Journal of Informetrics 7 (2013) 455–468

Contents lists available at SciVerse ScienceDirect

Journal of Informetrics

journal homepage: www.elsevier.com/locate/joi

Cross-field evaluation of publications of research institutes using their contributions to the fields' MVPs determined by *h*-index

Chung-Huei Kuan[a], Mu-Hsuan Huang[b], Dar-Zen Chen[c,*]

[a] Graduate Institute of Patent, National Taiwan University of Science and Technology, Taipei, Taiwan
[b] Department of Library and Information Science, National Taiwan University, Taipei, Taiwan
[c] Department of Mechanical Engineering and Institute of Industrial Engineering, National Taiwan University, Taipei, Taiwan

ARTICLE INFO

Article history:
Received 17 January 2012
Received in revised form 21 January 2013
Accepted 21 January 2013

Keywords:
Contribution
Cross-field evaluation
h-Index
Most visible publications
Research institutes

ABSTRACT

We propose a cross-field evaluation method for the publications of research institutes. With this approach, we first determine a set of the *most visible publications* (MVPs) for each field from the publications of all assessed institutes according to the field's *h*-index. Then, we measure an institute's production in each field by its percentage share (i.e., *contribution*) to the field's MVPs. Finally, we obtain an institute's cross-field production measure as the average of its contributions to all fields. The proposed approach is proven empirically to be reasonable, intuitive to understand, and uniformly applicable to various sets of institutes and fields of different publication and citation patterns. The field and cross-field production measures obtained by the proposed approach not only allow linear ranking of institutes, but also reveal the degree of their production difference.

1. Introduction

The *h*-index (Hirsch, 2005), originally designed as a characterization of a researcher's publication output or research performance, has its application quickly extended to institutional evaluation, which was suggested by Hirsch himself in the original paper.

Along one branch of study for such extension, institutes are considered as a higher-level aggregation of researchers. Prathap (2006) proposed a two-level approach: a level-one *h*-index (h_1) which is the original *h*-index obtained from the publications from an institute, and a level-two *h*-index (h_2) supplementing the $h_1$index which specifies that there are h_2 researchers in the institute, and each has an individual *h*-index at least h_2. Schubert (2007) proposed an approach called *successive h-indices* applicable to a hierarchy of aggregations in a bottom-up manner. According to Schubert, given the *h*-indices of the researchers of an institute, an index of the institute is determined exactly by the same method as what Prathap proposed.

Along another branch of study of applying the *h*-index to institutes, the original *h*-index is modified by taking into consideration the sizes of their publication sets. Molinari and Molinari (2008a, 2008b) decomposed the original *h*-index of an institute into the product of an impact index h_m and a factor related to the number of publications from the institute. By factoring the latter out of the *h*-index, the impact index h_m is considered as a characterization of an institute's "intrinsic visibility" and then used to compare institutes. Since h_m requires that the number of publications ranges above a few

* Corresponding author at: Department of Mechanical Engineering and Institute of Industrial Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei 10617, Taiwan. Tel.: +886 2 23692178; fax: +886 2 23631755.
E-mail addresses: maxkuan@mail.ntust.edu.tw (C.-H. Kuan), mhhuang@ntu.edu.tw (M.-H. Huang), dzchen@ntu.edu.tw (D.-Z. Chen).

1751-1577/$ – see front matter
http://dx.doi.org/10.1016/j.joi.2013.01.008

hundreds, Sypsa and Hatzakis (2009) further modified h_m by another factor and claimed that their modified h_m can be applied to institutes with large as well as small publication sets.

Even though these studies focused on institutes and some indeed applied the *h*-index and the above adaptations to interdisciplinary or cross-field institutional evaluation (cf. Arencibia-Jorge, Barrios-Almaguer, Fernández-Hernández, & Carvajal-Espino, 2008; Arencibia-Jorge & Rousseau, 2009), we notice that most applications were limited to specific programs (Pires Da Luz et al., 2008), departments (Lazaridis, 2010), facilities (Grothkopf & Stevens-Rayburn, 2007), research groups (Van Raan, 2006), or fields (Mugnaini, Packer, & Meneghini, 2008; Rousseau, Yang, & Yue, 2010; Sypsa & Hatzakis, 2009) of the assessed institutes.

Kinney (2007) pointed out the reason when he applied the impact index h_m to measure the federally funded science centers and institutes in the fields of physical sciences, engineering, and technology. Kinney specifically excluded the field biomedicine as he claimed that "the publications of many of the top ranked institutions are dominated by bio-medical research, which dwarfs the other scientific disciplines."

In other words, an institute's expertise usually spans across a number of different fields, subject areas, or disciplines (hereafter, *fields*), and these fields are of different bibliometric features (Vinkler, 2010b). Some fields (e.g., biomedicine) have a large number of publications with quickly accumulated citations whereas others (e.g., social science) have a limited set of publications with significantly fewer citations. We believe that, without taking such field-dependent publication and citation features into consideration, an approach to cross-field evaluation of publications of research institutes may very possibly deliver distorted result.

The cross-field evaluation of publications of research institutes has already been targeted by quite a number of authors. The most notable ones in recent years are the various variants to the crown indicator developed by the Centre for Science and Technology Studies (CWTS) at Leiden University. The crown indicator (Moed, De Bruin, & Van Leeuwen, 1995) is calculated by dividing the average number of received citations for aggregated publications from a specific unit with the average number that could be expected for publications of the same document type (e.g., articles, reviews, letters, etc.), from the same analyzed time span, published in journals within the same field. One variant to the crown indicator by Lundberg (2007) is based on an alternative normalization scheme where the normalization is carried out on the level of individual publication, rather than on aggregated levels as the crown indicator does. Empirical analysis and theoretical comparison to the two normalization schemes can be found by Waltman, Van Eck, Van Leeuwen, Visser, & Van Raan (2010, 2011). Another interesting improvement is the I3 indicator by Leydesdorff and Bornmann (2011).

As to the *h*-index, its being a citation-based indicator has made it susceptible to the field dependency issue as well. We can see this from a simplified example. An institute i has *h*-indices n_{if} and n_{ik} for its publications in two fields f and k (hereafter, the institute i's field *h*-indices), respectively, and an *h*-index n_i when the publications of both fields f and k are combined together (hereafter, the institute i's cross-field *h*-index). Clearly, $n_i \geq n_{if}$ and $n_i \geq n_{ik}$. Then, when we combine the publications of both fields together and determine the cross-field *h*-index n_i, we can ignore those field-f publications having citations less than n_{if} (and therefore n_i) and those field-k publications having citations less than n_{ik} (and therefore n_i). However, if the field f is a many-publication-high-citation field and the field k is a few-publication-low-citation field, n_{if} is usually greater than n_{ik}. Then n_{if} actually sets a high bar and those field-k publications having citations less than n_{if} can also be ignored. We as such would expect that the cross-field *h*-index n_i reflects more of the institute i's production in the many-publication-high-citation field f. In the worst case where all publications in the field k have citations less than n_{if}, we would have $n_i = n_{if}$ and the institute i's production in the few-publication-low-citation field k is completely dismissed by its production in the many-publication-high-citation field f.

Now, if another institute j has superior production in the many-publication-high-citation field f but inferior production in the few-publication-low-citation field k compared to the institute i (i.e., $n_{jf} > n_{if}$ but $n_{jk} < n_{ik}$), it does not seem fair to jump to conclusion that the institute j outperforms the institute i simply because $n_j > n_i$ when the institute i's better production in the few-publication-low-citation field k is largely, if not all, ignored.

Just like the crown indicator and other related cross-field measures, there are studies adapting the *h*-index for cross-field comparison using various normalization schemes. However, these studies have limited themselves to researchers specializing in different fields.

Batista, Campiteli, Kinouchi, and Martinez (2006) proposed to divide the *h*-index n of a researcher by the average number of authors in the considered n papers. Iglesias and Pecharromán (2007) suggested dividing the *h*-index of a researcher by the average number of citations per paper of the researcher's respective field. Valentinuzzi, Laciar, and Atrio (2007) proposed two indices claimed to be discipline independent with the whole spectrum of published and cited papers taken into consideration. Radicchi, Fortunato, and Castellano (2008) rescaled a researcher's publications and citations by dividing them with the average numbers of publications and citations per paper in the field, respectively. Then, a "generalized *h*-index" is obtained using the rescaled numbers.

Our greatest concern over these approaches, be it crown-indicator-like or *h*-index-based, is that they all require a thorough treatment or analysis for the publications from all institutes in a field in order to obtain the field's correction or normalization parameters (e.g., the size factor for the h_m index or the average numbers of publications and citations for rescaling), even though we are assessing only a limited set of institutes. Some of the approaches also have limitations such as the impact index h_m's requiring that the number of publications of the assessed institutes has to be large enough.

Additionally, from a practical point of view, a field or cross-field measure for the evaluation of publications of research institutes has to be intuitive so that its meaning can be easily communicated with, understood and accepted by the assessed institute because the measure may affect the distribution of resource or allocation of funding to the institutes. For example, it probably would not be easy to explain what "intrinsic visibility" really means, and why a correction or normalization parameter is fair.

We therefore consider that an ideal approach for the cross-field evaluation of publications of research institutes should deal with their production in various fields first. Then, the ideal approach combines the field measures of an institute into a cross-field measure for the institute without favoring or disfavoring certain many-publication-high-citation or few-publication-low-citation fields. We expect that the ideal approach is intuitive to understand, and uniformly applicable to large or small sets of institutes and fields of different publication and citation patterns. We also expect that the field and cross-field production measures obtained by the ideal approach should not only allow linear ranking of institutes, but also reveal the degree of their production difference.

In this paper, we detail our endeavor in developing such an ideal approach.

2. Methodologies

2.1. Most visible publications

The key successful factor of the ideal approach lies in the choice of a normalization scheme that can be uniformly applied to different fields despite of their publication and citation patterns, and the *elite set* concept introduced by Vinkler (2010a, 2011b) provides us a hint.

In determining the eminence of scientific journals, Vinkler designed a new index based on the relatively most important publications of these journals, and referred to this set of publications as the elite set of a journal's total publications. This concept is very much similar to the highly cited papers (HCPs) as a measure to a researcher's scientific performance (cf. Aksnes, 2003; Plomp, 1990).

Vinkler (2010a) proposed several ways to determine a journal's elite set such as using the Lotak law, the citation rate, the *h*-index, or the $(10 \log P) - 10$ most highly cited publications where P is the total number of publications.

The choice of *h*-index is particularly of interest to us. According to Vinkler, if the journal has *h*-index 20, the most highly cited 20 publications constitute the journal's elite set. On the other hand, Rousseau (2006) called these 20 publications collectively as Hirsch core or *h*-core, and these publications are considered as the most visible ones (cf. Burrell, 2007; Egghe, 2010). Neither Vinkler nor Rousseau made any improvement concerning Hirsch's definition of the *h*-index. They regard however the publications in the *h*-core as the elite. And because the elite set or the *h*-core has such a representative role, it is no wonder that a number of *h*-type indices, such as the *A*-, *R*-, *AR*-indices (Jin, 2007; Jin, Liang, Rousseau, & Egghe, 2007), are derived directly therefrom.

Using *h*-index to determine a field's eminence can also be found, for example, in Minasny, Hartemink, and McBratney (2007), Bar-Ilan (2008), Egghe and Rao (2008), etc.

In this paper, we borrow the elite set and *h*-core concepts from Vinkler and Rousseau and their use of the *h*-index to determine this set of publications. In other words, we build our elite set exclusively on the *h*-index. However we refer to these publications as the *most visible publications* (MVPs) of the field. The term "visibility" was used by Cole and Cole (1968) as the extent to which a researcher's work is familiar to the community of fellow researchers. For example, highly visible researchers refer to those known to 60 percent of the community. We consider the MVPs as those leading to the eminence of a field, and we therefore choose the term "visibility" instead of similar ones such as "importance" or "impact."

Additionally, we apply the *h*-index differently from Vinkler and Rousseau. The *h*-index is both a rank number and a citation count. Vinkler and Rousseau determined their set and core by choosing those ranked ahead of or equal to the *h*-index whereas we determine the MVPs as those whose received citations are greater than or equal to the *h*-index. The difference can be demonstrated by a simplified example as follows. A field has 5 publications with citations 5, 3, 3, 3, and 1, respectively, and therefore has *h*-index 3. The field's *h*-core (or elite set determined by the *h*-index) contains 3 publications whereas its MVPs contain 4 publications. The fourth publication does not belong to the *h*-core (or the elite set determined by the *h*-index) even though it also receives 3 citations. Therefore, the *h*-core (or elite set determined by the *h*-index) is always a subset of the MVPs and they are not necessarily identical. We think this is a more reasonable way of using the *h*-index as, for the three publications each receiving 3 citations, there is no reason leaving one of them out.

As Vinkler pointed out that there are various criteria in determining the elite set, the MVPs can be determined by other criteria other than the *h*-index. Especially, Waltman and Van Eck (2011) recently argued that the definition of the *h*-index actually involves arbitrariness and claimed that the original definition of the *h*-index is not necessarily better than alternative definitions (e.g., a researcher has an *h*-index n if n of his publications have at least $2n$ or $n/2$ citations each and his/her remaining publications have fewer than $2(n+1)$ or $(n+1)/2$ citations each). Additionally, besides those schemes proposed by Vinkler, we can also expect that some of the *h*-type indices can be potential candidates as well. For example, the *g*-index (Egghe, 2006a, 2006b) could be another choice in determining the MVPs.

The reasons that we choose *h*-index are that, in addition to the prior studies mentioned above that had made the same choice, the *h*-index has a number of features making this choice not an unreasonable one, such as its ready availability from online databases (e.g., Scopus and Web of Science), and its simplicity in calculation. Most importantly, the *h*-index integrates both quantity and quality (cf. Bornmann & Daniel, 2009; Egghe, 2010) and therefore we expect that using the *h*-index would be better than using criteria purely based on the number of total publications, or the number of total citations. Additionally, using the h-index prevents the MVPs from being influenced by the lowly cited publications that do not help the eminence of a field. Furthermore, the h-index has been found empirically to be comparable with peer judgment (cf. Lovegrove & Johnson, 2008; Van Raan, 2006), which seems to be consistent with our assuming that the h-index reflects a field's eminence to the scientific community.

This paper is positioned as an illustration of the approach using a field's MVPs to measure an institute's production in the field. Using the h-index to determine the MVPs is not an unreasonable choice. Yet whether the h-index is the "best" choice requires a more rigorous study and will be left for future study.

2.2. Contribution to the MVPs

If the MVPs of a field are those leading to the field's eminence, it seems reasonable to relate an institute's production in the field to the number of publications produced or contributed from the institute to the field's MVPs.

If there are M institutes and the publications from the M institutes in a field f are collected together, we can obtain the h-index n_f for the field f, and determine the MVPs V_f for the field f based on the h-index n_f. If there are N fields, we then repeat the process and determine the h-indices $n_1, \ldots, n_N$ and the corresponding MVPs $V_1, \ldots, V_N$ for the fields $1, \ldots, N$, respectively.

As the h-indices $n_1, \ldots, n_N$ are influenced by the fields' specific publication and citation patterns, we would expect that the determined MVPs $V_1, \ldots, V_N$ would be affected as well. For example, the MVPs of a many-publication-high-citation field may contain a larger number of publications whereas, for a few-publication-low-citation field, the number of the MVPs would be smaller. To avoid the bias by the field f's publication and citation pattern, we propose that an institute i's contribution is expressed as the percentage share to the MVPs V_f that is produced by the institutes i.

We then formally define an institute i's *field contribution* to a field f as follows. Assuming that a field f's MVPs V_f is a union of $V_{1f}, V_{2f}, \ldots, V_{Mf}$, where V_{if} is a subset of V_f containing publications produced by the institute i, the institute i's field contribution to the field f is calculated as follows:

$$C_{if} = \frac{|V_{if}|}{|V_f|} \times 100 \quad \text{for } 1 \leq i \leq M \tag{1}$$

where $|V_{if}|$ and $|V_f|$ are the numbers of the MVPs V_{if} and V_f. The field contribution C_{if} defined by Eq. (1) specifies that, for the $|V_f|$ publications of the field f's MVPs V_f, C_{if} percent is produced by the institute i. Please note that C_{if} could be zero if V_{if} is an empty set, meaning that the field f's MVPs V_f does not contain any publication from the institute i, or the institute i does not have any contribution to the field f's MVPs.

A major proposition of this paper is that we consider a greater contribution reflects a better production. The reasoning is as follows. For example, assuming that a field f's MVPs V_f has 100 publications and it is these 100 publications that lead to the field f's having certain degree of eminence in the scientific community. Then, for two institutes i and j having field contributions 50% (C_{if}) and 10% (C_{jf}), respectively, the institute i accounts for 50% of the field f's degree of eminence whereas the institute j's only accounts for 10%. We therefore suggest that the institute i should be considered to have better production than the institute j if $C_{if} > C_{jf}$.

The field contribution defined by Eq. (1) satisfies the consistency property proposed by Waltman and Van Eck (2009). Additionally, it has a nice feature that, for a field f, the field contributions from all M institutes satisfy the following equation:

$$\sum_{i=1}^{M} C_{if} = 1 \quad \text{for } 1 \leq f \leq N \tag{2}$$

The field contribution as such has the potential not only allowing us to rank the institutes as described above but also allowing us to infer the degrees of difference between the institutes' production in a field. Using the example above, we can speculate that the institute i's production is 5 times better than that of the institute j.

Eq. (2) specifies that the field contributions of the M institutes to each of the N fields are summed to 1, and this is a form of normalization over the fields' various publication and citation patterns. As such and following the same reasoning, an institute i has contributed more, and therefore is considered to have a better production, in a field f than in another field k if $C_{if} > C_{ik}$. For example, assuming that the field f is few-publication-low-citation and has 10 publications in its MVPs, the field k is many-publication-high-citation and has 100 publications in its MVPs, and the institute i's field contributions in the two fields f and k are 50% (C_{if}) and 10% (C_{ik}), respectively, we can consider that the institute i has better production in the field f than its production in the field k even though it has only produced 5 publications to the few-publication-low-citation field f's MVPs, smaller than its 10 publications to the many-publication-high-citation field k's MVPs.

Another nice feature of the field contribution defined by Eq. (1) is that its calculation does not require us to conduct a thorough treatment or analysis for the publications from all institutes in a field so as to obtain the field's correction or normalization parameters. Additionally, we can interpret the field contribution by itself without involving the other institutes. For example, if $C_{if} > 50\%$, we know right away that more than half of the field f's MVPs is produced by the institute i.

Based on the above definition of the field contribution, we can further define an institute i's *cross-field contribution* as follows:

$$C_i = \frac{\sum_{f=1}^{N} C_{if}}{N} \quad \text{for } 1 \le i \le M \tag{3}$$

According to Eq. (3), we simply calculate the arithmetic average of an institute's field contributions to the N fields as its cross-field contribution and, by using arithmetic average, we treat each field as having equal importance. Of course, if desired or required, an investigator can adopt a weighting scheme in Eq. (3) to place emphasis on certain fields. The cross-field contribution defined by Eq. (3) also satisfies the consistency property proposed by Waltman and Van Eck (2009). Additionally, if Eq. (2) holds, we can see that the cross-field contributions of all M institutes satisfy the following equation:

$$\sum_{i=1}^{M} C_i = 1. \tag{4}$$

The cross-field contribution of an institute i as defined by Eq. (3) can be considered as the institute i's overall contribution to the scientific community. Then, following the same reasoning, for two institutes i and j, the institute i on the average contributes a greater contribution, and therefore can be considered to have achieved a better cross-field production than the institute j does if $C_i > C_j$. Since the cross-field production of the M institutes are summed to 1, we can compare the relative production of any pair of institutes i and j without calculating and involving the rest of the institutes' cross-field contributions.

The approach describe above can be utilized at various scopes. If the M institutes are those of the entire world and the N fields encompass all research disciplines, the approach achieve a global evaluation. If the M institutes are those of a country, of a region, or of particular interest to the investigator, or if the N fields form a subset of all fields, the evaluation based on the approach is then restricted to this particular subset of institutes, or with respect to this particular subset of fields.

2.3. Multiple affiliations and zero ratios

As described in the previous section, the proposed field and cross-field contributions are intuitive to understand, uniform across fields of various publication and citation patterns, and possess some nice qualities such as there is no need for a thorough prior analysis so as to obtain some normalization parameter. However, we find that the approach has two problems requiring further treatment.

The first is the problem of multiple affiliations. The field contributions defined by Eq. (1) would satisfy Eq. (2) only if each of the MVPs is affiliated with one and only one institute whereas, in real life, it is common that a publication is affiliated with multiple institutes.

There is a great deal of research in the literature and various approaches have been proposed to deal with this type of credit distribution problem. However, the proposed field and cross-field contributions do not have to tie to a particular credit distribution scheme and an investigator can choose what is most appropriate to him/her as long as the scheme is uniformly applied to all fields. Here we simply choose a reasonable approach that seems the simplest to us: counting the credit repeatedly for each affiliated institute.

Formally, we define the extended MVPs W_f for a field f having MVPs V_f as containing a set of tuples (p, i) where, for each publication p of V_f, the institute i is one of publication p's affiliated institutes. Then, W_f is a union of $W_{1f}, W_{2f}, \ldots, W_{Mf}$, where W_{if} is a subset of W_f containing the tuples (p, i) whose publication p is affiliated with the institute i. For example, if a publication p of V_f is affiliated with institutes 1 and 2, W_f then would contain two tuples, $(p,1)$ and $(p, 2)$, with $(p,1)$ belonging to W_{1f} and $(p, 2)$ to W_{2f}. Then, we redefine the field contribution from the institute i to the field f as follows:

$$C_{if} = \frac{|W_{if}|}{|W_f|} \quad \text{for } 1 \le i \le M \tag{5}$$

It is clear that C_{if} thus defined satisfies Eq. (2).

The second problem is related to institutes having field contributions equal to zero. Additionally, if an institute has zero field contributions in all fields, the institute would have zero cross-field contribution as well according to Eq. (3). Of course, we can consider these institutes as having identical field or cross-field production. But, if there are a large number of these institutes, can we further differentiate them?

The differentiation in a single field can be achieved by repeating the proposed approach as follows. Let's say that we start with M institutes in a field. After a first application of the approach, say, there are M' institutes having zero field contribution. We then perform a second application of the approach to the M' institutes by compiling the M' institutes' publications, obtaining a new h-index, determining a new set of extended MVPs, and calculating the M' institutes' field contributions. Again, say, there are M'' institutes still having zero field contribution. We then can repeat the approach again on the M'' institutes until there is no institute or only a handful of them with zero field contribution left.

This process can actually become a categorization or classification scheme. For example, the set of $(M–M')$ institutes with non-zero field contributions from the first application can be considered as a first tier of institutes. Then, the set of $(M'–M'')$

institutes with non-zero field contributions from the second application can be considered as a second tier of institutes, and so on.

The differentiation for institutes with zero cross-field contributions can be achieved in various ways. We will leave the detail to future research but, for the moment, the simplest way is to follow the process for differentiation in a single field. More specifically, we start with M institutes and there are M' institutes having zero cross-field contributions from the initial application of the approach. We then conduct the proposed approach again to obtain new cross-field contributions only for the M' institutes as described above. The process is then repeated if required.

In the following, we will run the proposed approach against a sample set of data. Since the MVPs are derived from the h-index, we will compare the result from the proposed approach against that based on the h-index. For more detailed analysis, such as which criterion for the determination of the MVPs, which credit distribution scheme, etc., are better, we will leave them in future studies.

3. Research data

To test-drive the approach, we need to assemble a representative set of institutes and fields. For the fields, we determined to use the 21 fields adopted by the Essential Science Indicators (ESIs) in classifying journals and thereby publications of these journals.[1]

As to the institutes, we determined to use the top 10 institutes having the greatest numbers of citations[2] in at least two of the 21 fields[3] and there were totally 40 different institutes. The data was collected on 2010-03-03 from the SCI-EXPANDED and SSCI citation databases of Web of Science, and included the number of publications indexed between 2000 and 2009 and the number of citations of these publications. The publications considered contain the four types of documents (articles, reviews, research notes, and proceedings papers) used by ESI.[4] Please note that, as described in the previous section, if a publication is affiliated with multiple institutes, the publication is counted repeatedly for each of the affiliated institutes.

The 21 fields were too numerous for the result to present in a clear and concise manner. In addition, Zhou and Leydesdorff (2011) pointed out that the assigning a publication to a field simply based on the publication's appearance in a journal assumed to belong to the field is problematic, and Radicchi and Castellano (2011, 2012) also pointed out that different citation patterns also exists for different sub-fields within the same field and, for example, there may be greater differences between polymer chemistry and organic chemistry than between chemistry and physics. We therefore combined the 21 fields into 6 significantly distinct field groups and used the 6 field groups as the fields of the proposed approach so that the impact of aforementioned problem would be lessened. We refer to the field groups simply as *fields* hereafter so as to be consistent with the terminology used so far. We also refer to each field by the first three letters of its title for brevity. The six fields are: Agriculture, Biology & Environment Sciences[5] (Agr), Clinical Medicine (Cli),[6] Engineering, Computing & Technology[7] (Eng), Life Sciences[8] (Lif), Physical, Chemical & Earth Sciences[9] (Phy), and Social & Behavioral Science[10] (Soc).

Finally, we collected each and every publication affiliated with the 40 institutes in the 6 fields indexed between 2000 and 2010 from the SCI-EXPANDED and SSCI citation databases. The collection was conducted between 2011-02-05 and 2011-02-12. The various statistics for each of the 6 fields, including the size of the h-core or h-index ($|H|$), the number of the MVPs ($|V|$), the total citations of the h-core ($C(H)$), the number of the extended MVPs where publications affiliated with multiple institutes are repeated counted ($|W|$), and the total citations of the extended MVPs ($C(W)$), are summarized in Table 1. We can see from Table 1 that $|H|$ and $|V|$ are indeed different for some fields. We can also see that a significant number of publications are affiliated with more than one institute. For example, the h-core of the field Phy has 422 publications and on the average each is affiliated with at least two institutes.

The h-indices of the 40 institutes' publications in each of the 6 fields and of all 6 fields are summarized in Table 2, where the institutes are listed in descending order of their cross-field h-indices (in the column All). The 40 institutes' ranks by these field and cross-field h-indices are also included in the brackets.

In the first section, we have revealed our doubt about the adequacy of using an institute's cross-field h-index to reflect its production across different fields. We speculate that some of an institute's production in few-publication-low-citation fields of smaller h-indices may be dismissed by its production in many-publication-high-citation fields of higher h-indices, and as such its cross-field h-index reflects more of its production in the higher h fields. The empirical data provides numerous

[1] There are actually 22 fields, but we skipped the field Multidisciplinary since publications of this field are further assigned to the other 21 fields.
[2] The criterion can also be "the greatest number of publications." We chose "the greatest number of citations" as the selected institutes should have better visibility.
[3] Originally we chose the top 10 institutes having the greatest numbers of citations in at least one of the 21 fields. There were total 67 institutes, which was too numerous to present clearly.
[4] Please see http://sciencewatch.com/about/met/core-ins/ for details.
[5] This field contains the ESI fields: Plant & Animal Science, Environment/Ecology, Agricultural Sciences.
[6] This field contains the ESI fields: Clinical Medicine, Psychiatry/Psychology.
[7] This field contains the ESI fields: Engineering, Materials Science, Computer Science.
[8] This field contains the ESI fields: Biology & Biochemistry, Microbiology, Immunology, Neuroscience & Behavior, Molecular Biology & Genetics, Pharmacology & Toxicology.
[9] This field contains the ESI fields: Chemistry, Physics, Geosciences, Mathematics, Space Science.
[10] This field contains the ESI fields: Social Sciences (General), Economics & Business.

Table 1
The 6 fields' various statistics from the 40 institutes.

Field	Publications	Citations	|H|	|V|	C(H)	|W|	C(W)
Agr	120,935	1,658,645	215	216	73,731	273	94,542
Cli	464,654	10,000,581	506	510	430,290	767	658,302
Eng	164,806	2,052,452	296	297	183,200	372	238,266
Lif	354,120	10,105,971	491	491	399,447	656	535,406
Phy	435,608	8,399,728	422	422	317,665	876	880,816
Soc	119,199	1,198,278	191	194	56,399	265	78,263

$|H|$ number of publications in the h-core; $|V|$ number of publications in the MVPs, the total $C(H)$ citations of the h-core, the $|W|$ number of publications in the extended MVPs; and the total $C(W)$ citations of the extended MVPs.

evidences confirming this speculation. Taking Harvard University in Table 2 as example, after examining its data, we found that only 3 out of the 90 publications in the h-core of the field Agriculture, Biology & Environment Sciences (Agr) are included in the 394 publications of Harvard University's h-core when its publications in all 6 fields are combined together, whereas there are 173 out of the 302 publications in the h-core of the field Life Sciences (Lif) that are included.

Also, if the speculation is true, the ranking by the 40 institutes' cross-field h-indices should be more correlated with the rankings by their field h-indices in these many-publication-high-citation, higher-h fields. We therefore calculate the Spearman's rhos between these rankings, and the result is summarized in the first row of Table 5.

As shown in Tables 2 and 5, the 40 institutes' ranking by their cross-field h-indices is indeed most correlated to the rankings by their field h-indices in the most many-publication-high-citation fields Clinical Medicine (Cli) and Life Sciences (Lif). Similarly, the 40 institutes' ranking by their cross-field h-indices is indeed correlated more with the ranking by their field h-indices in the field Physical, Chemical & Earth Sciences (Phy) than with that in the field Engineering, Computing &

Table 2
The 40 institutes' cross-field (under the column All) and field h-indices, with their ranks in the brackets.

Institute	All	Agr	Cli	Eng	Lif	Phy	Soc
Harvard U.	394[1]	90[6]	303[1]	95[7]	302[1]	172[7]	123[1]
Johns Hopkins U.	310[2]	56[22]	244[2]	84[12]	208[4]	159[11]	65[15]
Stanford U.	301[3]	74[14]	205[6]	121[3]	208[4]	170[8]	88[4]
UW – Seattle	297[4]	86[8]	217[4]	99[6]	195[6]	175[6]	71[12]
UC – San Francisco	288[5]	29[30]	224[3]	40[30]	216[2]	68[30]	61[18]
MIT	285[6]	49[26]	117[26]	139[1]	209[3]	200[3]	86[5]
UC – San Diego	284[7]	78[12]	196[10]	82[14]	209[3]	135[20]	54[22]
UC – Los Angeles	280[8]	61[20]	208[5]	102[5]	189[7]	151[12]	82[7]
UC – Berkeley	280[8]	102[3]	117[26]	134[2]	172[12]	205[2]	81[8]
UMich – Ann Arbor	273[9]	78[12]	208[5]	93[8]	175[11]	148[13]	90[3]
Columbia U.	268[10]	53[24]	202[8]	64[23]	187[8]	147[14]	81[8]
U. of Pennsylvania	266[11]	49[26]	199[9]	70[21]	196[5]	136[19]	93[2]
Yale U.	263[12]	67[17]	184[14]	58[26]	196[5]	140[16]	73[11]
U. of Oxford	256[13]	75[13]	164[17]	75[19]	186[9]	146[15]	55[21]
U. of Cambridge	254[14]	65[19]	139[22]	91[10]	189[7]	179[5]	52[23]
U. of Toronto	249[15]	80[10]	187[12]	83[13]	180[10]	129[23]	58[19]
U. of Pittsburgh – Pittsburgh	244[16]	45[28]	204[7]	56[27]	158[16]	114[25]	61[18]
U. of Chicago	243[17]	54[23]	151[21]	51[29]	154[18]	159[11]	85[6]
Washington U. in St. Louis	241[18]	51[25]	172[16]	59[25]	195[6]	86[28]	44[25]
CIT	240[19]	46[27]	45[36]	95[7]	129[22]	216[1]	33[29]
Cornell U.	237[20]	104[2]	161[18]	81[15]	161[14]	133[22]	64[16]
UMN – Twin Cities	236[21]	91[5]	185[13]	91[10]	132[21]	138[18]	76[9]
Imperial College London	235[22]	71[16]	174[15]	77[17]	159[15]	134[21]	38[28]
U. of Tokyo	234[23]	71[16]	128[25]	74[20]	166[13]	180[4]	21[33]
UNC – Chapel Hill	228[24]	72[15]	188[11]	52[28]	166[13]	106[26]	74[10]
University College London	225[25]	54[23]	157[20]	61[24]	180[10]	106[26]	52[23]
UWisc – Madison	222[26]	99[4]	159[19]	75[19]	148[19]	139[17]	68[13]
Osaka U.	210[27]	36[29]	129[24]	67[22]	156[17]	128[24]	13[35]
Princeton U.	202[28]	60[21]	74[31]	88[11]	117[24]	163[9]	71[12]
UC – Davis	198[29]	109[1]	130[23]	76[18]	133[20]	114[25]	56[20]
PSU – University Park	189[30]	79[11]	78[30]	92[9]	105[26]	161[10]	67[14]
UC – Santa Barbara	180[31]	83[9]	62[34]	99[6]	78[30]	151[12]	39[27]
UI – Urbana-Champaign	178[32]	74[14]	81[28]	106[4]	112[25]	139[17]	62[17]
Swiss FIT – Zurich	173[33]	66[18]	67[32]	81[15]	119[23]	133[22]	27[31]
Tohoku U.	160[34]	46[27]	79[29]	79[16]	102[27]	135[20]	13[35]
National U. of Singapore	143[35]	51[25]	82[27]	92[9]	95[28]	91[27]	41[26]
U. of Georgia	123[36]	83[9]	64[33]	31[33]	83[29]	74[29]	45[24]
Wageningen U.	116[37]	88[7]	57[35]	34[32]	78[30]	61[32]	32[30]
Swedish U. of Agri. Sciences	99[38]	79[11]	35[38]	23[34]	68[31]	36[33]	16[34]
UMD – Baltimore County	79[39]	26[31]	39[37]	39[31]	44[32]	66[31]	23[32]

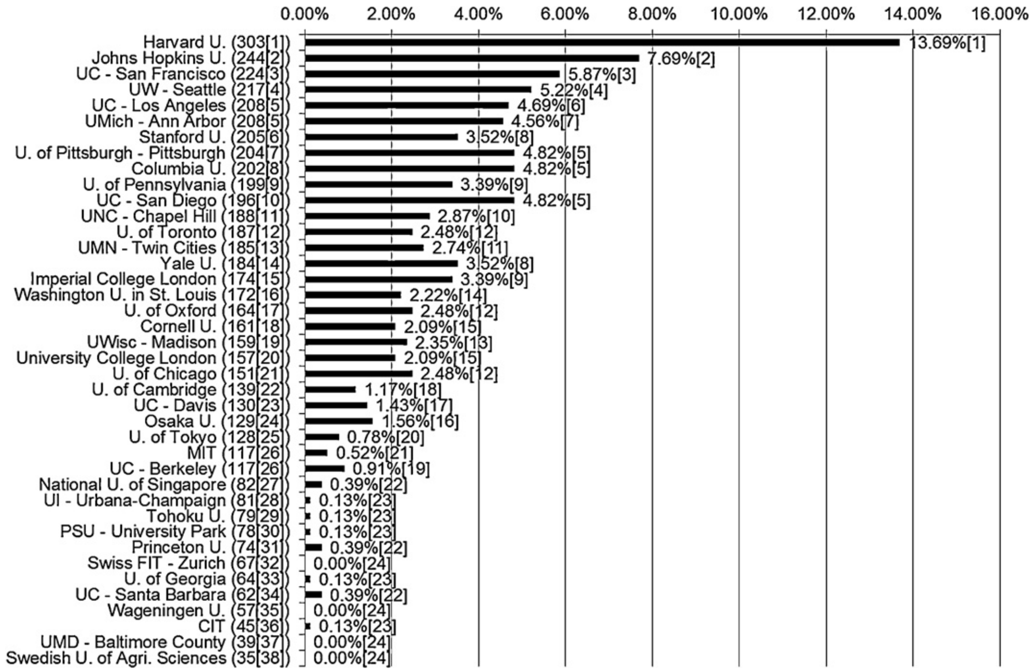

Fig. 1. The 40 institutes' field *h*-indices and contributions in the field Clinical Medicine.

Technology (Eng). Finally, as expected, the 40 institutes' ranking by their cross-field *h*-indices is poorly correlated with the ranking by their field *h*-indices in the field Agriculture, Biology & Environment Sciences (Agr). However, the 40 institutes show unexpected high correlation in the field Social & Behavioral Science (Soc). We found that it so happens that the ranking by their field *h*-indices is rather consistent with the ranking by their cross-field *h*-index.

4. Single-field production evaluation

According to the proposed approach, in order to obtain the 40 institutes' cross-field contributions for all 6 fields, we have to gather the 40 institutes' field contributions in each of the 6 fields. For brevity and also as the main focus of the paper is cross-field production evaluation, we only present in this section the 40 institutes' field contributions in the 3 fields: Clinical Medicine; Engineering, Computing & Technology; and Social & Behavioral Science, which have the greatest, a medium, and the smallest *h*-indices among the 6 fields according to Table 1.

In order to provide visual aid, we present the result of the 3 fields in Figs. 1–3, respectively. Within each figure, the 40 institutes are arranged along the vertical axis in descending order of their field *h*-indices, and their respective field contributions are represented by the lengths of horizontal bars, so that we can see how the two rankings are different from each other. To facilitate the comparison, we have included an institute's field *h*-index and the corresponding rank next to the institute's name, and its field contribution and the corresponding rank next to its horizontal bar. Institutes with identical *h*-index or contribution are ranked at the same place.

We can see from Figs. 1–3 that each field has a number of institutes with zero field contribution as speculated in the previous section. We can also see that the field contribution is not very discriminating. The 40 institutes have 24 different field contributions in the field Clinical Medicine, 19 in the field Engineering, Computing & Technology, and only 17 in the field Social & Behavioral Science. This is because that it is quite common to have two or more institutes producing the same number of publications in a field's MVPs. This clearly is field contribution's disadvantage as a field production measure. However, as will be shown in the next section, this lack of differentiation does not happen to the cross-field contribution when multiple fields are considered together.

From the downward shrinking trend of the horizontal bars shown in Figs. 1–3, we can expect that an institute having a greater field *h*-index is rather possible to have a higher field contribution as well. This seems to suggest a high correlation between the rankings by the field *h*-index and by the field contribution, which is confirmed by their Spearman's rho summarized in the second row of Table 5. This high correlation is not really a surprise. An institute having a greater field *h*-index would have more publications with better possibility to be included in the field's MVPs, thereby achieving a higher field contribution. However, there are plenty exceptions and these exceptions manifest the difference between the *h*-index and the proposed approach.

As shown in Figs. 1–3, there are numerous cases where institutes with high field *h*-indices are evaluated to have moderate or even low field contributions (and vice versa). For example, in the field Social & Behavioral Science shown in Fig. 3, University

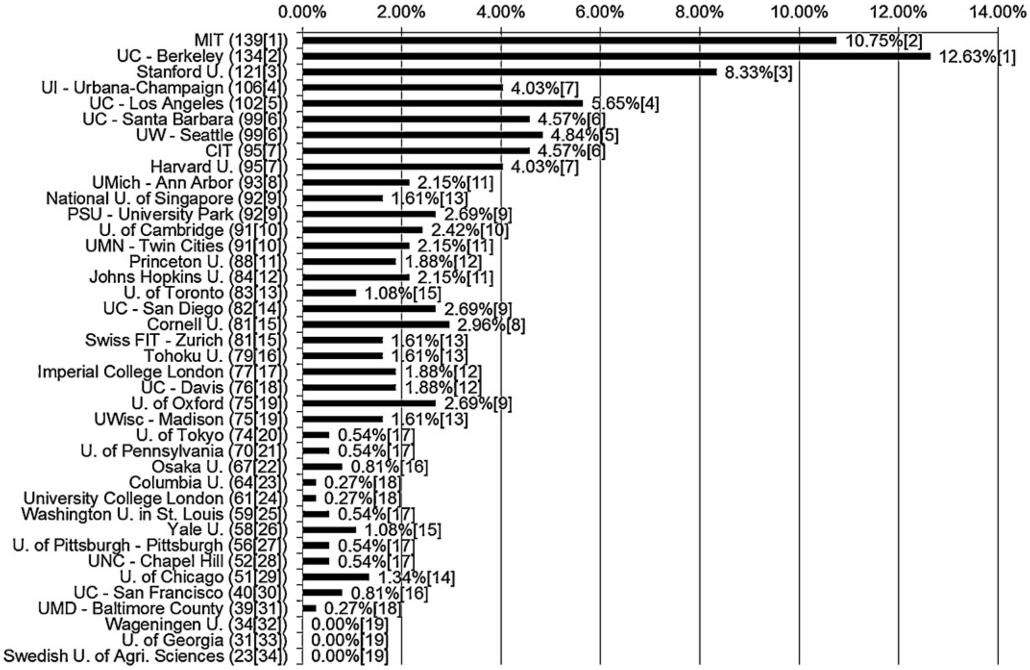

Fig. 2. The 40 institutes' and field *h*-indices and contributions in the field Engineering, Computing & Technology.

of Washington – Seattle's field *h*-index is ranked at the 12th place among 35 different ranks (hereafter 12/35) which is among the top one third. Yet its field contribution has a rank 14/17 which is among the last one third. In the field Clinical Medicine shown in Fig. 1, Yale University's field contribution has a rank 8/24 which is among the top one third but its field *h*-index has a rank 14/35 which is among the middle one third.

There are also plenty cases where institutes are of identical or close *h*-indices but are of significantly different field contributions (and vice versa). For example, in the field Engineering, Computing & Technology shown in Fig. 2, University of Toronto and University of California – San Diego have field *h*-indices 83 (at the 13th place) and 82 (at the 14th place),

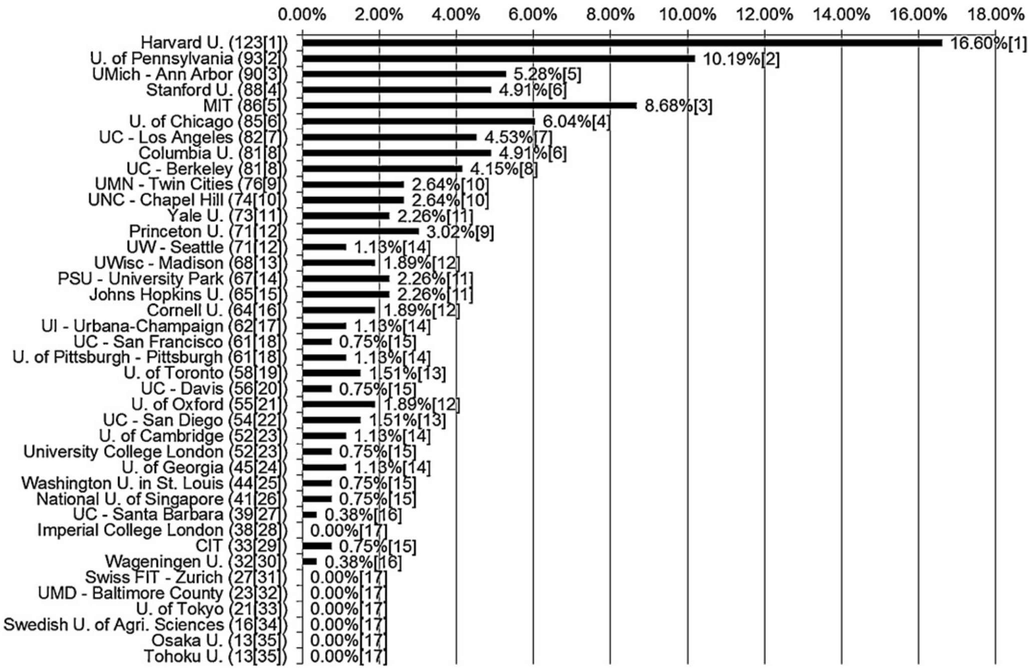

Fig. 3. The 40 institutes' field *h*-indices and contributions in the field Social & Behavioral Science.

Table 3
The numbers of ranks by the *h*-index and by the field contribution, and the numbers of zero field contributions for the 40 institutions in the 6 fields.

	Agr	Cli	Eng	Lif	Phy	Soc
# of ranks by *h*-index	31	38	34	32	33	35
# of ranks by field contribution	18	24	19	27	27	17
# of zero field contributions	5	4	3	2	2	7

respectively, but they have rather different and negatively related field contributions 1.08% (at the 15th place) and 2.69% (at the 9th place), respectively. Also in Fig. 2, we can see that Penn. State University – University Park, University of California, San Diego, and University of Oxford all have the same field contribution 2.69% (at the 9th place). Yet their field *h*-indices 92 (at the 9th pace), 82 (at the 14th place), and 75 (at the 19th place) are spaced apart.

The reason behind the above scenarios, from the proposed approach's perspective, lies in that an institute's field *h*-index is in essence a measure local to its own set of publications. Using the last example above, we know that Penn. State University – University Park's field *h*-index 92 in the field Engineering, Computing & Technology specifies that it has 92 publications in the field's *h*-core. However, the eminence of these 92 publications is relative to its own 5989 publications, not to the total 164,806 publications from all 40 institutes, in the field. When the 92 publications are compared against the publications from all other institutes, only 10 are included in the field's extended MVPs (372 publications) and the field contribution is therefore 2.69% (10/372). Similarly, for University of Oxford, despite its smaller field *h*-index 75, it also has 10 publications included in the field's extended MVPs, thereby achieving the same field contribution 2.69%.

From the illustrative cases above, we can clearly see a number of advantages of the field contribution and the proposed approach as mentioned in the previous section. For example, without involving the other institutes, Harvard University's greater contribution to the field Social & Behavioral Science (with field contribution 16.60%) than its contribution to the field Clinical Medicine (with field contribution 13.69%) suggests that Harvard University performs better in the former, despite that it ranks at the 1st place in both fields. Again, without involving other institutes, it is suggested that Harvard University in the two fields outperforms the runners-up University of Pennsylvania and Johns Hopkins University by 63% and 78%, respectively.

To conclude this section, we collect some data (the numbers of ranks achieved by the *h*-index and by the field contribution, and the numbers of zero field contributions) for the 40 institutes in the 6 fields and summarize them in Table 3. As illustrated, despite our careful choice of data, there are still institutes with zero field contribution in each field. Therefore, the zero-contribution problem is an inevitable issue of the proposed approach and must be handled appropriately. We have also calculated the Spearman's rhos between the rankings by the field *h*-index and by the field contribution and the result is listed in the middle row of the Table 5. As illustrated, the two rankings are indeed strongly correlated. The field Agriculture, Biology & Environment Sciences (Agr) is a bit exceptional due to its more dramatic scenarios. For one example, Penn. State University – University Park has a field *h*-index 79 (at the 11th place) but with a zero field contribution. However, its rho 0.789 still suggests a moderate to strong correlation.

5. Cross-field production evaluation

In this section we continue to apply the proposed approach to obtain the cross-field contributions for the 40 institutes according to Eq. (3), and the result is shown in Table 4. Since we have already empirically confirmed that the cross-field *h*-indices do not appropriately capture institutes' cross-field production, they are not included in Table 4 but can be cross-referenced from Table 2. Yet for comparison's sake, we have included the 40 institutes' field contributions for each of the 6 fields and the 2010 ARWU (Academic Ranking of World Universities) PUB scores by Shanghai Jiao Tong University[11] in Table 4. For each column of Table 4, the 40 institutes' values of the corresponding measures and their ranks (included in the brackets) by that measure are listed together.

As illustrated, the cross-field contributions achieve total 40 ranks and the field contribution's lack of differentiation problem is not happening here. This is because that it is quite uncommon for two or more institutes to have comparable contributions across all fields and therefore have identical cross-field contributions.

Some detailed examination also reveals that the cross-field contribution is a more reasonable measure where an institute's strong and weak fields are fairly considered and the field publication and citation patterns are uniformly normalized. For example, Harvard University has the best cross-field production as it is ranked at the 1st place by field contribution in 3 fields. As to the other 3 fields, it also has achieved moderate to good production by being ranked at 5/18, 7/19, and 8/27, respectively. University of California – Berkeley has the second best cross-field production as it is ranked at the 1st place in 2 fields, the 2nd place in 1 field, and it achieves moderate to good production in the other 3 fields by being ranked at 19/38, 14/32, and 8/35.

Johns Hopkins University is ranked at the 6th place according to its cross-field contributions. Compared to the runner-up, University of California – Berkeley, Johns Hopkins University has achieved the 2nd place in a single field and weak to good

[11] Available at: http://www.arwu.org/ARWU2010.jsp.

Table 4
The 40 institutes' cross-field and field contributions for the 6 fields, and ARWU PUB scores, with their ranks in the brackets.

Institute	Cross-field	Field contribution						ARWU PUB
	Contribution	Agr	Cli	Eng	Lif	Phy	Soc	
Harvard U.	9.85[1]	5.49[5]	13.69[1]	4.03[7]	16.31[1]	2.97[8]	16.60[1]	100[1]
UC – Berkeley	5.96[2]	8.79[1]	0.91[19]	12.63[1]	2.29[14]	6.96[2]	4.15[8]	70.6[7]
MIT	5.52[3]	0.73[16]	0.52[21]	10.75[2]	7.16[2]	5.25[3]	8.68[3]	61.4[22]
Stanford U.	4.70[4]	3.30[9]	3.52[8]	8.33[3]	4.73[6]	3.42[7]	4.91[6]	69.7[9]
UW – Seattle	3.87[5]	3.30[9]	5.22[4]	4.84[5]	3.81[7]	4.91[5]	1.13[14]	72.5[6]
Johns Hopkins U.	3.80[6]	1.47[14]	7.69[2]	2.15[11]	5.03[5]	4.22[6]	2.26[11]	64[17]
UC – Los Angeles	3.58[7]	1.10[15]	4.69[6]	5.65[4]	2.90[12]	2.63[10]	4.53[7]	75.1[5]
UC – San Diego	3.53[8]	3.30[9]	4.82[5]	2.69[9]	6.55[3]	2.28[13]	1.51[13]	65.1[16]
U. of Pennsylvania	3.36[9]	0.00[18]	3.39[9]	0.54[17]	3.05[11]	2.97[8]	10.19[2]	68.6[10]
UMich – Ann Arbor	3.25[10]	1.47[14]	4.56[7]	2.15[11]	2.59[13]	3.42[7]	5.28[5]	79.8[4]
Columbia U.	2.87[11]	1.83[13]	4.82[5]	0.27[18]	2.90[12]	2.51[11]	4.91[6]	69.9[8]
U. of Chicago	2.87[12]	1.47[14]	2.48[12]	1.34[14]	1.68[16]	4.22[6]	6.04[4]	50.5[33]
U. of Oxford	2.86[13]	3.66[8]	2.48[12]	2.69[9]	3.51[8]	2.97[8]	1.89[12]	68.5[11]
Cornell U.	2.81[14]	6.59[4]	2.09[15]	2.96[8]	1.37[18]	1.94[15]	1.89[12]	59.5[27]
UMN – Twin Cities	2.53[15]	4.40[6]	2.74[11]	2.15[11]	0.76[22]	2.51[11]	2.64[10]	66.6[13]
UWisc – Madison	2.51[16]	7.69[2]	2.35[13]	1.61[13]	1.07[20]	0.46[24]	1.89[12]	66.1[14]
CIT	2.50[17]	1.47[14]	0.13[23]	4.57[6]	0.91[21]	7.19[1]	0.75[15]	46.9[34]
UC – San Francisco	2.29[18]	0.00[18]	5.87[3]	0.81[16]	5.49[4]	0.80[22]	0.75[15]	60.7[23]
U. of Cambridge	2.28[19]	0.73[16]	1.17[18]	2.42[10]	3.20[10]	5.02[4]	1.13[14]	65.7[15]
Yale U.	2.25[20]	1.83[13]	3.52[8]	1.08[15]	3.35[9]	1.48[18]	2.26[11]	62[21]
UC – Davis	2.14[21]	6.96[3]	1.43[17]	1.88[12]	0.46[24]	1.37[19]	0.75[15]	63[19]
U. of Pittsburgh – Pittsburgh	1.90[22]	1.10[15]	4.82[5]	0.54[17]	1.98[15]	1.83[16]	1.13[14]	63.1[18]
Princeton U.	1.90[23]	1.10[15]	0.39[22]	1.88[12]	0.76[22]	4.22[6]	3.02[9]	44.3[35]
Imperial College London	1.82[24]	2.20[12]	3.39[9]	1.88[12]	1.52[17]	1.94[15]	0.00[17]	62.3[20]
U. of Toronto	1.73[25]	2.93[10]	2.48[12]	1.08[15]	0.91[21]	1.48[18]	1.51[13]	80.3[3]
U. of Tokyo	1.72[26]	1.83[13]	0.78[20]	0.54[17]	2.29[14]	4.91[5]	0.00[17]	80.4[2]
UI – Urbana-Champaign	1.69[27]	1.83[13]	0.13[23]	4.03[7]	0.61[23]	2.40[12]	1.13[14]	58.6[29]
Washington U. in St. Louis	1.69[28]	2.56[11]	2.22[14]	0.54[17]	3.81[7]	0.23[25]	0.75[15]	54.8[31]
UC – Santa Barbara	1.68[29]	2.56[11]	0.39[22]	4.57[6]	0.15[26]	2.05[14]	0.38[16]	42.6[37]
UNC – Chapel Hill	1.61[30]	1.47[14]	2.87[10]	0.54[17]	1.22[19]	0.91[21]	2.64[10]	60.6[24]
PSU – University Park	1.57[31]	0.00[18]	0.13[23]	2.69[9]	0.91[21]	3.42[7]	2.26[11]	56.1[30]
Osaka U.	1.35[32]	2.20[12]	1.56[16]	0.81[16]	2.29[14]	1.26[20]	0.00[17]	60.2[26]
University College London	1.23[33]	1.83[13]	2.09[15]	0.27[18]	1.98[15]	0.46[24]	0.75[15]	67[12]
Swiss FIT – Zurich	1.09[34]	2.56[11]	0.00[24]	1.61[13]	0.76[22]	1.60[17]	0.00[17]	53.6[32]
Tohoku U.	0.84[35]	0.00[18]	0.13[23]	1.61[13]	0.46[24]	2.85[9]	0.00[17]	60.3[25]
U. of Georgia	0.80[36]	2.56[11]	0.13[23]	0.00[19]	0.30[25]	0.68[23]	1.13[14]	44.2[36]
Wageningen U.	0.73[37]	4.03[7]	0.00[24]	0.00[19]	0.00[27]	0.00[27]	0.38[16]	39.3[38]
National U. of Singapore	0.67[38]	0.37[17]	0.39[22]	1.61[13]	0.76[22]	0.11[26]	0.75[15]	59.1[28]
Swedish U. of Agri. Sciences	0.57[39]	3.30[9]	0.00[24]	0.00[19]	0.15[26]	0.00[27]	0.00[17]	28.6[40]
UMD – Baltimore County	0.06[40]	0.00[18]	0.00[24]	0.27[18]	0.00[27]	0.11[26]	0.00[17]	38.6[39]

production in the other 5 fields. It is interesting to notice that, in Table 2, the two institutes' places, Johns Hopkins University at the 2nd and University of California - Berkeley at the 8th, are reversed by their cross-field *h*-indices. However, if we look at their ranks by field *h*-indices, Johns Hopkins University's sorted {2, 4, 11, 12, 15, 22} versus University of California – Berkeley's sorted {2, 2, 3, 8, 12, 26}, we would intuitively expect that University of California – Berkeley should have achieved a better cross-field production, which is indeed reflected by their cross-field contributions.

The above description may lead to a false impression that institutes with better field contributions would always have greater cross-field contributions. The cross-field contribution actually delivers something more. For example, University of Pennsylvania has inferior ranks in four fields compared to University of Michigan – Ann Arbor. However, University of Pennsylvania has a better cross-field contribution because, in one of the other two fields (i.e., Social & Behavioral Science), it has a much greater field contribution that makes up its deficit in the four inferior fields. This example also manifests the proposed approach's not ignoring an institute's strong production in any field regardless of the field's publication and citation patterns. If instead the cross-field *h*-index is used, University of Pennsylvania's superior production in the few-publication-low-citation field Social & Behavioral Science would be dismissed by its inferior production in the many-publication-high-citation field Clinical Medicine. This is why, in Table 2, University of Michigan – Ann Arbor is mistakenly considered to have outperformed University of Pennsylvania.

The included ARWU PUB scores are based on the total number of publications indexed in SCIE and SSCI in 2009 and only publications of 'Articles' and 'Proceedings Papers' types are considered. Therefore, ARWU PUB score is basically a quantity-based measure whereas cross-field contribution has implicitly incorporated the quality side of an institute's publications by relying on the *h*-index to determine the MVPs. Additionally, when calculating the total number of publications of an institute, ARWU PUB gives a special weight of two to publications indexed in SSCI. Therefore the ranking by ARWU PUB score is rather inconsistent with that by cross-field contribution, and some cases may seem implausible. For example, University of Tokyo and University of Toronto are ranked at the 2nd and 3rd places by ARWU PUB score whereas both of them are ranked behind

Table 5
Spearman's rhos between the 40 institutes' various rankings.

Between rankings by	Agr	Cli	Eng	Lif	Phy	Soc
Cross-field *h*-index and field *h*-index	−0.26	0.818*	0.382**	0.922*	0.535*	0.672*
Field *h*-index and field contribution	0.789*	0.972*	0.909*	0.956*	0.929*	0.956*
Cross-field and field contributions	0.198	0.695*	0.635*	0.746*	0.670*	0.752*

* Correlation is significant at the 0.01 level (2-tailed).
** Correlation is significant at the 0.05 level (2-tailed).

the 25th place by their cross-field contributions. If the special weight is for compensating the more scarce SSCI publications, the proposed approach deals with this issue more reasonably by not ignoring these few-publication-low-citation fields, instead of applying some artificial weight.

Finally, we calculate the Spearman's rhos between the 40 institutes' rankings by their field contributions in each of the 6 fields and their cross-field contributions, and the result is summarized in the last row of Table 5. In contrast to what is shown in the first row, the ranking by cross-field contribution has rather uniform correlation with the rankings by field contribution and this seems to indirectly confirm that cross-field contribution, unlike the cross-field *h*-index, does not favor or disfavor some specific fields. The field Agriculture, Biology & Environment Sciences (Agr) however is an exception. This should not be explained as that cross-field contribution disfavors the few-publication-low-citation field Agr. If we look at Table 4, we can see that the field Agr is quite special as it seems that an institute's good or bad production in this field is usually accompanied by a reversed production in some of the other fields. For some notable examples, University of Pennsylvania has zero field contribution in this field but has a strong cross-field contribution ranked at the 9th place. Swedish University of Agriculture Sciences has a poor cross-field contribution ranked at the 39th place but has a strong field contribution ranked at the 9th place in this field.

The advantages that we observed in the field evaluation, such as the interpretation to an institute's contribution without involving the other institutes, and the manifestation of the degree of production difference, are also applicable here to cross-field evaluation. Combining the observations from this and previous sections, we can see that the proposed approach is indeed reasonable, intuitive to understand, and uniformly applicable to various sets of institutes and fields of different publication and citation patterns.

6. Discussion and conclusion

In this paper we have introduced a new approach to cross-field evaluation of publications of research institutes that is proven empirically to be reasonable, intuitive to understand, and uniform across fields of various publication and citation patterns.

This new approach relies on the MVP concept and we propose to consider an institute's contribution to a field's MVPs as the institute's production in this field. We even boldly suggest that the difference in institutes' contributions also reflect their production difference. The reliability and significance of such equivalence is indeed dubious at the moment. Some rigorous analysis has to be conducted so as to establish a proper ground for the aforementioned equivalence. We will leave this to a future study.

In this paper we use the *h*-index to determine a field's MVPs. However, as mentioned in the paper, the *h*-index is by no means the only criterion and we at the moment cannot claim that the *h*-index, even though a reasonable choice, is superior to other criteria such as the *g*-index (Egghe, 2006a, 2006b), a percentage (e.g., 0.1%, 1%, 10%, etc.) of publications, etc. To determine the best criterion for the determination of the MVPs would require some further study and could be an interesting topic for future study.

As explained in this paper, the set of MVPs determined by the *h*-index is different from the *h*-core, and the *h*-core is always a subset of the set of MVPs based on the *h*-index. However, as revealed by the empirical data shown in Table 1, the difference (e.g., 215 vs. 216, 506 vs. 510, etc.) seems to be a negligible one.

We have also pointed out two major issues, the multiple affiliations and zero contributions, to the new cross-field evaluation method of publications of research institutes, and we have provided some possible solutions. However, there are actually other issues to address. For example, we have ignored the problem of institutes or publication sets having different sizes, and we have also ignored the problem of different publication and citation patterns across sub-fields in the same field. These can all be interesting topics for future study. For example, for the former, one possible approach is to divide an institute's contribution to a field's MVPs by the institute's contribution to the field's total publications.

The proposed approach can actually be expanded into a general evaluation system based on the concept of this paper that is adaptable to fulfill an investigator's specific requirement. Some possible adaptations are outlined as follows. Firstly, as mentioned in Section 2.1, the determination of the MVPs does not have to be fixedly tied to *h*-index. We can use, for example, an *h*-type index to determine the MVPs as long as the determination is uniformly applied to all fields. Then, for the problems of multiple affiliations and zero contributions, there are also various different ways to handle them. For example, we can choose to divide the credit evenly to the affiliated institutes instead of counting the credit repeatedly for each affiliated institute.

The definitions of field and cross-field contributions can also be different. For example, we can use the percentage share of the citations, instead of the percentage share of publications, of the MVPs in defining the field contribution. We speculate that this adaptation may resolve the lack of differentiation problem by the original definition of the field contribution.

Even though the paper has focused on the evaluation of publications of research institutes, we do not see specific reasons why the proposed approach cannot be applied to entities at other aggregate levels such as a set of researchers, a set of departments, or a set of countries, and why it cannot be applied to a set of patent assignees for innovation production evaluation across a number of technological areas.

However, it should be noted that we have built our model solely based on the *h*-index and, despite the many efforts by various researchers in the past, concerns over the *h*-index prevail even until now (cf. Bartneck & Kokkelmans, 2011; Ravallion & Wagstaff, 2011). Additionally, the production measures provided by this paper are about an institute's contribution, i.e., its share in the most influential set of papers within a field or on the average across all fields. They are relative indices about the institute's contribution and should not be regarded as true performance measures. Additionally, their not-so-significant difference from the *h*-core measures suggests there is still room for an even better solution.

There are also several recently introduced indicators that are also based on the elite set concept of papers such as the π-index (Vinkler, 2009), the π_v-index (Vinkler, 2010a), the CDS-index (Vinkler, 2011a). A number of these indicators are compared by Vinkler (2010b). An interesting topic for future research would be to compare our measures with these elite-set based indicators.

References

Arencibia-Jorge, R., Barrios-Almaguer, I., Fernández-Hernández, S., & Carvajal-Espino, R. (2008). Applying successive H indices in the institutional evaluation: A case study. *Journal of the American Society for Information Science and Technology*, *59*, 155–157.

Arencibia-Jorge, R., & Rousseau, R. (2009). Influence of individual researchers' visibility on institutional impact: An example of Prathap's approach to successive *h*-indies. *Scientometrics*, *79*, 507–516.

Aksnes, D. W. (2003). Characteristics of highly cited papers. *Research Evaluation*, *12*, 159–170.

Bar-Ilan, J. (2008). The *h*-index of *h*-index and of other informetric topics. *Scientometrics*, *75*, 591–605.

Batista, P. D., Campiteli, M. G., Kinouchi, O., & Martinez, A. S. (2006). Is it possible to compare researchers with different scientific interests? *Scientometrics*, *68*, 179–189.

Bartneck, C., & Kokkelmans, S. (2011). Detecting *h*-index manipulation through self-citation analysis. *Scientometrics*, *87*, 85–98.

Bornmann, L., & Daniel, H.-D. (2009). The state of *h* index research, is the *h* index the ideal way to measure research performance? *EMBO Reports*, *10*, 2–6.

Burrell, Q. L. (2007). On the *h*-index the size of the Hirsch core and Jin's *A*-index. *Journal of Informetrics*, *1*, 170–177.

Cole, S., & Cole, J. R. (1968). Visibility and the structural bases of awareness of scientific research. *American Sociological Review*, *33*, 397–413.

Egghe, L. (2006a). An improvement of the *h*-index: The *g*-index. *ISSI Newsletter*, *2*, 8–9.

Egghe, L. (2006b). Theory and practise of the *g*-index. *Scientometrics*, *69*, 131–152.

Egghe, L. (2010). The Hirsch-index and related impact measures. *Annual Review of Information Science and Technology*, *44*, 65–114.

Egghe, L., & Rao, I. K. R. (2008). The influence of the query formulation of a topic on its *h*-index: Models and examples of the *h*-index of N-grams. *Journal of the American Society for Information Science and Technology*, *59*, 1688–1693.

Grothkopf, U., & Stevens-Rayburn, S. (2007). Introducing the h-index in telescope statistics. In S. Ricketts, C. Birdie, & E. Isaksson (Eds.), *Proceedings of the 5th Library and Information Services in Astronomy Conference* (pp. 86–92).

Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. In *Proceedings of the National Academy of Sciences of United States of America* 102, (pp. 16569–16572).

Iglesias, J. E., & Pecharromán, C. (2007). Scaling the *h*-index for different scientific ISI fields. *Scientometrics*, *73*, 303–320.

Jin, B. (2007). The *AR*-index: Complementing the *h*-index. *ISSI Newsletter*, *3*, 6.

Jin, B., Liang, L., Rousseau, R., & Egghe, L. (2007). The *R*-and *AR*-indices: Complementing the *h*-index. *Chinese Science Bulletin*, *52*, 855–863.

Kinney, A. L. (2007). National scientific facilities and their impact on nonbiomedical research. In *Proceedings of the National Academy of Sciences of the United States of America* (pp. 17943–17947), 104

Lazaridis, T. (2010). Ranking university departments using the mean *h*-index. *Scientometrics*, *82*, 211–216.

Leydesdorff, L., & Bornmann, L. (2011). Integrated impact indicators compared with impact factors: An alternative research design with policy implications. *Journal of the American Society for Information Science and Technology*, *62*, 2133–2146.

Lovegrove, B. G., & Johnson, S. D. (2008). Assessment of research performance in biology: How well do peer review and bibliometry correlate? *Bioscience*, *58*, 160–164.

Lundberg, J. (2007). Lifting the crown-citation *z*-score. *Journal of Informetrics*, *1*, 145–154.

Minasny, B., Hartemink, A. E., & McBratney, A. (2007). Soil science and the *h* index. *Scientometrics*, *73*, 257–264.

Moed, H. F., De Bruin, R. E., & Van Leeuwen, T. N. (1995). New bibliometric tools for the assessment of National Research Performance – Database description, overview of indicators and first applications. *Scientometrics*, *33*, 381–422.

Molinari, J.-F., & Molinari, A. (2008a). A new methodology for ranking scientific institutions. *Scientometrics*, *75*, 163–174.

Molinari, J.-F., & Molinari, A. (2008b). Mathematical aspects of a new criterion for ranking scientific institutions based on the *h*-index. *Scientometrics*, *75*, 339–356.

Mugnaini, R., Packer, A. L., & Meneghini, R. (2008). Comparison of scientists of the Brazilian Academy of Sciences and of the National Academy of Sciences of the USA on the basis of the *h*-index. *Brazilian Journal of Medical and Biological Research*, *4*, 258–262.

Pires Da Luz, M., Marques-Portella, C., Mendlowicz, M., Gleiser, S., Coutinho, E. S. F., & Figueira, I. (2008). Institutional *h*-index: The performance of a new metric in the evaluation of Brazilian psychiatric post-graduation programs. *Scientometrics*, *77*, 361–368.

Plomp, R. (1990). The significance of the number of highly cited papers as an indicator of scientific prolificacy. *Scientometrics*, *19*, 185–197.

Prathap, G. (2006). Hirsch-type indices for ranking institutions' scientific research output. *Current Science*, *91*, 1439.

Radicchi, F., Fortunato, S., & Castellano, C. (2008). Universality of citation distributions: Towards an objective measure of scientific impact. In *Proceedings of the National Academy of Sciences of the United States of America* (pp. 17268–17272), 105.

Radicchi, F., & Castellano, C. (2011). Rescaling citations of publications in physics. *Physical Review E*, *83*, 046116.

Radicchi, F., & Castellano, C. (2012). Testing the fairness of citation indicators for comparison across scientific domains: The case of fractional citation counts. *Journal of Informetrics*, *6*, 121–130.

Van Raan, A. F. J. (2006). Comparison of the Hirsch-index with standard bibliometric indicators and with peer judgment for 147 chemistry groups. *Scientometrics*, *67*, 491–502.

Ravallion, M., & Wagstaff, A. (2011). On measuring scholarly influence by citations. *Scientometrics*, *88*, 321–337.

Rousseau, R. (2006). New developments related to the Hirsch index. *Science Focus*, *1*, 23–25 (in Chinese). An English translation is available on-line at http://eprints.rclis.org/6376/
Rousseau, R., Yang, L., & Yue, T. (2010). A discussion of Prathap's h_2-index for institutional evaluation with an application in the field of HIV infection and therapy. *Journal of Informetrics*, *4*, 175–184.
Schubert, A. (2007). Successive *h*-indices. *Scientometrics*, *70*, 201–205.
Sypsa, V., & Hatzakis, A. (2009). Assessing the impact of biomedical research in academic institutions of disparate sizes. *BMC Medial Research Methodology*, *9*, 33.
Valentinuzzi, M. E., Laciar, E., & Atrio, J. L. (2007). Two new discipline-independent indices to quantify individual's scientific research output. *Journal of Physics: Conference Series*, *90*, 012018.
Vinkler, P. (2009). The π-index: A new indicator for assessing scientific impact. *Journal of Information Science*, *35*, 602–612.
Vinkler, P. (2010a). The π_v-index: a new indicator to characterize the impact of journals. *Scientometrics*, *82*, 461–475.
Vinkler, P. (2010b). *The evaluation of research by scientometric indicators*. Cambridge: Woodhead Publishing Limited.
Vinkler, P. (2011a). Scientometrics and scientometricians in 2011. *Journal of the American Society for Information Science and Technology*, *62*, 1430–1432.
Vinkler, P. (2011b). Application of the distribution of citations among publications in scientometric evaluations. *Journal of the American Society for Information Science and Technology*, *62*, 1963–1978.
Waltman, L., & Van Eck, N. J. (2009). A taxonomy of bibliometric performance indicators based on the property of consistency. In *Proceedings of the 12th International Conference on Scientometrics and Informetrics* (pp. 1002–1003). Available at:. http://hdl.handle.net/1765/15182/
Waltman, L., & Van Eck, N. J. (2011). The inconsistency of the h-index. *arX*iv:1108.3901* at: http://arxiv.org/ftp/arxiv/papers/1108/1108.3901.pdf
Waltman, L., Van Eck, N. J., Van Leeuwen, T. N., Visser, M. S., & Van Raan, A. F. J. (2010). Towards a new crown indicator: An empirical analysis. arX*iv:1004.1632v1.
Waltman, L., Van Eck, N. J., Van Leeuwen, T. N., Visser, M. S., & Van Raan, A. F. J. (2011). Towards a new crown indicator: Some theoretical considerations. *Journal of Informetrics*, *5*, 37–47.
Zhou, P., & Leydesdorff, L. (2011). Fractional counting of citations in research evaluation: A cross- and interdisciplinary assessment of the Tsinghua University in Beijing. *Journal of Informetrics*, *5*, 360–368.