Evaluating research and researchers by the journal impact factor: is it better than coin flipping?

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The journal impact factor (JIF) is the average of the number of citations of the papers published in a journal, calculated according to a specific formula; it is extensively used for the evaluation of research and researchers. The method assumes that all papers in a journal have the same scientific merit, which is measured by the JIF of the publishing journal. This implies that the number of citations measures scientific merits but the JIF does not evaluate each individual paper by its own number of citations. Therefore, in the comparative evaluation of two papers, the use of the JIF implies a risk of failure, which occurs when a paper in the journal with the lower JIF is compared to another with fewer citations in the journal with the higher JIF. To quantify this risk of failure, this study calculates the failure probabilities, taking advantage of the lognormal distribution of citations. In two journals whose JIFs are ten-fold different, the failure probability is low. However, in most cases when two papers are compared, the JIFs of the journals are not so different. Then, the failure probability can be close to 0.5, which is equivalent to evaluating by coin flipping.

Key words: research evaluation, impact factor, failure probability,
1. Introduction

In a recent paper in *Nature World View*, John Tregoning (2018) upholds once more the opportunity of using the journal impact factor (JIF) to evaluate research or researchers: “The JIF is wrong in so many ways but it is so easy,” the article highlights. Notably, the same can be said of coin flipping, which is not an argument to propose its use to decide which of two similar projects is funded or who of two similar researchers most merits an academic appointment. This comparison is not an exaggeration, because we will show that failure probabilities almost as high as in coin flipping are in many cases associated with evaluations based on the JIFs.

The use of the JIF for research evaluations is extensive (Archambault & Larivière, 2009), alone or accompanied by other metrics (Hammarfelt & Rushforth, 2017), but it suffered an important setback in 2012 with the San Francisco Declaration on Research Assessment (DORA; https://sfdora.org/, accessed in 03/08/2018) and also because it is not used in the UK Research Excellence Framework (UK Forum for Responsible Research Metrics, 2018), by the European Molecular Biology Organization (http://www.embo.org/documents/LTF/LTF_Guidelines_for_Applicants.pdf, accessed in 21/08/2018), and by other funding agencies. Furthermore, in 2016 the American Society of Microbiology reported that “the ASM Journals Editors in Chief and Society leadership have decided that Journal Impact Factors (JIFs) will no longer be posted to the journal websites or used in advertising. Our goal is to stop contributing further to the misuse of JIF as a proxy for evaluating the quality of an individual’s scientific research” (https://www.asm.org/index.php/journals-impact-factor, accessed 06/08/2018).

Despite these notable rejections of the use of the JIF in research evaluation, the method is still in use, and opposite positions have been qualified and debated (e.g., Archambault & Larivière, 2009; Bornmann & Williams, 2017a; Bornmann & Williams, 2017b; Callaway, 2016; Hammarfelt & Rushforth, 2017; Peters, 2017). Regarding the high number of criticisms, Tregoning (2018) states: “But for all the invective heaped on the JIF as a metric, no alternative has emerged,” without considering that for something that is wrong, misleading, and inequitable the lack of an alternative is not a cause for continuing using it. The present study heaps more criticisms and rejects the use of the JIF for evaluation purposes but does not negate that publications in journals with high JIFs are associated with high scientific quality. Here a mathematical approach is applied to demonstrate that the use of the JIF to decide which of two papers has more merit for an academic appointment or project funding, in many cases, carries an inadmissible probability of taking a wrong decision.
The JIF “is calculated by dividing the number of current year citations to the source items published in that journal during the previous two years” (https://clarivate.com/essays/impact-factor/, accessed 08/14/2018), which implies that the JIF is an average of the merit of the papers published by a journal. In evaluations based on the JIFs, all papers in a journal have the same scientific merit, which is measured by the JIF of the publishing journal. Thus, the JIF says nothing about the real merit of a certain paper published in that journal. This means that a few papers will be correctly evaluated, when their number of citations coincides with the average, but most papers will be either over- or sub-evaluated because most papers will be below or above the average. The consequence of these mistakes is that when the merits of two papers in two journals are compared by using the JIFs the result will be wrong when a JIF-sub-evaluated paper in a journal is compared with a JIF-over-evaluated paper in another journal. The flaw of the method is especially important because citation distributions are lognormal (Rodríguez-Navarro & Brito, 2018a and references therein), in which the most cited papers conform a heavy tail. Thus, the method leads to wrong and inequitable decisions, for which the probability of occurrence can be calculated.

Before the Tregoning’s paper (2018) appeared, Waltman and Traag (2017) had raised an interesting debate about the validity of the JIF, finding that its use might not be wrong. However, the basis of this debate affects some principles that are normally assumed in scientometric. The study uses two concepts, the value of an article (which a “non observable concept”) and either the number of citations or the JIF (which are “observable” concepts), and presents two alternative scenarios. In scenario 1, “the number of citations of article is a relative accurate indicator of the value of an article” (p. 13) and “journals are rather heterogeneous in terms of the values of the articles they publish” (p. 14). In scenario 2, “the number of citations of an article is a relatively inaccurate indicator of the value of the article” and “journals are fairly homogeneous in terms of the values of the articles they publish” (p. 14).

Our reasoning above and the rest of this study situates in scenario 1 of Waltman and Traag (2017), but with a slight variation, because we describe the existence of a correlation between citation and the scientific value of a paper (section 2.1). This implies that only in an ideal case the number of citations is an accurate indicator of the value of an article.

For evaluations, the JIF is used in two different ways, assigning higher merit either to publications in journals with higher JIFs or to those that are in top percentiles of the lists of journals grouped in subject categories—for example, publications in Q1 journals (the top 25%; Bornmann & Marx, 2014; Bornmann & Williams, 2017a), versus publications in
Q2 journals (within the top 25%–50% interval) in subject category lists of journals. In more extreme evaluations, only journals in the Q1 list are considered.

The research goal of the present study is the evaluation of the merit of a paper based on the number of citations instead of the JIF of the journal where it has been published. With a different purpose, the same idea has been used in a previous article, where the probability that a random paper in a journal receives more citations than a random paper in another journal is used to calculate the “citation success index” (Milojevic et al, 2017). In particular, our goal can be illustrated through the analysis of two publications authored by researchers A and B: $P_a$ and $P_b$. These papers have been published in journals $J_a$ and $J_b$, which have journal impact factors $\text{JIF}_a$ and $\text{JIF}_b$, and have received $C_a$ and $C_b$ number of citations. Evaluating by the JIF, if $\text{JIF}_a$ is higher than $\text{JIF}_b$, it is concluded that $P_a$ has more merit than $P_b$. But assuming that $C_a$ and $C_b$ are direct measurements of merit, the use of the JIFs will provide a wrong result when $C_b$ is higher than $C_a$. In summary, in an evaluation by means of the JIFs, researcher A will be preferred to B when actually B has more merit than A. This study calculates the probability of this wrong evaluation, namely, the failure probability.

2. Theoretical basis and dataset

2.1. Research evaluations based on citations

The JIF is the mean of a certain number of citations. Therefore, its use in research evaluations implies that citations in some way measure the “research relevance” or “scientific merit” of a paper. These terms try to summarize the effect that a paper have had on the progress of its field of research or, in other words, how the field would have progress without this paper. This paper’s effect in the field is probably the most relevant datum in a scientific evaluation. However, whether the number of citations measures this or any other effect related to it is a notion that has been extensively debated (e.g., Leydesdorff et al, 2016). This debate is out of the scope of this study, which refers to the cases where the JIFs are applied and that implicitly assume that citations can be used for research evaluation.

In section 4.3, we assume that, as in most measurements, the link between the number of citations and the scientific merit is a correlation. This notion is behind a large number of publications (e.g., De Bellis, 2009) but it has a difficult study because it would require a numerical scale for the scientific merit. However, in some studies, where scientific merit is quantified by the number of Nobel Prizes awarded, this number correlates with some citation-based indicators (Rodríguez-Navarro, 2011, 2016).
2.2. Failure probability

To calculate the failure probabilities, we assume that the number of citations of journal papers follow a lognormal distribution, for which there is strong support (Rodríguez-Navarro & Brito, 2018a and references therein); a lognormal distribution for monodisciplinary journals has also been specifically investigated (Thelwall, 2016). The μ and σ parameters of the lognormal functions were calculated as the mean and standard deviation of the log transformed numbers of citations, omitting the publications with zero citations. We prefer this approach to that of adding 1 to all citations because it was found that in some journals the number of uncited articles was unexpectedly high. This occurs when journals include letters and comments, which frequently do not receive citations. The mix of these probably uncited publications with the statistically predetermined uncitable research articles (Thelwall, 2016) increases the number of zero citations. Considering this problem, this study does not include journals with a high number of uncited papers to avoid a probable bias, since uncited papers are included in the calculation of the JIF but not in this paper’s calculations. Furthermore, publications that are not cited because they are not real research publications do not fit the lognormal distribution of regular research publications.

To ascertain that the lognormal distribution of citations holds for the journals included in this study, the mean number of citations calculated from the actual data was compared with the mean calculated from the μ and σ parameters by the formula

\[ m = \exp(\mu + \sigma^2/2) \]  

In many cases the difference between the two referred means is small—less than 2%—but in others the difference is high. The most important reason for high deviations of the means calculated in these two ways is the publication of review articles together with original articles. This practice is so frequent that it constituted a real problem in the selection of high-JIF journals for this study. For example, in *Current Biology* and *Plant Cell* the deviations of the two means were 24.5% and 23.7%, respectively, considering “all publications” but only 1.9 and 2.6%, respectively, when only “articles” were considered. In order to avoid an excessive restriction of journals, especially in Q1, a limit of a 6% deviation was fixed for the journals included in this study, which supposed a small deviation from the lognormal distribution.

It is worth noting that the mean calculated by the two procedures explained above should be highly correlated with the JIF, but is not the JIF multiplied by four (see below) because the mean and the JIF have been calculated from different citation years.
Although citations are integers, the continuous variant of the lognormal distribution was used for the probability calculations, which is a reasonable approach (Thelwall, 2016). For this calculation we applied the formula described in the Appendix. If, in the case of integers, papers with the same numbers of citations are included as failures in the evaluation by the JIF, the discretized variant of the lognormal distribution will provide a slightly lower probability of failure than the continuous variant. However, this difference is very small; for example, in the two journals *Water Research*, JIF = 4.66, and *Environmental Toxicology and Pharmacology*, JIF = 2.01, the probabilities are 0.18 and 0.17, for the continuous and discretized distributions, respectively.

### 2.3. Searches and dataset

All citation data were obtained from the *Web of Science*; journal lists by categories and JIFs were obtained from the *Journal of Citation Reports* (*JCR* categories, which group journals with similar research subjects). We studied publications in 2012, recording the JIF in 2012 and the number of citations that these papers received in 2014–2017. This medium-term number of citations was used to avoid the variability that is associated with the number of citations in the first year after publication and with too-short citation windows. Although publications in 2012 are not considered to calculate the 2012 JIF, this JIF was used because in Spain, and probably in other countries, the JIF considered for the evaluation of a paper is that corresponding to the paper’s publication year. The database was accessed in July 2018.

### 3. Results

Even for those who reject the JIF for research evaluations, in specific circumstances its use might be accepted—for example, in the absence of expert reviewers and when a paper has been recently published—but only if the probability of failing is low. However, a priori, it seems that the use of the JIF for judging papers implies a high probability of failing because the citation distributions of two journals that have different impact factors overlaps at low numbers of citations (Lariviere et al, 2016), especially if the JIFs are not very different. Figure 1 illustrates this fact presenting the distribution of citations in 2014–2017 to 2012 papers in *Water Research* and *Chemosphere*. In 2012, the JIFs of these journals were 4.66 and 3.14, and they published 650 and 752 papers, respectively. The histogram suggests that papers with fewer than 20 citations are similarly probable in both journals. Papers with a higher number of citations are more probable in *Water Research* than in *Chemosphere*, but still it can be guessed that taking a paper at random from each journal, it is not improbable that the paper in *Chemosphere* is the one that receives more citations; in these cases, the evaluation by the JIF will be wrong.
On the basis that evaluating by the JIF implies a certain probability of assigning higher citation merit to the paper that has the lower number of citations, the research question is how wide the difference between two JIFs has to be in order that the probability of failure be low enough to make failure unlikely. This probability of failure depends on both the $\mu$ and $\sigma$ parameters of the citation distributions of the two journals under consideration (Appendix). These parameters are highly variable among journals, and their link with the JIF is complex as commented in section 2. Therefore, the relationship between the two JIFs involved and the probabilities of failing must be tackled empirically. For this purpose we selected 39 journals that fulfill the conditions described in section 2 and in which the JIF varied from 14.83 to 1.27. Table 1 shows the list of journals that were selected, which had JIFs ranging from 14.8 to 1.3 and that fulfilled the conditions described in section 2. As could be expected, the JIFs of these journals in 2012 are highly correlated with the annual mean number of citations in 2014–2017 of the papers published in 2012 (Pearson correlation coefficient = 0.91, $p < 10^{-15}$) but showed large individual deviations. Therefore, if the journals are ordered by the JIF, they are not ordered by the annual mean. For example, the mean of Water Research (journal #11 if ordered by the JIF) is three times higher than that of Clinical and Experimental Allergy (journal #10 if ordered by the JIF).
Table 1. Journals that have been used to calculate the failure probability when real merits are calculated by citation counting and evaluation merits are assigned according to the Journal Impact Factor (JIF)\(^a\)

| #  | Journal title               | Papers | JIF  | μ   | σ  | Mean |
|----|-----------------------------|--------|------|-----|----|------|
| 1  | Advanced Materials          | 893    | 14.83| 3.75| 1.10| 19.07|
| 2  | Genome Research             | 246    | 14.40| 3.71| 1.10| 18.62|
| 3  | Neuropsychopharmacology      | 312    | 8.68 | 2.88| 1.00| 6.10 |
| 4  | Cell Death and Differentiation | 210   | 8.37 | 2.96| 0.94| 7.45 |
| 5  | Biomaterials                | 905    | 7.60 | 3.38| 0.84| 10.21|
| 6  | Molecular Ecology           | 476    | 6.28 | 2.74| 1.07| 6.60 |
| 7  | Journal of Infectious Diseases | 629  | 5.85 | 2.47| 1.09| 4.47 |
| 8  | Neurobiology of Diseases    | 303    | 5.62 | 2.77| 0.85| 5.44 |
| 9  | Molecular Microbiology      | 359    | 4.96 | 2.62| 0.81| 4.44 |
| 10 | Clinical and Experimental Allergy | 338 | 4.79 | 2.32| 1.10| 2.38 |
| 11 | Water Research              | 650    | 4.66 | 3.05| 0.87| 7.41 |
| 12 | Experimental Neurology      | 362    | 4.65 | 2.63| 0.98| 5.12 |
| 13 | Journal of Molecular Biology| 439    | 3.90 | 2.35| 0.90| 3.59 |
| 14 | European Journal of Neuroscience | 368 | 3.75 | 2.30| 0.92| 3.54 |
| 15 | Pediatric Infectious Disease Journal | 334 | 3.57 | 1.83| 0.97| 2.16 |
| 16 | Plant Molecular Biology     | 133    | 3.52 | 2.51| 0.90| 4.26 |
| 17 | Neuropsychologia            | 389    | 3.48 | 2.43| 0.82| 3.82 |
| 18 | IEEE Transactions on Geoscience and Remote Sensing | 417 | 3.47 | 2.52| 1.10| 5.32 |
| 19 | Clinical Experimental Immunology | 182 | 3.41 | 2.17| 0.87| 2.99 |
| 20 | BMC Cancer                  | 620    | 3.33 | 2.39| 0.88| 3.99 |
| 21 | Science of the Total Environment | 1024 | 3.26 | 2.61| 0.88| 5.06 |
| 22 | Journal of Inorganic Biochemistry | 265 | 3.20 | 2.30| 0.90| 3.58 |
| 23 | Clinical Neurophysiology    | 345    | 3.14 | 2.04| 1.05| 0.50 |
| 24 | Chemosphere                 | 752    | 3.14 | 2.55| 0.88| 4.57 |
| 25 | Phytochemistry              | 249    | 3.05 | 2.25| 0.78| 3.20 |
| 26 | Journal of Neuroimmunology  | 645    | 3.03 | 1.98| 0.90| 0.66 |
| 27 | IEEE Transactions on Information Theory | 504 | 2.62 | 2.11| 1.12| 3.78 |
| 28 | Analytical Biochemistry     | 441    | 2.58 | 1.79| 0.93| 2.21 |
| 29 | Marine Pollution Bulletin   | 563    | 2.53 | 2.38| 0.92| 2.85 |
| 30 | Ecotoxicology and Environmental Safety | 372 | 2.20 | 2.36| 0.84| 3.63 |
| 31 | American Mineralogist       | 215    | 2.20 | 1.86| 0.94| 2.36 |
| 32 | IEEE Photonic Technology Letters | 684 | 2.04 | 1.78| 1.00| 2.15 |
| 33 | Environmental Toxicology and Pharmacology | 170 | 2.01 | 1.88| 0.91| 2.40 |
| 34 | Journal of the Science of Food and Agriculture | 418 | 1.76 | 1.88| 0.87| 2.25 |
| 35 | IEEE Transactions on Industry Applications | 227 | 1.67 | 2.43| 1.10| 4.72 |
| 36 | Engineering Applications of Artificial Intelligence | 157 | 1.63 | 2.15| 1.02| 3.58 |
| 37 | IEER transactions on Magnetics | 1013 | 1.42 | 1.64| 0.99| 1.87 |
| 38 | Journal of Mathematical Physics | 513 | 1.30 | 1.30| 0.89| 1.11 |
| 39 | Journal of Vacuum Science & Technology B | 334 | 1.27 | 1.39| 0.91| 1.29 |

\(^a\) JIF in 2012. Citations in 2014-2017 to publications in 2012. The values of μ and σ have been calculated based on a lognormal distribution. Annual mean number of citations in 2014-2017.
Next, the probability matrix of pairwise comparisons of these journals, which had been ordered from higher to lower JIFs, was constructed (Table 2; the matrix is large and has been divided by odd and even journal numbers for printing reasons; the complete matrix is presented as supplementary material, Table 1S). The most apparent characteristic of this matrix is that many probability values are very close to 0.5. In most cases, these high probability values correspond to journals with similar JIFs—they are close to the matrix diagonal—but this is not a perfect rule because, as mentioned earlier, the journals when ordered by their JIFs are not ordered according to the mathematical properties of their lognormal distributions. For this same reason a few probabilities are higher than 0.5; for example, journals #5 versus journal #11 is 0.68.

The general conclusion that can be drawn from the data recorded in Table 2 and Table 1S is that in many cases the failure probability of using the JIF for the evaluative comparison of the merit of two papers is quite high (≈ 0.5–0.3). This observation implies that judging the paper’s merit by their JIFs is not very different from making the selection by coin flipping. Only if the difference between the JIFs is very high—for example, 14.8 (journal #1) and 1.3 (journal #39)—is the failure probability really low (≈0.05).

The same general conclusion can be reached from Table 2 in (Milojevic et al, 2017). The figures in our study are similar but not identical to those previously published because the methods of calculation are different. These overall similarities add further support to the notion that, in many cases, evaluating by coin flipping would not be much more wrong than evaluating by the JIFs.

3.2. Probability of failure in evaluations based on the quartile position of journals

Some evaluations are performed by prioritizing papers published in Q1 journals (top 25%) versus those published in Q2 journals (within the top 25%–50% interval) in the same JCR category. Because it is obvious that the JIFs of the journals in the lower part of the Q1 set and in the upper part of the Q2 set will be very similar, the findings in the previous section (Table 2) suggest that the failure probability in evaluations by the Q1 indicator can be very close to 0.5. Furthermore, the data in Table 2 suggest that even in the comparison between journals in the upper part of Q1 and in the lower part of Q2, the expected differences in the JIFs will not be high enough as to predict low probabilities of failing.

To calculate the probabilities of failing in evaluations based on journal quartiles, we considered six journals in four JCR categories: Neurosciences, Biochemistry & Molecular Biology, Environmental Sciences, and Engineering, Electrical & Electronic. Three out of
Table 2. Failure probability when real merits are calculated by citation counting and evaluating merits are assigned according to the Journal Impact Factor (JIF)\(^a\)

| # | 1   | 3   | 5   | 7   | 9   | 11  | 13  | 15  | 17  | 19  | 21  | 23  | 25  | 27  | 29  | 31  | 33  | 35  | 37  | 39  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 0.50| 0.28| 0.39| 0.20| 0.20| 0.31| 0.16| 0.10| 0.17| 0.13| 0.21| 0.13| 0.13| 0.15| 0.17| 0.10| 0.10| 0.20| 0.08| 0.05|
| 3 | 0.50| 0.65| 0.39| 0.42| 0.55| 0.35| 0.23| 0.36| 0.30| 0.42| 0.28| 0.31| 0.30| 0.36| 0.23| 0.23| 0.38| 0.19| 0.14|
| 5 | 0.50| 0.25| 0.26| 0.39| 0.20| 0.11| 0.21| 0.16| 0.26| 0.16| 0.18| 0.21| 0.11| 0.11| 0.25| 0.09| 0.05|       |       |       |
| 7 | 0.50| 0.54| 0.66| 0.47| 0.33| 0.49| 0.41| 0.54| 0.39| 0.43| 0.41| 0.47| 0.34| 0.34| 0.49| 0.29| 0.22|       |       |       |
| 9 | 0.50| 0.64| 0.41| 0.27| 0.43| 0.35| 0.50| 0.33| 0.37| 0.36| 0.42| 0.27| 0.27| 0.27| 0.44| 0.22| 0.16|       |       |       |
| 11| 0.50| 0.29| 0.17| 0.30| 0.24| 0.36| 0.23| 0.25| 0.25| 0.30| 0.18| 0.18| 0.33| 0.14| 0.09|       |       |       |       |       |
| 13| 0.50| 0.35| 0.53| 0.44| 0.58| 0.41| 0.47| 0.43| 0.51| 0.35| 0.36| 0.52| 0.30| 0.23|       |       |       |       |       |       |
| 15| 0.50| 0.68| 0.60| 0.72| 0.56| 0.63| 0.57| 0.66| 0.51| 0.51| 0.66| 0.45| 0.37|       |       |       |       |       |       |       |
| 17| 0.50| 0.41| 0.56| 0.38| 0.44| 0.41| 0.48| 0.32| 0.33| 0.50| 0.27| 0.20|       |       |       |       |       |       |       |       |
| 19| 0.50| 0.64| 0.46| 0.53| 0.48| 0.57| 0.40| 0.41| 0.57| 0.34| 0.27|       |       |       |       |       |       |       |       |       |       |
| 21| 0.50| 0.34| 0.38| 0.36| 0.43| 0.28| 0.28| 0.45| 0.23| 0.17|       |       |       |       |       |       |       |       |       |       |       |
| 23| 0.50| 0.56| 0.52| 0.60| 0.45| 0.45| 0.60| 0.39| 0.32|       |       |       |       |       |       |       |       |       |       |       |       |
| 25| 0.50| 0.46| 0.54| 0.37| 0.38| 0.55| 0.31| 0.24|       |       |       |       |       |       |       |       |       |       |       |       |       |
| 27| 0.50| 0.57| 0.43| 0.44| 0.58| 0.38| 0.31|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 29| 0.50| 0.35| 0.35| 0.35| 0.51| 0.29| 0.22|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 31| 0.50| 0.51| 0.65| 0.44| 0.36|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 33| 0.50| 0.65| 0.43| 0.35|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 35| 0.50| 0.30| 0.23|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 37| 0.50| 0.43|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 39|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |

\(^a\) The name of the journals, JIF, and parameters \(\mu\) and \(\sigma\) of the lognormal distribution of citations of each journal are reported in Table I. Probabilities have been calculated as described in text.
Table 2 (continued)

| #  |  2  |  4  |  6  |  8  | 10  | 12  | 14  | 16  | 18  | 20  | 22  | 24  | 26  | 28  | 30  | 32  | 34  | 36  | 38  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 2  | 0.50| 0.30| 0.26| 0.25| 0.19| 0.23| 0.16| 0.20| 0.22| 0.17| 0.16| 0.20| 0.11| 0.09| 0.16| 0.10| 0.10| 0.15| 0.04|
| 4  | 0.50| 0.44| 0.44| 0.33| 0.40| 0.31| 0.36| 0.38| 0.33| 0.31| 0.38| 0.23| 0.19| 0.32| 0.19| 0.20| 0.28| 0.10|
| 6  | 0.50| 0.51| 0.39| 0.47| 0.38| 0.43| 0.44| 0.40| 0.38| 0.45| 0.29| 0.25| 0.39| 0.26| 0.27| 0.34| 0.15|
| 8  | 0.50| 0.37| 0.46| 0.35| 0.42| 0.43| 0.38| 0.35| 0.43| 0.26| 0.22| 0.37| 0.23| 0.23| 0.32| 0.12|
| 10 | 0.50| 0.58| 0.49| 0.55| 0.55| 0.52| 0.49| 0.56| 0.41| 0.36| 0.51| 0.36| 0.38| 0.45| 0.24|
| 12 | 0.50| 0.40| 0.46| 0.47| 0.43| 0.40| 0.48| 0.31| 0.27| 0.42| 0.27| 0.28| 0.37| 0.16|
| 14 | 0.50| 0.56| 0.56| 0.53| 0.50| 0.58| 0.40| 0.35| 0.52| 0.35| 0.37| 0.46| 0.22|
| 16 | 0.50| 0.50| 0.46| 0.43| 0.51| 0.34| 0.29| 0.45| 0.29| 0.31| 0.40| 0.17|
| 18 | 0.50| 0.46| 0.44| 0.51| 0.35| 0.31| 0.45| 0.31| 0.32| 0.40| 0.19|
| 20 | 0.50| 0.47| 0.55| 0.37| 0.32| 0.49| 0.32| 0.34| 0.43| 0.19|
| 22 | 0.50| 0.58| 0.40| 0.35| 0.52| 0.35| 0.37| 0.46| 0.21|
| 24 | 0.50| 0.33| 0.28| 0.44| 0.28| 0.29| 0.38| 0.16|
| 26 | 0.50| 0.44| 0.62| 0.44| 0.47| 0.55| 0.30|
| 28 | 0.50| 0.68| 0.60| 0.53| 0.60| 0.35|
| 30 | 0.50| 0.33| 0.35| 0.44| 0.19|
| 32 | 0.50| 0.53| 0.60| 0.36|
| 34 | 0.50| 0.58| 0.32|
| 36 | 0.50| 0.27|
| 38 | 0.50|
the six journals were distributed in Q1 and the other three were distributed in Q2. Table 3 shows the probability matrices of pairwise comparisons of the six journals in each JCR category. As expected, the lower probabilities of failure occurred when comparing the two journals with the highest and lowest JIFs, the first in Q1 with the last in Q2. However, even in this case the probability of failure was high—approximately 0.2.

Table 3. Failure probability when real merits are calculated by citation counting and evaluating merits are assigned according to the rank of the journal in Q1 (top 25%) and Q2 (within the top 25% and 50%) in the category lists of the Journal of Citations Reports

| #journal | JIF | #category | 1 | 2 | 3 | 4 | 5 | 6 |
|----------|-----|-----------|---|---|---|---|---|---|
| Neurosciences |
| 3        | 8.68| 1         | 0.50| 0.47| 0.43| 0.33| 0.36| 0.28 |
| 8        | 5.62| 2         | 0.50| 0.46| 0.35| 0.39| 0.29 |
| 12       | 4.65| 3         | 0.50| 0.40| 0.44| 0.34 |
| 14       | 3.75| 4         | 0.50| 0.54| 0.43 |
| 17       | 3.48| 5         | 0.50| 0.38 |
| 23       | 3.14| 6         |     |     |     |     | 0.50 |
| Biochemistry & Molecular Biology |
| 4        | 8.37| 1         | 0.50| 0.44| 0.39| 0.32| 0.31| 0.28 |
| 6        | 6.28| 2         | 0.50| 0.46| 0.39| 0.38| 0.36 |
| 9        | 4.96| 3         | 0.50| 0.41| 0.40| 0.37 |
| 13       | 3.90| 4         |     |     | 0.50| 0.48| 0.47 |
| 22       | 3.20| 5         |     |     |     | 0.50| 0.48 |
| 25       | 3.05| 6         |     |     |     |     | 0.50 |
| Environmental Sciences |
| 11       | 4.66| 1         | 0.50| 0.36| 0.34| 0.30| 0.28| 0.18 |
| 21       | 3.26| 2         | 0.50| 0.48| 0.43| 0.42| 0.28 |
| 24       | 3.14| 3         | 0.50| 0.45| 0.44| 0.30 |
| 29       | 2.53| 4         |     |     | 0.50| 0.49| 0.35 |
| 30       | 2.20| 5         |     |     |     | 0.50| 0.35 |
| 33       | 2.01| 6         |     |     |     |     | 0.50 |
| Engineering, Electrical & Electronic |
| 18       | 3.47| 1         | 0.50| 0.40| 0.31| 0.48| 0.28| 0.21 |
| 27       | 2.62| 2         | 0.50| 0.41| 0.58| 0.38| 0.31 |
| 32       | 2.04| 3         | 0.50| 0.67| 0.46| 0.39 |
| 35       | 1.67| 4         |     |     | 0.50| 0.30| 0.23 |
| 37       | 1.42| 5         |     |     |     | 0.50| 0.43 |
| 39       | 1.27| 6         |     |     |     |     | 0.50 |

* Probabilities have been calculated as described in text

b The name, ranking number, and parameters of the lognormal distributions are recorded in Table 1.

c The ranking number in category is the following: 1, 2, 3, and 4, 5, 6 correspond to journals in the upper, medium, and lower positions in the Q1 and Q2 sets of journals, respectively.

3.3. Probability of failure in evaluations based on publications in Nature and Science
Currently, researchers suffer great pressure to publish in some specific, highly prestigious journals (Lawrence, 2003), and among these journals, *Nature* and *Science* are the most valued. From a mathematical point of view, this method uses the same basis as evaluations by the JIF; i.e., all publications in these selected journals have the same high merit and it does not matter whether the method invokes the high JIFs of these journals.

To investigate the specific case of *Nature* and *Science*, two comparisons were performed, (i) papers in *Nature* and *Science* that are retrieved from a search on the topic “gene*” with papers published in *Genome Research*, and (ii) papers in *Nature* and *Science* that are retrieved from a search using the topic “material*” with papers published in *Advanced Materials* (the asterisk indicates a truncated word). As with cases already cited in Section 2, the distribution of citations of the *Nature* and *Science* papers published in the selected topics did not follow lognormal distributions—the deviations of the means cited in Section 2 were higher than 20%. Therefore, the search was restricted to those papers classified as “articles” by the database. Although the high deviations cited did not occur in either *Genome Research* or *Advanced Materials*, for consistency in all searches, the searches in these journals were also restricted to “articles” only. Table 4 summarizes the characteristics of the citations in the two comparisons, along with the failure probabilities.

Table 4. Failure probability of considering higher merits to papers in *Nature* or *Science* than to papers in specialized journals. Calculations based on lognormal distribution of citations.

| Journal and topic | Number of papers | Mean number of citations | Failure probability | α | σ |
|-------------------|------------------|--------------------------|---------------------|---|---|
| *Nature* and *Science* Topic = gene* | 695 | 217.8 | 0.96 | 4.84 | 0.22 |
| *Genome Research* | 238 | 77.0 | 1.05 | 3.75 | |
| *Nature* and *Science* Topic = material* | 111 | 177.9 | 1.01 | 4.65 | 0.24 |
| *Advanced materials* | 805 | 66.3 | 1.04 | 3.67 | |

*a* Citations in 2014-2017 to publications in 2012. Search restricted to “articles”

*b* *Nature* and *Science* versus *Genome Research* and *Nature* and *Science* versus *Advanced Materials*

Although the JIFs are not available in the conditions of the searches, the mean numbers of citations reflect the JIF difference between *Nature* and *Science* and the specialized journals: 217 versus 77, and 178 versus 66 for genes and material topics, respectively. However, despite these great differences, the failure probabilities were high: 0.22 and 0.24, respectively.
4. Discussion

4.1. JIFs must not be used as a substitute for citation analyses

The goodness of any process of decision making has to be judged by its probability of failure; that is, when the process leads to taking a wrong decision. The JIF is the average of the numbers of citations that the papers published in a journal have received, measured in a specific way; it is used as a metric of the scientific merit of all papers published that journal, with exactly the same merit for all. As has been explained, the use of JIFs for evaluating research or researchers is intuitively misleading because it is impossible that all the papers in a journal have the same number of citations. Consequently, many decisions based on the assumption of higher merit for papers published in journals with higher JIFs will be wrong. This failure occurs when a paper in a journal with a lower JIF receives more citations than another paper in a journal with a higher JIF and, despite this, it receives a lower evaluation.

However, it has to be admitted that in specific circumstances, for example, in recently published papers, the use of the JIFs might be reasonable if the risk of making a wrong decision is low. In fact, all processes of decision making carry a risk of failure, including expert reviews in research evaluations. Unfortunately, in many cases, this risk of failure cannot be calculated, and the goodness of a process has to be discussed only by reasoning, which leads to uncertain and always debatable conclusions. This is not the case with the use of JIFs in evaluations, because in this case the probability of failure can be mathematically calculated, as described in Section 2. Based on this probability the use of JIFs is unacceptable, for the reasons described next.

The results reported in Table 2 show that the failure probability varies depending on the magnitude of the difference between the JIFs that are considered. However, in many real evaluations, JIFs are used to distinguish between two or more candidates who work in similar research areas and that have similar scientific levels; consequently, the JIFs of the journals where they have published their papers are not very different. Small differences in the JIFs also occur when publications in Q1 journals are evaluated above those published in Q2 journals. In this dichotomous procedure, which is problematic in itself (DeCoster et al, 2009), it can be guessed that two publications, one in a journal in the lower part of the Q1 set of publications and the other in the upper part of the Q2 set will be very similar. Furthermore, in practice, even for publications in journals in the upper part of Q1 versus those in journals in the lower part of Q2, the difference between the JIFs is not high enough to lead to a low probability of failing (Table 3).
All this implies that, in most cases of evaluations, the JIFs are similar, and failure probabilities are very high (Tables 2 and 3): slightly below 0.5, which is the failure (or success) probability of coin flipping. Tregoning (2018) defends the use of the JIF, claiming that “papers published in journals with higher impact factors tend, on average, to be better and more important than those in journals with lower ones.” This is true, and the scientific relevance of the papers published in high-JIF journals is not questioned. The mistake arises when the merits of two papers are judged by the JIF. Aside from doubts about whether scientists can be evaluated by the average of the merits of the papers published by others, this paper’s mathematical calculations demonstrate that, in many cases, the risk of failure is unacceptably high. In many cases, it can be as high as in coin flipping, which dismantles all claims based on the tendency of the average.

Another relevant fact that explains the popularity of the use of the JIF for researchers’ evaluations is that the number of citations of approximately 70% of the papers published in a journal is below the mean (Rodríguez-Navarro & Brito, 2018b and references therein), which implies that the use of the JIF benefits to 70% of the papers. Taking together that (i) for those who distribute money and positions “it is easier to tot up some figures than to think seriously about what a person has achieved” (Lawrence, 2003 p. 259), (ii) the process “is also quick—scanning a list of journals takes very little time—and deeply ingrained” (Tregoning, 2018), and (iii) except in comparisons, it over-evaluates 70% of the authors. Therefore, it can be concluded that the use of the JIF might continue for a long time.

In many countries and institutions, researchers suffer an unbearable pressure to publish in one or two leading journals in their research field, making the journal more important than the scientific message (Lawrence, 2003). This procedure has much in common with the use of JIFs because it assigns the same merit to all publications in the blessed journal. Publications in *Nature* and *Science* occupy the zenith of this policy. Therefore, we calculated the failure probability when papers in two other journals in specific topics (genes and materials) are compared with papers in two other specific journals that cover the same topics, *Genome Research* and *Advanced Materials* (Section 3.3). Despite the great differences in the mean numbers of citations between papers in *Nature* and *Science* and in the other two journals (= 200 versus ≈ 70, respectively; Table 4), the failure probability of assigning more merit to *Nature* and *Science* papers is approximately 0.2. This probability is again too high to be acceptable.

If the failure probability in comparative evaluations of two papers by JIFs is high, e.g., 0.5–0.3, it might be considered that when the evaluation is based on many papers, the risk of making a wrong decision could decrease to a reasonably low level. The analysis of
this case is complex because it is not clear how to compare two sets of many papers and the result depends on the method of comparison. However, this analysis is irrelevant because the important conclusion from this paper’s results—that the JIF method is incorrect—is methodological and affects to the basis of the method. Furthermore, in real evaluations, this finding is only the tip of an iceberg as shown below (section 4.3).

Waltman and Traag (2017) consider that “the assumption that journals are very heterogeneous in terms of the values of the articles they publish” (p. 26) is not realistic. Our discussion above, as well as many other studies, is based on this assumption. Although statistical studies that settle whether it is valid could be convenient, experience tells us that it is correct. In fact, authors are conscious that not all papers they published in the same journal have the same value.

4.2. From mathematics to real evaluations

Our approach calculates failure probabilities by a mathematical technique based on an ideal case, which assumes (i) that the number of citations of a paper reveals its scientific merit and (ii) that papers published in different journals responds exclusively to the merits of the papers. The first assumption exceeds any consideration about the use of JIFs because it affects to the use of bibliometrics and will be treated in the next section. Regarding the second assumption (ii), it is fulfilled in very few cases. Real evaluations are more complex because the probability of citation of a paper depends not only on its merit but also on the research field (Waltman, 2016). To overcome this problem, evaluations are performed within lists of journals that have been grouped by research areas: for example, the JCR categories are used in many evaluations by JIF. The problem is that these and other journal lists correct large differences between the JIFs of the journals that are compared, but the differences that remain are still too large. In other words, papers in different fields within the same area and even in different topics within the same field have different probabilities of reaching a certain citation level.

Just to give an example, the JCR category of Dentistry, Oral Surgery & Medicine was selected. The first journal in this category is Periodontology 2000 (2017 JIF = 6.22) and the journal in sixth position is Journal of Clinical Periodontology (2017 JIF = 4.05); these two journals cover the dental specialty of periodontics. In contrast, the first journal that specifically covers the specialty of orthodontics and dentofacial orthopedics: Orthodontics & Craniofacial Research (2017 JIF = 2.08) is in the 26th position of a total of 91 journals, so it belongs to Q2. Thus, the best publications of top researchers in orthodontics will be in Q2 journals.
Consistent with the difference in the JIFs of the top journals, the highest probability that a paper from 2012 received 50 citations up to 2018 (16 October) is 0.058 in the field of periodontitis and of 0.008 in the field of orthodontics. This large difference between the citation probabilities in these two journals that belong to the same research category demonstrates that the research field penalizes some journals in evaluations by the JIF. The consequence of this issue is that if a faculty or college of dentistry selects its academics by the JIF in the JCR category of dentistry or even by citation counting, in a few years, it will end up having many academics working in dental infections and no one working in orthodontics.

In summary, probably few evaluations by the JIF are made in research areas that do not include journals with different citation probabilities due to their field scopes. This drawback has to be added to this paper’s findings of high failure probabilities that occur in the ideal case, where the probability of citation in all journals depends exclusively on the merit of the papers.

4.3. Will there be a bibliometric indicator for evaluating researchers?

In the previous section it is explained that the mathematical calculations of probabilities in this study are based on an ideal case, which assumes that the number of citations of a paper reveals its scientific merit. However, this is not strictly true: Merit and number of citations are only correlated (section 2.1).

A correlation implies that if the regression line is drawn across the data points, most of them will be either above or below the regression line, and many might be far above or below this line. It also implies that if 100 points are chosen at random in the lower, medium, and upper parts of the scatter plot, the average numbers of citations of these sets of data points versus their average scientific relevance will be in the regression line. The conclusion of this simple statistical reflection is that, in research assessment, the use of indicators based on citations has statistical support when the papers of many researchers are aggregated. However, this statistical support does not exist when the approach is applied to an individual paper, an individual researcher, or a low number of researchers.

Even assuming ideal cases in which citations measure merit and the lists of journals include a single research field, the use of the JIFs for the evaluation of researchers introduces a bias against novelty because the JIFs are based on a short-term citation window (Wang et al, 2017) and the citation of these novel papers is delayed. Furthermore, novel papers are not frequently published in journals with the highest JIFs (Wang et al, 2017).
In summary, this mathematical-based study demonstrates that in ideal papers, where the number of citations is a good indicator of relevance, and ideal lists of journals, where their JIFs are not affected by the field scope, the use of the JIFs leads to a high proportion of wrong decisions. For several reasons real evaluations are more complex and none of these reasons can be expected to decrease the failure probability of the JIF method that holds for ideal cases. Just the opposite, if the link between scientific merit and number of citations is a correlation, the conclusion is that for evaluating individual researchers, no type of citation-based indicators should be used; peer evaluation seems to be the only reasonable alternative.

In contrast with individual researchers, percentile-based double rank evaluation should be preferred over expert evaluation for research assessments in countries and institutions (Rodríguez-Navarro & Brito, 2018b). These conclusions outline the logical organization of research assessment in which institutions should evaluate or promote academic staff by expert evaluations. They should find the best experts in order to make the best evaluations and select the best candidates for the benefit of the institution. Then, the success of the institution in comparison to others should be evaluated by percentile-based double rank, assigning incentives to the more successful institutions.

Appendix

Let us consider two papers, A and B, published in two different journals called $J_a$ and $J_b$ respectively. We assume that the distributions of citations obey lognormal distributions $p_a(C_a)$ and $p_b(C_b)$, that depend on parameters $\mu_a, \sigma_a$, and $\mu_b, \sigma_b$, respectively. The mathematical expression of the lognormal probability distribution of obtaining $C$ citations is:

$$p(C) = \frac{1}{\sqrt{2\pi} C \sigma} \exp \left[-\frac{(\ln C - \mu)^2}{2\sigma^2}\right]$$

The goal of this appendix is to calculate the probability that paper B receives more citations than paper A. Start with the probability that A receives $C_a$ citations which is simply given by $p_a(C_a)$. Then the probability that B receives an equal or greater number of citations than A is:

$$P_b(C_b > C_a) = p_b(C_a) + p_b(C_a + 1) + p_b(C_a + 2) + \cdots \approx \int_{C_a}^{\infty} \! dC_b \, p_b(C_b)$$

where it is assumed that a paper B can receive an arbitrarily large number of citations, and, hence, the sum goes to $\infty$. The joint probability that publication A receives $C_a$ citations and B receives more than $C_a$ citations is the product of both expressions as the events are statistically independent:
\[ P(C_a C_b > C_a) = p_a(C_a) \int_{C_a}^{\infty} dC_b \ p_b(C_b) \]

Finally, to find the failure probability, which is the probability that B receives more citations than A, regardless of the number of citations of A, it is necessary to add all possible values of \( C_a \), from zero citations to an arbitrary number:

\[ P = \int_0^{\infty} dC_a \ p_a(C_a) \int_{C_a}^{\infty} dC_b \ p_b(C_b) \]

The last equation has been used to evaluate the probabilities displayed in Tables 2, 3, and 4.

**Acknowledgements**

This work was supported by the Spanish Ministerio de Economía y Competitividad, grant numbers FIS2014-52486-R and FIS2017-83709-R.

**Supplementary material**

Additional information may be found in the online version of this article

Table S1. Complete probability matrix of pairwise comparisons of 39 journals

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