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Maziar Montazerian, Edgar Dutra Zanotto & Hellmut Eckert

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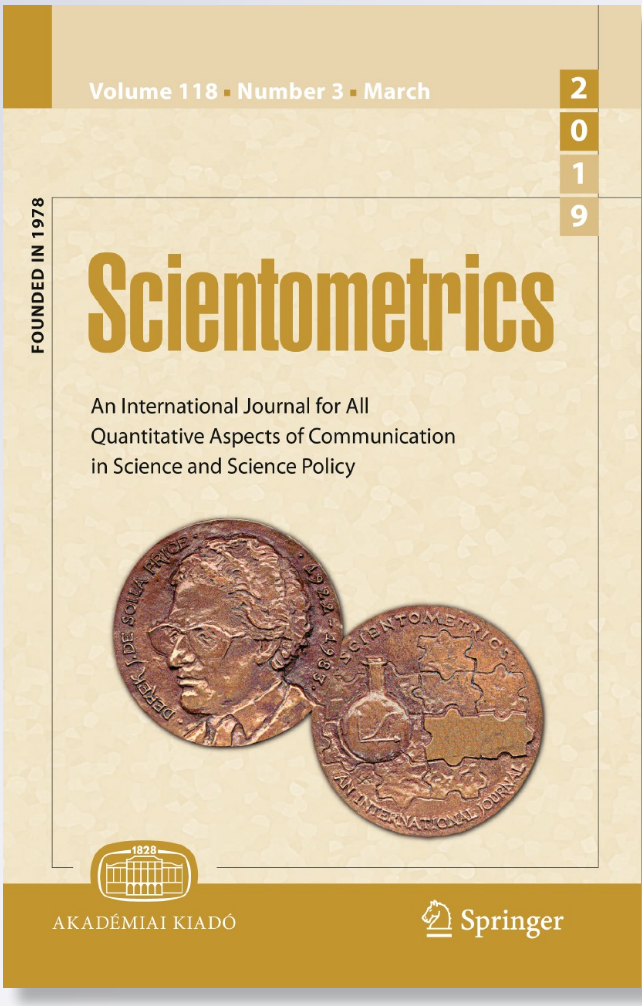

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A new parameter for (normalized) evaluation of *H-index*: countries as a case study

Maziar Montazerian[1,2] · **Edgar Dutra Zanotto**[1,2] · **Hellmut Eckert**[2,3]

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Abstract
It is known that the *H-indexes* of individuals, research groups, institutions, scientific journals, and countries strongly depend on the field of study, slowly increase with the number of publications, *N*, and can be described by empirical power-law functions of the type $H = C \times N^a$ (C and a are constants and depend on the specific field being analyzed). In this paper, we use this function and propose a new index [Montazerian–Zanotto–Eckert (*MZE*)], which is normalized by the number of publications and typically varies from -1 to $+1$, to characterize the relative standing of a research group, institution, or author to those of his/her peer groups. Due to the rich statistics available, as an example, here we analyzed and tested the new parameter against the citation-related performance (*H-index*) of countries. We found that the *MZE* index readily distinguishes between countries that stand above or below the average (for any given number of publications). Generally, publications of countries with a positive *MZE* index are more interesting or visible than the average. Analyzing publication output in this manner instead of the *H-index* allows for a less biased comparison between researchers, journals, universities, or countries for any particular combination of *H-index* and *publication output*.

Keywords Bibliometrics · Countries · *H-index* · *MZE-index* · Citations · Quality

Introduction

The *H-index* was introduced by Jorge E. Hirsch in 2005 to quantify the scientific impact of an individual's research (Hirsch 2005). It is based on the combination of the number of papers published by that person and the number of citations these papers have received.

✉ Edgar Dutra Zanotto
dedz@ufscar.br
http://www.certev.ufscar.br

[1] Department of Materials Engineering (DEMa), Federal University of São Carlos (UFSCar), São Carlos, SP 13.565-905, Brazil

[2] Center for Research, Technology and Education in Vitreous Materials (CeRTEV), Federal University of São Carlos (UFSCar), São Carlos, SP 13.565-905, Brazil

[3] Institute of Physics, São Carlos, University of São Paulo, São Carlos, SP 13.560-970, Brazil

This index is defined as the highest number *H* of publications that have been cited at least *H* times (Hirsch 2005).

The *H-index* has received much more attention and reached much wider acceptance from scientometricians, funding agencies, and university administrators than the 100+ other indexes (Wildgaard et al. 2014; Waltman 2016), including the *g*-index, the highest cited index proposed by Egghe (2006). The *H-index* has often been used to gauge the scientific quality of individual researchers, the impact of journals (Braun et al. 2006), universities, research groups and institutions (Prathap 2006; Meneghini and Packer 2006; Van Raan 2006), and countries (Moravcsik 1985; Jacsó 2009; Babić et al. 2016). Several authors, including ourselves, criticized the (ab)use of the *H-index* as the sole criterion to rank research quality (Montazerian et al. 2017). Shortly after the introduction of the *H-index*, the editorial board of Nature highlighted that journal impact factors, which strongly influence this index, do not tell us as much as some people think about the quality of the science that journals are publishing (Editorial 2005). Taylor et al. (2008) pointed out “Science is in a state of siege. Their ‘all is number’ rationale, made possible and perpetuated by single-parameter bibliometric indices, like the impact factor and the *H-index*, has led to a measurement of scientists, science and science communication with quality being reduced to quantity and with careers hanging in the balance of column totals”. Then, Waltman and Van Eck (2012) criticized the *H-index* from a theoretical point of view. They argued that the *H-index* fails in measuring the overall scientific impact of a scientist (or some other unit of analysis). Based on their insights, they paid special attention to and reviewed highly cited publications indicators. They believe that when scientists are evaluated and compared, it might be better to look at their overall citation distributions (as those shown in this article) rather than to focus on indicators derived from these distributions. Also, Wildgaard et al. (2014) analyzed 108 author-level bibliometric indicators, but could not identify a single indicator that captures the overall relevance of a researcher. Their categorization illustrated clearly that author-level indicators capture individual impact only partially. Finally, Hirsch realized in 2014 that “… The *H-index* can lead to unfair results and should, therefore, be used with care. We should always bear in mind that an *H-index* in a field or subfield is often not comparable with *H-indexes* in other fields or subfields. The *H-index* should never be used as the only factor to evaluate a researcher. There are many “typical” researchers whose *H-index* provides a true picture of their standing in their field compared to other researchers, but there are also many “atypical” researchers whose *H-index* can provide a distorted image” (Hirsch and Buela-Casal 2014). Therefore, several researchers have tried to normalize the *H-index* to career time, research field, number of publications, researchers’ age, and seniority. Extensive literature review on the *H-index* and its variants or normalizations has been provided by Alonso et al. (2009), Egghe (2010), Norris and Oppenheim (2010), Panaretos and Malesios (2009), and Waltman (2016). For the case of countries, Csajbok et al. (2007) have produced some ranked lists of world’s countries regarding their *H-index* in various scientific fields, and have concluded that EU countries have strong positions in all fields, but none of them can successfully compete with the USA. Guan and Gao (2008) have attempted to adapt the *H-index* to evaluate the research performance of different countries. They compared Chinese research performance in the field of bioinformatics using the *H-index* with other countries like USA, UK, Germany, Japan, and India. They found that, as far as publication activity in international journals is concerned, China is very productive in bioinformatics. However, further analyses on the citation share and some surrogate scientometric indicators showed that the publications of Chinese authors have the lowest international visibility compared with the above countries.

Then, Molinari and Molinari (2008) evaluated the *H-index* versus the number of publications, to compare the scientific productivity and visibility. They showed that the *H-index* always increases with the number of publications and follows a power-law model: $H = h_m N^{\gamma}$ (when a large number of papers is analyzed), in which $\gamma = 0.4$, h_m and $N^{0.4}$ are indicators of visibility and productivity, respectively. They suggested that due to its simplicity, in complement to existing indicators, h_m, called impact index, is useful for comparing journals or institutions within a given science field with constant γ.

Also, Prathap (2010) demonstrated that an indicator, having the property, $E = iC$, where i is expressed as the ratio of citations (C) to papers published (N), could be used for bibliometric research assessment. i and C were found to be orthogonal to each other and could be represented on a two-dimensional map, and this two-dimensionality feature could be exploited to devise a new method to rank the leading countries concerning scientific output.

More recently, Babić et al. (2016) collected the numbers of publications and the *H-indices* for the period 2005–2010 for 13 countries of southeast Europe and 251 scientific subfields listed in the Web of Science. They have defined and calculated a scientific performance quality level (SPQL) based on the established best fit of the power-law dependence of $H_{ave} = 3.68\ N^{0.32}$. The formula calculating the value for the SPQL level is:

$$\text{SPQL Level}\ (\%\ ) = 100 \times \frac{H}{H_{ave}} = 100 \times \frac{H}{3.68 \times N^{0.32}}, \tag{1}$$

where H and N are the values of *H-index* and number of publication for a specific country and H_{ave} is the corresponding value on the best average fit line ($H_{ave} = 3.68\ N^{0.32}$). The SPQL values are given in % indicating to which extent they deviate from the average *H-index*. In this manner, a quantitative measure of the quality of scientific output, based on the *H-index,* was proposed by Babić et al. (2016). We are reluctant to address this percentage value as a measure of quality. It is, however, a good representative of *visibility*, which is independent of the number of publications and enables one to compare the *H-indices* corresponding to units with very different quantitative publication output.

In addition to above example of empirical models for *H-index*, the existing theoretical models for the *H-index* include Hirsch's original approach (Hirsch 2005), the Egghe and Rousseau (2006), the Glänzel (2006), and the Schubert and Glänzel (2007) models. Ye (2011) has emphasized that these are power-law type models, and correlate the *H-index* to the number of papers (N) and a criterion for citation rate ($C1$) as follows:

$$H \propto C1^{\beta} \times N^{\alpha}, \tag{2}$$

where α and β are connected and proportional to the Lotka coefficient for the citation distribution (Ye 2011). $C1$ is a constant that, for example, in the simplified models of Schubert and Glänzel (2007), Redner (1998), and Iglesias and Pecharromán (2007), is estimated to be equal to the number of citations per paper (C_t/N, where C_t is the total number of citations).

Ye (2011) has compared three expressions for the *H-index*, including the Hirsch equation, $H \sim C_t^{0.4}$, the Egghe–Rousseau expression, $H \sim N^{0.5}$, and the Glänzel–Schubert equation $H \sim N^{\frac{1}{3}} \times \left(\frac{C_t}{N}\right)^{\frac{2}{3}}$. He concluded that the Glänzel–Schubert expression better correlates with experimental data than the aforementioned correlations. We will show in the "Results" section that the average *H-index* of countries, H_{ave}, indeed follows a power-law model, and the following function fits very well the available data:

$$H_{ave} \sim C \times N^{a}, \tag{3}$$

where C and a are country-specific fitting parameters.

This contribution pursues two distinct objectives:

1. The first is to differentiate the visibility (as inferred by citations) of individuals or groups of similar as well as of diverse scientific outputs (number of published articles). For this task, we introduce a new index (denominated Montazerian–Zanotto–Eckert, *MZE*) by which the standing of any given research group having any particular combination of *H-index* and publication output can be determined.
2. The second objective is to test the applicability and performance of the *MZE* parameter in determining the ranking of different countries concerning citation related performance. The country performance was chosen for this first test of the *MZE* index due to two reasons: the wealth of available statistics, and because the output could, in principle, be relevant and of broad interest to scientometric researchers, funding agencies, and government administrations.

Method

We used the SCImago Journal and Country Rank (SJCR) portal to obtain the number of publications (N) and *H-index* (H) of 235 countries. The SJCR determines N and H using information contained in the Scopus® database from 1996 to 2016 in all fields of knowledge (SCImago 2018). It should be stressed that articles resulting from international collaborations were likely counted multiple times. In other words, articles signed by co-authors affiliated to different countries were attributed to all those countries.

First, we listed the N and H of 235 countries with at least 2 publications in that period. Then we linearized the log(H) versus log(N) plot for data points of $N > 200$ and determined the slope (a), intercept (b), and fitting quality, R^2. In the sequence, we fitted a power-law function: $H_{\text{ave}} = C \times N^a$ to the H versus N data points using a and b, so that $C = 10^b$. As expected, the data points fall above and below the average exponential curve. To identify outliers, we defined two arbitrary, reasonable boundaries as $H_{\text{up}} = (C + 1) \times N^a$ and $H_{\text{low}} = (C - 1) \times N^a$.

Finally, we introduce a new index, *MZE*, formulated by Eq. (4) and shown in Fig. 1. This parameter normalizes the *H-index* by the number of publications and defines the position of each country (research group or an individual researcher) in relation to the upper and lower bounds:

$$MZE = \frac{H - H_{ave}}{\sigma} = \frac{H - H_{ave}}{\left|H_{up/low} - H_{ave}\right|} = \frac{H - CN^a}{N^a} = \frac{H}{N^a} - C \tag{4}$$

The values of C and a are the same for all countries (or group being analyzed). Their values are given in the section "Results". Considering the data range of $-1 \leq MZE \leq 1$, we can observe that

$MZE \sim 1$ implies that the country's research has achieved an exceptionally high average visibility level,

$MZE \sim 0$ indicates that the country´s research has an average visibility level,

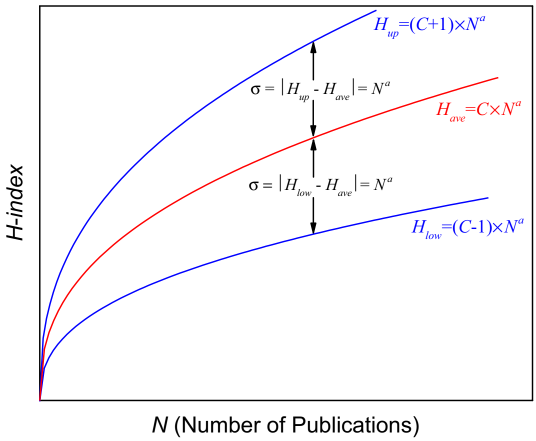

Fig. 1 Graphic definitions of H_{ave}, H_{up}, $H_{\text{low,}}$ and σ used to calculate the *MZE-index*

MZE ~ −1 suggests that the average visibility of the country's research stands close to the lower boundary.

Knowing *N* and the *H-index*, the *MZE-index* of each country can be determined using Eq. (4). The method presented here, Eq. (4), is similar to, but sufficiently different from those suggested by Molinari and Molinari (2008) and Babić et al. (2016). The Molinari article indicates that the higher the coefficient *C* for different groups (e.g., institution or journals) in the same field (constant $a = 0.4$) the better the performance or visibility. Babić et al. (2016) define the visibility by a percentage of *H-index* relative to H_{ave} (Eq. 1). To complement their studies, our index defines upper and lower bounds to find the position of each country (research group or an individual researcher) in relation to the average *H-index*.

Results

Figure 2 ranks the 30 most prolific countries regarding the number of scientific and technical publications in the period 1996–2016. The USA, with 10 million records, stands on the top. China ranks second, with approximately 4.5 million publications, and each of the remaining countries has published less than 3 million articles, with the 30th country, Norway, reaching ¼ million scientific papers in that period.

Figure 3 shows a log–log plot of the *H-index* and number of publications for 235 countries. This correlation is linear, confirming the power law function. We found that the correlation could be improved significantly by excluding the data points with $N < 200$ from the fits (blue data points in Fig. 3). Molinari and Molinari (2008) also built their power-law models on the observation of two zones on a log–log plot. They chose data points for a larger number of papers.

Then, the expression $\log H_{\text{ave}} = \log(C \times N^a) = \log C + a \times \log N$ was fitted to the remaining *H*, *N* data points, which yielded a slope $a = 0.37$ and an intercept $\log C = 0.57$. Therefore, $C = 10^{0.57} = 3.71$ which leads to $H_{\text{ave}} = 3.71 \times N^{0.37}$. It is good to note that the proposed value for the exponent of the power-law functions by Schubert and Glänzel (2007), Molinari and Molinari (2008), and Babić et al. (2016) are 0.33, 0.4, and 0.32 respectively.

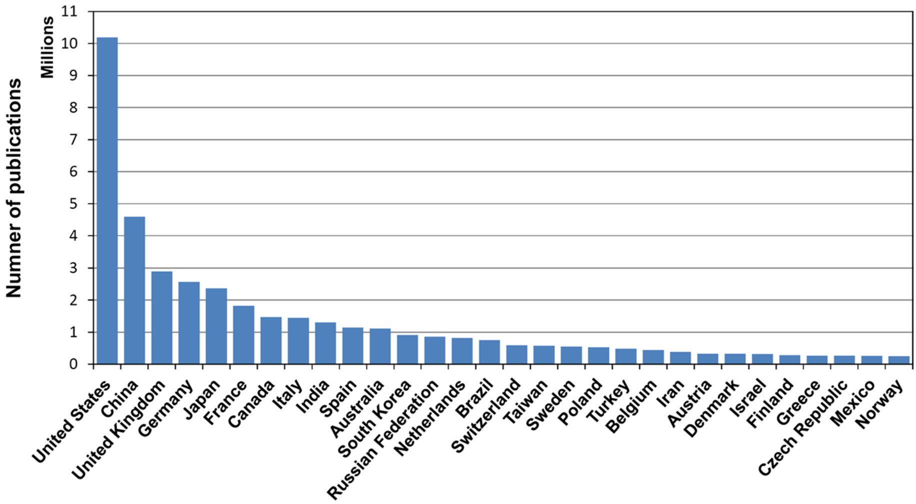

Fig. 2 Country ranking by the number of scientific and technical publications, in all languages, indexed by the SJCR database from 1996 to 2016

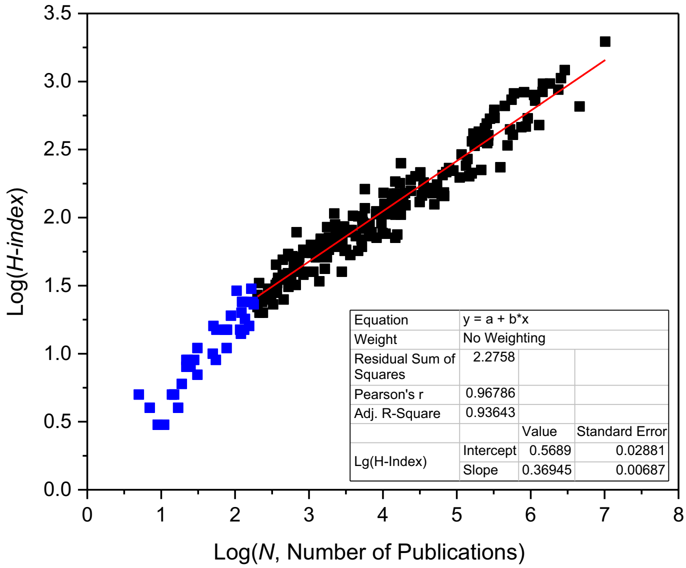

Fig. 3 Log(H) versus Log(N) plot for the 235 countries that have published at least two papers during the period 1996–2016. The slope (a) and intercept (b) of the linear fit are 0.37 and 0.57, respectively, with $R^2 = 0.94$. The blue data points related to $N < 200$ were not considered for the linear fitting. (Color figure online)

Additionally, the average number of total citations per paper (C_t/N) for these 235 countries is 12.56, which yields $(C_t/N)^{\beta} = 5.40$ (for $\beta = 2/3$ in Eq. 2). It should be noted that the studied data set here is highly specific owing to its huge time span, its high diversity of publications' type and the presence of all scientific fields, which perform differently with regard to the *H-index*. However, both the power-law exponent and the coefficient found empirically in this study are close to the values reported in the literature.

All the eleven countries that have more than 1 million publications in the period 1996–2016 are indicated in Fig. 4 by their 3-letter abbreviations. Due to the wide scatter observed in this figure, we defined (smooth) upper and lower bounds by introducing $H_{\mathrm{up}} = (3.71 + 1) \times N^{0.37}$ and $H_{\mathrm{low}} = (3.71 - 1) \times N^{0.37}$, respectively. Therefore, for a given number of publications, some countries fall above the average, and others fall below. In this latter category of countries, the *H-index* of China falls somewhat below the (smooth) lower bound, and India's is very close to it. We will debate possible reasons for these poor citation-related performances of these two countries in the Discussion.

Figure 5a and b show the data for countries with 300k–1M and 100–300k, publications, respectively. In Fig. 5a, the Netherlands, Switzerland, Sweden, Belgium, Denmark, Israel, and Austria are above the upper bound. In contrast, South Korea, Russia, Brazil, Taiwan, and Poland fall below the average but are still above the lower boundary. Iran and Turkey are the countries in this group that stands below or very close to the lower bound. Note that within this group the distribution by country is close to bimodal, with hardly any country showing a performance close to the group average. In Fig. 5b, Finland, Norway, Singapore, New Zealand, and Ireland have the highest *H-indexes* and, therefore, are above or close to the upper bound. On the contrary, Malaysia, Egypt, Ukraine, Romania, and Pakistan rest below or near the lower bound. The remaining countries in this category, such as Argentina, Portugal, Mexico, and Chile stand close to the average *H-index*.

The *MZE* could be used to locate the position of any country for any combination of *H-index* and *number of publications*. Figure 6 summarizes the *MZE-index* of the most prolific 30 countries listed in Fig. 2. A $MZE > 1$ means that the *H-index* is even above the upper boundary, which applies to United States, United Kingdom, Canada, Netherlands, Switzerland, Sweden, Belgium, Austria, Denmark, Israel, Finland, and Norway. Germany, France,

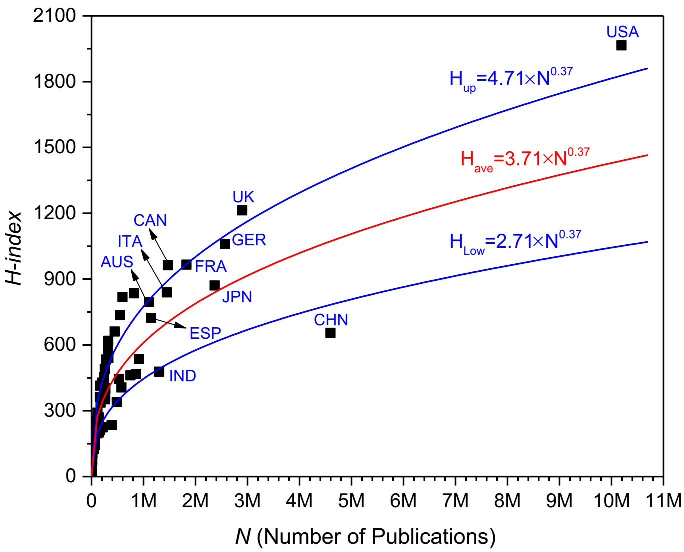

Fig. 4 Average, upper (smooth) and lower (smooth) bounds for the *H-index* versus *number of publications* for 235 countries. Three-letter abbreviations indicate the countries that have published (SJCR counting) more than 1 million articles in the period 1996–2016

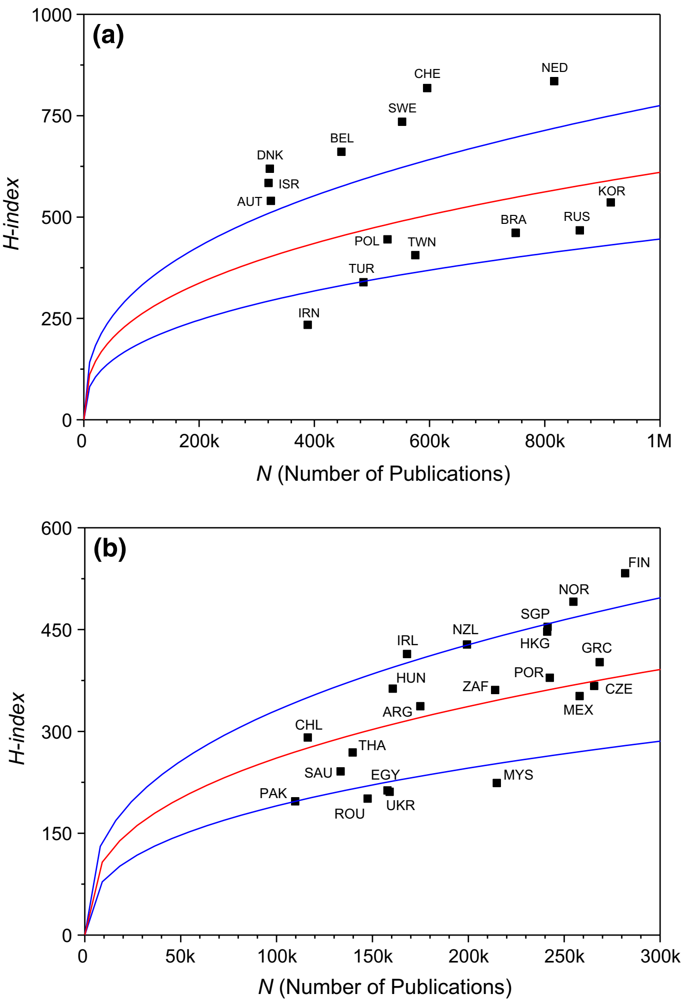

Fig. 5 Zoom-in view of Fig. 4 for **a** 14 countries with 300k–1M, and **b** 21 countries with 100–300k articles published in the period 1996–2016

Italy, and Australia are also close to *MZE* ~ 1. *MZE* ~ 0 signifies an average *H-index*, which is, e.g., applicable to Japan and Greece. South Korea, Russia, Brazil, Taiwan, Poland, Czech Republic, and Mexico have negative *MZE* but still above the lower bound. Turkey has a $MZE = -1$ and thus stands at the lower boundary. China, India and Iran are the only countries which have $MZE < -1$. The USA, with the highest number of publications in the world, has a $MZE = 1.3$ (above the upper bound), whereas Norway has an almost similar MZE of 1.2, but its number of publications is only 2.5% of that of the USA.

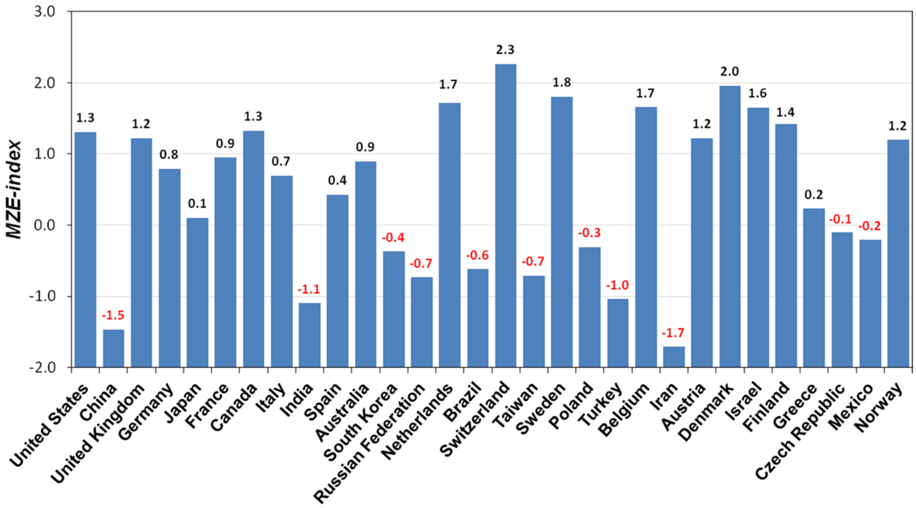

Fig. 6 *MZE-index* of the most prolific 30 countries, i.e., those that have published the largest number of scientific and technical articles in the period 1996–2016. They are listed from left to right according to the total number of publications indexed by the SJCR

Discussion

Considering Fig. 6, we observe that among the 11 countries that have published more than one million papers (Fig. 4) only three countries are found above the defined upper bound *MZE* = 1, whereas this outcome is observed for seven of the 14 countries that have published between 300,000 and 1 million papers (Fig. 5a). On the other hand, this distinction applies to only three of the 21 countries that have published between 100,000 and 300,000 articles (Fig. 5b). Based on this distribution we do not think that the *MZE* as a measure of comparative citation-related performance between countries is biased by the total number of publications but instead relates to profiles that reflect country-specific research and publication habits that are likely influenced by governmental scientific funding policies.

Taking the 30 most prolific countries (Fig. 2), it is seen that their positions relative to the average *H-index* are entirely different. It is relevant to note that among the countries which have published more than 1 million papers (Fig. 4), the most developed ones are close to or above the average *H-index*, but emerging countries, like China and India, are close to the lower bound. The US has an exceptionally large quantity of publications and a relatively high *H-index*. The United Kingdom, Germany, and Japan have almost the same output (~3 million publications), but the UK stands above the latter two. Canada and France stand on higher positions than Australia, Italy, and Spain.

It seems that India and China have not succeeded to attract a proportional amount of citations and visibility in the last 20 years in which their productivity increased significantly. These countries demand more careful analysis. During the period 1997–2001, China's percentage of the world share of citations was only 1.6%, standing in the thirteenth position in the world (King 2004). The citation per paper ratio was only 3 during this period, whereas the highest ratio was close to 10 for Switzerland (King 2004). Jin and Rousseau (2005) and Wu (2004) have analyzed this lag of citations as an indicator of a lack of quality in the system. According to these authors, the following factors in the production system of science contribute to affect Chinese citation-related performance: weak institutional evaluation system for research proposals, low investment in basic research, and lack of internationalization. An additional cause, a weakness in the national peer review system, has been pointed out by Zhou and Leydesdorff (2006). Another relevant aspect that might influence low citation-related performances may be a significant fraction of articles published in Chinese, barring these works from being recognized by the international community. This is a general concern with various other countries, which publish a significant fraction of their research in their national languages. Van Leeuwen et al. (2001) and Van Raan et al. (2011) reasonably suggested that for a fair comparison of countries, non-English publications should be excluded from the calculation of citation impact indicators. They argue that including non-English language publications creates a bias against countries in which researchers publish a lot in their language (Van Leeuwen et al. 2001; Van Raan et al. 2011; Wildgaard et al. 2014).

One might expect that the *MZE* index of such countries would be negatively impacted for three reasons: (1) their non-English articles tend to be scientifically weaker; most authors are aware that the very best journals are published in English; (2) journals that publish in national languages have restricted distribution, and a fraction of them is still difficult to access electronically, and (3) the language barrier severely limits the international readership. To examine the impact of such publication habits on the MZE index, we conducted another analysis limited to only those articles that are published in English. We used the Scopus database to calculate the percentage of non-English publications for the 50 most prolific countries in the period 1996–2016. Countries that published a significant amount of work in other languages during this period (as captured by Scopus) include China (27%), Brazil (16%), France (15%), Spain (15%), Germany (14%), Russia (10%), and Japan (8%). Our analysis indicates that these non-English publications have essentially no effect on the *H-index*. For this reason, the recalculated *MZE-indexes* ignoring the non-English publications tend to increase, reflecting the corresponding decrease of *N*. Overall, however, this re-normalization to papers published in English produces only moderate increases in the *MZE* index, amounting to ~0.2 for China, and ~0.1–0.2, at most, for the other countries. Hence, the overall picture summarized in Fig. 6 does not change significantly.

The effects of international collaboration have been analyzed by Glänzel and Zhang (2018) using the example of 16 developing countries and emerging economies. They found that several countries achieve an impressive citation impact with a considerable share of highly cited papers. A high impact is associated with the intensity of the international collaboration. They suggest that international cooperation might form challenges in building sustainable national science systems and research structures. This analysis could also be valid for most of the developing countries situated near the lower bound in Fig. 5a, b like South Korea, Taiwan, Brazil, Turkey, Iran, Malaysia, etc. It is envisaged that most countries with rather low or moderate visibility and citation impact have only a small share of internationally co-authored papers (<30%) (Glänzel and Zhang 2018). In these cases, the strong differences between papers limited to domestic authors and those involving international collaborators do have an evident effect on the total citation rate, leading to a low share of highly cited papers. This is also valid for Russia and Ukraine, which have a long and healthy scientific tradition, but with a strong focus on national issues and publication in national journals.

To summarize, we have introduced a new parameter (*MZE*) to gauge the citation-related performance of different countries with varying size of publication output. For the 1996–2016 review period, the research topics and resulting publications from the countries with MZE > 0 in Figs. 4 and 5 undoubtedly attracted more attention of their fellow scientists than those from countries with $MZE < 0$. As the *MZE* index normalizes *H-index* by the total number of publications, among countries having the same *H-index* those that published fewer papers show the highest *MZE* index. However, we have already stressed in our previous article (Montazerian et al. 2017) that for gauging quality, other, more holistic criteria, such as the originality, strength, reproducibility, and relevance, as judged by peer review, are better measures of quality than any citation based parameter and cannot be replaced by numerical indexes (Zanotto 2002, 2006).

To check the predicting power of the proposed index for the innovation power of countries, we noticed that all countries (except Hungary) which stand above the average line in Figs. 4 and 5 (or having positive *MZE-index* in Fig. 6) are among the top 30 countries that have reached the highest global innovative index (GII) in 2017 (Dutta et al. 2017). The GII relies on two sub-indexes—the Innovation Input Sub-Index and the Innovation Output Sub-Index—each built around key pillars. Five input pillars capture elements of the national economy that enable innovative activities: (1) institutions, (2) human capital and research, (3) infrastructure, (4) market sophistication, and (5) business sophistication. Two output pillars capture actual evidence of innovation outputs: (6) knowledge and technology outputs and (7) creative outputs. Hungary also has a good rank of 39.

Table 1 compares the rank of the top 30 most innovative countries in 2017 with their *MZE-index*. Except for the Czech Republic, South Korea, and China, all countries have a positive *MZE-index*. Interestingly, 10 top-ranked countries stand above or very close to the upper bound of *H-index*. Additionally, Fig. 7 shows a weak linear correlation of the *MZE-index* with global innovation scores. This comparison was performed for countries having more than 100,000 publications, and China was considered as an outlier to improve the linear fit. This observation proves that the *MZE-index* can capture the most innovative countries and can be regarded as a tool to rank countries according to their scientific visibility. However, we should keep in mind that scientific visibility normalized by the *MZE-index* is not the only parameter which influences the GII scores. The *MZE* index normalizes the *H-index* by the number of publications. In fact, GII is mostly influenced by its 7 pillars and, therefore, not dominantly by the visibility of scientific publications, but by many other factors as well. However, another challenge is whether and how to holistically normalize the *H-index* to account for differences across the scientific priorities of countries, the age and type of publications, language coverage, multi-authorship, international collaboration, and other factors. Ioannidis et al. (2016) discuss the *pros* and *cons* of normalizations using

Table 1 Top-ranked innovative countries in 2017 (Dutta et al. 2017) and their relative *MZE-index*

Rank	Country	*MZE*	Rank	Country	*MZE*	Rank	Country	*MZE*
1	Switzerland	2.26	11	South Korea	−0.37	21	New Zealand	0.97
2	Sweden	1.81	12	Luxembourg	0.18	22	China	−1.47
3	Netherlands	1.71	13	Iceland	3.04	23	Australia	0.90
4	United States	1.31	14	Japan	0.11	24	Czech Republic	−0.10
5	United Kingdom	1.22	15	France	0.95	25	Estonia	0.91
6	Denmark	1.96	16	Hong Kong	0.85	26	Malta	0.17
7	Singapore	0.92	17	Israel	1.65	27	Belgium	1.66
8	Finland	1.42	18	Canada	1.32	28	Spain	0.43
9	Germany	0.79	19	Norway	1.20	29	Italy	0.70
10	Ireland	1.12	20	Austria	1.22	30	Cyprus	0.16

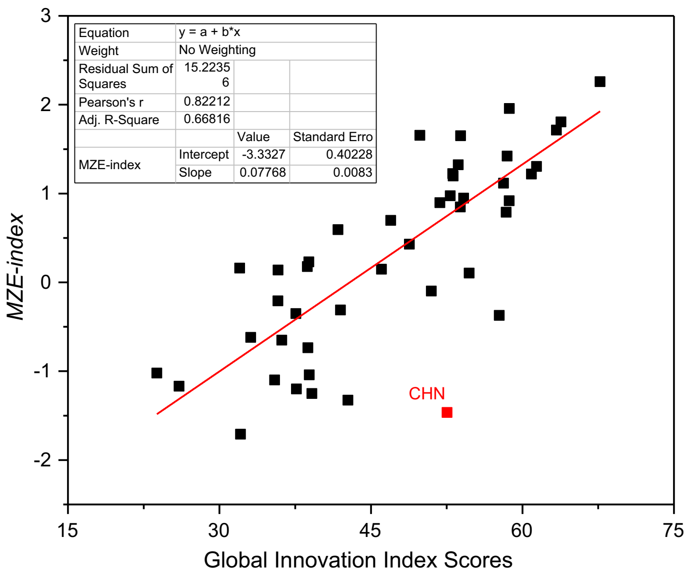

Fig. 7 *MZE-index* versus global innovation index (GII) scores for countries with more than 100,000 publications. China was considered as an outlier to improve the linear fit

different approaches. They believe that citation-based metrics (like the *MZE*) may offer complementary insights, but one should carefully consider the limitations, assumptions, and other factors that underlie their calculation.

Finally, while specific bibliometric indexes based on citations, like the *MZE-index*, indeed capture the most or least active, prolific and visible countries (or an individual or a group of researchers), we should keep in mind that progress or advancement of countries—evaluated by the 7 above-mentioned pillars—is more important than the number of published articles and citations, and this is where countries must concentrate efforts (Zanotto 2002, 2006). Nevertheless, our results corroborate the well-known fact that there is some correlation between both the level of scientific activity and the generation of technology and wealth!

Conclusion

We proposed a new index, denominated *MZE*, which characterizes the relative standing of a research group, institution, or author to those of his/her peer groups. We tested this parameter against the citation-related performance of 235 countries and found that it readily distinguishes countries that stand above or below the average. This index thus provides much better information about the research visibility than solely the *H-index*, and allows for a normalized comparison between journals, universities, countries, and even authors of a particular science field, for any combination of *H-index* and publication output.

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