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Prolificacy and visibility versus reputation in the hard sciences

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Abstract

Some authors (including ourselves) have argued that the research quality of an individual or group has to be evaluated by peer review based on the originality, strength, reproducibility, and relevance of their publications. As a result, a reputation is built up by the community. In this article, we dwell on complementary indicators of a scientist performance—prolificacy and visibility—by critically analyzing a plethora of scientometric data for the hard sciences. Our investigation corroborates the notion that the *H*-indexes (which correlate to both prolificacy and visibility) of the most prolific and most cited researchers strongly depend on the field of study and increase with the total number of publications, *N*. Here we use the MZE-index (defined in a previous article) to distinguish the *H*-indexes of authors that stand at, above or below the average of their field for any number of publications. In addition, we propose a field normalization factor (FNF) which allows one to scale the *H*-indexes of any author or group belonging to different research fields. While neither the MZE nor FNF- normalized *H* indices can guarantee quality or reputation, they show how visible by their community a researcher, research group, or institution is. We also explore a potential correlation of prolificacy and visibility with scientific reputation by comparing the performances of the most cited scientists with those of the winners of important awards in five macro-areas of the hard sciences. This comparison reveals strongly field-dependent features, suggesting that citation-based parameters can be useful, complementary scientometric evaluators, but should not be confused with quality.

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

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Introduction

Performance evaluation of research units (individuals, groups, departments) is an important measure for academic and research funding institutions to optimize the use of their (limited) resources and to improve their mission in research and education. The most important part of this appraisal involves a detailed analysis of the publication output, to be judged by the criterion of "quality and significance". Important aspects of this criterion are (1) the strength of the data and the completeness of the work done in support of the conclusions drawn, (2) the degree of novelty the contributions bring to the current state of the field, and (3) the overall significance of the work in terms of fundamental insight or technology development. Obviously this assessment requires a detailed analysis by experts, which frequently turns out to be unrealistic for lack of time. As a consequence, evaluations are increasingly being based upon bibliometric criteria, to be derived from the total number of publications N (which we call *prolificacy*) and the total number of citations, C_t (which can be viewed as some measure of *visibility*) of the research unit. Because both numbers can only increase with increasing career time of a researcher or the number of members of a given research unit, some procedure of normalization is required.

In 2005, a scholarly paper entitled "*An index to quantify an individual's scientific research output*" (Hirsch 2005) ignited a revolution in bibliometry. Hirsch proposed the H-index, which is the number H of publications that have been cited at least H times as a criterion rating a scientists' impact in the community by a single number. Fourteen years later, it is likely that no other single indicator has had such a profound influence on the professional behavior of researchers, university administrators, and grant funding agencies. At the same time, many, but not all, leading scientists admit that neither the H index nor any of the other circa 110 citation-based indicators proposed subsequently (Wildgaard et al. 2014) are by themselves indications of intellectual value or scientific quality. Some believe that these indicators should be normalized to career time, number of publications, researchers' age, co-authorship, seniority, etc. (Alonso et al. 2009; Egghe 2010; Norris and Oppenheim 2010; Panaretos and Malesios 2009; Waltman 2016), whereas others discuss the *pros* and *cons* of normalization using different approaches. For example, Ioannidis et al. (2016) believe that citation-based metrics may offer complementary insights, but one should carefully consider their limitations, assumptions, and several other factors that underlie their calculation or normalization.

It is now well-accepted that the H-index is also strongly field-dependent (Iglesias and Pecharromán 2007), which creates a serious barrier to a fair evaluation and comparison of the scientific performance of individuals or institutions working in different fields. Some normalized H-indices have been proposed for across field normalization, for instance, by Liang (2006), Sidiropoulos et al. (2007), Iglesias and Pecharromán (2007), Radicchi et al. (2008), Namazi and Fallahzadeh (2010), Claro and Costa (2011). Although some of these parameters are relatively simple to calculate, they have severe limitations. For example, the N-index (Namazi and Fallahzadeh 2010) divides H by the highest H-index of the journals the researcher publishes in. However, in reality, most authors' H-index is based on several articles of different sub-fields of science, hence have no relation to the highest H-index of the journals of his/her major field of study, making this normalized index meaningless. More elaborated alternatives are the X (Claro and Costa 2011), H_f (Radicchi et al. 2008), H-index sequences and matrices indicators (Liang 2006), but they entail multiple complex calculations, dedicated algorithms and software, and the determination of cut-off values, or stretching the exponential distribution to fit the dataset or field characteristics, which significantly increase the complexity and confusion over which data is included in the calculation and how they are evaluated. Also, information lost during data manipulation challenges the validity of the estimates (Wildgaard et al. 2014).

A seemingly more straightforward approach is the field-weighted citation index (FWCI), which can be extracted from the Scopus database for each publication with one mouse click. This index is a number between zero and infinite, and characterizes how well-cited one article is in relation to "comparable articles in the field." An FWCI < 1 indicates a lower citation rate, an FWCI = 1 means that the article is cited with comparable frequency as other articles in the field, and an FWCI > 1 implies higher visibility than the average. The general visibility of an author can then be characterized by performing the FWCI analysis on all of the author's publications, and determine the fraction of those papers that gain an FWCI > 1. An advantage of this method is its ability to evaluate the visibility of authors contributing publications to several research areas. On the other hand, the methodology used in determining what "comparable articles in the field" actually means is rather ill defined and nowhere clearly described, requiring unacceptable leaps of faith on the part of the evaluators in applying this criterion for decision making.

For the above-stated reasons, normalizing the *H*-index to account for the field dependence of citation statistics has remained a challenge. This is probably because proper normalization should take into account various important factors, such as field size (number of researchers), fragmentation (number of sub-areas within a given science field), interdisciplinary effects, and the community publication and citation culture (e.g., mathematicians publish and cite other articles much less frequently than chemists). All these variables are difficult to be extracted and quantified from available databases. In addition, the most relevant question on how H, C_t, and N are related to quality/significance needs to be addressed.

This article explores the possible relationships between the two scientometric indicators: *prolificacy*, and *visibility* on the one hand, and the "quality/significance" criterion which should actually be the relevant one for decision making by university administrators and funding agencies, on the other. We propose and test a way to evaluate an author's visibility normalized by the number of published articles in any research field. For this task, we first use the MZE parameter extracted from H versus N data for the most prolific and the most cited individuals in different science fields. We then propose a research field- and prolificacy-normalized factor (FNF) to account for different publication and citation cultures of different research fields. Finally, we compare the FNF parameters of the most cited researchers in various fields with those of prestigious award winners to assess how prolificacy and visibility are related to scientific *reputation*, which may be accepted as the criterion most closely approximating the *quality/significance* criterion. As the majority of prizes are bestowed upon individuals, we will focus on the latter, as the smallest possible research units.

Methods

Assessing visibility from plots of *H*-index versus number of publications

Among the numerous relations between H and N that have been proposed (Iglesias and Pecharromán 2007; Molinari and Molinari 2008; Babić et al. 2016; Montazerian et al. 2017, 2019) the most straightforward approach is to use the empirical expression

$$H_{\mathrm{ave}} = C \times N^{\mathrm{a}}, \tag{1}$$

for any individual or group being analyzed. The exponent *a* and the coefficient *C* are both proportional to publication and *citation rates*, respectively; describing the sensitivity with which the *H*-index varies with *N*. Theoretical and empirical evaluations of these two parameters have been provided by Ye (2011), Schubert and Glänzel (2007), Redner (1998), Molinari and Molinari (2008), Babić et al. (2016) and Montazerian et al. (2019). For example, the proposed theoretical value for the exponent of the power-law function of Schubert and Glänzel (2007) is 0.33, while Molinari and Molinari (2008), Babić et al. (2016), Montazerian et al. (2019) empirically found 0.40, 0.32, and 0.37, respectively for the special case of countries' *H*-index. *C* has been suggested to be proportional to the average number of citations per paper (Schubert and Glänzel 2007; Redner 1998; Iglesias and Pecharromán 2007). In a specific group being analyzed, e.g., countries, institutions or individuals, a higher *C* reflects higher visibility (Molinari and Molinari 2008; Babić et al. 2016; Montazerian et al. 2019). Based on this reasonable supposition, we recently defined upper and lower bounds for the *H*-index through up/down-scaling *C* by a constant value, δ, as follows:

$$H_{\mathrm{upper}} = (C + \delta) \times N^{\mathrm{a}} \text{ and } H_{\mathrm{lower}} = (C - \delta) \times N^{\mathrm{a}}. \tag{2}$$

We obtained reasonable results for $\delta = 1$ in analyzing the performance of countries (Montazerian et al. 2019). Then, we introduced the MZE-index formulated by Eq. 3. This parameter normalizes the *H*-index by the number of publications and defines the position of any group of interest, e.g., country, institution or a researcher, in relation to the upper and lower bounds of any given research field (Montazerian et al. 2019):

$$\mathrm{MZE} = \frac{H - H_{\mathrm{ave}}}{\left| H_{\mathrm{upper/lower}} - H_{\mathrm{ave}} \right|} = \frac{H - C \times N^{\mathrm{a}}}{\delta \times N^{\mathrm{a}}} = \frac{H}{\delta \times N^{\mathrm{a}}} - \frac{C}{\delta} \tag{3}$$

The MZE differentiates the visibility (as inferred by citations) and determines the standing of any research unit in relation to the average *H*-index for any particular combination of *H*-index and publication output, within a given field. Applied to an individual researcher, an MZE ~ 1 implies that the researcher has achieved a very high visibility level, whereas an MZE ~ 0 indicates that the researcher has an average visibility level, and finally MZE ~ − 1 suggests that the average visibility of the researcher stands close to the lower border (Montazerian et al. 2019).

Data extraction

Most prolific individuals

We used the Scopus database, which indexes more than 22,000 serial scientific titles, to find the most prolific scientists in the fields of cosmology, graphene, lithium ion battery, metallic glasses, oxide glasses, and number theory. We searched Scopus in the subject area of hard sciences for publications from 1815 up to December 31, 2017, using the keywords listed in Table 1, selecting researches who published more than 10 papers. In the specific case of Number Theory, we also extracted the *H* and *N* for the editors of the Journal of Number Theory to improve the statistics. Then, we listed all researchers of these different science fields based on their total of publications (*N*) in that area. For each scientist, the *N*, the *H*-index, the total number of citations, as well as the first and last publication year were

Table 1 Keywords used to find the 100 most prolific in different fields. *Source*: www.scopus.com

Fields	Search strategy
Cosmology	TITLE(cosmology) AND PUBYEAR < 2017
Graphene	TITLE(graphene) AND PUBYEAR < 2017
Lithium ion battery	TITLE(lithium ion battery) AND PUBYEAR < 2017
Metallic glasses	TITLE(glass* AND metal) OR TITLE(amorphous AND metal) OR TITLE(glass* AND alloy) OR TITLE(amorphous AND alloy) AND NOT TITLE(Oxide OR Ceramic* OR seal* OR organic OR polymer* OR macromolecule* OR macro-molecule* OR glass–ceramic* OR electrode OR spin OR ionomer)) AND PUBYEAR < 2017
Oxide glasses	TITLE(glass* OR glass–ceramic* OR vitreous* OR non-cryst*) AND NOT TITLE (organic OR polymer* OR macromolecule* OR macro-molecule* OR metal* OR alloy* OR steel* OR electrode OR spin OR ionomer)) AND PUBYEAR < 2017
Number theory	TITLE("number theory") AND PUBYEAR < 2017 AND Editors in Journal of NUMBER THEORY

extracted. Scientists who stopped publishing five or more years ago were excluded. While the group of the 100 most prolific individuals comprises those individuals who have the highest number of publications in the field selected, i.e., in cosmology, graphene, oxide glasses, etc., the H versus N plots are based on the *total number of papers* published by those individuals and thus may also include papers in other subject areas. Since it was impossible to obtain a statistic for all the workers active in each given field, we had to select representative groups for each field. To make a valid comparison, these different groups should have something in common. To us, the idea of comparing the 100 most prolific scientists for each area was a convincing common feature, based on which the field dependence of H versus N plots could be documented. If one chose, instead, the 1000 most prolific scientists in each field, the statistics would be improved, of course.

Most cited researchers and award winners

In a separate but related analysis of macro-fields, we obtained the list of the most cited individuals in space science, chemistry, physics, materials science, and mathematics in 2017 from the clarivate webpage (http://www.clarivate.com), and then all the above-mentioned bibliometric data for these most cited scholars were also extracted from Scopus. The selection of the highly cited researchers was taken from the Essential Science Indicators (ESI) in the period 2003–2016, which includes highly cited papers—each paper ranked in the top 1% by total citations according to their ESI field assignment and year of publication. All the papers were assigned to one of 22 broad science fields. A ranking of author names in each ESI category by the number of highly cited papers produced in that period determined the selection of the most cited researchers. Finally, we also determined bibliometric data for prestigious prize winners (pw) in the above-mentioned science fields. We chose the unquestionably outstanding awards listed in Table 2.

H_{ave} and MZE-index

We listed the N and H of all most prolific and most cited researches with at least 10 publications for the keywords used and in the period. Then we linearized the lg(H) versus lg(N)

Table 2 The search strategy used to find most cited researchers and award winners in different fields. *Source*: www.clarivate.com

Fields	Search strategy
Space science	102 most cited in 2017 + Gruber prize winners in cosmology
Chemistry	212 most cited in 2017 + Nobel prize winners in last 15 years
Materials science	150 most cited in 2017 + Acta materialia/biomaterialia gold medalists
Physics	192 most cited in 2017 + Nobel prize winners in last 15 years
Mathematics	96 most cited in 2017 + Fields medal winners that are still alive

plot and determined the slope (*s*), intercept (*b*), and fitting quality, R^2. In the sequence, we fitted a power-law function: $H_{ave} = C \times N^a$ to the *H* versus *N* data points using *s* and *b,* so that $C = 10^b$. The fitting quality (R^2) values for most prolific/cited researchers were only ~ 0.5–0.6 indicating, as expected, the unavoidable scatter of these data. However, Montazerian et al. (2019) have shown that if richer statistics are analyzed, e.g., in the case of countries, the *H*-index, log–log correlation of *H* and *N* would be, in fact, very close to linear ($R^2 > 0.9$). Examples for $\lg(H) - \lg(N)$ graphs are given in the Results Section (Fig. 2) and Figure S1 and S2 (supplementary material). Above all, the fitted functions show the power-law trend lines for the H_{ave} versus *N* plots. To identify outliers in H_{ave} versus *N* graphs; we defined two arbitrary, yet reasonable boundaries using Eq. 2, in which we selected $\delta = 1$ and 2 for the most prolific researchers and most cited scientists, respectively. Finally, we used the MZE-index, formulated by Eq. 3, to normalize the *H*-index by the number of publications and to define the position of each researcher in relation to the upper and lower bounds. By knowing the *N* and *H*-index, and the *C*-value for the research field considered, the MZE-index of each individual can be determined using Eq. 3.

Field normalized factor (FNF)

Using the expression for H_{ave}, which was found empirically for different fields, we introduce a field normalized factor (FNF_{N_1}) for a particular number of publications (N_1), which is formulated by Eq. 4 and shown in Fig. 1. The FNF is defined by the area under

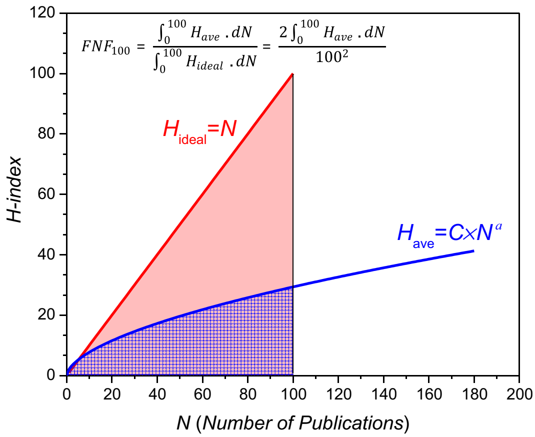

Fig. 1 Graphic definitions of H_{ave} and H_{ideal}, and calculation of field normalized factor (FNF) for an arbitrary number of publications, here taken as 100 ($N_1 = 100$)

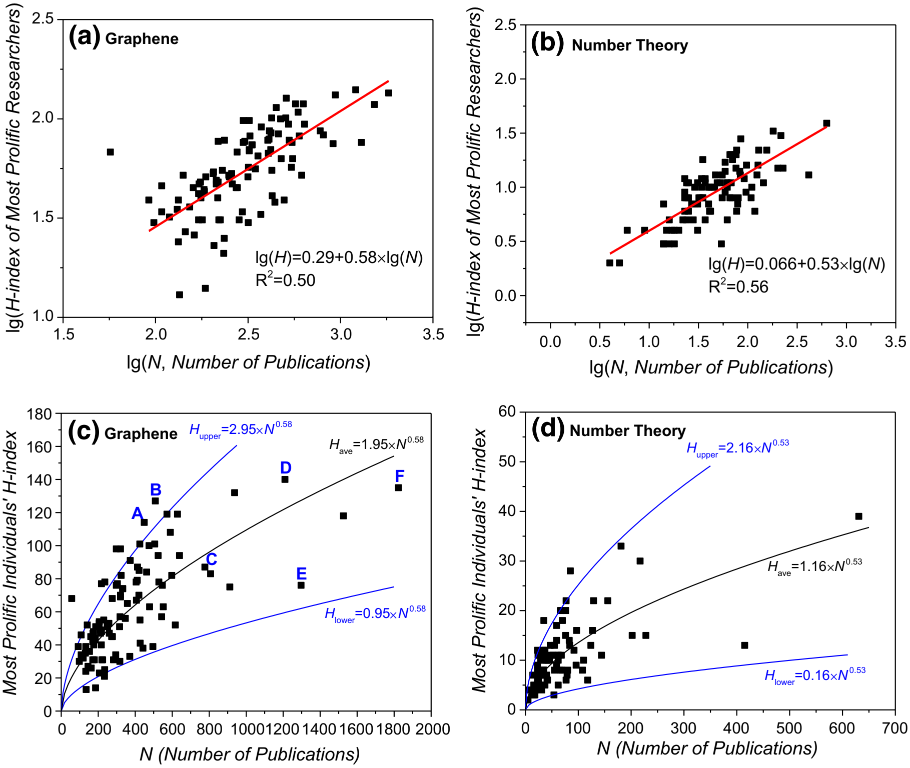

Fig. 2 Examples of lg(H) versus lg(N) plots for Most prolific researchers in the fields of **a** graphene and **b** number theory. Examples of H-index (H_{ave}, H_{upper} and H_{lower}) versus N plots, obtained for the same researchers in the fields of **c** graphene and **d** number theory. Performances of six individual researchers denoted as A through F are discussed later by MZE index (see Table 3 for further analysis)

the H_{ave} versus N curve (of a given science field) divided by the maximum area calculated from $H_{ideal} = N$.

$$\mathrm{FNF}_{N_1} = \frac{\int_0^{N_1} H_{ave} \cdot \mathrm{d}N}{\int_0^{N_1} H_{ideal} \cdot \mathrm{d}N} = \frac{2\int_0^{N_1} C \times N^a \cdot \mathrm{d}N}{N_1^2} = \frac{2C \times N_1^{a+1}}{(a+1) \times N_1^2} = \frac{2C \times N_1^{a-1}}{a+1}, \quad (4)$$

where N_1 is an arbitrary number of publications used for normalization (e.g., taken as 100 in Fig. 1).

Then, the normalized H-index of each researcher can be calculated by Eq. 5 for any particular number of publications:

$$H_{normalized} = \frac{H \times \mathrm{FNF}_{ref.}}{\mathrm{FNF}_{field}}, \quad (5)$$

where $\mathrm{FNF}_{ref.}$ means the FNF of a reference field. Note that because of the non-linear dependence of H upon N the FNF is dependent on the number N_1 of publications from which it is computed. Thus, to assess the field-normalized visibility of a researcher, $H_{normalized}$ must be obtained by using FNF_{field} for the same number, N_1, of publications.

Table 3 Number of publications, *H*-index and MZE for researchers A, B, C, D, E and F in the field of graphene as indicated in Fig. 2c

Researchers	A	B	C	D	E	F
Number of publications	450	509	777	1210	1297	1823
H-index	114	127	87	140	76	135
MZE-index	1.35	1.47	−0.12	0.33	−0.76	−0.22

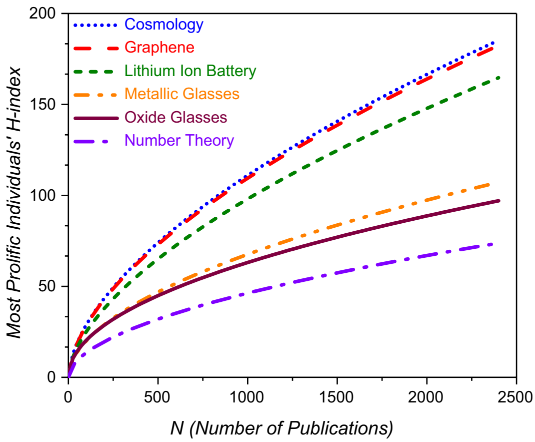

Fig. 3 H_{ave} versus *N* plots of the most prolific individuals in different interdisciplinary fields

Results and discussion

H_{ave}, MZE and FNF parameters for most prolific individuals

Figure 2a, b show log–log plots of the *H*-index versus number of publications for the *most prolific* researchers in two selected research fields, graphene and number theory. Other graphs are shown in Figure S1 in the supplementary material. The best function fitted to the log–log data points is linear, showing the trend. Then, Fig. 2c, d show the power-law functions ($H_{ave} = C \times N^a$) fitted to the *H* versus *N* data points using the slope and intercept obtained from Fig. 2a, b. Likewise, all H_{ave}–*N* plots for the groups of interest in this study are provided in Figure S3 in the supplementary material.

To illustrate the utility of the MZE-index consider the values calculated for the six researchers A–F in Fig. 2c (see Table 3). We observe that among these researchers who have published a very high number of articles (researchers C, D, E, F) in the field of graphene, none of them could get close to the defined upper bound MZE = 1, whereas this outcome is observed for the researchers A and B, whose *N* is significantly less (cf. Table 3 and Fig. 2c). Based on this distribution, we argue that the MZE, as a measure of comparative citation-related performance between individuals, is not biased by the total number of publications but, instead, relates to profiles that reflect researcher-specific visibility.

Figures 2 and S3 illustrate that within the group of the most prolific researchers, the dependence of H_{ave} on *N* depends greatly on the field of study. This field dependence is most compactly illustrated in Fig. 3. Note how the *H*-indexes in the fields of cosmology and graphene increase much more steeply with *N* compared to the slow increase of *H*-index in the fields of oxide glasses or number theory. Renormalization via Eq. 5

makes it possible to compare the visibilities of researchers working in these two different areas. For example, a researcher who works in the field of oxide glasses and has published a total number of 200 papers reaches, on average, an *H*-index of 28. If his/her *H*-index is normalized relative to the field of cosmology using Eq. 5 and the FNF factors in Table 4, his/her *H* would be raised to $28 \times \frac{0.26}{0.19} = 38$, very close to the average value (~41) in cosmology for the same number of articles.

H_{ave}, MZE and FNF parameters for most cited individuals

We also analyzed the *H*-indices of the *most cited* researchers in five different macro-fields. Examples of the corresponding lg(*H*) versus lg(*N*) plots are shown in Fig. 4 and S2, indicating again a linear correlation. Further details can be seen from the power law fits presented in Fig. 5 and also comparatively in Fig. 6. In this case, reasonable upper and lower bounds were found by selecting $\delta = 2$ (Eq. 2) which is twice as large as in the case of most prolific researchers. This is not truly surprising as the numbers of citations received by the most cited researchers are by definition higher than those of the most prolific scientists. Table 5 is the summary of the H_{ave}, H_{upper}, H_{lower}, MZE, and FNF obtained from these figures using Eqs. 3 and 4. Similarly to the results for the most prolific researchers, the MZE index, formulated by Eq. 3 and shown in Table 5, can be used to find the position of each researcher. Note that within the group of the ~100 most cited researchers the H_{ave} versus *N* curves for five out of six macro-fields resemble each other, while the plot for the field of mathematics stands out as very different.

Additionally, Fig. 5a–e include the data of the winners of prestigious prizes that are awarded in the different macro-fields (see Table 2). Again, some are close to upper bounds; but there are several others that stand near the average *H*-index, or even fall below it. As detailed further below, this relation between citation statistics and *reputation* appears to be highly dependent on the macro-field considered.

As discussed above the vast differences observed in the *H* versus *N* plots of the most prolific researchers working in different research fields (Fig. 3) may be accounted for by the FNF scaling factor, allowing visibilities of researchers of different research areas, but having comparable quantitative research outputs, to be compared to each other.

Table 4 H_{ave}, H_{upper}, H_{lower}, and formulation of MZE and FNF parameters for the most prolific researchers in different multidisciplinary fields. The FNF was calculated for $N_1 = 200$

Fields	H_{ave}	H_{upper}	H_{lower}	MZE	FNF	FNF_{200}
Cosmology	$1.95 \times N^{0.58}$	$2.95 \times N^{0.58}$	$0.95 \times N^{0.58}$	$\frac{H}{N^{0.58}} - 1.95$	$\frac{3.9 \times N_1^{-0.42}}{1.58}$	0.26
Graphene	$1.95 \times N^{0.58}$	$2.95 \times N^{0.58}$	$0.95 \times N^{0.58}$	$\frac{H}{N^{0.58}} - 1.95$	$\frac{3.9 \times N_1^{-0.42}}{1.58}$	0.26
Lithium ion battery	$1.64 \times N^{0.59}$	$2.64 \times N^{0.59}$	$0.64 \times N^{0.59}$	$\frac{H}{N^{0.59}} - 1.64$	$\frac{3.28 \times N_1^{-0.41}}{1.59}$	0.23
Metallic glasses	$1.77 \times N^{0.53}$	$2.77 \times N^{0.53}$	$0.77 \times N^{0.53}$	$\frac{H}{N^{0.53}} - 1.77$	$\frac{3.54 \times N_1^{-0.47}}{1.53}$	0.20
Oxide glasses	$2.11 \times N^{0.49}$	$3.11 \times N^{0.49}$	$1.11 \times N^{0.49}$	$\frac{H}{N^{0.49}} - 2.11$	$\frac{4.22 \times N_1^{-0.51}}{1.49}$	0.19
Number theory	$1.16 \times N^{0.53}$	$2.16 \times N^{0.53}$	$0.16 \times N^{0.53}$	$\frac{H}{N^{0.53}} - 1.16$	$\frac{2.32 \times N_1^{-0.47}}{1.53}$	0.12

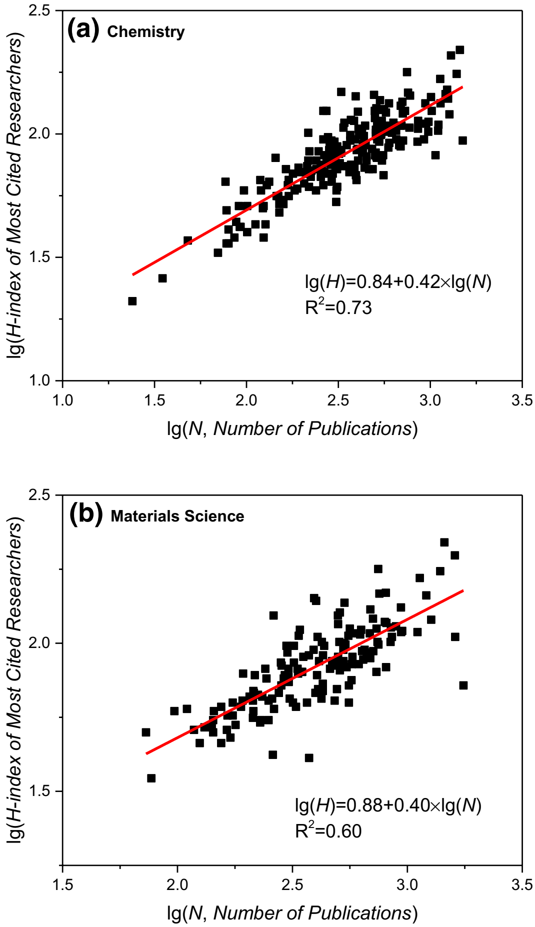

Fig. 4 Examples of lg(*H*) versus lg(*N*) plots for the most cited researchers in **a** chemistry and **b** materials science. The figures for other fields are provided as supplementary material (Figure S2)

Correlation of prolificacy and visibility with reputation

The current preoccupation of researchers with their citation impact statistics arises from the legitimate desire of University administrators and funding agencies to base decisions regarding the distribution of research infrastructure and financial support on the *quality and significance* criterion. In the past, such scientometric analysis mostly involved the numbers *N* (prolificacy), C_t (citation impact) and *H* index, with their obvious bias problematics discussed above. At the level of the individual researcher, this *quality/significance* is most effectively embodied in the *scientific reputation* as documented by professional awards and prizes. Figure 5 investigates a potential correlation between prolificacy, visibility and reputation on the basis of the *H* versus *N* plots of the most cited scientists working in the five macro fields—space science, mathematics, physics, chemistry, and materials science—with those of the holders of prestigious awards in those areas.

As for *prolificacy,* there appears to be a strong correlation with reputation only in the area of space science (Fig. 5a). In contrast, in other areas, prize winners, in general, publish much less than most cited researchers! For example, Fig. 5d, e suggest that in the areas of

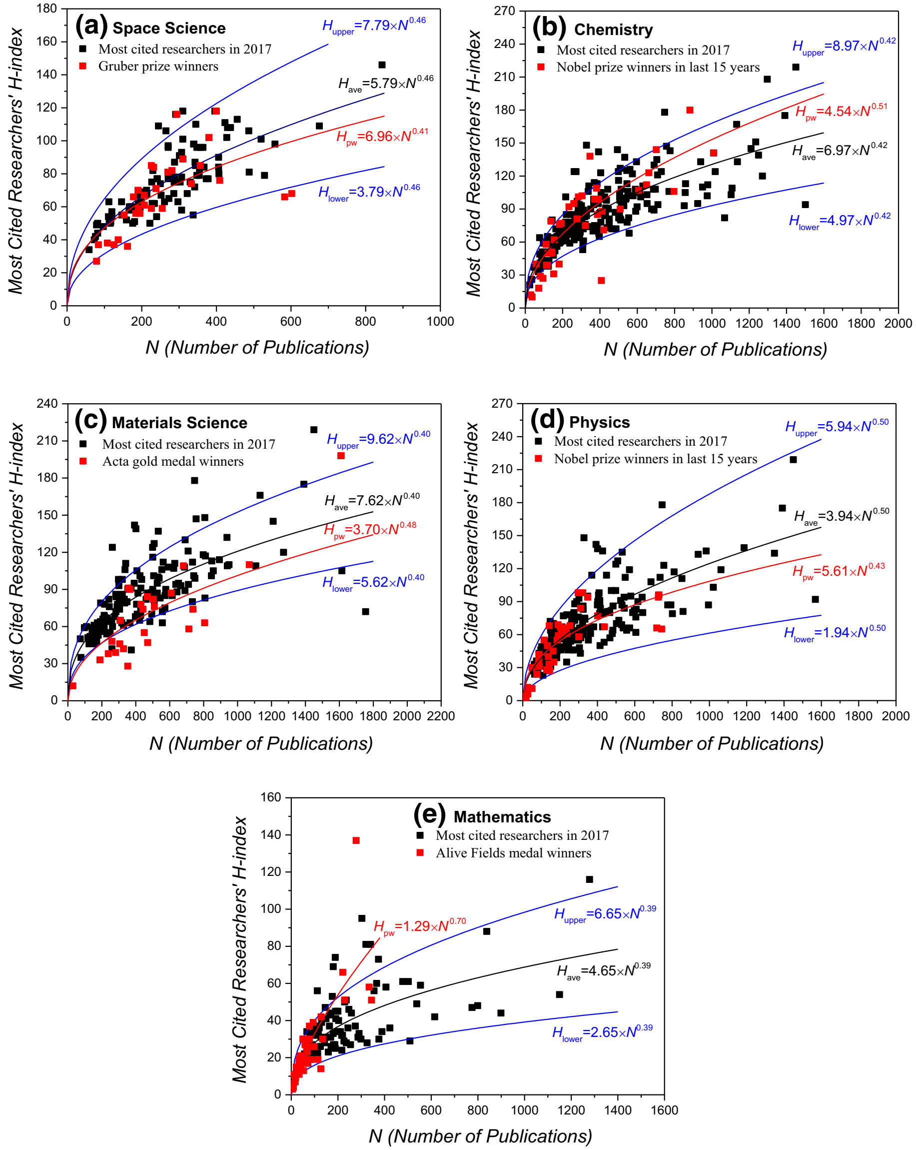

Fig. 5 H-index (H_{ave}, H_{upper} and H_{lower}) versus N plots for the most cited researchers in the five macro-fields of **a** space science, **b** chemistry, **c** materials science, **d** physics, and **e** mathematics. The positions of prize winners and their average H-index ($H_{pw} = H$-indexes of prize winners) are indicated by red points and lines, respectively

mathematics and physics, prize winners tend to publish significantly fewer papers on average than the 100 most cited scientists. Only five of the prestigious Fields Medal winners in mathematics and three Noble Laureates in physics have published more than 200 and 500 papers, respectively. On the whole, these data suggest rather an *anti-correlation* between prolificacy and reputation in these two areas. While there is an overall wider scatter of the

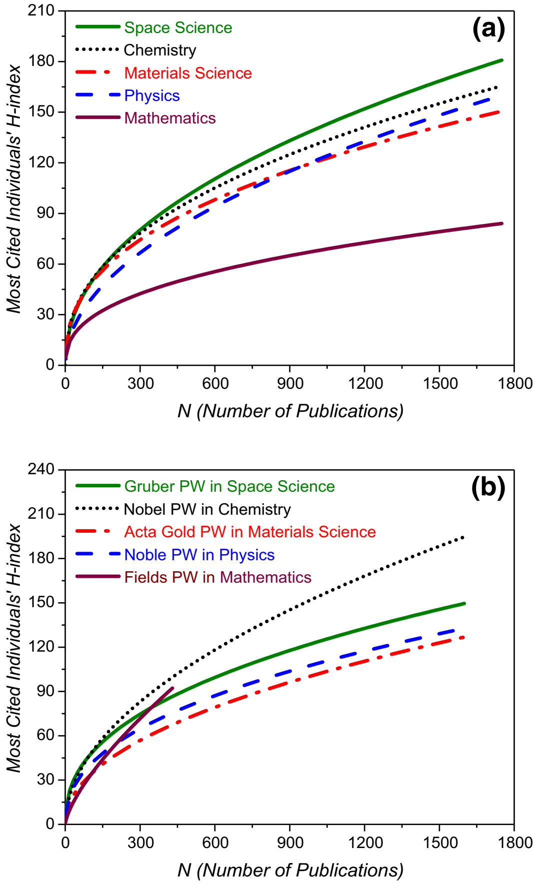

Fig. 6 Comparison between the **a** H_{ave} of the most cited individuals in different interdisciplinary fields and **b** H_{pw} of prize winners (pw) in the same fields

data in the areas of Chemistry and Materials Science, Fig. 5b, c do not suggest any correlation between prolificacy and reputation either. It is also relevant that the average *H versus N* curves for the prestigious award winners of four fields are quite close to the overall average of each field. The exception is Mathematics, for which the average *H* versus *N* of the Fields prize winners is close to the upper limit.

Ioannidis et al. (2018) have pointed out that “there are thousands of scientists who publish a paper every 5 days,” while they concede that “such hyper-prolific authors might include some of the most energetic and excellent scientists.” They also observed that “such modes of publishing might also reflect “idiosyncratic field norms, to say the least.” We agree with their view that loose definitions of authorship, bred by the previous emphasis of evaluations based on *N*, make it increasingly difficult to assign credit appropriately. Given the fact that a researcher’s most precious and limited resource is time, dividing up this annual resource into 100 small parcels, 10 substantial contributions or one monumental work is best left up to the individual’s discretion (Zanotto 2006). Based on this consideration, a correlation between prolificacy and quality is not even expected. At best prolificacy measures a researcher`s devotion to the creation of texts and his/her effectiveness of getting them published somewhere. At worst it measures an individual`s networking and shareholding abilities (or at the very worst—abuse

Table 5 H_{ave}, H_{upper}, H_{lower}, and formulation of MZE and FNF parameters for most cited researchers and prize winners (pw) in different multidisciplinary fields

Fields	H_{ave}	H_{upper}	H_{lower}	MZE	FNF	FNF_{200}
Space Science	$5.79\times N^{0.46}$	$7.79\times N^{0.46}$	$3.79\times N^{0.46}$	$\frac{H}{2\times N^{0.46}}-\frac{5.79}{2}$	$\frac{11.58\times N_1^{-0.54}}{1.46}$	0.46
Chemistry	$6.97\times N^{0.42}$	$8.97\times N^{0.42}$	$4.97\times N^{0.42}$	$\frac{H}{2\times N^{0.42}}-\frac{6.97}{2}$	$\frac{13.94\times N_1^{-0.58}}{1.42}$	0.45
Materials Science	$7.62\times N^{0.40}$	$9.62\times N^{0.40}$	$5.62\times N^{0.40}$	$\frac{H}{2\times N^{0.40}}-\frac{7.62}{2}$	$\frac{15.24\times N_1^{-0.60}}{1.40}$	0.45
Physics	$3.94\times N^{0.50}$	$5.94\times N^{0.50}$	$1.94\times N^{0.50}$	$\frac{H}{2\times N^{0.50}}-\frac{3.94}{2}$	$\frac{7.88\times N_1^{-0.50}}{1.50}$	0.37
Mathematics	$4.65\times N^{0.39}$	$6.65\times N^{0.39}$	$2.65\times N^{0.39}$	$\frac{H}{2\times N^{0.39}}-\frac{4.65}{2}$	$\frac{9.30\times N_1^{-0.61}}{1.39}$	0.26
Gruber pw in space science	$6.96\times N^{0.41}$	$8.96\times N^{0.41}$	$4.96\times N^{0.41}$	$\frac{H}{2\times N^{0.41}}-\frac{6.96}{2}$	$\frac{13.92\times N_1^{-0.59}}{1.41}$	0.43
Nobel pw in chemistry	$4.54\times N^{0.51}$	$6.54\times N^{0.51}$	$2.54\times N^{0.51}$	$\frac{H}{2\times N^{0.51}}-\frac{4.54}{2}$	$\frac{9.08\times N_1^{-0.49}}{1.51}$	0.44
Acta gold pw in materials science	$3.70\times N^{0.48}$	$5.70\times N^{0.48}$	$1.70\times N^{0.48}$	$\frac{H}{2\times N^{0.48}}-\frac{3.70}{2}$	$\frac{7.40\times N_1^{-0.52}}{1.48}$	0.31
Nobel pw in physics	$5.61\times N^{0.43}$	$7.61\times N^{0.43}$	$3.61\times N^{0.43}$	$\frac{H}{2\times N^{0.43}}-\frac{5.61}{2}$	$\frac{11.22\times N_1^{-0.57}}{1.43}$	0.38
Fields pw in mathematics	$1.29\times N^{0.70}$	$3.29\times N^{0.70}$	$0.29\times N^{0.70}$	$\frac{H}{2\times N^{0.70}}-\frac{1.29}{2}$	$\frac{2.58\times N_1^{-0.30}}{1.70}$	0.31

FNF was calculated for $N_1=200$

of administrative power) to get his/her name included in the authors` list of as many papers as possible, even if the own contribution has been marginal.

As for *visibility*, a correlation with *reputation* may be expected as researchers very much appreciate scientific achievements from which their own work can draw benefits. As such, works inspiring new ways of thinking, new techniques offering widespread utility, or the resolution of long-standing scientific issues or controversies are considered particularly valuable by the community and considered of higher *quality and significance* than papers confirming anticipated conclusions or being of interest to only small communities. Figure 5 illustrates a rather complicated situation that turns out to be highly field-dependent. In the area of space science, materials science, and physics, visibility and reputation appear *anti-correlated*. Clearly, prize winners in these latter groups tend to receive fewer citations than the 100 most cited scientists (H_{pw} falls below H_{ave} leading to negative MZE for most of the prize winners). Part of the lower citation rates may be due to the fact that truly innovative ideas are frequently off-mainstream and often too complex to be immediately understood, accepted and appreciated by the broad community. This situation is somewhat different in the area of chemistry, where the citation statistics of the award winners—although still quite widely spread—show an overall closer match to those of the most cited researchers. Finally, in the area of mathematics, the normalized visibility of the prize winners is significantly higher than that of the most 100 cited researchers in the field! This may suggest that new ground-breaking developments in chemistry and mathematics are recognized more rapidly by the broad community than is the case in the other three areas. Altogether we have to conclude that if one accepts the reputation of a scientist as a measure of the quality and significance of his/her research, the visibility measured by C_t, MZE or otherwise normalized H indices is a poor predictor of research performance or at best, strongly field dependent.

Conclusions

The need for decision making on career advancement and research resource distribution between competing research units or individuals requires comparative assessments of research performances. The use of bibliometric indicators based on prolificacy and visibility for this purpose faces multiple challenges including (a) differences in these individuals` quantitative publication outputs, for example due to differences in age or career stage, (b) differences in field size, publication and citation cultures in different research communities, and (c) the open question of whether high visibility also implies high quality/significance. Regarding issue (a) we show that the MZE index can be a good basis for normalization in judging visibilities between individuals working in similar fields, but having different publication outputs. Issue (b) is most vividly documented by the vastly different H versus N plots of the most prolific researchers working in different research fields (Fig. 3). To account for these differences, this contribution proposes the FNF scaling factor to allow visibilities of researchers of different research areas, but having comparable quantitative research outputs to be compared to each other. Using both indexes *in tandem*, the visibility of each research individual within his/her community can be gauged, allowing a comparative assessment of individuals at different career stages and working in different fields of science. Issue (c), however, the correlation of these parameters with the quality/significance of the work remains unresolved. Figure 5 reveals strongly field dependent features casting serious doubts upon this correlation.

We conclude that basing career advancement and research funding decisions on bibliometric indicators, even after normalization for quantitative output and research area, remains a highly unsafe process. For properly evaluating an individual`s research performance, there is still no substitute to actually reading their publications and judging them in the context of the state of the art of the field by the appropriate experts. We strongly advocate a return to a more holistic evaluation approach, based on peer-reviewed criteria, such as the number of genuinely invited review papers in reputable journals, invited and plenary talks at prestigious congresses, celebrated awards granted, editorships of scientific periodicals, science prizes conferred by scientific societies and journals, the number and value of research grants, and the social or economic impact of the research work. This much more robust set of criteria will allow a researcher's standing among his/her peers, scientific merit and reputation to be estimated much more reliably. While it takes much more than a few mouse clicks to gather and evaluate such data, the increased effort is well-invested considering the decade-long consequences of institutional hiring and promotion decisions.

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