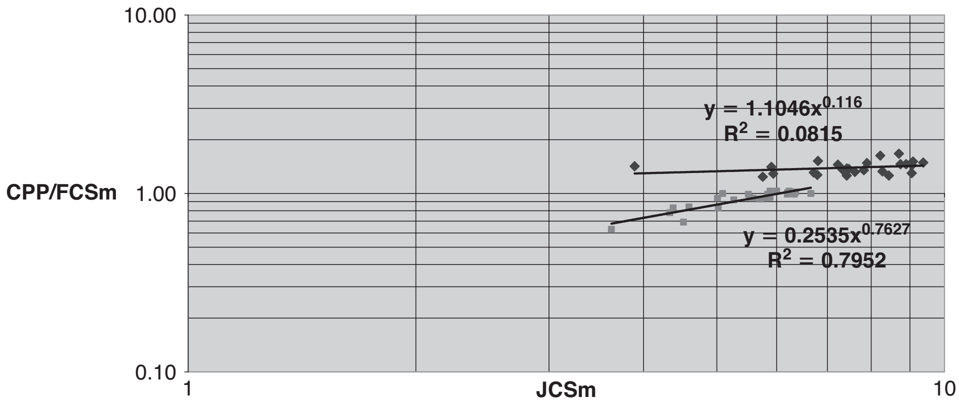

FIG. 11. Correlation of *CPP/FCSm* with *JCSm* for the top 25% (◆) and the bottom 25% (■) of *CPP/FCSm* distribution of the 100 largest European universities.

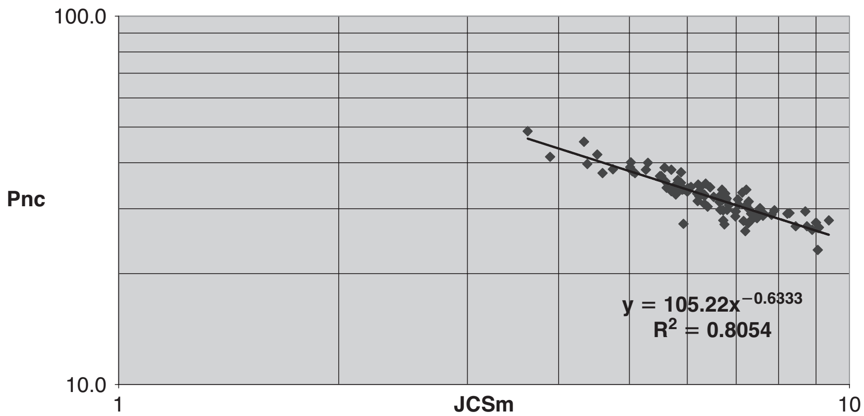

FIG. 12. Correlation of the relative number of notcited publications (*Pnc*) with the mean journal impact (*JCSm*) of the 100 largest European universities.

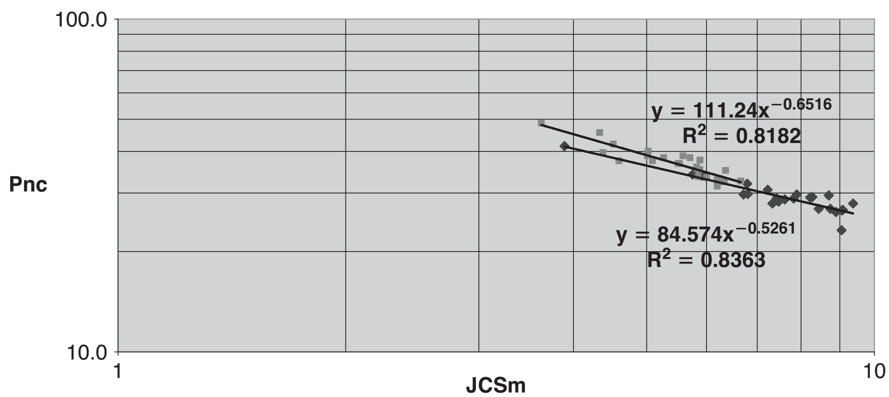

FIG. 13. Correlation of the relative number of noncited publications (*Pnc*) with the mean journal impact (*JCSm*) for the top 25% (of *CPP/FCSm*) universities (◆), and the bottom 25% universities (■).

performance universities. Figure 11 shows the correlation of *CPP/FCSm* with *JCSm* for the top performance and lower performance universities.

We observe that the research performance of the top universities is independent of field citation density (*FCSm*). For the lower performance universities there is a slight increase of performance as a function of *FCSm*. The results for the average journal impact (*JCSm*) are similar but more outspoken. Again we notice that top performance universities have a strong preference for the higher-impact journals.

Finally, we analyzed the correlation between the number of noncited publications (*Pnc*) of a university and its average journal impact level (*JCSm*). The results are shown in Figure 12 for the entire set of 100 universities and in Figure 13 for the top and lower performance universities. We see a quite significant correlation between these two variables. Very clearly, the top universities have the lowest *Pnc*. Given the strong correlation between *CPP* and *JCSm* (see Figure 12) we can also expect a significant correlation between *Pnc* and *CPP*, as confirmed nicely by Figure 14 for the entire set of

DOI: 10.1002/asi

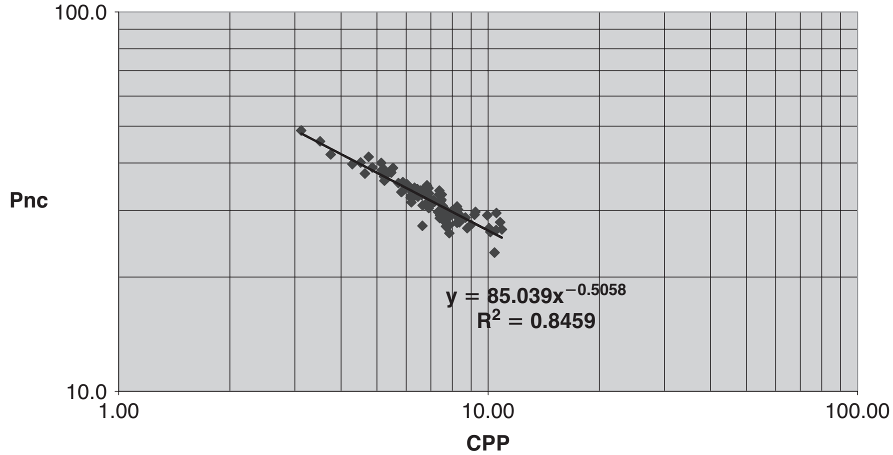

FIG. 14. Correlation of the relative number of noncited publications (*Pnc*) with the mean number of citations per publication (*CPP*) of the 100 largest European universities.

100 universities and in Figure 15 for the top and lower performance universities. Thus, we find that the higher the average journal impact of the publications of a university, the lower the number of noncited publications. In addition, the higher the average number of citations per publication in a university, the lower the number of noncited publications. In other words, universities that are cited more per article also have more cited articles. These findings underline the generally good correlation at the university level between the average number of citations per publication in a university, and its average journal impact.

We also find that the relation between the relative number of noncited publications (*Pnc*) and the mean number of citations per publication (*CPP*) can be written in good approximation as $Pnc = 1/\sqrt{(CPP)}$. This expression reflects the characteristics of the citation-distribution function as it is the relation between the number of publications with zero citations and the average number of citations per publication.

Characteristics of Self-Citations

In this section, we present a first analysis of a specific feature of the science system, the statistical properties of self-citations. We calculated the correlation between size (the total number of publications *P*) and the total number of citations *C* for all 100 largest European universities. We show the results for the top/bottom 10% of the *CPP/FCSm* distribution in Figure 16. We see that the group of highest performance universities (top 10%) does not have a cumulative advantage ($\alpha \sim 1$), whereas the bottom 10% exponent is heavily determined by the same outliers as discussed earlier. Results for the top 25% and the bottom 25% show a slight cumulative advantage ($\alpha = 1.11$ and 1.15, respectively). If we divide the entire set of universities in a top and bottom 50%, we see that both subsets have more or less equal exponents (around 1.11).

Figure 17 shows that the fraction (percentage) of self-citations (*%Sc*) decreases slightly with size (*P*), but this correlation is not very significant. More significant is the decrease of the fraction of self-citations as a function of research performance *CPP/FCSm* (see Figure 18). We also observe a decrease of self-citations for the 100 largest universities in Europe as a function of average field citation density *FCSm* (Figure 19) and as a function of average journal impact *JCSm* (Figure 20).

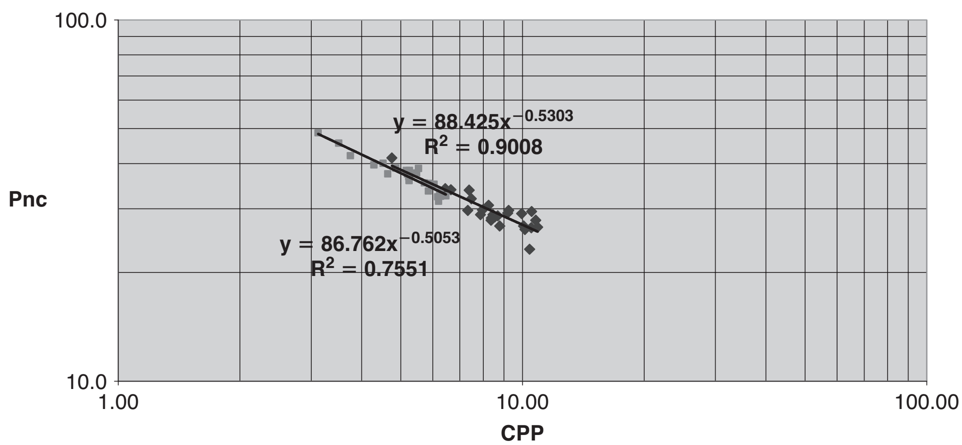

FIG. 15. Correlation of the relative number of noncited publications (*Pnc*) with the mean number of citations per publication (*CPP*) for the top 25% (of *CPP/FCSm*) universities (◆), and the bottom 25% universities (■).

DOI: 10.1002/asi

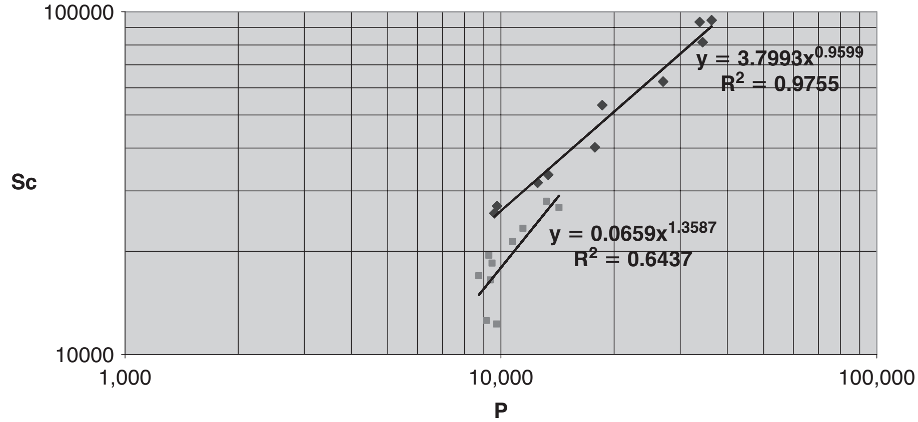

FIG. 16. Correlation of the number of self-citations (*Sc*) received per university with the number of publications (*P*), for the top 10% (of *CPP/FCSm*) universities (◆), and the bottom 10% universities (■) with the 100 largest European universities.

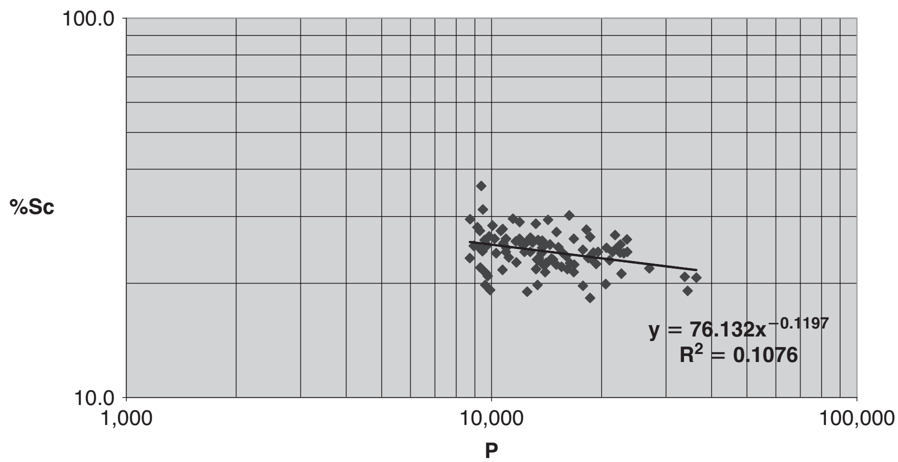

FIG. 17. Correlation of the relative number of self-citations (*%Sc*) per university with the number of publications (*P*) of these universities, for all 100 largest European universities.

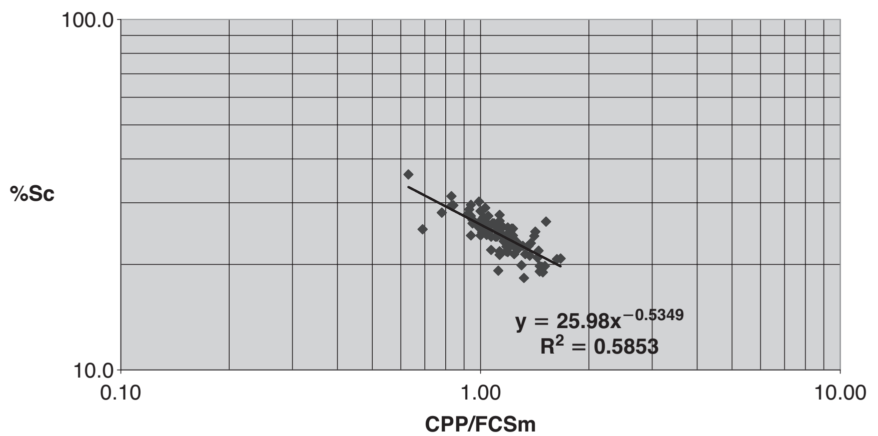

FIG. 18. Correlation of the relative number of self-citations (*%Sc*) per university with the performance (*CPP/FCSm*) of these universities, for all 100 largest European universities.

Summary and Concluding Remarks

For the 100 largest European universities we studied statistical properties of bibliometric characteristics related to research performance, field citation density, and journal impact. Our five main observations are as follows.

First, we find a size-dependent cumulative advantage for the impact of universities in terms of total number of citations. Quite remarkably, lower performance universities have a larger size-dependent cumulative advantage for receiving citations than top performance universities. We found in previous

DOI: 10.1002/asi

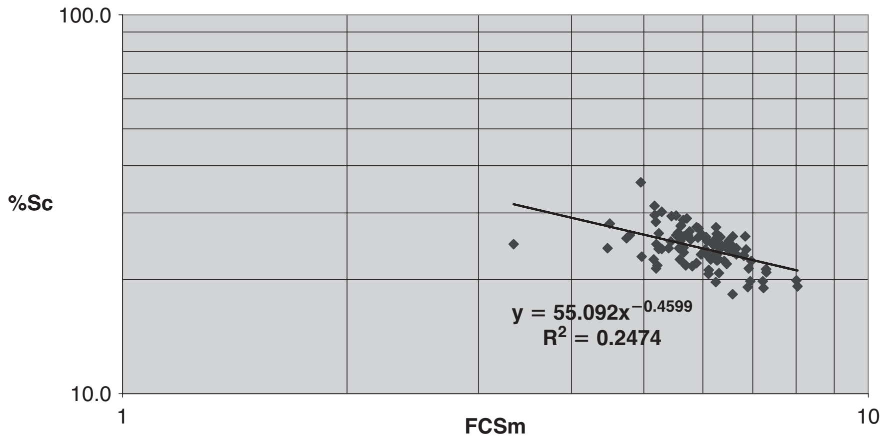

FIG. 19. Correlation of the relative number of self-citations (*%Sc*) per university with the field citation density (*FCSm*) of these universities, for all 100 largest European universities.

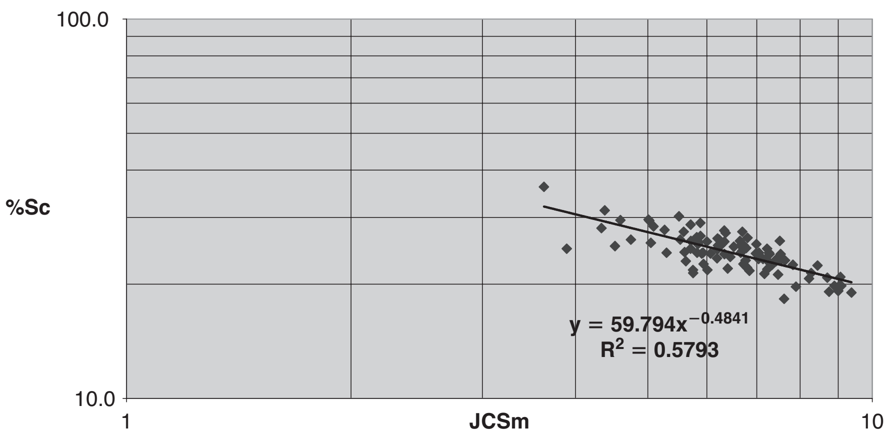

FIG. 20. Correlation of the relative number of self-citations (*%Sc*) per university with the average journal impact (*JCSm*) of these universities, for all 100 largest European universities.

work a similar scaling rule at the level of research groups and therefore we conjecture that this scaling rule is a prevalent property of the science system. We also observe that the top universities are about twice as efficient in receiving citations (*C*) as compared to the bottom performance universities. Our criterion of top or low performance is based on the field-normalized indicator *CPP/FCSm*. We hypothesize that in network terms this indicator represents the "fitness" of a university as a node in the science system. It brings a university in a better position to acquire additional links (in terms of citations) based on quality (high performance).

Second, we find that for the lower performance universities the fraction of noncited publications decreases with size. We explain this phenomenon with a model in which size is advantageous in an "internal promotion mechanism" to get more publications cited. Thus, in this model size is a distinctive parameter, which acts as a bridge between the macro-picture (characteristics of the entire set of universities) and the micro-picture (characteristics within a university). We find that the higher the average journal impact of a university, the lower the number of noncited publications. In addition, the higher the average number of citations per publication in a university, the lower the number of noncited publications. In other words, universities that are cited more per article also have more cited articles.

Third, we find that the average research performance of university measured by our crown indicator *CPP/FCSm* does not dilute with increasing size. Apparently, large universities, particularly the top performance universities are characterized by being "big and beautiful." In other words, they succeed in keeping a high performance over a broad range of activities. This is an indication of their overall scientific and intellectual attractive power.

Fourth, we observe that particularly the low field citation density and the low journal impact universities have a considerably size-dependent cumulative advantage for the total number of citations. We find that particularly for the lower performance universities the field citation density (*FCSm*) provides a strong cumulative advantage in citations per publication (*CPP*). We also observe clearly that most top performance universities publish in journals with significantly higher journal impact as compared to the lower performance universities. Moreover, the top universities perform in terms of citations per publications (*CPP*) with a factor of about 1.3

DOI: 10.1002/asi

better than the bottom universities in journals with the same average impact. The relation between number of citations and field citation density found in this study can be considered as a second basic scaling rule of the science system.

Fifth, we find a significant decrease of the fraction of self-citations as a function of research performance *CPP/FCSm*, of the average field citation density *FCSm*, of the average journal impact *JCSm*, and of the field-normalized journal impact *JCSm/FCSm*.

We conclude our article with several science policy-related observations and recommendations. Our target group consists of the 100 largest European research universities. This set of universities is the result of a study on the scientific strengths of the EU and its member states. Essential elements of this EU study are the accurate definition and unification of universities worldwide and the corrections for practically all errors and inconsistencies in the raw publication and citation data (van Raan 2006c, Moed 2006). Based on this study, we are currently developing a new ranking system entirely based on its own bibliometric indicators. The first results for European universities are published on our Web site (CWTS, 2007). This Leiden Ranking covers all universities worldwide with more than 5,000 CI-indexed publications. This implies that the 400 largest (in terms of number of publications) universities in the world are covered, and that our bibliometric analysis is based on the scientific output of at least 600 active researchers in each of these universities.

A crucial policy-relevant issue that also becomes clear in this article is that based on the same data and the same technical and methodological starting points, different types of impact-indicators can be constructed, for instance, one focusing entirely on impact, and another in which scale (size of the institution) is taken in to account. Rankings based on these different indicators are not the same, although they originate from exactly the same data. The Leiden Ranking consists of four lists: (a) ranking by size, i.e., number of publications (*P*); (b) ranking by average number of citations per publication (CPP); (c) ranking by the size-independent, field-normalized average impact (our crown indicator *CPP/FCSm*); and (d) ranking by the size-dependent "brute force" impact indicator, the multiplication of *P* with the university's field-normalized average impact (*P*CPP/FCSm*). Moreover, rankings are strongly influenced by the size-threshold used to define the set of universities for which the ranking is calculated. This is very clearly illustrated by comparison of the top 100 versus the top 50 European universities in our Leiden Ranking.

In our current ranking work, we found a quite surprising phenomenon (van Raan, 2006c): it appears clearly that the group of outstanding universities will not be much larger than around 200 members. Most of the top universities are large, broad-based, research universities. Based on their reputation, they have attracted the best students and scientists. These universities are the "natural attractors" in the world of science, and, apparently, around 200 of these institutions are able to acquire and hold onto the vast majority of top scientists. After ranking position 200 or so, there will certainly be smaller universities with excellent research in specific fields of science. There is, however, not much room anymore for further "power houses of science" because of the limited availability of excellent scientists.

Returning to the results presented in this article, we observe that similar scaling rules as found at the level of research groups are also working at the level of entire universities. Clearly, the scaling rule is a prevalent property of the science system. Large, internationally successful universities of high reputation are characterized at the same time by a high number of publications, a strong capacity to acquire funding, and intellectual and financial attractiveness for the best scholars who publish in higher impact publications. This all works out in mutually reinforcing forces, resulting in disproportionately increasing impact. We are currently extending our analysis to the 400 largest universities worldwide.

Acknowledgments

The author would like to thank his CWTS colleagues, Henk Moed and Clara Calero for the work to define and to delineate the universities, and for the data collection, data analysis, and calculation of the bibliometric indicators.

References

Centre for Science and Technology Studies (CWTS). (2007). The Leiden Ranking, Centre for Science and Technology Studies (CWTS), Leiden University. Retrieved March 23, 2007 from http://www.cwts.nl/cwts/LeidenRankingWebSite.html

Katz, J.S. (1999). The self-similar science system. Research Policy, 28, 501–517.

League of European Research Universities (LERU). (2007). League of European Research Universities home page. Retrieved March 23, 2007 from http://www.leru.org/

Merton, R.K. (1968). The Matthew effect in science. Science, 159, 56–63.

Merton, R.K. (1988). The Matthew effect in science, II: Cumulative advantage and the symbolism of intellectual property. Isis, 79, 606–623.

Moed, H.F. (2006) Bibliometric rankings of world universities. Retrieved March 23, 2007 from http://www.cwts.nl/hm/bibl_rnk_wrld_univ_full.pdf

van Raan, A.F.J. (1996). Advanced bibliometric methods as quantitative core of peer review based evaluation and foresight exercises. Scientometrics, 36, 397–420.

van Raan, A.F.J. (2004). Measuring science. Capita selecta of current main issues. In: H.F. Moed, W. Glänzel, & U. Schmoch (Eds.). Handbook of quantitative science and technology research (pp. 19–50). Dordrecht: Kluwer.

van Raan, A.F.J. (2005a). Fatal attraction: Conceptual and methodological problems in the ranking of universities by bibliometric methods. Scientometrics, 62, 133–143.

van Raan, A.F.J. (2005b). Measurement of central aspects of scientific research: Performance, interdisciplinarity, structure. Measurement, 3, 1–19.

van Raan, A.F.J. (2006a). Statistical properties of bibliometric indicators: Research group indicator distributions and correlations. Journal of the American Society for Information Science and Technology, 57, 408–430.

van Raan, A.F.J. (2006b). Performance-related differences of bibliometric statistical properties of research groups: Cumulative advantages and hierarchically layered networks. Journal of the American Society for Information Science and Technology, 57, 1919–1935.

van Raan, A.F.J. (2006c). Challenges in the ranking of universities. In J. Sadlak & N. Cai Liu (Eds.), The world-class university and ranking: Aiming beyond status (pp. 81–123). Bucharest: UNESCO-CEPES.

van Raan, A.F.J. (2007). Scaling rules in the science system: Influence of field-specific citation characteristics on the impact of research groups. Journal of the American Society for Information Science and Technology, accepted for publication.

DOI: 10.1002/asi

Seglen, P.O. (1992). The skewness of science. Journal of the American Society for Information Science, 43, 628–638.

Seglen, P.O. (1994). Causal relationship between article citedness and journal impact. Journal of the American Society for Information Science, 45, 1–11.

Shanghai Jiao Tong University (SJTU). (2006). Academic ranking of world universities 2006. Shanghai: Shanghai Jiao Tong University. Retrieved March 22, 2007 from http://ed.sjtu.edu.cn/ranking.htm

Times Higher Education Supplement (THES). (2006). The Times Higher World University Rankings 2006. Retrieved March 22, 2007 from http://www.thes.co.uk/worldrankings/

Warton, D.I., Wright, I.J., Falster, D.S., & Westoby, M. (2006). Bivariate line-fitting methods for allometry. Biological Reviews 81, 259–291.

Appendix

In italics, we indicate two outliers as discussed in the Impact Scaling and Research Performance subsection.

	University		*P*	*C*	*CPP*	*Pnc*	*CPP/FCSm*
85	UNIV GRENOBLE I JOSEPH FOURIER	FR	*9.851*	61.890	6,28	33,3	1,13
86	UNIV BASEL	CH	*9.761*	102.592	10,51	26,6	1,44
87	*NATL & KAPODISTRIAN UNIV ATHENS*	*EL*	*9.733*	***36.458***	*3,75*	*42,1*	*0,69*
88	HEINRICH HEINE UNIV DUSSELDORF	DE	*9.631*	79.327	8,24	27,8	1,13
89	UNIV LAUSANNE	CH	*9.607*	104.735	10,90	26,7	1,51
90	UNIV MARBURG	DE	*9.564*	66.132	6,91	31,3	1,05
91	UNIV LEIPZIG	DE	*9.468*	40.659	4,29	39,7	0,83
92	UNIV DUISBURG ESSEN	DE	*9.443*	55.492	5,88	35,6	1,04
93	*CHARLES UNIV PRAGUE*	*CZ*	*9.372*	*29.232*	*3,12*	*48,7*	*0,63*
94	UNIV ULM	DE	*9.318*	64.413	6,91	30,4	1,07
95	UNIV GENOVA	IT	*9.286*	51.334	5,53	38,8	0,94

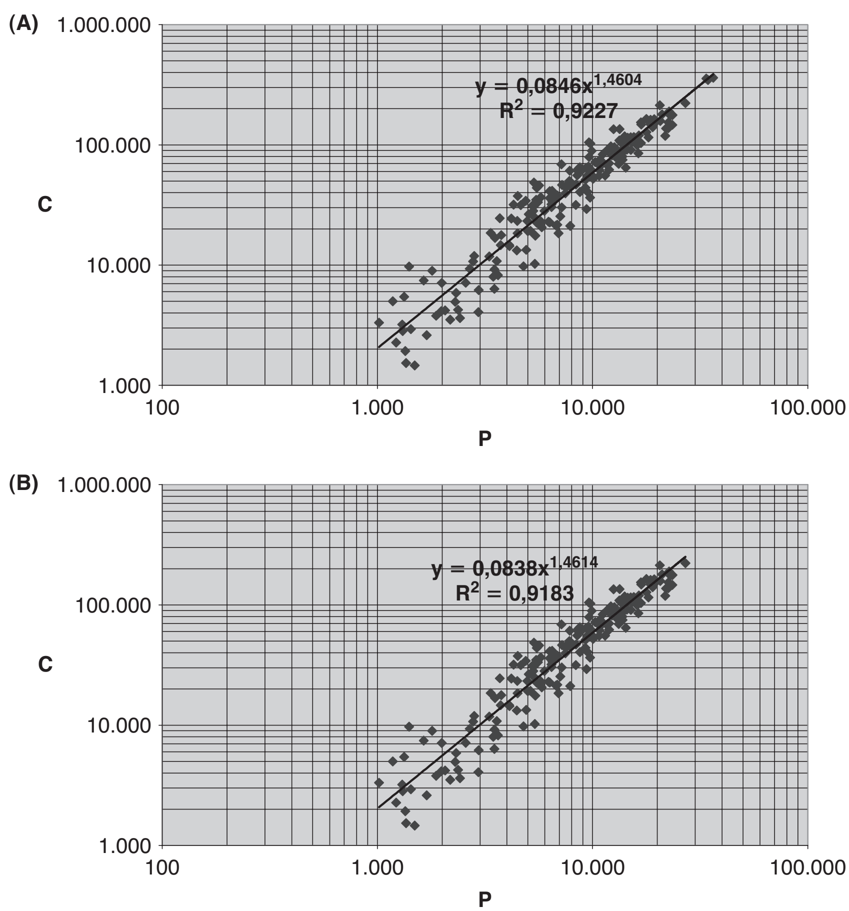

FIG. A1. Correlation of the number of citations (*C*) received per university with the number of publications (*P*) of these universities for the extended set of the 200 largest European universities with (A) and without (B) the top three universities.

DOI: 10.1002/asi