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## Analyzing Research Impact via Functional Data Analysis: A Powerful Tool for Scholars, Insiders, and Research Organizations

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### Abstract

In recent decades, also due to the development of the Internet and software systems, there has been a substantial increase in electronic publications and the possibility of collecting numerous data to compile statistics on researchers and scientific journals. This has led scientific research to become a real business for many actors involved. In fact, the economic interests on research concern not only researchers but especially publishers, who pursue profit, and scientific organizations dealing with recruiting the best researchers in the worldwide “market”. For this reason, in the last decades, there has been a considerable increase of studies looking for the best methods and indicators for analyzing the impact of researchers and scientific journals in the various scientific communities. Most of the indicators proposed in the literature for assessing researchers’ impact are very simple synthetic indexes, such as the number of citations, h-index and number of publications. Instead, for journals, the most used indexes are impact factors, SCImago Journal Rank, and h-index. In this research, we propose the use of functional analysis to obtain new advanced statistical indicators starting from the classical bibliometric indexes. Specifically, we will show through an application to real data how to use functional data analysis to add interesting new indicators through the analysis of classical bibliometric indexes.

**Keywords:** FDA, Research Impact, Research Statistics, Business Analytics, SCImago Journal Rank

### Introduction

The 21st century, with the development of internet and electronic publications, has brought the importance of bibliometric indicators to the attention of the international scientific research community [e.g. Meho and Sugimoto, 2008; Jacsò, 2011]. The possibility of collecting and disseminating huge amounts of data related to the impact of research by scholars and scientific journals has led to the intensification of the search for more suitable indexes to measure such phenomena. Indeed, the impact of the research seems to have great importance from an economic point of view for multiple actors [Brzezinski, 2015]. The reputation of researchers today is almost exclusively based on bibliometric indicators such as h-index and the number of citations. The quality of publishing placement of a publication is based on the publisher’s bibliometric indicators. The best universities in the world are looking for the best scholars and the best researchers able to attract research funds to their institutions. Universities and even research organizations are perpetually looking for those who can attract new gains and new funding both public and private. Therefore, it is evident that scientific research, unlike last century, has assumed economic goals that were previously very limited. For this reason, when we deal with the statistical analysis of bibliometric indicators, we are involved in real business analytics. This huge amount of data deserves great methodological attention and must be treated with the most sophisticated tools from a mathematical statistical perspective.

To date, there are many databases that collect biometric data concerning scientific research both for researchers and scientific journals. In any case, the most important databases are surely SCOPUS

(<https://www.scopus.com/>), Web of Science (WOS - <https://webofknowledge.com/>), and Google Scholar (<https://scholar.google.it/>). All these databases provide a set of indicators that can be used to assess the impact of scholars' scientific research and the importance of international scientific journals. Many type of indices have been proposed in the literature but the most important are certainly the number of citations, h-index and number of publications for researchers whereas the SCImago Journal Rank, the impact factor (I.F.), and h-index are the most informative for journals.

The h-index is one of the recent indicators in the field of scientometric which was introduced by Jorge Hirsch. It rates a scientist's performance based on his or her career publications, as measured by the lifetime number of citations each article receives. The measurement depends on both quantity (number of publications) and quality (number of citations) of an academic's publications. h-index is considered one of the best indicators [e.g. see Bar-Ilan, 2007; Jacsò, 2011] because it is objective and can be extended also to scholarly journal as well as a group of scientists, such as a department or university or country. Exactly, we can say that a scholar with an index of "h" has published "h" papers each of which has been cited in other papers at least "h" times. Another important indicator is the absolute number of citations an author has received. However, some doubt may arise about it given that it is few useful to check the recent productivity of a researcher.

Regarding journals, many indexed are available, but a primary role is played also by the journals' h-index and their impact factor, i.e. a measure reflecting the yearly average number of citations to recent articles published in that journal. Furthermore, a more sophisticated index is the SCImago Journal Rank (SJR), that ranks journals by their "average prestige per article".

Despite these indicators are interesting summary statistics, and some of them also attempt to consider dynamics (e.g. 2-years I.F., 3-years I.F., and 4-years I.F.), they seem to neglect the importance of time evolution. In truth, both for researchers and for scientific journals, it would seem much more interesting to analyze the dynamics and therefore the evolution of these indicators over time rather than analyzing them in the last instant of available time. As the measurement of these indices is repeated over time, they can be analyzed with sophisticated statistical tools such as functional data analysis (FDA). In fact, with this type of analysis we can highlight very interesting aspects that are not captured with other methods [e.g. see Horová and Vopatová, 2011; Hofmann and Hošková-Mayerová, 2016, Talhofer et al., 2015; Maturo et al., 2017, Maturo and Di Battista, 2018; Fortuna and Maturo, 2018; Maturo, 2018; Maturo et al. 2018].

The theory and practice of statistical methods in situations where the available data are functions (instead of real numbers or vectors) is often referred to as FDA. This subject has become increasingly popular from the end of the 1990s and is now a major research field in statistics [Ramsay and Dalzell, 1991; Ramsay and Silverman, 2002; Cuevas, 2014]. Analyzing functional data has had a significant impact on statistical methods and thinking, changing the way in which we display, model and forecast data [e.g. Horová et al., 2012, 2013; Hasilová and Vališ, 2018]. The theoretical and practical developments in FDA are mainly from the last four decades, due to the rapid development of computer recording and storing facilities [Shang, 2013].

FDA [Ramsay and Silverman, 2005; Ferraty and Vieu, 2003, 2006; Aguilera et al., 2011] addresses problems in which the observations are described by functions rather than finite dimensional vectors. The classical statistical method works with data that are observed on units and, in general, they are scalars. However, there are cases in which the observations on units are logically measurable on a real domain [Ramsay et al., 2009]. Therefore, in FDA analysis, it is studied the characteristics of the functions instead of the simple data [Ramsay et al., 2009].

The remainder of this paper is structure as follows. Section 2 presents our material and methods, and thus illustrates the basic concepts of FDA. Section 3 displays a real application of this method to 16 scientific journals. The paper ends with our discussion and conclusions.

## Material and Methods

In the literature, many scholars have stressed the numerous reasons for using FDA. For example, Ramsay and Dalzell [1991] underlined that the objective of an analysis can be functional in nature; Ferraty and Vieu [2006] highlighted that sometimes relevant information is included in the derivatives rather than in the data themselves; Cuevas [2014] remarked that, in the context of FDA, unlike time series analyses, no assumptions of stationarity are made, and data can not be sampled at equally spaced time points; and finally, Ramsay and Silverman [2005] emphasized that FDA allows us studying important further sources of pattern and variation among data.

The basic idea of FDA is to deal directly with the function generating the data instead of the sequence of observations, and thus to treat observed data functions as single entities. In real applications, functional data are often observed as a sequence of point data, and thus the function denoted by  $y = f(x)$  reduces to record of discrete observations that are denoted by the  $T$  pairs  $(x_j; y_j)$  where  $x \in \mathbb{R}$  and  $y_j$  are the values of the function computed at the points  $x_j, j = 1, 2, \dots, T$  [Ramsay et al., 2009].

The first step in FDA is to convert the values  $y_{i1}, y_{i2}, \dots, y_{iT}$  for each unit  $i = 1, 2, \dots, N$  to a functional form computable at any desired point  $x$ . Therefore, we need a flexible method for constructing functions from raw discrete data, which should be able to reproduce any feature that interests us in a function. A functional variable  $X$  is just a random variable taking values in a functional space  $\xi$ . Thus, a functional data set is just a sample  $X_1, \dots, X_N$  (also denoted  $X_1(t), \dots, X_N(t)$ ) drawn from a functional variable  $X$ . Usually,  $\xi$  is assumed to be a normed or seminormed metric space [Ferraty and Vieu, 2006].

Because, in this context, the data are functions, the observed random variables are stochastic processes, i.e., random elements taking values in a function space. Hence, many essential notions and theorems of classical statistics should be extended and adapted to the infinite-dimensional framework of FDA [Cuevas, 2014].

Supposing that the functional data  $Y(t)$  is observed through the model  $Y(t_i) = X(t_i) + \varepsilon(t_i)$  where the residuals  $\varepsilon(t)$  are independent with  $X(t)$ , we can to get back the original signal  $X(t)$  using a linear smoother [Ramsay et al., 2009]:

$$\hat{X}(t_i) = \sum_{j=1}^n s_j(t_i) Y(t_j) \Rightarrow \hat{X} = SY \quad (1)$$

where  $s_j(t_i)$  is the weight that the point  $t_j$  gives to the point  $t_i$ .

In the literature, many methods have been proposed to estimate the functional datum. However, the most common adopted criteria are the b-spline approximation, the Fourier basis approximation, the kernel smoothing, and the functional principal component analysis (FPCA). In this study, we focus on the b-spline approximation and FPCA.

The most used method for representing functions is the finite representation in a fixed basis [Ramsay and Silverman, 2005]. Let  $X(t) \in L_2$ . A basis function system is a set of  $K$  known functions  $\phi_j(t)$ , that are linearly independent of each other and can be extended to include any number  $K$  in the system. Thus, a function  $X(t)$  can be constructed as a linear combination of these basis functions:

$$X(t) = \sum_{j=1}^K c_j \phi_j(t) \quad (2)$$

where  $c_j$  is the vector of coefficient defining the linear combination and  $\varphi_j(t)$  is the vector of basis functions. Once we have the approximation, we obtain the observed residual series:

$$\varepsilon_i(t) = X_i(t) - \widehat{X}_i(t) \quad (3)$$

from which we get a standard measure of quality of fit for an individual series [see Ramsay and Silverman, 2005; Ramsay et al., 2009].

$$s_i^2 = \frac{1}{n-K} \sum_{j=1}^n \varepsilon_i(t_j)^2 \quad (4)$$

There are many different types of basis functions, i.e. Fourier basis that are useful to represent periodic functions; b-splines that are sets of polynomials (of order  $m$ ) defined in subintervals constructed in such a way that in the border of the subintervals the polynomials coincide (up to  $m-2$  derivative); wavelets that are good in case the grid is a power of 2; and polynomials.

Another interesting method for representing functions is the functional principal component decomposition [Cardot et al., 1999; Ramsay and Silverman, 2005; Ferraty and Vieu, 2006; Aguilera et al., 2011; Febrero-Bande and de la Fuente, 2012; Escabias et al., 2014]. It allows us displaying the functional in a few components. Thus, the functional data can be rewritten as a decomposition in an orthonormal basis by maximizing the variance of  $X(t)$ :

$$\widehat{X}_i(t) = \sum_{k=1}^K f_{ik} \xi_k(t) \quad (5)$$

where  $f_{i,k}$  is the score of the generic FPC  $\xi_k$  for the generic function  $X_i$  ( $i = 1, 2, \dots, n$ ).

The advantage of PCA is that it finds a lower-dimensional representation, while preserving the maximum amount of information from the original data. In the functional context, in the point cloud space, FPCA looks for finding the direction vector with greatest population variation, in the sense of maximizing the variance of the data projected onto the vector. This direction is found by either an eigenvalue analysis of the covariance matrix, or by a singular value decomposition of the data matrix [Zhao et al., 2004].

Starting from the representation of functions, a plethora of classical statistical concepts have been adapted to the FDA context, e.g. functional mean, functional variance, functional covariance, functional distance, functional clustering, functional regression, and many others [e.g. see Ramsay and Silverman, 2005; Ferraty and Vieu, 2006; Aguilera et al., 2011; Febrero-Bande and de la Fuente, 2012; Escabias et al., 2014; Di Battista et al., 2016a,b].

However, a complete dissemination of these statistical methods in a functional context is not the aim of these paper. Hence, we concentrate on the application and possible development of FDA in the framework of business statistics, specifically on research analytics.

## Application and Results

As suggested in the introduction, our idea is to extend the FDA to the analysis of research data, and therefore to the study of statistics of scientific journals and researchers. We could focus on many indices and study them over time with the FDA approach, e.g. h-index, number of citations, impact factor, SNIP, number of views, and many others. However, in this context, we will limit ourselves to providing an FDA application on the analysis of SCImago Journal Rank (SJR indicator), being aware that the study can also be extended to researchers and other indicators for scientific journals.

*“The SJR is a size-independent prestige indicator that ranks journals by their average prestige per article”. “It is based on the idea that all citations are not created equal. SJR is a measure of scientific*

*influence of journals that accounts on both the number of citations received by a journal and the importance or prestige of the journals where such citations come from. It measures the scientific influence of the average article in a journal, it expresses how central to the global scientific discussion an average article of the journal is (<http://www.scimagojr.com/>)". The SJR indicator is a free journal metric which provides an alternative to the impact factor.*

Our sample is composed of 16 scientific journals (randomly selected) belonging to the areas of “applied mathematics” and “decision science”. The data are gathered from the above website that shows many information about the scientific journals indexed by the SCOPUS database. In our study, we focus on the values of SJR for 11 years, from 2006 to 2016.

Table 1 shows the data of the index SJR over 11 years for the 16 scientific journals. Figures 1 and 2 illustrate the SJR and the smoothed version (see Equation 2) of the functions over time. We observe that, in our sample, the Journal of the American Mathematical Society is the most important according to the SJR for the whole period whereas the other journals have different trends over time. Assessing the impact of journals according to scalar measures, e.g. the value of SJR in 2016, strongly limits the information about the trend and its variability over time. As suggested by many scholars, the objective of an analysis can be functional in nature [Ramsay and Dalzell, 1991] as in this framework; moreover, sometimes derivatives are more informative than the function themselves and give relevant information about phenomena [Ferraty and Vieu, 2006].

**Table 1: The full name of the journal are: Organizational Research Methods, Structural Equation Modeling, Journal of Behavioral Decision Making, International Journal of Management Reviews, Computational and Mathematical Organization Theory, Theory and Decision, Annals of Operations Research, Journal of Sport Management, Ecological Indicators, Journal of the American Mathematical Society, Communications on Pure and Applied Mathematics, IEEE Transactions on Fuzzy Systems, Biometrika, Journal of Econometrics, SIAM Journal on Mathematical Analysis, Biometrics.**

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1.ORM	1.38	2.74	3.24	3.60	4.29	4.75	4.85	5.56	5.44	5.96	5.64
2.SEM	1.47	2.29	2.81	2.75	3.39	2.02	2.57	2.64	2.70	2.29	2.57
3.JBDM	1.22	1.00	1.21	1.11	0.90	1.45	1.09	1.79	1.90	1.91	1.82
4.IJMR	0.59	1.51	1.42	1.18	1.67	1.73	2.39	2.58	2.18	2.58	3.36
5.CMOT	0.17	0.46	0.58	0.46	0.26	0.21	0.36	0.34	0.43	0.27	0.37
6.TD	0.22	0.31	0.63	0.73	0.99	0.66	0.79	1.03	1.13	0.82	0.53
7.AOR	0.66	1.16	0.88	0.94	0.86	0.89	1.06	1.26	0.97	1.04	1.01
8.JSM	0.33	0.28	0.52	0.62	0.79	0.86	0.76	0.89	0.96	0.73	1.09
9.ECOLIND	0.68	0.77	0.91	1.05	1.24	1.21	1.26	1.35	1.46	1.48	1.31
10.JAMS	6.97	5.38	7.22	6.20	6.71	7.12	7.92	8.63	7.20	6.75	9.99
11.CPAM	3.81	2.85	4.29	3.19	3.76	3.63	4.51	4.12	5.11	3.96	4.18
12.TFS	1.95	2.04	2.81	2.27	1.73	2.95	3.24	3.64	4.38	4.75	3.78
13.Bio1	2.64	3.07	3.24	3.50	3.99	3.35	3.48	4.36	3.88	2.64	2.92
14.JE	3.72	4.16	2.94	4.24	5.05	4.33	5.22	4.58	4.33	3.82	3.10
15.JMA	1.63	1.88	1.96	2.31	2.29	2.08	2.01	1.92	2.08	2.08	2.28
16.Bio2	1.70	1.80	2.22	2.18	2.10	2.13	1.72	2.07	2.24	2.00	1.63

Effectively, in this context, the value of SJR, in a single year, is few interesting. Suppose to deal with a new scientific journal; its impact is certainly lower than those of the existing journals but derivatives could preliminarily underline future trends and detect journals with high potentiality. In fact, the first derivative shows if a function is increasing or decreasing, but also how much it is increasing or decreasing (velocity). While the first derivative can tell us if the function is increasing or decreasing, the second derivative tells us if the first derivative is increasing or decreasing. Thus, the second derivative is

a measure of acceleration in increasing or decreasing. These simple tools can help detecting early signals of declining or increasing of scientific journals' conditions better than the simple values of the functions or the scalar values of SJR in a year.

Figures 3 and 4 display the first and second derivative of SJR over time. The former highlights interesting additional information; for example, focusing on ORM, we observe that its first derivative is always decreasing over time; this suggests that this journal could have reached its maximum and maybe is going to face a period of decline or steady. Regarding Journal of Econometrics, from 2012 onwards, the value of the first derivative is always negative suggesting a slow continuous decline in its SJR. Concerning, Journal of the American Mathematical Society, despite its SJR is the highest in 2016, the first derivative shows that it is going towards an additional increase. The second derivative underlines the acceleration of SJR's curves. Thus, it is very sensitive to changes in first derivative and useful to detect early signs of change of the indicator SJR. As an example, we could note that, from 2008, IEEE Transactions on Fuzzy Systems has suffered a strong acceleration.

Figure 5 illustrates the functional principal components decomposition (Equation 5). The first two FPCs explain 96.67% of the total variability. The first FPC mainly detects the second part of the domain, i.e. from the 7-th year (2012) to 2016. The second one explains better the first six years, i.e. the first part of the domain (2006- 2011). The biplot graphs allow us interpreting the condition of the scientific journals according to the first two FPCs. Referring to the numbers of Figure 1, we can observe that the journal n. 10 (Journal of the American Mathematical Society) is highly correlated with the first FPC. Moreover, the journal n. 12, has a low positive correlation with the first FPC and a negative correlation with the second FPC; this means that IEEE Transactions on Fuzzy Systems had not a very high SJR from 2006 to 2012, but in the following periods, it has strongly improved its importance. The distance between IEEE Transactions on Fuzzy Systems and Journal of the American Mathematical Society in the biplot graphs detects that, considering the whole period, the two journals are very different. Contrary, journals that are close in the biplot graph, are characterized by similar shapes according to both the two FPCs. For example, Ecological Indicators (n.9) and Journal of Sports Management (n.8) present very comparable trends over time. Following these reasonings, journals metrics may be easily compared considering the whole period or specific intervals.

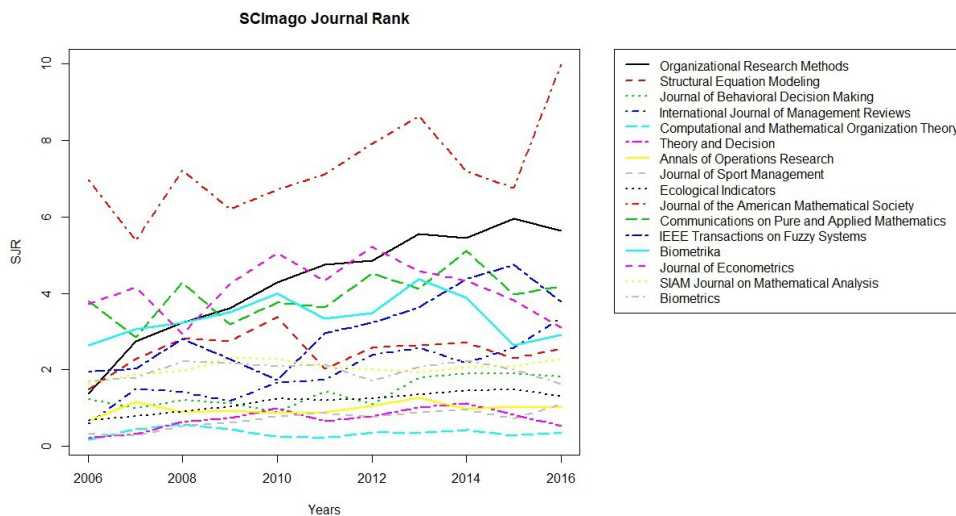
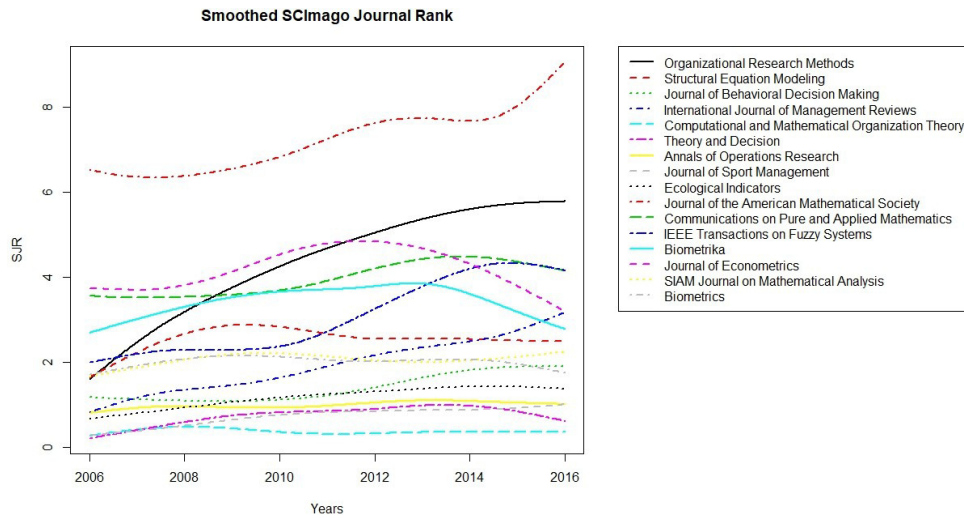
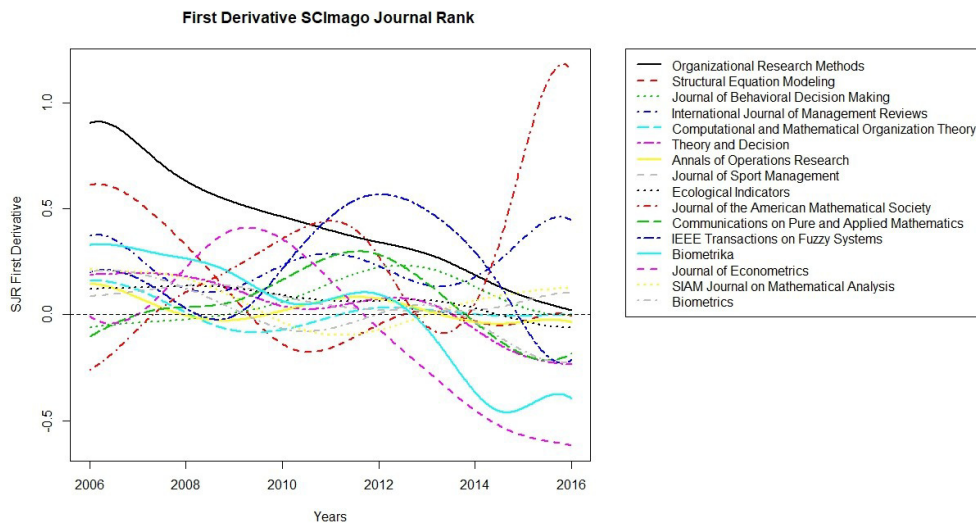


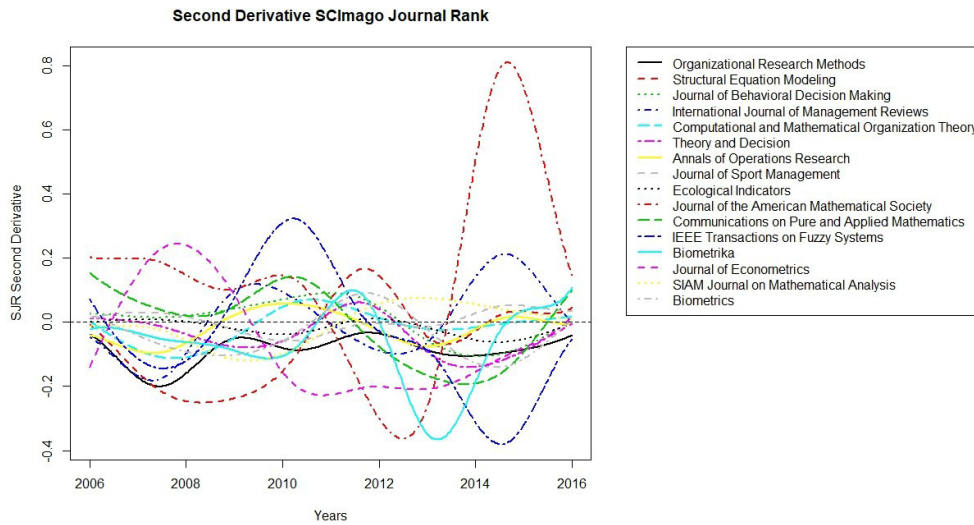
Fig. 1: SJR over 11 years for the 16 scientific journals.



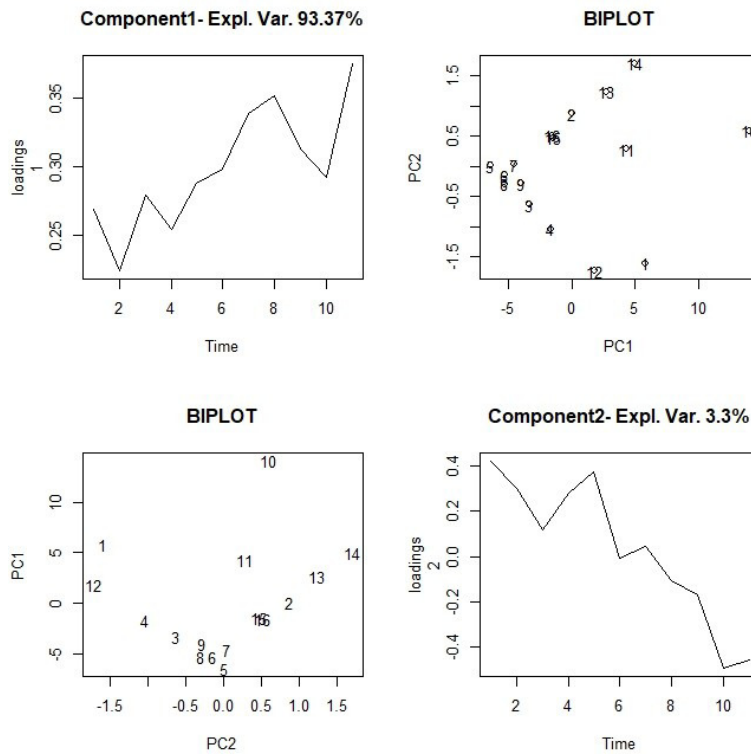
**Fig. 2: Smoothed SJR over 11 years for the 16 scientific journals.**



**Fig. 3: SJR First Derivative over 11 years for the 16 scientific journals.**



**Fig. 4: SJR Second Derivative over 11 years for the 16 scientific journals.**



**Fig. 5: First two functional principal components.**



## Discussion and Conclusions

Due to the development of the internet and electronic publications, the impact assessment of research has also undergone significant changes. Some indices have become daily used to assess the quality and quantity of research of scholars and scientific journals. The only limit that these indicators present is that too often they are considered in the individual time instants and are not treated considering their trends. This research proposes to study the classical bibliometric indexes by exploiting functional data analysis and its additional insights.

Due to its practical advantages, FDA has received considerable attention in diverse areas of application, such as the analysis of price dynamics in online auctions, agricultural sciences, behavioral sciences, climatic variation forecasting, climatology, data mining, demographic forecasting, electronic commerce research, medical research, and many other. To the best of our knowledge, this is the first article proposing this approach for assessing research impact.

In this paper, we have suggested an additional tool to measure and compare to impact of the SJR indices of different journals using a real dataset gathered from SCIMAGO. This real application is an example of how to adopt FDA for research assessment purposes; however, we have limited to comment SJR focusing only on the impact of scientific journals. Clearly, this method may consider also other indicators such as Impact Factor (I.F.), Source Normalized Impact factor (SNIP), h-index, total number of citations, and many other journal's metrics. Naturally, this approach could be extended to scholars, and thus to the trend of the number of received citations, authors' h-index, the number of visits to papers and authors' personal webpages, and other similar statistics.

From a methodological perspective, this study presents the original idea to improve existing metrics for research analytics via the use of derivatives and functional principal component decomposition; however, many other statistical techniques based on FDA could be adopted in this framework, e.g. functional clustering, prediction, functional regression, functional analysis of variance, and on so on.

Therefore, starting from this study, many additional tools for scholars, practitioners, insiders, and businessmen involved in activities related to scientific research, may be developed.

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