ARTICLE IN PRESS
INDOR-02162; No of Pages 6
International Journal of Industrial Organization xxx (2014) xxx–xxx
Contents lists available at ScienceDirect
International Journal of Industrial Organization
journal homepage: www.elsevier.com/locate/ijio

Axiomatic measures of intellectual influence☆

Ignacio Palacios-Huerta [b,*], Oscar Volij [a]

[a] Ben-Gurion University of the Negev, Israel
[b] London School of Economics and Ikerbasque Foundation at UPV/EHU, United Kingdom

ARTICLE INFO

Available online xxxx

PsycINFO classification:
D70
D71
D89

Keywords:
Intellectual influence
Rankings
Axiomatic approach

ABSTRACT

Measuring influence allows the study of such issues as the impact and reputation of scientists and scientific publications, the dynamics of innovation, and the construction of ranking algorithms for search engines in the world wide web. Ranking methods that measure influence are typically based on the information contained in the network of communications between different entities (scholarly publications, patents, web pages). This paper presents within the same framework recent developments that use the axiomatic approach to derive ranking methods. Two related but essentially different ranking problems are studied: journal ranking problems and scholar ranking problems. The paper concludes with open theoretical and empirical questions for future research.

1. Introduction

In the past few years there has been a significant growth in the use of influence measures and numerical indices that quantify "impact" using the network of citation data between entities such as scholarly publications, patents, web pages, and other forms of documentation.

The information contained in these networks is valuable because it allows us to make a first attempt at a rigorous quantitative analysis of elusive phenomena. In academic and scientific environments, for instance, these data are useful to measure reputation, the quality of journals, and the productivity of scholars, universities and others. Citation analysis is in fact widely used as a management tool for making decisions on hiring, promotion, salary, etc., in academic institutions. In the literature on the dynamics of innovation and technological change, patent citation data are used for examining the pattern of knowledge spillovers and evaluating the importance of private and public patenting (see Jaffe and Trajtenberg (2002)). And in the world wide web, citation analysis plays a fundamental role in the development of search algorithms that find and rank web pages.

Beginning at least with Garfield's (1972) impact factor, there was a proliferation of ranking methods in economics and other social sciences. Unfortunately this early literature made little effort to justify the use of one method over another. Rather, the justification was simply based on intuitive grounds or on the impression that they yielded introspectively plausible results. Posner (2000, p. 383) lamented these shortcomings by arguing that "citation analysis is not an inherently economic methodology: most of it has been conducted without any use of the theories or characteristic techniques of economists".

This situation has somewhat changed in recent years when several studies begun to apply the axiomatic methodology to address the problem of measuring intellectual influence. Instead of proposing ranking methods on intuitive grounds, the idea is to derive them from first principles. Thus, this methodology allows us to characterize and compare different measures according to the properties that they satisfy.

The literature on intellectual influence has developed two related but essentially different branches of problems: journal ranking problems and scholar ranking problems. This paper combines them into a single framework and presents some of the more interesting axiomatic results which have been derived over the last few years. Needless to say, this presentation is not exhaustive. We conclude with a few open questions.

2. Framework for ranking problems

In what follows we use the terms "article" and "journal" to refer to the cited unit of publication and to the citing unit, respectively. We also use the word "citations" to refer to the citations obtained by an

☆ We thank Tommaso Valletti, Marco Ottaviani and participants in seminars at the universities of Zurich and East Anglia, and at the 40th Annual Conference of EARIE in Évora for useful comments. Financial support from the Ministerio de Economía y Competitividad (ECO2012-31626, ECO2012-31346), and from the Departamento de Educación, Política Lingüística y Cultura of the Gobierno Vasco (IT869-13, IT568-13) is gratefully acknowledged.

* Corresponding author at: Department of Management, London School of Economics, Houghton Street, London WC2A 2AE, London, UK.
E-mail addresses: i.palacios-huerta@lse.ac.uk (I. Palacios-Huerta), ovolij@bgu.ac.il (O. Volij).

http://dx.doi.org/10.1016/j.ijindorg.2014.02.011
0167-7187/© 2014 Elsevier B.V. All rights reserved.

article, and "references" to mean citations made by a journal. As indicated earlier, other interpretations can be given to the problem of measuring influence based on communication data depending on the specific application.

Within the academic context, a typical CV, as will likely be required by tomorrow's university, may look like this:

$$\begin{array}{c} \\ \text{Art } a \\ \text{Art } b \\ \text{Art } c \end{array} \begin{array}{c} \begin{array}{cccc} JPE & AER & JET & IJIO \end{array} \\ \begin{pmatrix} 2 & 3 & 0 & 1 \\ 5 & 2 & 4 & 3 \\ 1 & 7 & 0 & 2 \end{pmatrix} \end{array}$$

Here, each row represents a published article and each column represents a journal. An entry represents the number of citations that the corresponding article obtains from a paper published in the corresponding journal. Thus, for instance, Article b has been cited three times by the papers published in *IJIO* while *AER* made seven references to Article c.

One can identify in the literature two approaches to evaluating a CV like this one. According to the first approach, which is typically applied when the CV belongs to a journal, all articles are considered equal and the references of each journal are condensed into a single number, namely the total number of references made by the journal. Thus, the relevant data are exhibited as

$$\begin{array}{cccc} JPE & AER & JET & IJIO \\ (8 & 12 & 4 & 6) \end{array}$$

According to the second approach, which is typically applied when the CV belongs to an individual scholar, the citations obtained by a given article are considered equal and are usually condensed into a single number, namely its total number of citations. Thus, the relevant data are exhibited as

$$\begin{array}{c} \text{Art } a \\ \text{Art } b \\ \text{Art } c \end{array} \begin{pmatrix} 6 \\ 14 \\ 10 \end{pmatrix}$$

These two approaches lead to two different ranking problems, journal ranking problems and scholar ranking problems, which are analyzed next.

3. Journal ranking problems

A journal ranking problem consists of a group of journals and their respective citation records. For instance, in this journal ranking problem:

$$\begin{array}{c} \\ IJIO \\ AER \\ JPE \end{array} \begin{array}{c} \begin{array}{ccc} IJIO & AER & JPE \end{array} \\ \begin{pmatrix} 100 & 100 & 150 \\ 50 & 200 & 100 \\ 100 & 50 & 150 \end{pmatrix} \end{array}$$

the first row represents the *IJIO*'s citation record and the first column represents the *IJIO*'s "opinion" about the various journals.

Formally, a journal ranking problem consists of a set of journals $\mathcal{J} = \{1, \ldots, J\}$ and a $J \times J$ irreducible matrix C. The entry c_{ij} is the number of citations that Journal i received from Journal j. Each column represents the corresponding journal's *opinion* about the journals in $\mathcal{J}$. The *reference intensity* of Journal $j \in \mathcal{J}$ is the number of citations it issues, namely $r_j = \sum_{i \in \mathcal{J}} c_{ij}$. In any given journal ranking problem, different journals may have different reference intensities.

The objective is to take a journal ranking problem and aggregate the journals' opinions into an "objective opinion". Formally, we are interested in a ranking method f that takes a journal ranking problem $\langle \mathcal{J}, C \rangle$ and returns a list of scores $v = (v_j)_{j \in \mathcal{J}}$, which represents the objective opinion. As with prices, the absolute values v_j are meaningless. Only the relative values v_i/v_j are important. For this reason, if one needs a unique list of values, some normalization is required. In what follows, if two lists of scores $v = (v_i)_{i \in \mathcal{J}}$ and $w = (w_i)_{i \in \mathcal{J}}$ are proportional to each other, we will write $v \propto w$.

3.1. Examples of ranking methods

In what follows, we describe a number of ranking methods.

Impact Factor Method. This method is given by the function that assigns to each ranking problem $\langle \mathcal{J}, C \rangle$ an opinion proportional to the total sum of citations it obtained:

$$\left(\sum_{j \in \mathcal{J}} c_{1j}, \ldots, \sum_{j \in \mathcal{J}} c_{Jj} \right).$$

Invariant Method. This method is given by the function that assigns to each ranking problem $C = \{c_{ij}\}_{(ij) \in \mathcal{J}^2}$ an opinion $(v_i)_{i \in \mathcal{J}}$ that satisfies

$$v_i = \sum_{j \in \mathcal{J}} \frac{c_{ij}}{r_j} v_j \quad i \in \mathcal{J}.$$

That is, the Invariant Method assigns to each journal a weighted sum of its citations, where the weights are the scores of the citing journals divided by their respective reference intensities.

Handicap Method. This method is given by the function that assigns to each ranking problem $C = \{c_{ij}\}_{(ij) \in \mathcal{J}^2}$ an opinion $(v_i)_{i \in \mathcal{J}}$ that satisfies

$$v_i = \sum_{j \in \mathcal{J}} \frac{c_{ij}}{q_j} \quad i \in \mathcal{J}$$
$$q_j = \sum_{i \in \mathcal{J}} \frac{c_{ij}}{v_i} \quad j \in \mathcal{J}$$

The Handicap Method issues for each journal i two values. One is its score—v_i, and the other is its "competence"—$1/q_i$. The score measures the impact of the journal on other journals and depends on how much it is cited. Its "incompetence"—q_i, measures the influence he gets from other journals, and depends on how much it cites. The score of the journal according to this method is the sum of its citations weighted by the citing journal's competence. And the incompetence of a journal is the weighed sum of its references where the weights are the inverse of the cited journal's score.

3.2. Special problems

It is sometimes convenient to focus attention not on all the general problems, possibly arising from complicated networks of citations, but only on some simple ones. The following are two such problems.

Normalized problems. These are problems in which all the journals have the same reference intensity. That is, for some r

$$r_j = \sum_{i \in \mathcal{J}} c_{ij} = r \quad j \in \mathcal{J}.$$

Row-balanced problems. These are problems in which all journals have the same number of citations. That is, for some c

$$\sum_{j \in \mathcal{J}} c_{ij} = c \quad i \in \mathcal{J}.$$

3.3. Axioms

We now list various axioms against which different ranking methods can be compared. The first two axioms are based on the simple problems just described.