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Usefulness of Hirsch's *h*-index to evaluate scientific research in Spain

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The applicability of Hirsch's *h* index (HIRSCH, 2005) for evaluating scientific research in Spain has been investigated. A series of derivative indexes that take into account: i) the overall low scientific production in Spain before the '80s; ii) differences among areas due to size (overall number of citations for publications in a given area); and iii) the number of authors, are suggested. Their applicability has been tested for two different areas in the Biological Sciences. The proposed set of indexes accurately summarizes both the success and evolution of scientists' careers in Spain, and it may be useful in the evaluation of other not well established national scientific research systems.

Introduction

Science policy agencies in Spain and in many other countries have long pursued a simple parameter allowing formal evaluation of scientific research quality (SEGLEN, 1997, and references therein). Although it is widely acknowledged that no simple method can replace peer evaluation if it is properly conducted (MULLIGAN, 2004), it is also clear that this is not an easy task. The British research system, through its Research Assessment Exercise (http://www.rae.ac.uk), has achieved a high-quality level of evaluation, and is probably the example to follow. However, the Spanish and other

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national research systems, both because of the scarcity of their funding and because of their small size, are far from reaching that research evaluation level.

In this situation, many science policy agencies in Spain have relied heavily on the use of ISI's Impact Factor (GARFIELD, 1994) either by directly applying journal impact factors to lists of publications or by correcting for the journal's relative position in its scientific area, as listed in Thomson Scientific's *Journal Citation Reports*. The validity of using an index developed for the evaluation of scientific journals to assess the quality of a scientist's publications has been repeatedly questioned (SEGLEN, 1997; HECHT et al., 1998; AMIN & MABE, 2000). The key criticism is that there is no correlation between a given journal's impact factor and the number of citations for the papers appearing in that journal. This is explained by the fact that a journal's impact factor is determined by a small fraction of highly cited papers, while many of its remaining papers receive very few citations. This discrepancy is magnified if the journal, as many do nowadays, publishes review articles together with research papers. The former receive a much higher average number of citations, and thus have a stronger effect on the journal's impact factor than research papers.

The National Commission for the Evaluation of Research Activity (CNEAI) was the first Spanish national agency to apply a generalized evaluation of the research activity of Spanish scientists relying on relevance and quality of publication rather than on purpose-specific peer review. In the CNEAI evaluation, scientists do not compete against each other. Rather, the CNEAI's task is to distinguish between two populations of tenured scientists, those carrying active and competitive research and those with no significant scientific productivity. The existence of these two populations and their large productive differences were revealed by the distribution of citations, which fits perfectly to the sum of a normal distribution plus a Poisson distribution, the latter with a very low mean that is at least two orders of magnitude lower than that of the former (RODRIGUEZ-NAVARRO, 1994). The success of the CNEAI's evaluations (documented in JIMENEZ-CONTRERAS et al., 2003), which in the described conditions was rather predictable, led to a widespread use of its methodology by other Spanish agencies for purposes (competitive grant and fellowship evaluations, job promotions, among other) different to those of the CNEAI, and for which these formal criteria are inappropriate. Over the years this has resulted in a number of problems, some ill-advised decisions, and some discontent among scientists.

Recently HIRSCH (2005) proposed the *h* index to quantify a scientist's research output. A scientist has index *h* if *h* of his/her publications have been cited at least *h* times each. Hirsch suggests that the *h* index is a better quality indicator than commonly used indexes: i) number of publications; ii) total number of citations; iii) average citation number per publication; iv) number of "significant" publications; or v) number of citations of the highly cited publications. This index has already received some attention (BALL, 2005; BORNMANN & DANIEL, 2005; BRAUN et al., 2005). In this work we investigate the application of the *h* index to evaluate scientific research in Spain.

Methods

Databases

The Science Citation Index Expanded (1945-present) database from Thomson's Web of Science, the *Journal Citation Reports*, and the Essential Science Indicators databases from Thomson's Web of Knowledge were used throughout.

Indexes and parameters

The *h* index (number of publications with citation number ≥ *h*) and the *m* parameter (the slope of *h* versus the number of years in a scientific career) have been defined (HIRSCH, 2005).

We define *f* as the average impact factor of the top journals that characterize a given scientific area or subarea. From *h* we derive h_R or reference *h* as the average value of *h* for the top scientists of a given scientific area or subarea. BATISTA et al. (2006) defined the h_I index as the result of dividing *h* by the mean number of authors in the *h*. For scientific areas where the first and last positions within the author list have a special meaning, we propose another transformation, h_K, calculated exactly as *h*, except that those publications where the evaluated scientist is not first or last author are eliminated from the list.

Calculation of h values

Citation data were those of the Science Citation Index Expanded. Scientists with common Spanish names cannot be easily distinguished by the topics of publication. To avoid errors, these scientists have not been included in this study. For use by evaluation agencies we recommend using the list of publications provided by each scientist under evaluation. For compound, hyphenated names, very common for Spanish scientists, different conventions were used in the database before and after 1998. Therefore, the "$" wild-card character between both parts of the compound name was used. Displayed publications for a given scientist were sorted by the "Times cited" criterion, and the publications counted while their number of citations is higher than, or equal to, the number of publications counted. That number is the value of *h* for that particular scientist.

For determination of *f* values in different areas, a variable number of high impact journals specific to the area which accurately reflect the state-of-the-art in that particular area were selected, and their average impact factor was chosen as *f*. This process is clearly subjective and depends on a profound knowledge of the area. For that reason a peer selection process was followed, either directly by the authors in their areas of specialization, or through knowledgeable colleagues in other areas. In some areas the highest (or two highest) impact journals were not considered because they deviate from the overall distribution of impact factors within the area. Finally, those journals exclusively publishing reviews were also excluded because their relevance varies in different areas and, when they exist, they usually have the highest impact factors.

Two different methods were used to determine h_R values, and they are described in the Results section.

Values for h_I were calculated as described by BATISTA et al. (2006) and h_K as described above.

Results

As HIRSCH (2005) pointed out, the general application of the *h* index faces several problems, such as the influence of the size of the publishing research group (number of authors per publication), and the variability of *h* among areas with very different population sizes, which determines the average number of citations per publication. For evaluation of scientific research in Spain, application of the *h* index faces specific problems derived from a generally low productivity before the '80s and extremely low *h* values in some areas. We approach these problems below.

The h_R index

The range of *h* values varies in different scientific areas (HIRSCH, 2005). In general, publications in applied areas are less cited that publications in dynamic, basic areas, and therefore, scientists in the former areas show lower values of *h*. These differences are mainly caused by: i) the different sizes of the populations that can potentially cite the publication; ii) the lower emphasis placed on research by scientists in applied areas. The effect of the citing population size was exemplified by HIRSCH (2005) by comparing Physics and Biology, the latter reaching much higher *h* values. Although the complex dependence of *h* on the citing population size precludes an overall *h* normalization across scientific areas, we empirically observed that the highest *h* values attained for a given area correlate well with the impact factor of journals in that area. For Physics, where very highly cited scientists have $h \approx 80$, the impact factors of the top journals that can be considered as characteristic of the area range between 7 (*Physical Review Letters*) and 5 (*Physical Review D*). For Biology, where very highly cited scientists have $h \approx 150$, the impact factors of top neurosciences, immunology or cell biology journals range between 15 and 9. In both areas, maximum *h* factors are ca. twelve times higher than the average impact factor of top specific journals. It is clear that this linear dependence does not extend to low *h* values, which are easily attainable irrespective of the citing population size and the relative journal impact factors. Among the various "noise" factors that become relevant at low *h* values, chance citation and self-citation can be mentioned.

We calculated *h* indexes for the most highly cited scientists in different areas and subareas (reference *h* index or h_R) and observed that h_R indexes are more dependent on journal impact factors than on specific publication patterns. For instance, the Food Science and Material Science areas have very different publication habits: food scientists have less publications and these have more citations than material scientists. However, h_R is 35-40, and journal impact factor is ca. 2 for both areas. For Crop Science, the highest *h* values for scientists publishing in *Crop Science* (impact factor 0.96) are ca. 30. In general, and for most areas, we observe

$$h_R \sim 16 + 11f \qquad (1)$$

where *f* is the impact factor of the top journals that characterize that specific scientific area or subarea. Since h_R exhibits a linear dependence on *f*, it is possible to compute it as an average for scientists who publish in more than one area. For instance, a food microbiologist with publications both in Microbiology and Food Science would have an h_R of ca. 55, the average of 38 for Food Science (f=2; h_R =38) and 70 for Microbiology (f=5; h_R =70).

In Equation (1), determination of both the specific area where a scientist must be included and of a correct *f* value for that area is crucial, and this task must be carried out by peers of the evaluated scientist. The Spanish scientific system is characterized by the publication of many data of little relevance, and it would be a mistake to apply a low value of *f*, only because a scientist or group of scientists do not approach relevant problems or publish in lesser journals. It would also be in error to use general interest journals, in which scientists working on applied problems can only exceptionally publish, to characterize a given area. Another limitation is exemplified by top rated journals, such as *Physical Review Letters* for physics or *Plant Cell* for plant sciences. They both have a wide scope of publication, so, in theory, any scientist in those areas would be able to publish in them. However, due to their high demands, the research of many physicists and plant molecular biologists outside dynamic fields have low chances of being published in those journals. Therefore, we exclude these top journals in the characterization of scientific areas.

Finally, each scientist's *h* value must be compared to the corresponding h_R, but h/h_R is not a parameter that can universally define the position of a given scientist in any field. For that purpose one would need to know the frequency distribution of *h* values in each particular research area. This determination is feasible, but it is beyond the scope of this work. In very simple terms, we can say that in scientific areas with a low h_R it is easier to reach an h/h_R of, say 0.5, than in areas with a very high h_R.

The h_I and h_K indexes

The notion that large research groups obtain higher h values because scientists in the group co-author more publications is hardly questionable, but correcting this discrepancy is very complicated, because multiple authorship responds in many occasions to different and complex reasons, and because not all the authors are responsible of possible abuses when the publication is unfairly co-authored by additional scientists. BATISTA et al. (2006) addressed the problem of multi-authorship in their calculations of h values for Brazilian scientists, and proposed the h_I index, obtained by dividing h by the mean number of authors in the h works. Although this transformation of h can have advantages, it cannot be applied to publications that respond to large collaborations, as in genomic sequencing or particle physics. Medical research can also require the collaborative work of clinicians and molecular biologists, forming large groups where most of the experimental work is carried out by a few, but where everyone's input is necessary. Despite these reservations, application of the h_I index in Spain would help foreground many scientists who have worked in isolation in many of the peripheral Universities created in later years, and would also correct abuses in multi-authorship. Unfair multiple authorship occurs in most countries, but in Spain it is a notorious practice, although not equally distributed. It is clear that an excess of formal evaluations relying heavily on publication numbers in the past has been determinant of this response from the Spanish scientific community. Hence, it is up to the Spanish scientific policy agencies to correct a problem that they have helped magnify. One final consideration is that it would be unfair to many junior scientists to have their published work penalized because of the appearance of multiple authors with little or no participation when they were in no position to decide. In many scientific areas, where the first and last position in the author list have a special meaning, it would be possible to consider just those publications where the scientist being evaluated appears as first or last author. The corresponding index, h_K, appears to be very interesting and is currently under investigation.

The m parameter

The h index depends on the number of years of scientific activity (HIRSCH, 2005). This dependence can be very complex, but in simple cases Hirsch proposes a linear relationship of the form

$$h \sim mn \tag{2}$$

where *n* is the number of research years. In the case of Spain, at least for the study of scientific activity in Universities, a consideration about the *m* parameter is a necessity, because in the '60s-'70s, scientific research in Spanish Universities was practically negligible (JIMENEZ-CONTRERAS et al., 2003), and in the '80s the differences in research capabilities between established Universities and new Universities were still very large. For that reason, *h* values for Spanish scientists working in the new Universities of the '70s-'80s are lower. For Physics, Hirsch suggests $m \approx 1$ for a successful scientist, $m \approx 2$ for an excellent scientist, and $m \approx 3$ for an extraordinary scientist. In Spanish Universities many scientists reach the success levels suggested by Hirsch in the last 10-20 years, but this is almost impossible if the calculation period is extended to the '70s-'80s.

Case studies

We chose two Biological areas, Microbiology and Veterinary Sciences, to illustrate our use of *h* indexes for evaluation of scientific research in Spain. Our initial perception was that, while Microbiology is a reasonably well-developed research area in Spain, the more applied, highly professionalized Veterinary Sciences, is not. In order to calculate reference *h* indexes, two different methods were attempted. With Microbiology, since this area coincides with one of the 22 "broad areas" defined in the Essential Science Indicators database (Thomson's ISI Web of Knowledge), we calculated *h* indexes for those highly cited scientists appearing in the Citation Rankings database (Thomson's ISI Web of Knowledge) with a high enough number of publications. Perusal of the highly cited scientist rankings shows how the appearance of hyper-cited genomic sequence publications has distorted these rankings as a measure of the impact of a scientist's publication output. After calculation, we observed that the highest *h* values (four out of the top five) correspond to virologists, a category separate of Microbiology in the *Journal Citation Reports* database classification, and virologists were excluded for all subsequent analyses. With Veterinary Sciences, the area is included within the "Plant & Animal Science" broad area, which precludes the use of highly cited scientist rankings to calculate reference values of *h*. Instead, candidates for high *h* values within Veterinary Sciences were derived from analysis of a search for highly cited publications in any of thirty-six journals with impact factor above 1 (2.824 – 1.015) within the Veterinary Sciences category of the *Journal Citation Reports.* This approach was also followed for Microbiology with the top fourty-eight journals in the JCR Microbiology category (impact factors 17.037 – 1.835), and similar results were obtained with both methods (data not shown).

Stanley Falkow, the Stanford microbiologist who pioneered molecular studies of microbial pathogenesis, tops the list of microbiologists with h=103, distantly followed by molecular microbiologists John Beckwith (Harvard), Milton Saier (UC San Diego), and genome scientist J. Craig Venter, all with h=73. Thirteen microbiologists in our list had h values above 60, and their average h was taken as the Microbiology reference h (h_{RMICRO}=70.2). This value can also be obtained from equation (1), provided the f value for Microbiology journals is defined. In order to calculate f, only top research journals (excluding review journals) should be considered (see Methods). For the top five journals up to, and including, *Journal of Bacteriology*, f=5.2, and the derived h_{RMICRO} =73. Since Microbiology is a diverse area, the top five journals leave out most of the best research published on applied microbiology and microbial ecology. However, even if the list is expanded to the three following journals to include *Environmental Microbiology* and *Applied and Environmental Microbiology*, the values for f and h_{RMICRO} (4.7 and 67, respectively) still show excellent agreement with the h_{RMICRO} computed from the average of the top thirteen microbiologists.

For Spanish microbiologists (excluding virologists), the list is headed by clinical microbiologist Fernando Baquero and, oddly, molecular microbiologist David Vázquez (deceased 1986), both with h=42, and molecular microbiologist Juan Luis Ramos (h=39). Eight microbiologists had h values above 30, with an average of 36.8. However, when h indexes were computed for the period 1985-2006, h_{RMICRO} dropped from 71 to 56, while the average of the top seven Spanish microbiologists (excluding D. Vázquez) went down much less, from 36 to 34.

For Veterinary Sciences, the international list is headed by parasitologist J.P. Dubey (USDA) with h=57, followed by Hugh Miller (Edinburgh, h=42), David Lindsay (Virginia Tech, h=38), Alan Pickering (h=36), Max Appel (h=31) and Gerald Wells (h=29), above a large number of researchers with h values between 25 and 22. As with Microbiology, the average of the above six h values can be taken as Veterinary Sciences h_{RVET}=38. This value for h_{RVET} coincides with that derived from equation (1) when f is calculated by averaging the impact factors of the nine top Veterinary Sciences journals (up to *Journal of Veterinary Internal Medicine*) from the *Journal Citation Reports* database, which is f=1.99 and results in a derived h_{RVET}=37.9.

For Spanish scientists in the area, the highest values for h were obtained for Mariano Domingo (h=22), Lucas Domínguez (h=20), and Lluis Ferrer (h=17). Aside from the fact that some of the scientists with the highest h in this area are in part microbiologists and, as described above, their individual h_{R} should be an intermediate between h_{RMICRO} and h_{RVET}, the key observation for Veterinary Sciences in Spain is that only eight Spanish scientists in this area have h values above 10, with an average h of 15.9, and that the thirty remaining Full Professors in Veterinary Sciences have an average h of 5.4, suggesting that Spanish contributions to research in this area are of little relevance. As it was the case for Microbiology, computation of h values for the period 1985-2006, had little effect on Spanish scientists, with the average for top eight scientists dropping from 15.9 to 15.1, whereas h_{RVET20} dropped from 38 to 31.

Discussion

Advantages and disadvantages of h and derivative indexes

Contrary to journal impact factors, the *h* index and its derivatives (h_R, h_I, h_K, and *m*) have been designed for the evaluation of scientists and have been tested in scientists' evaluations. However, they cannot be used to replace peer evaluation by a purely formal evaluation. Even the determination of reference values for specific scientific areas (h_R) must be a peer-determined process (see Results).

Keeping in mind that there is no entirely quantitative procedure for scientific evaluation, we believe that there are two main advantages derived from use of these indexes: i) for the bulk of the scientific contingent they reasonably reflect the outcome of peer evaluation, and thus they provide a scaffold that can be helpful both for peer evaluation and to oversee such a process; and ii) in a number of situations where highly dissimilar scientific performances must be evaluated in the same context (eg. application for generic fellowships, such as "Life Sciences," or comparison of molecular biologists and clinical oncologists working in a Cancer centre), the indexes provide a reasonable degree of normalization of performances that allows direct their comparison.

For our purpose we find it useful to tabulate values of *h*, h_I, h_K, *m* for the last 10-20 years (if necessary), and h_R for each scientist. Overall consideration of all these indexes is much more informative than the use of any single one in an immature scientific system, such as the Spanish system. For instance, establishment of many collaborations with other groups (as in the case of scientists specializing on technical aspects of research) increases *h*, but lowers h_K or h_I.

In using these indexes two considerations must be kept in mind. First, the number of citations does not always reflect the quality of the publication, as it sometimes happens with applied publications which are extremely useful, and used, but still receive few citations in the scientific literature. And second, the scientific productivity of the average Spanish scientist is extremely dependent on the immediate research environment (see considerations on *m* parameter). This is compounded by a chronically insufficient funding in the areas heavily dependent on experimental research, which makes it difficult for Spanish groups to be competitive at the forefront of scientific research in those areas. As a result, it is possible that, in some cases, *h* might not accurately reflect the scientific potential of a given Spanish scientist.

Application of h indexes for evaluation of research in Spain: Case studies

Microbiology and Veterinary Sciences were chosen as examples of application of *h* indexes for evaluation of scientific research in Spain. They represent two biological areas with different degrees of development in the Spanish scientific system. To our knowledge, no comprehensive studies have been carried to date, but the overall understanding is that, in terms of research, Microbiology is an area better developed in Spain than Veterinary Sciences, a more highly applied and professionalized area than Microbiology. It was interesting to compare both areas side by side because the recent impact of Bovine Spongiform Encephalopathy and the impending Avian Influenza epidemics have emphasized the need for scientific expertise in these areas at the country level.

When both areas were compared, both h and f values were much lower for Veterinary Sciences at the international level, which probably results from a lower citing population. Two different methods were used to calculate h_R values, and both gave equivalent results. In the first, formally more correct but labour-intensive, a list of highly cited publications in each area (as defined in the Journal Citation Reports database) was obtained, and from those a list of highly cited scientists, whose h values were computed. The average h of the top scientists in each area was taken as h_R. In the second method, h_R was calculated from Equation (1) after estimation of f.

For the Spanish situation, our results confirm the perception that the contribution of Spanish scientists to knowledge in their area is more relevant for Microbiology than for Veterinary Sciences. The differences between areas are probably more important than what the direct comparison of h values for the top scientists in these areas suggest, for two reasons: i) very low h values have little meaningfulness because chance citations and self-citations become very relevant, and ii) comparison of the average h values for most of the Spanish Full Professors in both areas (123 for Microbiology and 38 for Veterinary Sciences) increases the differences between both areas (our unpublished results).

An interesting conclusion of this study is that limiting the time frame for calculation of h values increases the relevance of contributions from Spanish scientists in both areas, as can be expected from a young research system. As pointed out above (section on m parameter), research output of Spanish Universities was negligible before the '80s. This is demonstrated by our analyses, which show that restricting the time frame for calculation to the period 1985-present has virtually no effect on the overall values for Spanish h indexes.

Use of h and science policy in Spain

As a result of the highly successful formal evaluations carried out in Spain by the National Commission for the Evaluation of Research Activity (CNEAI), this methodology has seen widespread use in the evaluation of scientific research in Spain. This is problematic because, once more, this methodology was devised to address a different set of questions. It is surprising that, although starting November 2003 all publicly funded Spanish Universities and Research Centres have unrestricted access to Thomson's Web of Knowledge, no science policy agency has requested incorporation of citation data (either total citation number or citations per publication excluding self-citations) in the publication list they require from scientists when they apply for different types of funding, fellowships, salary complements, and so on.

We suggest that the h index and its derivatives could be used as an excellent measure, based exclusively on formal criteria, of scientific performance in all the above situations. However, we believe it is very important to keep in mind the limitations of using exclusively h in science policy. Perhaps the most important of these limitations in this respect is that h values are dependent on the size of the scientific citing population for a certain area: those scientists in highly popular (or fashionable) areas are more likely to obtain higher h values. If an evaluation system is established that blindly favours high h values, the adaptive response of scientists will be to crowd high h areas or subareas, thus deserting low h areas or subareas, which, in a small Science and Technology system such as that in Spain, would be disastrous. For that reason, referring h to h_R is a must. Reference to h_R would not be necessary when similar institutions are compared, for instance if we want to use h to rank Schools of Medicine, or Chemistry, in Spain. However, use of h for evaluation of institutions, rather than scientists, is beyond the scope of this work.

Although with caution, HIRSCH (2005) suggested that h values could be used as formal criteria to determine promotional advancement of individual scientists in their careers. Given the current uncertainties and criticism surrounding criteria for promotion of scientific staff in Spanish Universities, application of h indexes and its derivatives in these situations would help establish a much needed non-arbitrary and non-subjective promotions system.

One final note is that, regrettably, this system is not generally applicable to social sciences and the humanities because, in many cases, these areas lack extensive journal databases and because a large part of the research in these areas is published in book-length form, and this escapes current citation analyses.

Although our discussion on use of the h index and its derivatives has centered on the Spanish scientific research system, we believe many of the above considerations should be valid for evaluation of scientific performance in other immature national scientific research systems that could also benefit from a set of unbiased, formal indexes to complement evaluation by peers.

References

AMIN, M., MABE, M. (2000), Impact factors: use and abuse. *Perspectives in Publishing,* No. 1. Elsevier Science. http://www.elsevier.com/wps/find/editorsinfo.editors/perspectives

BALL, P. (2005), Index aims for ranking scientists. *Nature,* 436 : 900.

BATISTA, P. D., CAMPITELLI, M. G., KINOUCHI, O., MARTINEZ, A. S. (2006), Is it possible to compare researchers with different scientific interests? *Scientometrics,* 68 (1) : 179–189.

BORNMANN, L., DANIEL, H. D. (2005), Does the h-index for ranking of scientists really work? *Scientometrics,* 65 : 391–392.

BRAUN, T., GLÄNZEL, W., SCHUBERT, A. (2005), A Hirsch-type index for journals. *Scientist,* 19 (22) : 8.

BRAUN, T., GLÄNZEL, W., SCHUBERT, A. (2006), A Hirsch-type index for journals. *Scientometrics,* 69 (1) : 169–173.

GARFIELD, E. (1994), The ISI impact factor. *Current Contents.* June 20. http://scientific.thomson.com/free/essays/journalcitationreports/impactfactor/

HECHT, F., HECHT, B. K., SANDBERG, A. A. (1998), The journal "impact factor": a misnamed, misleading, misused measure. *Cancer Genetics and Cytogenetics,* 104 : 77–81.

HIRSCH, J. E. (2005), An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences USA,* 102 : 16569–16572.

JIMÉNEZ-CONTRERAS, E., DE MOYA ANEGÓN, F., DELGADO LÓPEZ-COZAR, E. (2003), The evolution of research activity in Spain. The impact of the National Commission for the evaluation of research activity (CNEAI). *Research Policy*, 32 : 123–142.

MULLIGAN, A. (2004), Is peer review in crisis? *Perspectives in Publishing*, No. 2. Elsevier Science. http://www.elsevier.com/wps/find/editorsinfo.editors/perspectives

RODRÍGUEZ-NAVARRO, A. (1994), La reforma de la Universidad española. *Boletín de la Institución Libre de Enseñanza*, 20 : 7–32.

SEGLEN, P. O. (1997), Why the impact factor of journals should not be used for evaluating research. *British Medical Journal*, 314 : 497–507.