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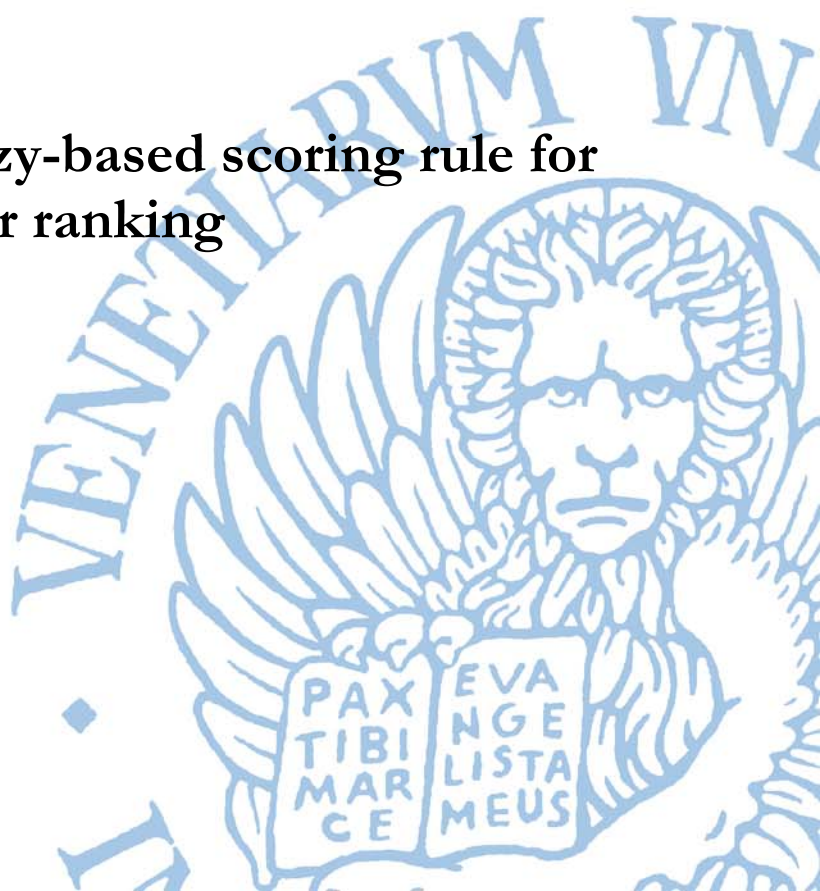
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A fuzzy-based scoring rule for author ranking

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Abstract

The measurement of the quality of research has reached nowadays an increasing interest not only for scientific reasons but also for the critical problem of researchers' ranking, due to the lack of grant assignments. The most commonly used approach is based on the so-called h -index, even if the current literature debated a lot about its pros and cons. This paper, after a brief review of the h -index and of alternative models, focuses on the characterization and the implementation of a modified scoring rule approach by means of a fuzzy inference system *a la* Sugeno

Keywords

Research evaluation, bibliometrics, author ranking, h -index, scoring rules, fuzzy inference system.

JEL Codes

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1 Introduction

Evaluating research is an important issue, especially when cuts in government spending forces to rank and to discriminate among projects and researchers. However, finding an appropriate, not discretionary, evaluation method is not an easy task. About this problem there is a vast debate in literature (see for example Adler, Ewing, Taylor (2009), Alonso, Cabrerizo, Herrera-Viedma, Herrera (2009), and Costas, Bordons (2007)).

In effect, there is no a perfect research evaluation approach. On the one hand the traditional method based on peer review may be accurate (see for instance Franceschet, Costantini (2011)) but subjective and often very time consuming and expensive (see Campanario (1998a, 1998b)). On the other hand, each bibliometric indicators (such as total number of publications, total number of citations, citations per paper, number of highly cited papers, and so on) is able to highlights a particular dimension of research output, while suffering of some drawbacks.

Conceptually, a good approach could consist in combining together different indicators in order to take simultaneously into account the various aspects related to the multidimensional nature of research output (see for example Martin (1996)).

Nevertheless, in practice, only some quantitative data – such as the number of publications, the number of citation for each paper, and the journal impact factor – are used in order to rank authors, papers, departments or journals. This is mainly due to the fact that other kind of information may be harder to obtain, whereas publications and citations are provided also by some international databases such as Google Scholar, ISI Web of Sciences and Scopus.

In any case, it is important that statistics collected on individuals' research output can be used both correctly and wisely, as for instance a 2009 Report from the International Mathematical Union underlines for citation statistics (see Adler, Ewing, Taylor (2009)). Citations are often considered the prevalent measure of research quality, but the meaning of citations is not simple and citation-based statistics are not as objective as many affirm.

Anyway, at present there is a huge number of indexes that have been proposed to evaluate scientists' research output and many of them are based also on citation statistics. In this paper

we remind one of the most used, the so-called h -index, and we discuss some of its properties in comparison with a recently proposed scoring rule approach for ranking scientists. We then propose a modified scoring rule which is based on a fuzzy logic approach.

In the literature on the assessment of the quality of research, fuzzy reasoning have been used in different ways and applications. For example, Beliakov, James (2011) use the Choquet integral in the problem of ranking scientific journals. Hussain, Grahn (2008) propose a fuzzy inference model to rank journals, conferences and authors and apply this model in the field of computer science. Turban, Zhou, Ma (2004) propose a group decision support system based on fuzzy set theory in order to integrate objective and subjective judgments in evaluating and ranking journals, and test the model by considering a real research evaluation problem in Hong Kong.

In this paper we consider a fuzzy logic approach in order to deal with the problem of ranking scientists. In particular, we propose to use a fuzzy inference system, analogously to Hussain, Grahn (2008), but in a different context, since we work in the framework of scoring rule-based approach.

The remainder of the paper is organized as follows. In Section 1 we present the h -index together with its advantages and drawbacks, and we discuss the meaning of the scoring rules. In Section 2 we focus on the axiomatic characterization of such rules and we discuss whether the h -index satisfies given properties associated to the scoring rules themselves. In Section 3 we propose the characterization and the implementation of a modified scoring rule by means of a fuzzy inference system, whereas in Section 4 we provide a simulative application of the proposed approach. Some final remarks are reported in Section 5.

2 The h -index vs scoring rules

In order to rank scientists and to measure the impact of research works, Hirsch (2005) proposes a very simple numerical index which takes simultaneously into account both a quantitative and a qualitative dimension of the research, evaluated respectively by the numbers of papers written by a given scientist and the number of citations of each paper.

In particular, the h -index of a researcher is the maximum number h of papers of the considered scientist having at least h citations each.

Computing the h -index is an easy task and the scientific community has shown a considerable interest for this indicator (see for instance Mingers (2008)). Moreover, the h -index has other advantages, as pointed out by some authors (see Egghe (2010), Alonso, Cabrerizo, Herrera-Viedma, Herrera (2009), Costas, Bordons (2007), Vanclay (2007), and Egghe, Rousseau (2006)). For example, it is an objective indicator and it is insensitive to a set of lowly cited papers.

On the other hand, there are many drawbacks that the specialized literature has put in evidence. The most important one, according to our opinion, is the fact that the h -index considers only a subset of an author's publications, that is the first most productive publications each having at least h citations. In the literature this subset is called *Hirsch core* (or h -core), while the set of publications which have at most $h - 1$ citations is called *tail-core* (see Ye, Rousseau (2010)). We illustrate some possible consequences of this drawback by the following couple of examples.

Example 1. Let us consider two authors, A and B , both having 20 publications and each of these publications with 20 citations; further, B has in addition 100 publications with 19 citations. Both authors have an h -index equal to 20. Nevertheless, we can reasonably think that they are not equivalent.

Example 2. Let us consider two authors, C and D ; C has 10 publications each with 1 citation, whereas D has only 1 publication that received 100 citations. Each of the two authors have an h -index equal to 1. So, the h -index does not identify researchers that have a moderate level of production but a very high impact.

Other limitations associated to the h -index have been underlined in the literature and many other bibliometric indicators have been proposed in order to overcome some of these drawbacks (see for instance Cabrerizo, Alonso, Herrera-Viedma, Herrera (2010), and Jin, Liang, Rousseau, Egghe (2007)), such as for example the g -index, the q^2 index, the a -index, the r -index, and the m -index.

Among the various alternative approaches we recall the one proposed by Marchant (2009) and Bouyssou, Marchant (2010) which is based on the concept of scoring rule. This approach considers summation-based rankings and therefore authors are ranked according to the sum over all their publications, where each paper is evaluated by some partial scores.

It is interesting to note that the scoring rule approach always satisfies the independence of preferences (on following: independence), contrary to the h -index, as emphasized in the following example presented in Bouyssou, Marchant (2011).

Example 3. Let us consider two authors, E and F ; E has 4 papers with 4 citations each and the F has 3 papers with 6 citations each. So, according to the h -index, E is judged better than F since the h -index for E is equal to 4, whereas the h -index for F is 3. Then, let us suppose that each of the two authors publish an additional paper receiving 6 citations. Now, the two authors are judged equivalent because the h -index is equal to 4 for both of them.

On the contrary, if we consider the scoring rules instead of the h -index, independence is always satisfied. Indeed, a scoring rule is based on the sum of the partial evaluations of all publications of a given author. In the next section we will analyze more in detail the properties of the scoring rules and also we axiomatically characterize these ranking rules.

Another different approach consists in considering the average number of citations of the publications that are in the h -core (see Jin, Liang, Rousseau, Egghe (2007)). In this way, it allows to take into account the most important publications, as in the h -index, and at the same time all the citations of these papers, as in the case of the scoring rules.

3 An axiomatic characterization of the scoring rules

In this section we aim at defining and representing a scoring rule for author ranking, based on different criteria, such as the number of citations, the number of papers and the quality of the journals.

Let $K \subseteq \mathbb{N}$ be the set of the authors and let $J \subset \mathbb{N}$ be the set of the journals. Each author

is represented by the set of his publications and each publication is characterized by the quality of the journal in which the paper is published, by the number of its citations and by the number of coauthors.

We denote by $A_{k,j}$ the set of publications of author k ($k \in K$) in journal j ($j \in J$); moreover, we indicate by $j_{i,k}$ the journal which contains publication $i \in A_{k,j}$ for author k , by $x_{i,k} \in \mathbb{N}$ the number of citations of publication $i \in A_{k,j}$ for author k and by $a_{i,k} \in \mathbb{N}$ the number of coauthors of publication $i \in A_{k,j}$ for author k .

As in Marchant (2009), a bibliometric ranking is a not constant function $R: K \rightarrow \mathbb{R}^+$, increasing with respect to the number of citations.

Now, let us consider the function $v: J \times \mathbb{N} \times \mathbb{N} \rightarrow \mathbb{R}^+$, where $v(j_{i,k}, x_{i,k}, a_{i,k})$ represents the valuation of paper i published in journal $j_{i,k}$, with $x_{i,k}$ citations and $a_{i,k}$ coauthors. We assume that the function $v(j_{i,k}, x_{i,k}, a_{i,k})$ is increasing with respect to citation number and let \mathcal{V} be the set of all functions $v: J \times \mathbb{N} \times \mathbb{N} \rightarrow \mathbb{R}^+$ that are increasing in the second argument.

A function $S: K \rightarrow \mathbb{R}^+$ is a scoring rule if there exists an evaluation function $v \in \mathcal{V}$ such that

$$S(k) = \sum_{j \in J} \sum_{i \in A_{k,j}} v(j_{i,k}, x_{i,k}, a_{i,k}). \quad (1)$$

Let us introduce the properties of independence and archimedeaness of a bibliometric ranking.

Intuitably, a bibliometric ranking satisfies independence if, given two authors, h and k , such that k is better or equally evaluated than h , when each author publishes an additional paper in the same journal, with the same number of citations and with the same number of coauthors, then k continues to be evaluated not worse than h .

More formally, if we denote by $h \oplus k$ the author which has the publications of h and those of k , we state the following axioms for a bibliometric ranking R :

Independence. For all $h, k, r \in K$, $R(h) \leq R(k)$ if and only if $R(h \oplus r) \leq R(k \oplus r)$.

In order to define archimedeaness property, let $n \odot h$ (with $n \in \mathbb{N}$ and $h \in K$) be the author which has n times the publications of author h , publications with the same characteristics in terms

of journals, citations and coauthors.

Archimedeaness. For all $h, k, r, s \in K$, with $R(h) \leq R(k)$, there exists $n \in \mathbb{N}$ such that $R((n \odot h) \oplus r) \leq R((n \odot k) \oplus s)$.

For a detailed analysis of the archimedeaness property and for the proof of the following theorem see Marchant (2009).

Theorem. A bibliometric ranking is a scoring rule if and only if it satisfies independence and archimedeaness properties.

Anywise, it is debatable if independence and archimedeaness are necessarily desirable properties for a bibliometric ranking. For instance, independence implies complete compensativeness, not a required property in some cases (see the reference above for a more complete discussion). However, from now on, we consider this framework justifying the scoring rule choice as a practical and appealing approach based, despite the h -index, on the sum of the utilities of all the contributions.

4 A fuzzy based proposal for calculating the function ν

As illustrated in the previous section, the axiomatic system which ensures the existence of a scoring rule like (1) does not suggest how to specify the function $\nu(j_{i,k}, x_{i,k}, a_{i,k})$. In this section we advance a proposal for building up such a function by means of a fuzzy inference system *a la* Sugeno (on following: FIS-S), see for example Takagi, Sugeno (1985). By so doing we develop an operative tool for scoring that, on the one hand, is able to manage the uncertainty usually present in the bibliometric data¹ and, on the other hand, is coherent with the previously considered axiomatic system. Further, this tool results particularly appropriate in case of consistent aggregation of experts' opinions (like exactly for author ranking).

In order to implement our FIS-S several aspects have to be considered like, for instance, the inputs, the number and the types of the membership functions, the conjunction operators, the number and the types of the rules, the output and so on. Since now we emphasize that an effective specifi-

¹We underline that different bibliometric databases very often answer in different manners to the same interrogation.

cation of all these objects should require the intervention of suitable focus groups. So, our setting has to be considered as a first step in that direction.

As far the inputs and the membership functions are concerned, we consider the arguments of the function $v(j_{i,k}, x_{i,k}, a_{i,k})$ in (1), that is:

- $j_{i,k}$, the journal quality, that we measure by the impact factor, an index widely accepted by the scientific community. We characterize this input, and the other two ones, by three conditions that we classify as “Bad”, “Average” and “Good”. In particular, as higher impact factor is better, we describe these conditions by, respectively, a z-shaped membership function, a Gaussian one and an s-shaped one;
- $x_{i,k}$, the number of citations. Although citations can be both positive and negative, noticing that they are mainly positive, we assume that more citations is better. In particular, we describe the conditions “Bad”, “Average” and “Good” by, respectively, a z-shaped membership function, a π -shaped one and a s-shaped one. Notice that the choice of a π -shaped membership function for representing the condition “Average” permits to consider as equally average different (but close) numbers of citations;
- $a_{i,k}$, the number of coauthors. Generally, but not always², less coauthors is better. So, we describe the conditions “Bad”, “Average” and “Good” by, respectively, an s-shaped membership function, a Gaussian one and a z-shaped one.

Of course, the choice of the analytical forms of the implied membership functions is personalizable by the user.

As far the conjunction operators and the if-then-else rules are concerned, in table 1 we propose a system constituted by 27 rules in which the “and” operator is a triangular norm (on following: T-norm). Observe that the choice of a conjunction operator of T-norm type is also due to its easy interpretability in the framework of probabilistic metric spaces (see for example Coletti, Scozzafava

²For an average researcher, is it better to publish a paper as only author or having as coauthor a Nobel prize winner?

(2004), and Klement, Mesiar, Pap (2000)). In the table, “B” stands for “Bad”, “A” stands for “Average” and “G” stands for “Good”.

Table 1: System of the rules.

#	Rule
1	If ($j_{i,k}$ is B) and ($x_{i,k}$ is B) and ($a_{i,k}$ is B) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.00$ over 1.00)
2	If ($j_{i,k}$ is B) and ($x_{i,k}$ is B) and ($a_{i,k}$ is A) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.00$ over 1.00)
3	If ($j_{i,k}$ is B) and ($x_{i,k}$ is B) and ($a_{i,k}$ is G) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.00$ over 1.00)
4	If ($j_{i,k}$ is B) and ($x_{i,k}$ is A) and ($a_{i,k}$ is B) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.10$ over 1.00)
5	If ($j_{i,k}$ is B) and ($x_{i,k}$ is A) and ($a_{i,k}$ is A) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.20$ over 1.00)
6	If ($j_{i,k}$ is B) and ($x_{i,k}$ is A) and ($a_{i,k}$ is G) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.30$ over 1.00)
7	If ($j_{i,k}$ is B) and ($x_{i,k}$ is G) and ($a_{i,k}$ is B) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.20$ over 1.00)
8	If ($j_{i,k}$ is B) and ($x_{i,k}$ is G) and ($a_{i,k}$ is A) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.30$ over 1.00)
9	If ($j_{i,k}$ is B) and ($x_{i,k}$ is G) and ($a_{i,k}$ is G) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.40$ over 1.00)
10	If ($j_{i,k}$ is A) and ($x_{i,k}$ is B) and ($a_{i,k}$ is B) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.10$ over 1.00)
11	If ($j_{i,k}$ is A) and ($x_{i,k}$ is B) and ($a_{i,k}$ is A) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.10$ over 1.00)
12	If ($j_{i,k}$ is A) and ($x_{i,k}$ is B) and ($a_{i,k}$ is G) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.20$ over 1.00)
13	If ($j_{i,k}$ is A) and ($x_{i,k}$ is A) and ($a_{i,k}$ is B) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.30$ over 1.00)
14	If ($j_{i,k}$ is A) and ($x_{i,k}$ is A) and ($a_{i,k}$ is A) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.40$ over 1.00)
15	If ($j_{i,k}$ is A) and ($x_{i,k}$ is A) and ($a_{i,k}$ is G) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.50$ over 1.00)
16	If ($j_{i,k}$ is A) and ($x_{i,k}$ is G) and ($a_{i,k}$ is B) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.45$ over 1.00)
17	If ($j_{i,k}$ is A) and ($x_{i,k}$ is G) and ($a_{i,k}$ is A) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.50$ over 1.00)
18	If ($j_{i,k}$ is A) and ($x_{i,k}$ is G) and ($a_{i,k}$ is G) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.60$ over 1.00)
19	If ($j_{i,k}$ is G) and ($x_{i,k}$ is B) and ($a_{i,k}$ is B) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.50$ over 1.00)
20	If ($j_{i,k}$ is G) and ($x_{i,k}$ is B) and ($a_{i,k}$ is A) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.60$ over 1.00)
21	If ($j_{i,k}$ is G) and ($x_{i,k}$ is B) and ($a_{i,k}$ is G) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.70$ over 1.00)
22	If ($j_{i,k}$ is G) and ($x_{i,k}$ is A) and ($a_{i,k}$ is B) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.60$ over 1.00)
23	If ($j_{i,k}$ is G) and ($x_{i,k}$ is A) and ($a_{i,k}$ is A) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.70$ over 1.00)
24	If ($j_{i,k}$ is G) and ($x_{i,k}$ is A) and ($a_{i,k}$ is G) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.80$ over 1.00)
25	If ($j_{i,k}$ is G) and ($x_{i,k}$ is G) and ($a_{i,k}$ is B) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.80$ over 1.00)
26	If ($j_{i,k}$ is G) and ($x_{i,k}$ is G) and ($a_{i,k}$ is A) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 0.95$ over 1.00)
27	If ($j_{i,k}$ is G) and ($x_{i,k}$ is G) and ($a_{i,k}$ is G) then ($v(j_{i,k}, x_{i,k}, a_{i,k}) = 1.00$ over 1.00)

Of course, as for the analytical forms of the membership functions, also the values of the valuation function can be personalized by the user.

5 A simulative application

In this section we present some results of a simulative application of our FIS-S³. The application is simulative in the sense that, as described in the previous section, the setting we use is not related to a real context but, more simply, to a reasonably realistic one.

At first we synthetically provide some further details about the inputs and the membership functions which have impact to our application:

- we perform the analysis considering as (sound) ranges of the inputs proper subsets of their “natural” domains. In particular: $j_{i,k} \in [0.0, 7.5]$, $x_{i,k} \in \{0, 1, \dots, 24, 25\}$ and $a_{i,k} \in \{0, 1, \dots, 29, 20\}$;
- with reference to $j_{i,k}$: the condition “Bad” is strictly decreasing in its range; the condition “Good” is strictly increasing in $[0.0, 5.0]$ and is equal to 1 in $[5.0, 7.5]$ ⁴;
- with reference to $x_{i,k}$: the condition “Bad” is strictly decreasing in its range; the condition “Average” shows equally average numbers of citations in $\{6, 7, 8\}$; the condition “Good” is strictly increasing in $\{0, 1, \dots, 9, 10\}$ and is equal to 1 in $\{11, 12, \dots, 24, 25\}$;
- with reference to $a_{i,k}$: the condition “Bad” is equal to 0 in $\{0, 1, \dots, 3, 4\}$ and is strictly decreasing in $\{5, 6, \dots, 19, 20\}$; the condition “Good” is equal to 1 in $\{0, 1, 2\}$, is strictly decreasing in $\{3, 4, \dots, 9, 10\}$ and is equal to 0 in $\{11, 12, \dots, 19, 20\}$.

In figure 1 we show for each input the associated membership functions (for simplicity’s sake all the membership functions are graphically represented as continuous while some inputs are not).

At this point our FIS-S is able to compute the score for author ranking. As example, in table 2 we report some scoring computed in correspondence of input values determined as:

$$\text{worst_input_value} + \alpha \cdot \text{signum}(\text{best_input_value} - \text{worst_input_value}) \cdot \text{input_range},$$

³The fuzzy inference system has been implemented by using the Fuzzy Logic Toolbox™ of MATLAB.

⁴In other terms, the condition “Good” shows equally good journals’ impact factors in $[5.0, 7.5]$. Similarly for analogous situations implying the other conditions “Bad” and “Good”.

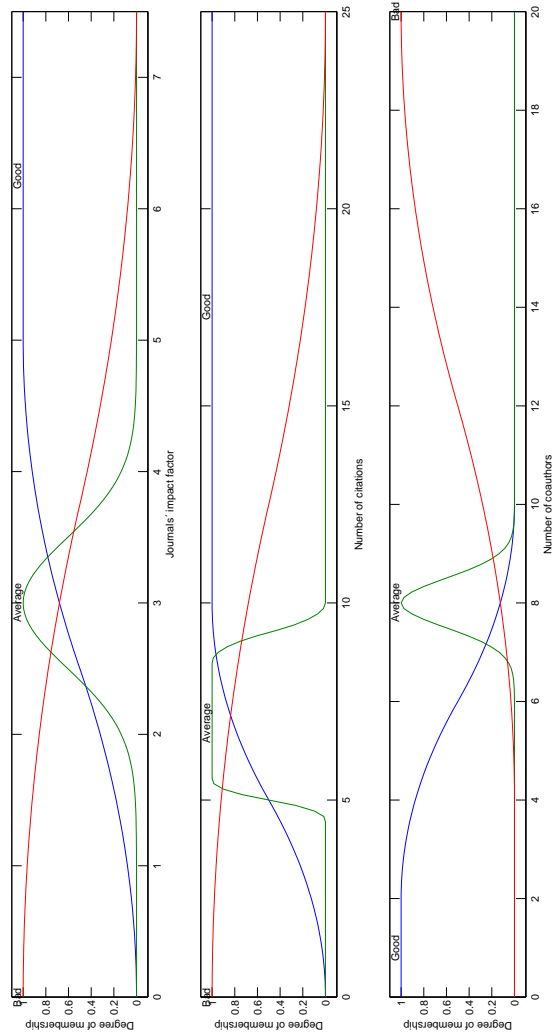


Figure 1: Membership functions associated to each input.

with $\alpha \in [0, 1]$ ^{5,6}.

In qualitative terms, we determine the value of each input as a percentage (α) of its range added/subtracted to/from the worst value of the input itself (we add with respect to $j_{i,k}$ and $x_{i,k}$; we subtract with respect to $a_{i,k}$).

Notice the nonlinear response of $v(j_{i,k}, x_{i,k}, a_{i,k})$ with respect to the inputs. In fact, when the

⁵For instance, the *worst_input_value* of $j_{i,k}$ is 0, whereas the *worst_input_value* of $a_{i,k}$ is 20.

⁶Of course, the values of the numbers of citations and of coauthors are suitable rounded.

Table 2: Some computed scoring.

α	$j_{i,k}$	$x_{i,k}$	$a_{i,k}$	$v(j_{i,k}, x_{i,k}, a_{i,k})$
1.00	7.500	25	0	1.000 over 1.000
0.75	5.625	19	5	0.865 over 1.000
0.50	3.750	13	10	0.589 over 1.000
0.50	3.750	12	10	0.574 over 1.000
0.25	1.875	6	15	0.505 over 1.000
0.00	0.000	0	20	0.000 over 1.000

value of each input is far α of its range from its own worst value, generally $v(j_{i,k}, x_{i,k}, a_{i,k})$ is different from α .

6 Final remarks

As previously stated, important aspects of our approach to take care are the inputs, the number and the types of the membership functions, the conjunction operators, the number and the types of the rules, the output and so on. A so articulated framework permits a high degree of flexibility to this tools, but contemporary makes it complex and difficult to set (for instance, the number of rules grows as a power with respect to the number of inputs and of the membership functions describing each condition). So, in order to be able to manage this complexity in real application, we intend to investigate the possibility to resort to teams of experts or to focus groups by which to determine or, at least, to circumscribe the choices to perform for each aspect. Notice that this is not painless. In fact, it opens the door to other problems like, for instance, the ones related to the aggregation of opinions and the consistency of the opinions themselves (see for example Giove, Corazza (2009) and the references therein).

A further source of improvements can surely be the wise definition of the inputs. For instance, it should be effective to consider in different ways the number of self-citations and the number of others-citation. Similarly, with respect to the coauthors, it should be effective to take into account, beyond their number, also their quality.

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