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# A methodology for Institution-Field ranking based on a bidimensional analysis: the $IFQ^2A$ index

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**Abstract** The problem of comparing academic institutions in terms of their research production is nowadays a priority issue. This paper proposes a relative bidimensional index that takes into account both the net production and the quality of it, as an attempt to provide a comprehensive and objective way to compare the research output of different institutions in a specific field, using journal contributions and citations. The proposed index is then applied, as a case study, to rank the top Spanish universities in the fields of Chemistry and Computer Science in the period ranging from 2000 until 2009. A comparison with the top 50 universities in the ARWU rankings is also made, showing the proposed ranking is better suited to distinguish among non-elite universities.

**Keywords** rankings · universities · higher education · bibliometrics · Shanghai ranking · bidimensional analysis · evaluation models · research performance assessment · h-index

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## 1 Introduction

There is an increasingly pressing demand for an objective way to measure the research output in terms of quantity and quality of different scientific agents [15,17]. The analysis and comparison of research output, whether it is among individuals or institutions, is a topic that has been raising an increasing amount of interest in the last few years. Most bibliometric studies focus on citations, tracking back to Price's original work in 1965 [26].

There are two main branches in academic ranking studies, the first of which tries to compare individual researchers productions and those that analyze institutions. In the first one, one of the most influential proposals is the h-index by Hirsch [20], which has been subject of multiple extensions and corrections [10]. Other individual researcher indices have also been proposed extending the h-index, such as the g-index [19], $q^2$-index [16], and others [14,21].

The relevance of these rankings lays, for the most part, in the help it provides to allocate limited funds as fairly as possible. However, funding agencies often make their decisions based on partial or biased measures, resulting in unfair assessments of the production of some of the studied institutions. The research output of academic institutions is mostly meaningless in a vacuum, the interesting issue lays in the comparison between several institutions, often resulting in their ranking. There have been a number of proposals for this purpose [18,30], and according to Buela-Casal et al. [15], 'there is a growing international convergence on the measurement of academic quality based primarily on research and production and on academic reputation'. Some of these rankings deal with worldwide universities, and they are mainly focused on the results and impact of research, which is why bibliometric indicators have a high importance in their composition. The most notable among them include:

- Academic Rankings of World Universities (ARWU) [27]. Provides a series of metrics and also an aggregation measure for them, resulting in a global ranking.
- Scimago Institutions Rankings (SIR) [2]. Based upon the Scopus database [3], it provides world and iberoamerican institutions rankings using differences indicators such as raw production, % of papers published in top quartile journals or normalized citation impact.
- Leiden rankings [5]. Ranks universities according to measures that are size-independent and normalized by the importance of each field (crown indicators). It has also been used to compare research group productions' [25].
- QS World University Rankings [4]. Provides both a general rank and also a field-by-field analysis. Quite different from the others due to its employment of a number of non-bibliometric measures.

The previously mentioned rankings all provide a global analysis of universities; but some of them also study each subject field independently. The ARWU field rankings are probably the better known studies in this line.

These types of issues and the different rankings derived [7] have provoked some controversy around university rankings. Adler and Harzing claim that it is neccesary to have 'an immediate examination of existing ratings systems, not only as a legitimate scholarly question vis a vis performance − a conceptual lens with deep roots in management research − but also because the very health and vibrancy of the field are at stake' [6]. They are worried about how the current system rewards

raw production rather than 'scholarship that addresses the questions that matter most to society'.

Due to the importance of studying each subject field separately; as most rankings focus on top universities using elitist indicators, and because of the concerns expressed by some authors in regard with the inadequacy of most bibliometric indicators when applied to smaller size institutions [28]; a new methodology is needed. Said methodology should take into account these factors in order to create rankings that allow the comparison between universities that cannot reach tops 100, 250 or 500 worldwide, and do so in a given subject field.

This contribution presents a bidimensional quantitative-qualitative index to compare the research output of a group of institutions in a given field (what we call Institution-Field).

- The quantitative dimension shows the net production of an Institution-Field during a period of time by using raw indicators that may be correlated with staff of the institution.
- The qualitative dimension (which can be seen as a measurement for academic excellence) focuses on the ratio of high-quality production on each Institution-Field during the same period of time, and is mostly independent of the size of the institution.

A combination of both dimensions provides a robust and objective way to compare research outputs. We have named this measure the Institution-Field Quantitative and Qualitative Analysis index ($IFQ^2A$ index).

This paper is organized as follows: In section 2 the proposed indicator is described. Section 3 includes a case study with data from Spanish universities in the fields of Chemistry and Computer Science, along with Principal Component and correlation analysis among the indicators that compose the $IFQ^2A$ index, and a comparison with the ARWU ranking. Lastly, some concluding remarks are made in section 4.

## 2 Methodology: The $IFQ^2A$ index

This section is divided as follows: in subsection 2.1, the proposed index is explained and justified, while the procedure to obtain the data is presented in subsection 2.2.

### 2.1 Definition and mathematical conceptualization of the $IFQ^2A$ index

Focusing on the idea of ranking a set of universities by their research output in a given field, we propose a new ranking that:

- Does not take into account elitist measures such as Nobel, Turing or Fields medals awards obtained by alumni, since these type of indicators only favor elite universities and make it harder to differentiate between the rest.
- Provides an aggregated ranking that makes it easier for decision makers to analyze where each university is ranked within its context.
- Takes into account the relative size of the university by providing a bidimensional quantitative-qualitative index, to avoid giving an unfair advantage to bigger institutions.

The $IFQ^2A$ index can be formally defined as a bidimensional bibliometric measure to compare and rank different institutions according to their research output and impact in a given field. The indicators considered in both dimensions correspond to:

- QuaNtitative Institution-Field index ($QNIF$), based on raw number of publications, citations and h-index [20].
- QuaLitative Institution-Field index ($QLIF$), based on relative measures of impact and visibility, i.e. JCR journal first quartile, average citations and ratio of highly cited papers. The "qualitative" denomination is linked to academic excellence in this work.

We have used six bibliometric indicators to compute the two partial indices $QNIF$ and $QLIF$, detailed in Table 1.

**Table 1** Bibliometric measures used to calculate $QNIF$ and $QLIF$

| Code | Measure | Character | Dimension | Description |
|---|---|---|---|---|
| I1 | NDOC | Quantitative | Output | Raw number of citable papers published in scientific journals: articles, reviews letters, notes or proceeding papers |
| I2 | NCIT | Quantitative | Observed impact | Number of citations received by all citable papers |
| I3 | H-index | Quantitative | Observed impact | h-index, as proposed by Hirsch, over all the publications of the institution. |
| I4 | %1Q | Qualitative | Journal quality | Ratio of papers published in journals in the top JCR quartile ($\frac{100*N1Q}{NDOC}$) |
| I5 | ACIT | Qualitative | Observed impact | Average number of citations received by all citable papers |
| I6 | TOPCIT | Qualitative | Observed impact | Ratio of papers that belong to the top 10% most cited (highly cited)[1] |

A brief justification for the chosen measures follows:

- NDOC: Basic indicator for total amount of raw production, it may depend on the number of researchers in the institution focused on the field of study, and how active they are.
- NCIT, ACIT, TOPCIT: According to Bornmann and Daniel [13], 'In bibliometrics the resonance, or impact, of a scientific work is measured via the number of citations. It can be assumed that the more important a work is for the further development of a field, the more frequently it is cited.' That is, NCIT is a raw indicator of scientific relevance, and ACIT and TOPCIT indicate quality of the research output and ratio of very high-quality papers [8,9], respectively.
- H-index: Probably the better known index in current bibliometrics, it has proven to be a robust measure of impact. By limiting its scope to the period of study, we avoid the seniority dependence the basic h-index usually presents.

[1] The top 10% most cited papers are calculated within the group of interest. For example, if the institutions in the study have published 194821 papers, a paper is considered highly cited if it is among the 19482 most cited.

– %1Q: The impact factor is widely considered a reliable measure of journal quality [12], so centering the analysis in the top quartile provides an indicator of top-quality papers. The ratio of citable papers that are top-quality serves as a relative size-independent indicator, %1Q.

These measures are normalized in $[0, 1]$, setting the highest value to 1, and the rest proportionally.

$QNIF$ and $QLIF$ are respectively calculated as

$$QNIF = \sqrt[3]{I1 \times I2 \times I3} \tag{1}$$

$$QLIF = \sqrt[3]{I4 \times I5 \times I6} \tag{2}$$

We can define an index that aggregates the two previous ones as a hypervolume measure (the surface area associated to both indices, the area under the position in the map):

$$IFQ^2A = QNIF \times QLIF \tag{3}$$

This approach provides a high interpretability, since the index can be shown in a 2-dimensional graph where the end user can easily identify the relative ranking of the institutions both in terms of raw production and quality of production.

A summary of the procedure to calculate the $IFQ^2A$ index over a set of Institution-Fields can be found in Algorithm 1.

**Algorithm 1** $IFQ^2A$ index calculation procedure

1. Obtain measures I1,...,I6 for the period of interest from the ISI Web of Science.
2. Normalize measures I1,...,I6 in $[0, 1]$, setting the maximum to 1 and the rest proportionally.
3. Calculate $QNIF$ and $QLIF$ from the normalized values applying equations 1 and 2.
4. Calculate $IFQ^2A$ from $QNIF$ and $QLIF$ applying equation 3.

## 2.2 Information processing

First, the set of universities and knowledge field of interest need to be chosen, along with a period of time. Once they are decided, the data is downloaded. The research output of each university indexed in the Science Citation Index of the ISI-Web of Knowledge [1], using the field "Address" as a filter and taking into account all the different names each university receives. Next, the production of each of the universities within the field of interest is extracted. A scientific work is considered to be part of the field if it was published in a journal indexed in one of the eight JCR journal categories in Table 2. In order to calculate the indicators related to journal Impact Factor, the editions of the JCRs for the period of time of interest should be used.

Once the data is compiled into a relational database, the indicators defined in Table 1 are computed, and the $IFQ^2A$ index for each university is calculated according to Algorithm 1.

With the goal of comparing the results obtained by the proposed indicator against those in existing rankings, the $IFQ^2A$ index was also calculated for the

universities included in the top 50 of the ARWU-subject ranking 2010 in the fields of Chemistry and Computer Science[27]. The ARWU ranking was chosen since it is the only one among the research-oriented rankings that provides per-field classifications. The indicators were calculated as described above, with the only difference being the period of study, 2005-2009 in this case. Finally, the correlation between the $IFQ^2A$ index and the ARWU-subject ranking was studied and the difference in university positioning analyzed.

## 3 Case study

This section is divided as follows: Subsection 3.1 defines the specific domain for an example study to showcase the application of the $IFQ^2A$ index: the set of all Spanish universities in the fields of Chemistry and Computer Science. In subsection 3.2, an analysis of the aggregations among indicators and partial indices is presented, based on principal component analysis and Pearson correlations. Subsection 3.3 presents the results of the application of the $IFQ^2A$ index to the case study. Lastly, an analysis of the similarities and differences between the $IFQ^2A$ index and the ARWU-subject rankings is shown in subsection 3.4.

### 3.1 Spanish universities in the fields of Chemistry and Computer Science

For the validation and practical application example of the $IFQ^2A$ index, the fields of Chemistry and Computer Science, and the set including all Spanish universities were chosen. The field of Chemistry was chosen due to being one of the best represented within Thomson Reuters' databases [24], with 640 JCR journals. Computer Science was selected because it is a well-defined one with 535 Journal Citation Reports (JCR) journals; but also one where a relevant part of the production is not represented within said databases; thus providing a measure of the stability of the index. Two different fields were selected to obtain a broader picture of the usefulness of the proposed index, along with its stability. The choice of Spanish universities was due to them being underrepresented in the main worldwide rankings. Once the framework of study was fixed, the period ranging from 2000 until 2009 was chosen as the period of study.

**Table 2** Thomsom Reuters - JCR Chemistry and Computer Science categories

| **Field: Chemistry** | **Field: Computer Science** |
|---|---|
| Chemistry, Analytical | Computer Science, Artificial Intelligence |
| Chemistry, Applied | Computer Science, Cybernetics |
| Chemistry, Inorganic & Nuclear | Computer Science, Information Systems |
| Chemistry, Medicinal | Computer Science, Interdisciplinary Applications |
| Chemistry, Multidisciplinary | Computer Science, Hardware & Architecture |
| Chemistry, Organic | Computer Science, Software Engineering |
| Chemistry, Physical | Computer Science, Theory & Methods |
| Electrochemistry | Imaging Science & Photographic Technology |
| Polymer Science | |

### 3.2 Principal Component and Correlation analysis for the validation of the $IFQ^2A$ index

To validate the grouping of indicators that make up the $QNIF$ and $QLIF$ indices, we first performed a Principal Component Analysis (PCA) over the data obtained for the set of Spanish universities in the fields of Chemistry and Computer Science. The results of this analysis are shown in Table 3; and suggest that data can be reduced to a bidimensional representation where the first dimension is composed of NDOC, NCIT and H (which corresponds to $QNIF$); and the second one is composed of %1Q, ACIT and TOPCIT ($QLIF$).

**Table 3** PCA of the six bibliometric indicators used to compute the $IFQ^2A$ index.

| Chemistry | $QNIF$ | $QLIF$ |
|---|---|---|
| NDOC | 1.042 | |
| NCIT | 0.990 | |
| H | 0.870 | |
| %1Q | | 0.789 |
| ACIT | | 0.877 |
| TOPCIT | | 0.897 |

| Computer Science | $QNIF$ | $QLIF$ |
|---|---|---|
| NDOC | 1.035 | |
| NCIT | 0.944 | |
| H | 0.843 | |
| %1Q | | 0.941 |
| ACIT | | 0.784 |
| TOPCIT | | 0.859 |

Values lower than absolute 0.300 omitted

The correlations between each single bibliometric indicator are shown in Table 4, obtained from the universities analyzed. There are correlations within the quantitative indicators (NDOC, NCIT, and H), and also, but to a lesser degree, within the qualitative ones (%1Q, ACIT and TOPCIT). What is more interesting is that the correlations among crossed indicators (a quantitative indicator with a qualitative one) are in general very low, with ACIT and H being the highest one at 0.6810 in Chemistry. We consider this correlation low enough to conclude that the $QNIF$ and $QLIF$ indices are composed of indicators that describe different information.

Regarding the correlation between the $QNIF$ and $QLIF$ index, Table 5 shows how they correlate against each other, and also against each of the individual bibliometric indicators in Table 1. Both $QNIF$ and $QLIF$ correlate strongly with the indicators that compose them (which shows they manage to synthetize the information of three indicators each); but the correlation between them ($QNIF$ against $QLIF$) is extremely low, indicating they are independent and thus the $IFQ^2A$ index is a truly bidimensional measure.

Judging by these results, it would seem justifiable to substitute the 6 original indicators for the 2 constructed variables obtained from PCA. The main limitation of this approach would be the loss of interpretability of the rankings for decision

**Table 4** Correlation analysis among basic indicators. Data from the top 75% Spanish universities in 2000-2009

| Chemistry | NDOC | NCIT | H | %1Q | ACIT | TOPCIT |
|---|---|---|---|---|---|---|
| NDOC | 1 | 0.9840 | 0.8950 | 0.1670 | 0.3800 | 0.3430 |
| NCIT | | 1 | 0.9390 | 0.2200 | 0.5090 | 0.4750 |
| H | | | 1 | 0.2340 | 0.6810 | 0.6290 |
| %1Q | | | | 1 | 0.4260 | 0.4230 |
| ACIT | | | | | 1 | 0.9440 |
| TOPCIT | | | | | | 1 |
| | | | | | | |
| Computer Science | NDOC | NCIT | H | %1Q | ACIT | TOPCIT |
| NDOC | 1 | 0.8986 | 0.8122 | -0.0669 | 0.1845 | 0.1750 |
| NCIT | | 1 | 0.8721 | 0.1637 | 0.5394 | 0.4097 |
| H | | | 1 | 0.2901 | 0.5089 | 0.6608 |
| %1Q | | | | 1 | 0.5724 | 0.6722 |
| ACIT | | | | | 1 | 0.6819 |
| TOPCIT | | | | | | 1 |

**Table 5** Correlation analysis of $QNIF$ and $QLIF$ against the basic indicators. Data from the top 75% Spanish universities in 2000-2009

| Chemistry | NDOC | NCIT | H | %1Q | ACIT | TOPCIT | $QNIF$ | $QLIF$ |
|---|---|---|---|---|---|---|---|---|
| $QNIF$ | **0.988** | **0.994** | **0.952** | 0.205 | 0.498 | 0.453 | 1.000 | 0.470 |
| $QLIF$ | 0.362 | 0.489 | 0.635 | **0.604** | **0.954** | **0.971** | 0.470 | 1.000 |
| | | | | | | | | |
| Computer Science | NDOC | NCIT | H | %1Q | ACIT | TOPCIT | $QNIF$ | $QLIF$ |
| $QNIF$ | **0.959** | **0.972** | **0.923** | 0.099 | 0.414 | 0.394 | 1.000 | 0.368 |
| $QLIF$ | 0.133 | 0.440 | 0.582 | **0.836** | **0.863** | **0.914** | 0.368 | 1.000 |

makers, since measures I1,...,I6 are easily understandable while artificially constructed variables would be much harder to understand. For this reason, we believe keeping all 6 indicators and obtaining the bidimensional ranking by aggregating them is a better solution.

### 3.3 Ranking of the Spanish universities in Chemistry according to the $IFQ^2A$ index

This subsection shows the $IFQ^2A$ index rankings for the top Spanish universities in Chemistry. As an example, Table 6 shows the raw values of the six bibliometric indicators along with the normalized ones for each university. Only the top 20 universities are shown due to space concerns.

Table 7 and Figure 1 show the results for the partial quantitative index $QNIF$, the qualitative one $QLIF$ and also for the $IFQ^2A$ index which determines the rankings, for all the universities studied. It is remarkable how the $IFQ^2A$ index achieves a balance between quantity and quality of production, shown as an example in a university that can achieve a high ranking with a small research output if said output is high-quality; the *Universitat Politècnica de València.*

**Table 6** Raw and normalized bibliometric measures for the top 20 Spanish universities in Chemistry (2000-2009)

| | Raw bibliometric measures | | | | | | Normalized bibliometric measures | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quantitative | | | Qualitative | | | Quantitative | | | Qualitative | | |
| Institution | I1 | I2 | I3 | I4 | I5 | I6 | I1 | I2 | I3 | I4 | I5 | I6 |
| Barcelona | 4210 | 57742 | 77 | 0.594 | 13.715 | 0.127 | 1.000 | 1.000 | 1.000 | 0.856 | 0.822 | 0.802 |
| Valencia | 3334 | 44194 | 67 | 0.573 | 13.256 | 0.118 | 0.792 | 0.765 | 0.87 | 0.825 | 0.794 | 0.745 |
| Polit. Valencia | 1665 | 27116 | 64 | 0.651 | 16.286 | 0.148 | 0.395 | 0.47 | 0.831 | 0.938 | 0.976 | 0.931 |
| Complutense | 2679 | 32941 | 62 | 0.528 | 12.296 | 0.111 | 0.636 | 0.57 | 0.805 | 0.76 | 0.737 | 0.699 |
| Aut. Madrid | 1943 | 28476 | 64 | 0.562 | 14.656 | 0.132 | 0.462 | 0.493 | 0.831 | 0.809 | 0.878 | 0.833 |
| Zaragoza | 1942 | 24606 | 52 | 0.607 | 12.67 | 0.119 | 0.461 | 0.426 | 0.675 | 0.874 | 0.759 | 0.749 |
| País Vasco | 2302 | 26793 | 59 | 0.527 | 11.639 | 0.095 | 0.547 | 0.464 | 0.766 | 0.759 | 0.697 | 0.597 |
| Santiago Compostela | 2651 | 30541 | 55 | 0.476 | 11.521 | 0.085 | 0.63 | 0.529 | 0.714 | 0.685 | 0.69 | 0.537 |
| Alicante | 1263 | 20654 | 62 | 0.511 | 16.353 | 0.143 | 0.3 | 0.358 | 0.805 | 0.737 | 0.98 | 0.903 |
| Aut. Barcelona | 2001 | 23449 | 51 | 0.6 | 11.719 | 0.095 | 0.475 | 0.406 | 0.662 | 0.864 | 0.702 | 0.598 |
| Oviedo | 1717 | 20704 | 47 | 0.683 | 12.058 | 0.097 | 0.408 | 0.359 | 0.61 | 0.984 | 0.722 | 0.613 |
| Rovira i Virgili | 1242 | 16933 | 53 | 0.647 | 13.634 | 0.134 | 0.295 | 0.293 | 0.688 | 0.931 | 0.817 | 0.842 |
| Jaume I Cast. | 838 | 13989 | 48 | 0.617 | 16.693 | 0.159 | 0.199 | 0.242 | 0.623 | 0.888 | 1.000 | 1.000 |
| Sevilla | 1506 | 15747 | 44 | 0.533 | 10.456 | 0.082 | 0.358 | 0.273 | 0.571 | 0.767 | 0.626 | 0.515 |
| Vigo | 1441 | 17153 | 51 | 0.38 | 11.904 | 0.083 | 0.342 | 0.297 | 0.662 | 0.548 | 0.713 | 0.52 |
| Granada | 1470 | 15604 | 45 | 0.49 | 10.615 | 0.076 | 0.349 | 0.27 | 0.584 | 0.705 | 0.636 | 0.476 |
| Murcia | 906 | 10180 | 39 | 0.613 | 11.236 | 0.086 | 0.215 | 0.176 | 0.506 | 0.882 | 0.673 | 0.542 |
| Córdoba | 1099 | 10641 | 35 | 0.67 | 9.682 | 0.058 | 0.261 | 0.184 | 0.455 | 0.964 | 0.58 | 0.367 |
| La Laguna | 869 | 9571 | 39 | 0.501 | 11.014 | 0.085 | 0.206 | 0.166 | 0.506 | 0.721 | 0.66 | 0.537 |
| Girona | 699 | 8674 | 38 | 0.522 | 12.409 | 0.1 | 0.166 | 0.15 | 0.494 | 0.752 | 0.743 | 0.631 |

**Table 7** Ranking of the top Spanish Universities in the field of Chemistry during the period 2000-2009 according to the $IFQ^2A$ index

| Institution | $QNIF$ | $QLIF$ | $IFQ^2A$ | Rank |
|---|---|---|---|---|
| Barcelona | 1 | 0.826 | 0.826 | 1 |
| Valencia | 0.808 | 0.787 | 0.636 | 2 |
| Polit. Valencia | 0.536 | 0.948 | 0.508 | 3 |
| Complutense | 0.664 | 0.731 | 0.485 | 4 |
| Aut. Madrid | 0.574 | 0.839 | 0.482 | 5 |
| Zaragoza | 0.51 | 0.792 | 0.404 | 6 |
| País Vasco | 0.579 | 0.681 | 0.394 | 7 |
| Santiago Compostela | 0.62 | 0.633 | 0.392 | 8 |
| Alicante | 0.442 | 0.867 | 0.383 | 9 |
| Aut. Barcelona | 0.504 | 0.713 | 0.359 | 10 |
| Oviedo | 0.447 | 0.758 | 0.339 | 11 |
| Rovira i Virgili | 0.391 | 0.862 | 0.337 | 12 |
| Jaume I Cast. | 0.311 | 0.961 | 0.299 | 13 |
| Sevilla | 0.382 | 0.628 | 0.24 | 14 |
| Vigo | 0.407 | 0.588 | 0.239 | 15 |
| Granada | 0.381 | 0.598 | 0.227 | 16 |
| Murcia | 0.268 | 0.685 | 0.184 | 17 |
| Córdoba | 0.28 | 0.59 | 0.165 | 18 |
| La Laguna | 0.259 | 0.634 | 0.164 | 19 |
| Girona | 0.231 | 0.707 | 0.163 | 20 |
| Castilla la Mancha | 0.261 | 0.62 | 0.162 | 21 |

| Institution | $QNIF$ | $QLIF$ | $IFQ^2A$ | Rank |
|---|---|---|---|---|
| Valladolid | 0.273 | 0.546 | 0.149 | 22 |
| Almería | 0.191 | 0.722 | 0.137 | 23 |
| Salamanca | 0.227 | 0.6 | 0.136 | 24 |
| Málaga | 0.216 | 0.629 | 0.136 | 25 |
| Islas Baleares | 0.165 | 0.791 | 0.13 | 26 |
| A Coruña | 0.211 | 0.582 | 0.123 | 27 |
| Cádiz | 0.17 | 0.596 | 0.101 | 28 |
| Polit. Catalunya | 0.23 | 0.44 | 0.101 | 29 |
| Alcalá Henares | 0.184 | 0.505 | 0.093 | 30 |
| UNED | 0.152 | 0.608 | 0.092 | 31 |
| Extremadura | 0.185 | 0.489 | 0.09 | 32 |
| La Rioja | 0.121 | 0.715 | 0.086 | 33 |
| Burgos | 0.146 | 0.553 | 0.081 | 34 |
| Pública Navarra | 0.094 | 0.852 | 0.08 | 35 |
| Huelva | 0.102 | 0.769 | 0.079 | 36 |
| Navarra | 0.111 | 0.575 | 0.064 | 37 |
| Lleida | 0.089 | 0.677 | 0.06 | 38 |
| Jaén | 0.13 | 0.412 | 0.054 | 39 |
| Polit. Madrid | 0.107 | 0.477 | 0.051 | 40 |
| Miguel Hernández | 0.069 | 0.472 | 0.032 | 41 |
| | | | | |

The situation described above is well represented in Figure 1, where we can place each university in a quadrant. That way, the top right area includes the high-production universities with high-quality research, the bottom right shows the high-production ones with a lower impact, top left includes small but high-impact universities and finally bottom left those that do not stand out in any of the dimensions.

### 3.4 Comparing with the ARWU-subject ranking for Chemistry and Computer Science

This subsection includes a comparison between the $IFQ^2A$ index and the ARWU-subject rankings for the fields of Chemistry and Computer Science. To do so, the $IFQ^2A$ index was calculated for the universities in the top 50 of the ARWU-subject ranking of Computer Science in 2010. A summary of the results is presented in Tables 8 and 9 for Chemistry and CS respectively (see http://www.rankinguniversidades.es/ARWU_Comparison.xls for the values of the bibliometric indicators). Both rankings are fairly different,

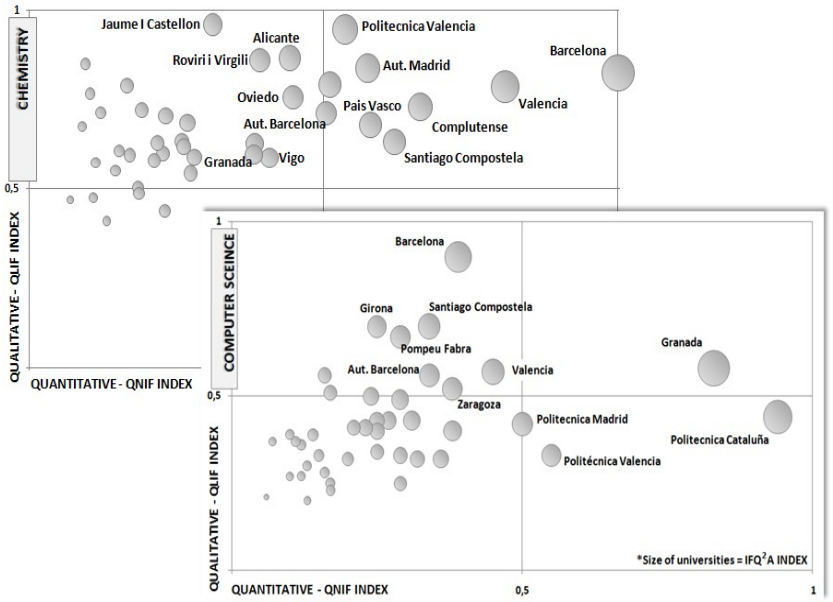


**Fig. 1** Bidimensional mappings for Chemistry and Computer Science, top Spanish universities during 2000-2009 ranked by the $IFQ^2A$ index.

with the average correlation between total scores being 0.648 and 0.628 in ranks in the field of Chemistry, and 0.757 for scores, 0.630 between ranks in Computer Science.

The main difference in the rankings appears in universities with low or no score in the Alumni, Award or HiCi indicators, since they include a different information from the one used to compose the $IFQ^2A$ index. For example, the rank given in the field of Computer Science to institutions like Harvard University, California Institute of Technology (Caltech) o Swiss Federal Institute of Technology is significantly better in $IFQ^2A$ index than in ARWU. On the other hand, institutions with a mid-level production but high scores in Alumni, Award or HiCi are ranked higher in ARWU than in $IFQ^2A$ index rankings, such as the Weizmann Institute of Science. A similar phenomenon can be observed in the Chemistry study, with institutions like California Davis and Illinois Urbana-Champaign having a much better rank according to the $IFQ^2A$ index; and Columbia having a much lower rank.

## 4 Concluding remarks

The $IFQ^2A$ index is a bidimensional bibliometric measure that summarizes six bibliometric indicators to compare the research output of academic institutions in a given field, both in terms of raw output and relative quality of their research

**Table 8** Ranking of the top 50 institutions in the ARWU-subject ranking for the field of Chemistry during the period 2005-2009 according to the $IFQ^2A$ index

| Institution | ARWU | | $IFQ^2A$ | |
|---|---|---|---|---|
| | Total | Rank | Total | Rank |
| California Berkeley | 100 | 1 | 0.744 | 1 |
| MIT | 80.5 | 8 | 0.609 | 2 |
| Northwestern | 76.1 | 10 | 0.558 | 3 |
| Harvard | 98.7 | 2 | 0.481 | 4 |
| Georgia Inst. Tech. | 58.5 | 38 | 0.465 | 5 |
| California Davis | 58.5 | 39 | 0.465 | 6 |
| Illinois Urbana-Champaign | 61.3 | 32 | 0.459 | 7 |
| Tokyo | 74.6 | 11 | 0.438 | 8 |
| Michigan Ann Arbor | 60.4 | 35 | 0.436 | 9 |
| California Los Angeles | 70.2 | 15 | 0.435 | 10 |
| Stanford | 94 | 4 | 0.426 | 11 |
| Cambridge | 97.8 | 3 | 0.396 | 12 |
| Kyoto | 82.5 | 7 | 0.392 | 13 |
| California Santa Barbara | 68.2 | 18 | 0.386 | 14 |
| Swiss Fed. Inst. Tech. Zurich | 87 | 5 | 0.364 | 15 |
| California Inst. Tech. | 85.2 | 6 | 0.358 | 16 |
| Texas Austin | 67.6 | 19 | 0.340 | 17 |
| Minnesota Twin Cities | 63.5 | 28 | 0.319 | 18 |
| Imperial College | 62.3 | 30 | 0.315 | 19 |
| Oxford | 76.4 | 9 | 0.295 | 20 |
| Rice | 66.2 | 20 | 0.292 | 21 |
| Cornell | 64.7 | 23 | 0.290 | 22 |
| Purdue W Lafayette | 64.1 | 27 | 0.270 | 23 |
| Pennsylvania | 68.4 | 17 | 0.270 | 24 |
| Toronto | 64.6 | 24 | 0.258 | 25 |

| Institution | ARWU | | $IFQ^2A$ | |
|---|---|---|---|---|
| | Total | Rank | Total | Rank |
| Wisconsin Madison | 56.9 | 44 | 0.253 | 26 |
| Tohoku | 62.6 | 29 | 0.249 | 27 |
| Texas A&M | 64.6 | 25 | 0.242 | 28 |
| California San Diego | 69.8 | 16 | 0.230 | 29 |
| Yale | 65.5 | 21 | 0.224 | 30 |
| N Carolina Chapel Hill | 60.8 | 33 | 0.223 | 31 |
| Florida | 60.6 | 34 | 0.215 | 32 |
| Tokyo Inst. Tech. | 60.1 | 36 | 0.215 | 33 |
| Columbia | 74.2 | 12 | 0.214 | 34 |
| Utrecht | 57 | 43 | 0.206 | 35 |
| Strasbourg | 71 | 14 | 0.205 | 36 |
| Stockholm | 55.1 | 47 | 0.202 | 37 |
| Swiss Fed. Inst. Tech. Lausanne | 58.3 | 41 | 0.191 | 38 |
| University of Chicago | 65.4 | 22 | 0.186 | 39 |
| Tech. Uni. Munich | 73.1 | 13 | 0.185 | 40 |
| Nagoya | 62.1 | 31 | 0.181 | 41 |
| California Irvine | 64.6 | 26 | 0.179 | 42 |
| Iowa St. | 54.7 | 50 | 0.173 | 43 |
| Washington St. Louis | 54.9 | 48 | 0.152 | 44 |
| Southern California | 57.3 | 42 | 0.147 | 45 |
| Wuerzburg | 59.1 | 37 | 0.140 | 46 |
| Colorado Boulder | 58.4 | 40 | 0.140 | 47 |
| Goettingen | 55.2 | 46 | 0.136 | 48 |
| Ohio St. Columbus | 54.9 | 49 | 0.134 | 49 |
| Heidelberg | 55.5 | 45 | 0.131 | 50 |

**Table 9** Ranking of the top 50 institutions in the ARWU-subject ranking for the field of Computer Science during the period 2005-2009 according to the $IFQ^2A$ index

| Institution | ARWU | | $IFQ^2A$ | |
|---|---|---|---|---|
| | Total | Rank | Total | Rank |
| MIT | 94.8 | 2 | 0.706 | 1 |
| Stanford | 100 | 1 | 0.676 | 2 |
| Harvard | 65.6 | 9 | 0.620 | 3 |
| California Berkeley | 82.7 | 3 | 0.595 | 4 |
| California Inst. Tech. | 63 | 11 | 0.497 | 5 |
| Swiss Fed. Inst. Tech. Zurich | 54.4 | 24 | 0.470 | 6 |
| Illinois Urbana-Champaign | 62.5 | 13 | 0.441 | 7 |
| Maryland College Park | 61.9 | 14 | 0.407 | 8 |
| California Los Angeles | 54.1 | 25 | 0.383 | 9 |
| California San Diego | 58.5 | 16 | 0.347 | 10 |
| Minnesota Twin Cities | 46.3 | 42 | 0.337 | 11 |
| Princeton | 78.7 | 4 | 0.335 | 12 |
| Carnegie Mellon | 76.4 | 5 | 0.328 | 13 |
| Columbia | 56.2 | 20 | 0.306 | 14 |
| Georgia Inst. Tech. | 54.6 | 23 | 0.303 | 15 |
| Washington | 55 | 22 | 0.297 | 16 |
| Toronto | 65.5 | 10 | 0.296 | 17 |
| City Univ. Hong Kong | 45.1 | 45 | 0.294 | 18 |
| Southern California | 66.6 | 7 | 0.293 | 19 |
| National Univ. Singapore | 45 | 46 | 0.289 | 20 |
| Cornell | 67.9 | 6 | 0.286 | 21 |
| Tel Aviv | 49.2 | 31 | 0.275 | 22 |
| Cambridge | 50.2 | 30 | 0.268 | 23 |
| Texas Austin | 66.3 | 8 | 0.266 | 24 |
| Michigan Ann Arbor | 57.4 | 18 | 0.262 | 25 |
| British Columbia | 50.9 | 29 | 0.257 | 26 |

| Institution | ARWU | | $IFQ^2A$ | |
|---|---|---|---|---|
| | Total | Rank | Total | Rank |
| Technion Israel Inst. Tech. | 61.1 | 15 | 0.248 | 27 |
| Pennsylvania | 46.6 | 41 | 0.234 | 28 |
| Manchester | 46.3 | 42 | 0.228 | 29 |
| Oxford | 57.5 | 17 | 0.228 | 30 |
| California Davis | 44.1 | 50 | 0.227 | 31 |
| Purdue W Lafayette | 56.6 | 19 | 0.217 | 32 |
| Ohio St. Columbus | 47.9 | 38 | 0.216 | 33 |
| Chinese Univ. Hong Kong | 48.3 | 35 | 0.208 | 34 |
| N Carolina Chapel Hill | 48.3 | 35 | 0.208 | 35 |
| Hong Kong Univ. Sci.&Tech. | 52.2 | 26 | 0.202 | 36 |
| California Irvine | 48.1 | 37 | 0.197 | 37 |
| Yale | 49.2 | 31 | 0.195 | 38 |
| Rutgers | 47.4 | 39 | 0.192 | 39 |
| Brown | 44.2 | 49 | 0.176 | 40 |
| California Santa Barbara | 45.3 | 44 | 0.176 | 41 |
| Duke | 48.9 | 34 | 0.169 | 42 |
| Weizmann Inst. Science | 62.8 | 12 | 0.139 | 43 |
| National Chiao Tung Univ. | 48.2 | 36 | 0.137 | 44 |
| Colorado Boulder | 49 | 33 | 0.135 | 45 |
| Hebrew Univ. Jerusalem | 55.4 | 21 | 0.134 | 46 |
| Northwestern | 44.1 | 50 | 0.132 | 47 |
| National Taiwan Univ. | 51 | 28 | 0.131 | 48 |
| Ghent | 44.8 | 47 | 0.107 | 49 |
| Massachusetts Amherst | 46.7 | 40 | 0.077 | 50 |
| Oslo | 44.6 | 48 | 0.068 | 51 |
| | | | | |

output, providing an easily interpretable bidimensional graphical ranking of the institutions of interest.

The proposed ranking has as its primary goal to capture the international research of highest impact and visibility; for this reason the calculation of the $IFQ^2A$ index has to be made from international citation tools that also include journals impact assessment; so a similar ranking could also be extracted from the Scopus database instead of the ISI-Web of Knowledge. Also, given its exclusively bibliometric nature, there are two points to clarify:

1 The $IFQ^2A$ index is applicable only to fields that can be configured from the categories present in the JCR or similar.
2 The period of study should encompass at least five years so that the citation indicators are consistent and significative.

The $IFQ^2A$ index follows the line of other bibliometric rankings such as the CWTS-Leiden [5] or more recently the SCImago Institutions Rankings (SIR) [2]. Regarding the Leiden ranking, and considering the criticism received recently by its "Crown Indicator" [22,29], the $IFQ^2A$ index provides more transparent and easy to replicate rankings. Its advantage over the SIR rankings is that it provides a global measure that aggregates the indicators used. Lastly, in its comparison with the ARWU-subject rankings [27], the main advantage the $IFQ^2A$ index provides is the avoidance of the elitist indicators (Alumni, Award and HiCi) which might be more indicative of quality past than present [11], a problem that is aggravated by the high weight (over 50% combined) these indicators have in the ARWU ranking [23].

Lastly, a comprehensive study of the state of research in Spanish universities by field (considering twelve different knowledge areas) has been carried out using the $IFQ^2A$ index, and can be found in www.rankinguniversidades.es. In that same website, under the url www.rankinguniversidades.es/ARWU_Comparison.xls; a document with all the indicators for the top 50 ARWU universities in Chemistry and Computer Science is included.

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## References

1. ISI Web of Science. Science Citation Index. See http://isiknowledge.com.
2. SCImago Institutions Rankings, 2007. See http://www.scimagoir.com.
3. Elsevier B.V. Scopus, 2010. See http://www.scopus.com.
4. QS World University Rankings, 2010. See http://www.topuniversities.com/university-rankings/world-university-rankings/home.
5. Universiteit Leiden. Leiden University Rankings, 2010. See http://www.socialsciences.leiden.edu/cwts/products-services/leiden-ranking-2010-cwts/.
6. N. Adler and A.-W. Harding. When Knowledge Wins: Transcending the Sense and Nonsense of Academic Rankings. *The Academy of Management Learning & Education*, 8(1):72–95, 2009.
7. I. F. Aguillo, J. Bar-Ilan, M. Levene, and J. L. O. Priego. Comparing university rankings. *Scientometrics*, 85(1):243–256, 2010.
8. D. Aksnes. Characteristics of highly cited papers. *Research Evaluation*, 12:159–170, 2003.
9. D. Aksnes and G. Sivertsen. The effect of highly cited papers on national citation indicators. *Scientometrics*, 59:213–224, 2004.
10. S. Alonso, F. Cabrerizo, E. Herrera-Viedma, and F. Herrera. h-Index: A review focused in its variants, computation and standardization for different scientific fields. *Journal of Informetrics*, 3(4):273 – 289, 2009.
11. J.-C. Billaut, D. Bouyssou, and P. Vincke. Should you believe in the Shanghai ranking?: An MCDM view. *Scientometrics*, 84(1):237–263, 2010.
12. L. Bornmann and H.-D. Daniel. Selecting manuscripts for a high-impact journal through peer review: A citation analysis of communications that were accepted by Angewandte Chemie International Edition, or rejected but published elsewhere. *J. Am. Soc. Inf. Sci. Technol.*, 59(11):1841–1852, 2008.
13. L. Bornmann and H.-D. Daniel. What do citation counts measure? A review of studies on citing behavior. *Journal of Documentation*, 64(1):45–80, 2008.
14. L. Bornmann, R. Mutz, and H.-D. Daniel. The h index research output measurement: Two approaches to enhance its accuracy. *Journal of Informetrics*, In Press, Corrected Proof, 2010.

15. G. Buela-Casal, O. Gutiérrez-Martínez, M. P. Bermúdez-Sánchez, and O. Vadillo-Muñoz. Comparative study of international academic rankings of universities. *Scientometrics*, 71(3):349–365, 2007.
16. F. Cabrerizo, S. Alonso, E. Herrera-Viedma, and F. Herrera. $q^2$-index: Quantitative and qualitative evaluation based on the number and impact of papers in the Hirsch core. *Journal of Informetrics*, 4(1):23 – 28, 2010.
17. C. Dehon, A. McCathie, and V. Verardi. Uncovering excellence in academic rankings: a closer look at the Shanghai ranking. *Scientometrics*, 83(2):515–524, 2010.
18. D. D. Dill and M. Soo. Academic quality, league tables, and public policy: A cross-national analysis of university ranking systems. *Higher Education*, 49:495–533, 2005. 10.1007/s10734-004-1746-8.
19. L. Egghe. Theory and practise of the g-index. *Scientometrics*, 69(1):131–152, 2006.
20. J. E. Hirsch. An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences*, 102(46):16569–16572, 2005.
21. M. Kosmulski. New seniority-independent Hirsch-type index. *Journal of Informetrics*, 3(4):341 – 347, 2009.
22. L. Leydesdorff and T. Opthof. Normalization, CWTS indicators, and the Leiden Rankings: Differences in citation behavior at the level of fields., 2010. Available at http://www.leydesdorff.net/reply2cwts/reply2cwts.pdf.
23. N. C. Liu and Y. Cheng. Academic Ranking of World Universities: Methodologies and Problems. *Higher Education in Europe*, 30(2):127–136, 05.
24. H. F. Moed. *Citation Analysis in Research Evaluation*. Springer, 2005.
25. H. F. Moed. CWTS crown indicator measures citation impact of a research group's publication oeuvre. *CoRR*, abs/1003.5884, 2010.
26. D. J. d. S. Price. Networks of scientific papers. *Science*, 149(3683):510–515, 1965.
27. Shanghai Jiao Tong University. Academic Ranking of World Universities (ARWU), 2009. See http://www.arwu.org/index.jsp.
28. V. Sypsa and A. Hatzakis. Assessing the impact of biomedical research in academic institutions of disparate sizes. *BMC Medical Research Methodology*, 9:33–42, 2009.
29. A. F. J. van Raan, T. N. van Leeuwen, M. S. Visser, N. J. van Eck, and L. Waltman. Rivals for the crown: Reply to Opthof and Leydesdorff. *Journal of Informetricx*, 4(3):431–435, 2010.
30. E. Vieira and J. Gomes. A research impact indicator for institutions. *Journal of Informetrics*, 4(4):581 – 590, 2010.