Scientometrics (2010) 85:415–427
DOI 10.1007/s11192-010-0255-z

A new author's productivity index: p-index

N. Assimakis · M. Adam

Received: 3 December 2009 / Published online: 17 June 2010

Abstract In this paper a new author's productivity index is introduced, namely the golden productivity index. The proposed index measures the productivity of an individual researcher evaluating the number of papers as well as the rank of co-authorship. It provides an efficient method to measure the author's contribution in articles writing, compared to other ordinary methods. It gives emphasis to the first authors contributions due to the fact that traditionally the rank of each author shows the magnitude of his contribution in the article.

Keywords Metrics · Productivity · Author rank · Co-authorship

Introduction

This paper is devoted to the problem: "how to distribute the credit of publications among coauthors?". The problem of how to count multiauthored papers has been discussed for a long time. Vinkler (1993) stated that ideally, information obtained directly from the authors concerning their contributions should be used. The magnitude of collaboration cannot be easily determined by the usual methods of observations, interviews or questionnaires, as has been remarked by Ajiferuke et al. (1988). So we need a measure based on the information the papers give.

Trueba and Guerrero (2004) sated three principles of authorship crediting:

1. The value of a given publication should be shared among all its authors,
2. Total publication credit should be divided among authors,
3. First authors should be credited more than the later authors in the same paper.

N. Assimakis (✉)
Department of Electronics, Technological Educational Institute of Lamia, Lamia, Greece
e-mail: assimakis@teilam.gr

M. Adam
Department of Computer Science and Biomedical Informatics, University of Central Greece, Lamia, Greece
e-mail: madam@ucg.gr

There exist a number of different methods for accrediting multiauthored papers. The number of articles (papers) as well as the rank of co-authorship are very important in this task. Various scoring methods dealing with the distribution of credit of publications among coauthors have been proposed:

– Rounsefell (1961) describes how credits are assigned between multiple authors in a linear way.
– Lindsey (1980), Price (1981), Folly et al. (1981), Dizon and Sadorra (1995) and Von Hooydonk (1997) suggested the fractional authorship assigning credit proportionally to the authors, i.e. the linear distribution of the credit of publications among coauthors.
– The Collaboration Index (CI) proposed by Lawani (1980) uses the mean number of authors per paper.
– The Degree of Collaboration (DC) proposed by Subramanyam (1983) uses the proportion of multiauthored papers.
– The Collaborative Coefficient (CC) proposed by Ajiferuke et al. (1988) is a measure that combines some of the merits of both (CI and DC) measures.
– Boxenbaum et al. (1987) applied the Waring distribution.
– The geometric distribution of the credit of publications among coauthors has been introduced by Howard et al. (1987)) and Ellwein et al. (1989).
– Trenchard (1992) proposed the Raw Weight (the author's rank divided by the sum of all) which is a linear distribution.
– Lukovits and Vinkler (1995) and Trueba and Guerrero (2004) suggest some kind of discounting.
– The scoring system described by Vinkler (2000) rewards co-authors according to their rank number, assuming that the measure of the contribution of co-authors is reflected by their rank and is close to the geometric distribution.
– Trueba and Guerrero (2004) suggested the Refined Weight using three arbitrary chosen coefficients.

The above mentioned third principle of authorship crediting is generally followed in the most scoring methods and is discussed by many researchers e.g. Hoen et al. (1998), Bhandari et al. (2003), Schreiber (2009) and Tscharntke et al. (2007).

Of course, there exists also the consideration that in multiauthored papers, all signing positions have the same function. Schreiber (2009) stated that "it is most appropriate to share the credit equally among all authors, as long as one does not have good information about their relative contributions". The uniform distribution of the credit of publications among coauthors has been proposed by Price and Beaver (1966).

However there exist several exceptions concerning the third principle of authorship crediting:

– Sometimes names are sorted alphabetically as it has been noticed by Endersby (1966) and Zuckerman (1968) who found that a significant percentage of physics papers have names in alphabetical order.
– Various studies indicate that first, second and last positions play an important role in the creation of a paper; last author plays an important role; for example Shapiro et al. (1994) found that the contributions of first and the last authors are of great significance in multiauthored biomedical research papers (see Table 3).
– The last position is more popular than the others due to tradition reasons.
– The author list is randomized.

- The responsibility of the "Corresponding Author" does not always reflected in the position.
- Sometimes coauthors specify that they have equally contributed in the paper.

In the general case we believe that the rank plays an important role, because traditionally the rank of each author shows the magnitude of his contribution in the article. The predominant role of the first authors in all activity fields in paper producing is depicted by Vinkler (1993). In fact, it was found by Vinkler (1993) that first authors perform about 70% of the total work needed for two authored papers, which decreases to 54% for papers with four authors. Furthermore, Tscharntke et al. (2007) stated that "in multiauthored papers, the first author position should be assigned to the individual making the greatest contribution, as in common practice".

In this paper we propose a new method to measure the scientific productivity of researchers taking under consideration their papers and their rank. The paper is organized as follows: In "Classical productivity indicators presentation" section classical productivity indicators are presented. In "The golden productivity index" section the proposed golden productivity index is introduced: it measures the productivity of an individual researcher taking into account the number of papers as well as the rank of co-authorship. The proposed scoring method gives emphasis to the first authors' contributions due to the fact that traditionally the rank of each author shows the magnitude of his contribution in the article. In "The author's golden productivity index" section the corresponding author's golden productivity index is defined. It is pointed out that it provides an efficient method to measure the author's contribution in articles writing, compared to other ordinary methods in the general case where the rank of each author shows the magnitude of his contribution.

Classical productivity indicators presentation

Assume that:

- an author has published N articles (papers),
- the ith paper ($i = 1,\ldots,N$) is co-authored by a_i authors,
- each single paper is a productivity unit; it has to be shared into its co-authors in a fair way.

The uniform productivity index (up-index)

The uniform distribution of the credit of publications among coauthors has been proposed by Price and Beaver (1966).

The uniform productivity index is rank-independent. The number of co-authors plays an important role. The author's rank does not play any role; the rank does not affect the author's productivity index. Each single paper is a productivity unit. This unit for the ith paper has to be shared into a_i authors in a uniform way: for this paper, the productivity indices of all the co-authors are constant. The joint contribution of the author in the ith paper is related only to the number of authors. The productivity unit (paper) is shared in equal parts to all authors. So there exists a uniform distribution of all the co-authors' productivity indices for the ith paper. The jth author's uniform productivity index for the ith paper is denoted as up_{ij} for $j = 1,\ldots,a_i$, and is defined as:

Table 1 Uniform up-index: the authors' uniform productivity indices for 1–5 authors

Co-authors	Author 1	Author 2	Author 3	Author 4	Author 5
1	1.00	–	–	–	–
2	0.50	0.50	–	–	–
3	0.33	0.33	0.33	–	–
4	0.25	0.25	0.25	0.25	–
5	0.20	0.20	0.20	0.20	0.20

$$\mathrm{up}_{ij} = \frac{1}{a_i}, \quad j = 1, \ldots, a_i, \quad \forall i \tag{1}$$

This author's productivity index expresses the *equivalent* joint contribution for all co-authors.

Obviously, the sum of all co-authors' productivity indices for the ith paper is equal to 1:

$$\sum_{j=1}^{a_i} \mathrm{up}_{ij} = 1, \quad \forall i \tag{2}$$

Concerning a single paper, the authors' uniform productivity indices for 1–5 authors are calculated by (1) in Table 1.

The linear productivity index (lp-index)

The linear distribution of the credit of publications among coauthors has been described by Rounsefell (1961), Lindsey (1980), Folly et al. (1981), Price (1981), Trenchard (1992), Dizon and Sadorra (1995) with a slight modification and Von Hooydonk (1997).

The lp-index is rank-independent. Considering that the rank plays an important role, because traditionally the rank of each author shows the magnitude of his contribution in the article, the next productivity indices depend on the co-authors' ranks, which are denoted $r_j = j$ for every $j = 1,\ldots,a_i$.

The personal contribution of each author in the ith paper is related to the author's rank in a linear way, the jth author's lp-index for the ith paper is denoted as lp_{ij} for $j = 1,\ldots,a_i$. Since the productivity index for the ith paper of each author has to be connected linearly to his rank, two real numbers $\delta > 0$ and c have to be determined such that

$$\mathrm{lp}_{ij} = -\delta r_j + c, \quad j = 1, \ldots, a_i, \quad \forall i \tag{3}$$

Furthermore, since the sum of all co-authors' productivity indices for the ith paper has to be equal to 1,

$$\sum_{j=1}^{a_i} \mathrm{lp}_{ij} = 1, \quad \forall i \tag{4}$$

summarizing all the productivity indices by (3) and combining by (4) we conclude:

$$c = \frac{a_i + 1}{2}\delta + \frac{1}{a_i} \tag{5}$$

Then, by (5) the linear formula in (3) is written as:

$$\mathrm{lp}_{ij} = \left(\frac{a_i + 1}{2} - r_j\right)\delta + \frac{1}{a_i},\ \ j = 1, \ldots, a_i, \quad \forall i \tag{6}$$

Note that, when the ith paper has only one author ($a_i = 1$), then by (6) the author's productivity index is $\mathrm{lp}_{i1} = 1$.It is obvious that the last author's productivity index is or calculated by (6) for $j = a_i$, and is equal to:

$$\mathrm{lp}_{i\,a_i} = \frac{1 - a_i}{2}\delta + \frac{1}{a_i}, \quad \forall i \tag{7}$$

We propose to use in (6) as δ the last author's productivity index for the ith paper,

$$\delta = \mathrm{lp}_{i\,a_i} \tag{8}$$

and then combining (9) and (8) we derive:

$$\delta = \frac{2}{a_i(a_i + 1)} \tag{9}$$

Thus, by (6) and (9) the special (for this choice of δ) jth author's lp-index for the ith paper is written as:

$$\mathrm{lp}_{ij} = \frac{-2}{a_i(a_i + 1)}r_j + \frac{2}{a_i}\ \ j = 1, \ldots, a_i, \quad \forall i \tag{10}$$

The above choice is not arbitrary. Indeed, we remark that lp_{ij} in (6) consist of the consecutive terms of an arithmetic sequence with the common difference to be equal to $-\delta$, i.e.:

$$\mathrm{lp}_{i2} - \mathrm{lp}_{i1} = \mathrm{lp}_{i3} - \mathrm{lp}_{i2} = \cdots = \mathrm{lp}_{ia_i} - \mathrm{lp}_{ia_{i-1}} = -\delta < 0, \quad \forall i \tag{11}$$

that means that the productivity index for the ith paper of each author is greater than the next author's productivity index for the same paper, and this is justified because the author's contribution decreases as his rank increases:

$$\mathrm{lp}_{i\,1} > \mathrm{lp}_{i\,2} > \cdots > \mathrm{lp}_{i\,a_{i-1}} > \mathrm{lp}_{i\,a_i} \tag{12}$$

Moreover, if we suppose that the productivity index of the first author is a_i times the productivity index of the last author, the productivity index of the second author is $(a_i - 1)$ times the productivity index of the last author, and so on, then, for $j = 1,\ldots,a_i$, the consecutive terms of the sequence lp_{ij} are constructed by:

$$\mathrm{lp}_{ij} = (a_i - r_j + 1) \cdot \mathrm{lp}_{i\,a_i},\ \ j = 1, \ldots, a_i, \quad \forall i \tag{13}$$

Furthermore, since the sum of all co-authors' productivity indices for the ith paper has to be equal to 1, by (4) and (13) we have:

$$\sum_{j=1}^{a_i} \{(a_i - r_j + 1) \cdot \mathrm{lp}_{i\,a_i}\} = 1 \tag{14}$$

whereby we conclude:

$$\mathrm{lp}_{i\,a_i} = \frac{2}{a_i(a_i + 1)} \tag{15}$$

Table 2 Linear lp-index: the authors' linear productivity indices for 1–5 authors

Co-authors	Author 1	Author 2	Author 3	Author 4	Author 5
1	1.00	–	–	–	–
2	0.67	0.33	–	–	–
3	0.50	0.33	0.17	–	–
4	0.40	0.30	0.20	0.10	–
5	0.33	0.27	0.20	0.13	0.07

Comparing (9) with (15), the choice in (8) becomes obvious and in this case substituting (15) in (13) we derive (10).

Concerning a single paper, the authors' linear productivity indices for 1–5 authors are calculated by (10) in Table 2.

The geometric productivity index (gp-index)

The geometric distribution of the credit of publications among coauthors has been introduced by Howard et al. (1987), Ellwein et al. (1989)) and Vinkler (2000) with a slight modification.

The gp-index is rank-independent. The author's rank plays an important role. The personal contribution of each author in the ith paper is related to the author's rank in an exponential way, the jth author's gp-index for the ith paper is denoted as gp_{ij} for $j = 1,\ldots,a_i$. Since the productivity index for the ith paper of each author has to be connected exponential to his rank, two positive real numbers λ and k have to be determined such that

$$\mathrm{gp}_{ij} = \lambda^{-a_i + r_j} \cdot k, \quad j = 1, \ldots, a_i, \quad \forall i \tag{16}$$

Obviously, for $j = 1,\ldots,a_i$ the numbers gp_{ij} consist of the consecutive terms of a geometric sequence with the common ratio to be equal to:

$$\frac{\mathrm{gp}_{i2}}{\mathrm{gp}_{i1}} = \frac{\mathrm{gp}_{i3}}{\mathrm{gp}_{i2}} = \cdots = \frac{\mathrm{gp}_{i\,a_i}}{\mathrm{gp}_{i\,a_{i-1}}} = \lambda, \quad \forall i \tag{17}$$

If we suppose $0 < \lambda < 1$, then the common ratio in (17) means that the productivity index for the ith paper of each author is greater than the next author's productivity index for the same paper, i.e., the author's contribution decreases as his rank increases:

$$\mathrm{gp}_{i1} > \mathrm{gp}_{i2} > \cdots > \mathrm{gp}_{i\,a_{i-1}} > \mathrm{gp}_{i\,a_i} \tag{18}$$

Consequently, gp_{ij} in (16) consist of the consecutive terms of a decreasing geometric sequence only for $0 < \lambda < 1$.

Since the sum of all co-authors' productivity indices for the ith paper has to be equal to 1:

$$\sum_{j=1}^{a_i} \mathrm{gp}_{ij} = 1, \quad \forall i \tag{19}$$

by (16) and (19) we have:

$$k = \frac{1-\lambda}{\lambda^{1-a_i} - \lambda} \tag{20}$$

Then, from (16) and (20) we conclude:

$$\mathrm{gp}_{ij} = \frac{1-\lambda}{\lambda - \lambda^{1+a_i}} \lambda^{r_j}, \quad j = 1, \ldots, a_i, \quad \forall i \tag{21}$$

It is obvious that the first author's productivity index is calculated by (21) for $j = 1$ and is equal to:

$$\mathrm{gp}_{i1} = \frac{1-\lambda}{1-\lambda^{a_i}}, \quad \forall i \tag{22}$$

We propose to use in (21) as $0 < \lambda < 1$ the first author's productivity index for the ith paper:

$$\lambda = \mathrm{gp}_{i1} \tag{23}$$

and then combining (22) and (23) we conclude:

$$\lambda^{a_i+1} - 2\lambda + 1 = 0 \quad \text{for} \quad 0 < \lambda < 1 \tag{24}$$

The value of λ depends on the number of co-authors a_i and can be computed by solving Eq. 24.

Then, from (21) and (24), the special (for this choice of λ) j—the author's gp-index for the ith paper is written as:

$$\mathrm{gp}_{ij} = \lambda^{r_j}, \ \ j = 1, \ldots, a_i, \quad \forall i \tag{25}$$

It is obvious that the contribution of each author the ith paper is weightened in a geometric basis concerning his rank.

Remarks When $a_i = 1$ (the ith paper has only one author), then by (21) the author's productivity index is $\mathrm{gp}_{i1} = 1$.

When $a_i \geq 2$, λ has to be determined in order to calculate the authors' productivity indices. Since the sum of all co-authors' productivity indices for the ith paper has to be equal to 1, by (24) and (25) we derive:

$$\lambda^{a_i} + \lambda^{a_i-1} + \cdots + \lambda^2 + \lambda = 1 \tag{26}$$

The value of $0 < \lambda < 1$ can be computed by solving (24) or (26).

When $a_i \geq 2$, the Eq. 26 has exactly one solution λ such that $0 < \lambda < 1$.

Proof We define the polynomial $f(\lambda) = \lambda^{a_i} + \lambda^{a_i-1} + \cdots + \lambda^2 + \lambda - 1$.

We observe that $f(0) = -1$ and $f(1) = a_i - 1 > 0$.

Then $f(0) \cdot f(1) < 0$, that means that the polynomial has at least one root in (0,1) by the Bolzano's Theorem.

In the following, the polynomial $f(\lambda)$ has a positive derivative:
$\frac{\mathrm{d}f(\lambda)}{\mathrm{d}\lambda} = a_i\lambda^{a_i-1} + (a_i - 1)\lambda^{a_i-2} + \cdots + 2\lambda + 1 > 0$, that means that the polynomial is an increasing function with respect to λ and then it has at the most one root in (0,1).

Then it becomes obvious that the polynomial has exactly one root in (0,1). □

When $a_i = 2$ (the ith paper has two authors), then the Eq. 26 has $\lambda = 0.6180$ as the unique acceptable solution and from (25) the authors' productivity indices are $\mathrm{gp}_{i1} = 0.62$ and $\mathrm{gp}_{i2} = 0.38$. Note that, in this case, λ is connected to the *golden number* $\phi = 1.6180$ of the Ancient Greeks with the relation $\phi = \frac{1}{\lambda}$.

Table 3 Geometric gp-index: the authors' geometric productivity indices for 1–5 authors

Co-authors	Author 1	Author 2	Author 3	Author 4	Author 5
1	1.00	–	–	–	–
2	0.62	0.38	–	–	–
3	0.54	0.30	0.16	–	–
4	0.52	0.27	0.14	0.07	–
5	0.51	0.26	0.13	0.07	0.03

Concerning a single paper, the authors' geometric productivity indices for 1–5 authors are calculated by (25) using (24) or (26) in Table 3.

The golden productivity index

We present a formula to weight authorship according to the relative ranks of authors in co-authored papers.

The golden productivity index is rank-dependent. A new method of measuring the productivity of an author evaluating the number of papers as well as the rank of co-authorship is presented.

The method is based on the use of the golden number $\phi = 1.6180$ and it uses $\varphi = \frac{1}{\phi} = 0.6180$ as a basis for sharing the productivity unit.

Note that φ has the following property:

$$1 - \varphi = \varphi^2 \tag{27}$$

When the ith paper has only one author, then the author's productivity index is equal to 1. When the paper has two authors, then the first author's productivity index is φ and the second author's productivity index is $1 - \varphi$ (golden share). When the paper has three authors, then the first author's productivity index is φ and the rest of the productivity unit $1 - \varphi = \varphi^2$ is shared into the second and the third authors in the golden share way. When the paper has four authors, then the first author's productivity index is φ, the second author's productivity index is φ^3 and the rest of the productivity index $1 - \varphi = \varphi^2$ is shared into the third and the fourth authors in the golden share way, and so on.

Observe that, when the authors are at least two, a sequence of numbers is constructed with the following properties:

- The first $a_i - 1$ numbers consist of the consecutive terms of a geometric sequence, where φ is the initial term of the sequence, φ^2 is the common ratio of the sequence and the last term of sequence is equal to φ^{2a_i-3}, and
- the last a_ith number is equal to φ^{2a_i-2}.

The jth author's golden productivity index for the ith paper is denoted as φp_{ij} for $j = 1,\ldots,a_i$ and is defined as:

$$\varphi p_{ij} = \begin{cases} 1, & a_i \\ \varphi^{2r_j-1}, & j = 1,\ldots,a_i - 1, \quad a_i \geq 2, \quad \forall i \\ \varphi^{2r_j-2} = \varphi^{2a_i-2}, & j = a_i, \quad a_i \geq 2 \end{cases} \tag{28}$$

The sum of all co-authors' productivity indices for the ith paper is equal to 1:

$$\sum_{j=1}^{a_i} \varphi p_{ij} = 1, \quad \forall i \tag{29}$$

Proof The following statements consist of the method of mathematical induction:

For $a_i = 1$, we derive

$$\varphi p_{i1} = 1$$

directly from (28).

For $a_i = 2$, by (28) and the property of φ in (27), we derive:

$$\sum_{j=1}^{2} \varphi p_{ij} = \varphi + \varphi^2 = 1$$

For $a_i = 3$, by (28) and the property of φ in (27), we derive:

$$\sum_{j=1}^{3} p\varphi_{ij} = \varphi + \varphi^3 + \varphi^4 = (1 - \varphi^2) + \varphi^3 + \varphi^4 = 1 + \varphi^2(-1 + \varphi + \varphi^2) = 1$$

Assume that (29) holds for a_i. Then using (28) we derive:

$$\sum_{j=1}^{a_i} \varphi p_{ij} = \varphi + \varphi^3 + \cdots + \varphi^{2a_i-5} + \varphi^{2a_i-3} + \varphi^{2a_i-2} = 1$$

which can be written as

$$\varphi + \varphi^3 + \cdots + \varphi^{2a_i-5} + \varphi^{2a_i-3} = 1 - \varphi^{2a_i-2} \tag{30}$$

Then, for $a_i + 1$, by (28), the induction hypothesis in (30) and the property of φ in (27), we derive:

$$\sum_{j=1}^{a_i+1} \varphi p_{ij} = \varphi + \varphi^3 + \cdots + \varphi^{2a_i-3} + \varphi^{2a_i-1} + \varphi^{2a_i} = (1 - \varphi^{2a_i-2}) + \varphi^{2a_i-1} + \varphi^{2a_i}$$
$$= 1 + \varphi^{2a_i-2}(-1 + \varphi + \varphi^2) = 1$$

Thus, equation in 29 holds for every $a_i \geq 1$.

Concerning a single paper, the authors' golden productivity indices for 1–5 authors are calculated by (28) in Table 4.

The proposed golden productivity index (φp-index) is related to the general case where we consider that the rank plays an important role. The predominant role of the first authors

Table 4 Golden φp-index: the authors' golden productivity indices for 1–5 authors

Co-authors	Author 1	Author 2	Author 3	Author 4	Author 5
1	1.00	–	–	–	–
2	0.62	0.38	–	–	–
3	0.62	0.24	0.15	–	–
4	0.62	0.24	0.09	0.06	–
5	0.62	0.24	0.09	0.03	0.02

Table 5 Example 1: p-index computation

Paper	Co-authors	Rank	Productivity index for each paper			
			Uniform	Linear	Geometric	Golden
1	1	1	1.00	1.00	1.00	1.00
2	2	1	0.50	0.67	0.62	0.62
3	2	2	0.50	0.33	0.38	0.38
4	3	1	0.33	0.50	0.54	0.62
5	3	2	0.33	0.33	0.30	0.24
6	3	3	0.33	0.16	0.16	0.15
7	4	1	0.25	0.40	0.52	0.62
8	4	3	0.25	0.20	0.14	0.09
Papers/author	3.49	p-index	3.49	3.60	3.66	3.72

in all activity fields in paper writing is depicted by Vinkler (1993) (see Table 3). The proposed scoring method gives emphasis to the first authors contributions due to the fact that traditionally the rank of each author shows the magnitude of his/her contribution in the article. Especially first author takes the 62% of credit for multiauthored papers.

It is remarkable that the proposed golden productivity index is in line with previous observations:

- The proposed golden productivity index is very close to the average contribution of the first authors for multiauthored papers, as calculated by Vinkler (1993) using the Total Contribution Factor (TCF), which reflects the percentage activity shares due to each co-author in order to produce a scientific paper (see Table 5). In fact, the golden productivity index of the first author for multiauthored papers (62%) is equal to the average TCF of the first author for papers with 2–4 authors, while the golden productivity index of the second author for multiauthored papers (24%) is very closed to the corresponding average TCF (25%) for papers with 2–5 authors.
- Slone (1996) provides the percentages of contributions to major papers by coauthors: 63, 20, 10, 7% for the first four authors (see Table 4), concerning the overall contribution mean. It is obvious that these percentages are similar to those proposed by the golden productivity index.
- Hwang et al. (2003) found that “according to the researcher position in the byline, the contribution of the first author was noteworthy, with percentages exceeding 60% contribution in all categories”, which is very close to the percentage of 62% that the proposed golden productivity index gives to the first author.

Of course, for someone who does not admit that first authors are more important than the rest, so they deserve more credit, the proposed golden index is useless. Furthermore, there exist obvious limitations of the proposed index concerning the special cases where the last author plays an important role (for example in Biomedicine) or when the coauthors appear in alphabetical order. The proposed productivity index does not take into account the role of the “Corresponding Author” and does not make sense when coauthors specify that the contribution have been equally for all them.

The proposed golden productivity index (φp-index) can be computed using the formula in (28). It is easy to apply this formula because only the calculation of the corresponding powers of φ is required.

The author's golden productivity index

The author's uniform/linear/geometric/golden productivity indices, up/lp/gp/φp-index, are defined as the sum of all uniform/linear/geometric/golden productivity indices for all the papers of this author, as calculated in (1), (10), (25) and (28), respectively:

$$\mathrm{up} = \sum_{i=1}^{N} \mathrm{up}_{ij}, \quad \forall j \tag{31}$$

$$\mathrm{lp} = \sum_{i=1}^{N} \mathrm{lp}_{ij}, \quad \forall j \tag{32}$$

$$\mathrm{gp} = \sum_{i=1}^{N} \mathrm{gp}_{ij}, \quad \forall j \tag{33}$$

$$\varphi p = \sum_{i=1}^{N} \varphi p_{ij}, \quad \forall j \tag{34}$$

Remarks

1. The author's uniform productivity index is equivalent to the ordinary method of measuring the papers per author index.
2. It is clear that the linear, geometric and golden productivity indices measure the productivity of an author evaluating the number of papers and the rank of co-authorship.
3. The author's golden productivity index takes into consideration the principal role of the first authors in paper writing.

The efficiency of the proposed method to measure the author's productivity is investigated through the following simulation examples.

Example 1: Author's p-index computation Let an author who has published $N = 8$ articles (papers). Table 5 depicts the rank in each paper and the corresponding author's productivity indices for each paper; the proposed productivity indices are also calculated by (31)–(34).

Comments

1. We notice that the uniform productivity index is equivalent to the usual method of measuring the papers per author index.
2. We notice that the proposed golden productivity index and the ordinary productivity indices are close to each other. So, the author's golden productivity index provides an efficient, reasonable and reliable method to measure the author's contribution in articles writing, compared to other ordinary methods.
3. The proposed author's golden productivity index is greater than the other indices because it takes into consideration the principal role of the first authors in paper writing (the author is the first author of four papers). It is obvious that the proposed scoring method can be applied in the case where the rank of each author shows the magnitude of his contribution, as in common practice.

Acknowledgments We are grateful to the reviewers for their critical comments and guidance to prepare this paper.

References

Ajiferuke, I., Burrel, Q., & Tague, J. (1988). Collaborative coefficient: A single measure of the degree of collaboration in research. *Scientometrics, 14*(5–6), 421–433.

Bhandari, M., Einhorn, T. A., Swiontkowski, M. F., & Heckman, J. D. (2003). Who did what? (Mis). Perceptions about authors' contributions to scientific articles based on order of authorship. *The Journal of Bone and Joint Surgery (American), 85*, 1605–1609.

Boxenbaum, H., Pivinski, F., & Ruberg, S. J. (1987). Publication rates of pharmaceutical scientists: Application of the Waring distribution. *Drug Metabolism Reviews, 18*(4), 553–571.

Dizon, L. B., & Sadorra, M. S. M. (1995). Patterns of publication by the staff of an international fisheries research center. *Scientometrics, 32*(1), 67–75.

Ellwein, L. B., Khachab, M., & Waldman, R. H. (1989). Assessing research productivity: Evaluating journal publication across academic departments. *Academic Medicine, 64*(6), 319–325.

Endersby, J. W. (1966). Collaborative research in the social sciences: Multiple authorship and publication credit. *Social Science Quarterly, 77*(2), 375–392.

Folly, G., Hajtman, B., Nagy, J. I., & Ruff, I. (1981). Some methodological problems in ranking scientists by citation analysis. *Scientometrics, 3*(2), 135–147.

Hoen, W. P., Walvoort, H. C., & Overbeke, A. J. P. M. (1998). What are the factors determining authorship and the order of the authors' names? A study among authors of the Nederlands Tijdschrift voor Geneeskunde. *Dutch Journal of Medicine JAMA, 280*(3), 217–218.

Howard, G. S., Cole, D. A., & Maxwell, S. E. (1987). Research productivity in psychology based on publication in the journals of the American Psychological Association. *American Psychologist, 42*(11), 975–986.

Hwang, S. S., Song, H. H., Baik, J. H., Jung, S. L., Park, S. H., Choi, K. H., et al. (2003). Researcher contributions and fulfillment of ICMJE authorship criteria: Analysis of author contribution lists in research articles with multiple authors published in Radiology. *Radiology, 226*(1), 16–23.

Lawani S. M. (1980). *Quality, collaboration and citations in cancer research: A bibliometric study*. Ph.D. dissertation, Florida State University, p. xvii.

Lindsey, D. (1980). Production and citation measures in the sociology of science: The problem of multiple authorship. *Social Studies of Science, 10*(2), 145–162.

Lukovits, I., & Vinkler, P. (1995). Correct credit distribution: A model for sharing credit among coauthors. *Social Indicators Research, 36*, 91–98.

Price, D. de Solla (1981). Multiple authorship. *Science, 212*(4498), 986. doi:10.1126/science.212.4498.986-a.

Price, D. de Solla, & Beaver, D. B. (1966). Collaboration in an invisible college. *American Psychologist, 21*(11), 1011–1018.

Rounsefell, G. (1961). How can research production be measured? *Proceedings of the Culf and Caribbean Fisheries Institute, 13*, 139–150.

Schreiber, M. (2009). A case study of the modified Hirsch index h_m accounting for multiple co-authors. *Journal of the American Society for Information Science and Technology, 60*(6), 1274–1282.

Shapiro, D. W., Wenger, N. S., & Shapiro, M. F. (1994). The contributions of authors to multiauthored biomedical research papers. *JAMA, 271*(6), 438–442.

Slone, M. R. (1996). Coauthors' contributions to major papers published in the AJR: Frequency of undeserved coauthorship. *American Journal of Roentgenology, 167*, 571–579.

Subramanyam, K. (1983). Bibliometric studies of research collaboration: A review. *Journal of Information Science, 6*(1), 33–38.

Trenchard, P. M. (1992). Hierarchical bibliometry: A new objective measure of individual scientific performance to replace publication counts and to complement citation measures. *Journal of Information Science, 18*(1), 69–75.

Trueba, F. J., & Guerrero, H. (2004). A robust formula to credit authors for their publications. *Scientometrics, 60*(2), 181–204.

Tscharntke, T., Hochberg, M. E., Rand, T. A., Resh, V. H., & Krauss, J. (2007). Author sequence and credit for contributions in multiauthored publications. *PLoS Biology, 5*(1), e18.

Vinkler, P. (1993). Research contribution, authorship and team cooperativeness. *Scientometrics, 26*(1), 213–230.

Vinkler, P. (2000). Evaluation of the publication activity of research teams by means of scientometric indicators. *Current Science, 79*(5), 602–612.

Von Hooydonk, G. (1997). Fractional counting of multiauthored publications: Consequences for the impact of authors. *Journal of the American Society for Information Science, 48*(10), 944–945.

Zuckerman, H. A. (1968). Patterns of name ordering among authors of scientific papers: A study of social symbolism and its ambiguity. *The American Journal of Sociology, 74*, 276–279.