Proposals for evaluating the regularity of a scientist’sresearch output

Proposals for evaluating the *regularity* of a scientist's research output

Fiorenzo Franceschini · Domenico Maisano

Abstract Evaluating the career of individual scientists according to their scientific output is a common bibliometric problem. Two aspects are classically taken into account: overall productivity and overall diffusion/impact, which can be measured by a plethora of indicators that consider publications and/or citations separately or synthesise these two quantities into a single number (e.g. *h*-index). A secondary aspect, which is sometimes mentioned in the rules of competitive examinations for research position/promotion, is time *regularity* of one researcher's scientific output. Despite the fact that it is sometimes invoked, a clear definition of regularity is still lacking. We define it as *the ability of generating an active and stable research output over time,* in terms of both publications/quantity and citations/diffusion. The goal of this paper is introducing three analysis tools to perform qualitative/quantitative evaluations on the regularity of one scientist's output in a simple and organic way. These tools are respectively (1) the *PY*/*CY* diagram, (2) the publication/citation Ferrers diagram and (3) a simplified procedure for comparing the research output of several scientists according to their publication and citation temporal distributions (Borda's ranking). Description of these tools is supported by several examples.

Keywords Research evaluation · Individual scientist · Publication regularity · Citation regularity · Ferrers diagram · *h*-index · Citation/publication distribution · Borda's method

Introduction

Evaluating the scientific output of individual scientists is a relevant problem, with important consequences for academics or scientists seeking promotion, tenure, faculty positions, research grants etc. (Van Raan 2000). Bibliometric indicators, which are the

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most practicable instrument in case of large-scale evaluations (in opposition to peer review methods), usually take into account two important aspects: overall productivity—generally measured in terms of publications—and overall diffusion/impact—generally measured in terms of received citations (Cronin 1984; Franceschini et al. 2007; Bornmann 2011). These two aspects, which have been largely debated in the literature, can be evaluated separately—e.g. two of the simplest indicators are given by the total number of publications (P) and citations (C) of a researcher—or together, by aggregated indicators such as the h-index or other variants (Hirsch 2005; Alonso et al. 2009; Franceschini and Maisano 2011).

Another aspect, which is sometimes mentioned in the rules of competitive examinations for research position/promotion, is time *regularity* of one researcher's scientific output. In some universities, regularity is a requirement for doctoral supervisors or for assigning public research funds or positions to individual scientists (Gingras 1996; Collegio dei presidenti di corso di studi in Matematica 2008; IPEA 2009; ASPHER 2010). Also, the fact that public funds of many university departments and research institutions are received annually, depending on the scientific output of the year ahead, denotes the importance of having a research staff with a relatively *regular* scientific output.

The basic idea is that a scientist with a temporally steady and continuative scientific output should be preferred to another scientist, with equivalent overall scientific output, but not homogeneously distributed over time and with significant fluctuations. To clarify the concept, let consider the example in Fig. 1, concerning the scientific output of two anonymous scientists (scientist 1 and scientist 2) with similar career lengths and who are involved in the same discipline. From the point of view of the most popular indicators of overall output, the two scientists look similar: h-index is 8 for both, since they have at least 8 publications with 8 or more citations each, P values are 49 and 45, and C values are 135 and 185 respectively. However, since their published contributions are differently distributed over time, two questions may arise: (1) how the regularity of a scientist's research output can be evaluated? and (2) which of the two scientists is the most regular?

Despite the fact regularity is sometimes invoked in bibliometric evaluations, a clear definition is still lacking, as well as a structured and objective way of evaluating it. Among the works that concern regularity at least indirectly, Burrell (2007) proposed an analysis of the career of scientists based on their h-sequence, while Glänzel and Zhang (2010) recently studied one scientist's output by the mean age of publication of the h-core sequence, to see whether—among the "top" papers—the more recent or the older publications are predominant. However, these (and other) analyses are generally aimed at investigating the career of "leading" scientists and the regularity issue is never made explicit.

Regarding other scientific disciplines, the notion of regularity may have very different meanings; for example:

- in mathematics, a regular (or holomorphic) function is a single-valued function that is continuous and differentiable at each point of its domain (Mathews and Walker 1970);
- in public transports, regularity of a service is related to its frequency and punctuality with respect to the timetable (Van Oort and Van Nes 2009);
- in the field of machine vision, regularity of a surface texture pattern depends on its isotrophy, periodicity and smoothness (Peteri and Chetverikov 2005).

In a bibliometric context regarding the scientific production of a single researcher, we could define regularity as *the ability of generating an active and stable research output over time*, in terms of both quantity and diffusion. It is worth focusing the attention on the two adjectives used to characterize the research output of a regular scientist: (1) *active*

scientist 1	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	
P_y	1	-	-	2	-	2	6	9	6	4	1	2	6	4	6	$P = \Sigma P_y = 49$
citations received by every single paper	1			4		0	14	8	0	5	2	2	8	4	1	
	0			0		0	10	5	0	3		1	8	4	1	
							10	2	0	3			4	3	1	
							9	1	0	0			3	3	1	
							9	1	0				2		0	$h = 8$
							1	1	0				1		0	
								0								
								0								
								0								
C_y	1	-	-	4	-	0	53	18	0	11	2	3	26	14	4	$C = \Sigma C_y = 136$

scientist 2	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	
P_y	1	3	1	1	3	2	5	4	4	4	1	6	1	3	6	$P = \Sigma P_y = 45$
citations received by every single paper	8	16	6	1	11	6	9	17	11	7	1	5	1	5	1	
		11			9	2	5	6	10	1		4		4	0	
		0			8		3	3	2	1		3		3	0	
							2	0	2	1		0			0	
							0					0			0	$h = 8$
												0			0	
C_y	8	27	6	1	28	8	19	26	25	10	1	12	1	12	1	$C = \Sigma C_y = 185$

Fig. 1 Published contributions of two anonymous scientists with similar career lengths and who are involved in the same discipline, considering 15 consecutive years. P_y are the publications associated to a specific year, while C_y the citations accumulated by these publications up to the moment of the analysis. It can be noted that the two scientists look similar according to some indicators of overall output (h, P and C; see the column on the *right*), but which of them is the most regular?

means that the output has to be substantial and (2) *stable* means that the scientist should "spread" (i.e. not concentrate) his/her research output over time. In this sense, a scientist with a perfectly constant but very poor scientific output (in the most extreme case, zero publications and zero citations) cannot be considered as regular. Regularity evaluation can be carried out according to the temporal distribution of the two typical bibliometric proxies, i.e. number of publications and/or corresponding citations.

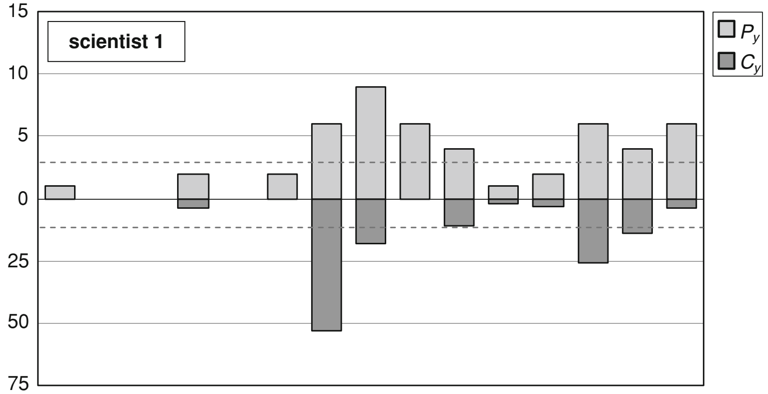
The purpose of this paper is introducing some tools to perform qualitative/quantitative evaluations on the regularity of one scientist's output in a simple and organic way. Input data for the proposed evaluation consist of the distribution of P_y values, namely the total number of publications for each year of one researcher's career, and the distribution of C_y values, namely the total number of citations accumulated by the (P_y) publications of each year, up to the moment of the analysis. These data are immediately available from the most diffused bibliometric search engines (e.g. Google Scholar, Web of Science and Scopus).

The remaining of this paper is organised into three sections. "Proposed tools" Section introduces the three analysis tools—i.e. (1) the *PY*/*CY* diagram, (2) the publication/citation Ferrers diagram and (3) a simplified procedure for comparing several scientists according to their publication and citation temporal distributions (Borda's ranking). Description of these tools is supported by several examples. Section 3 goes over "advantages and limitations of the proposed tools". Finally, the conclusions are given, summarising the original contribution of the paper.

Proposed tools

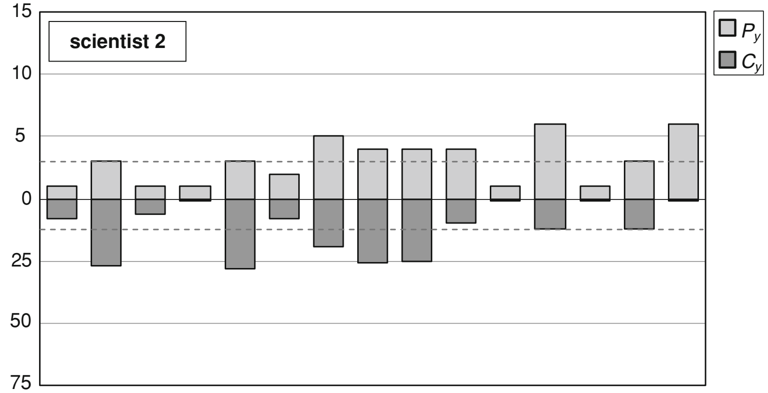
PY/CY diagram

A simple tool for depicting the temporal evolution of one researcher's scientific output is given by the *PY/CY* diagram in Fig. 2, which plots the *PY* distribution—i.e. the yearly distribution of publications according to the age—at the upper-hand side of the horizontal axis, and the *CY* distribution—i.e. the yearly distribution of the citations accumulated up to the moment of the analysis—at the lower-hand side. In order to facilitate visualisation,



	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10
P_y	1	0	0	2	0	2	6	9	6	4	1	2	6	4	6
C_y	0	0	0	4	0	0	53	18	0	11	2	3	26	14	4

μ	*MED*	σ	*IQR*
3.3	2.0	3.8	5.0
11.3	4.0	15.5	13.5



	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10
P_y	1	3	1	1	3	2	5	4	4	4	1	6	1	3	6
C_y	8	27	6	1	28	8	19	26	25	10	1	12	1	12	1

μ	*MED*	σ	*IQR*
3.0	3.0	1.8	3.0
12.3	10.0	10.2	18.5

Fig. 2 *PY/CY* diagrams of the two anonymous scientists in Fig. 1, reporting respectively the yearly distribution of publications (P_y) at the *upper-hand side* of the horizontal axis, that of the citations (C_y) at the *lower-hand side*. P_y and C_y values are reported in the tables below diagrams. For each distribution the following indicators are reported: mean value (μ, also graphically represented by *horizontal dotted lines*), median (*MED*), standard deviation (σ), interquartile range (*IQR*)

citations are rescaled by factor 5. The choice of using yearly time-buckets derives from the need for a reasonable analysis resolution.

A similar graphical representation was used by Glänzel and Zhang (2010), with the only difference that three-year time-buckets were used to avoid fluctuations and periods of relative inactivity. We think that the *PY*/*CY* diagram is suitable for a regularity analysis, since it depicts the overall diffusion of the publications issued in a specific year of interest.

Different information can be deduced from this diagram:

- the shape of the *PY*/*CY* distributions;
- first year of publication activity (1996 for both scientist 1 and scientist 2);
- duration of publication activity (15 years in the example);
- amount of publications for each year (P_y) and corresponding diffusion in terms of total citations (C_y) accumulated up to the moment of the analysis;
- presence of discontinuities/interruptions in the scientific output, represented by null P_y or C_y values. In the example, publication activity of scientist 1 is null in 1997, 1998 and 2000, while publications of 2001 and 2004 have not yet received any citation. To quantify this aspect, two rough indicators of continuity can be the percentage of years with $P_y > 0$ and the percentage of years with $C_y > 0$. Of course, in case of absence of discontinuities, the indicator values are 1. For the two scientists in Fig. 1, publication continuity is respectively $12/15 = 0.80$ for scientist 1 and 1 for scientist 2, while citation continuity is $10/15 \approx 0.67$ for scientist 1 and 1 for scientist 2.

Some indicators of central tendency, such as the mean value (μ, represented by horizontal dotted lines in Fig. 2) or the median (MED), and dispersion, such as the standard deviation (σ) or the interquartile range (IQR), can be associated to *PY* and *CY* distributions. *MED* and IQR are more robust than μ and σ, because they are less influenced by outlayers.

In particular, indicators of dispersion can be used to provide a rough indication on the distribution regularity, under the (questionable) assumption that an ideally regular pattern is constant over time (uniform distribution).

A significant difference between the *PY* and *CY* distribution is that, considering the years before the moment of the analysis, the first distribution is “frozen”, i.e. it will never change. *CY* distribution, on the other hand, may change because of the future accumulation of new citations by the publications issued in the past. Also, it is worth remarking that the citation accumulation process requires a certain amount of time to become stable. According to some authors, from two to ten years depending on the scientific field (Amin and Mabe 2000; Castillo et al. 2007). This “physiological” behaviour entails that, in the most recent years, C_y values tend to decrease and are significantly smaller than in the previous years. Thus, they do not provide a well-defined indication on the diffusion of the most recently issued publications and, much less, they are not suitable to make comparisons with the past years (Franceschini and Maisano 2010a).

Ferrers diagram

An alternative representation of the P_y and C_y statistics can be obtained by a Ferrers diagram. The use of this type of diagram in the field of bibliometrics was introduced for the first time by Anderson et al. (2008), to generalize the *h*-index. Considering the *PY* distribution, each row of the diagram represents a partition of the publications amongst years (see the example in Fig. 3). Years are sorted in descending order according to P_y and if there are several years with exactly the same publications, priority is given to the most recent ones. The largest completed (filled in) square of points in the upper left hand corner

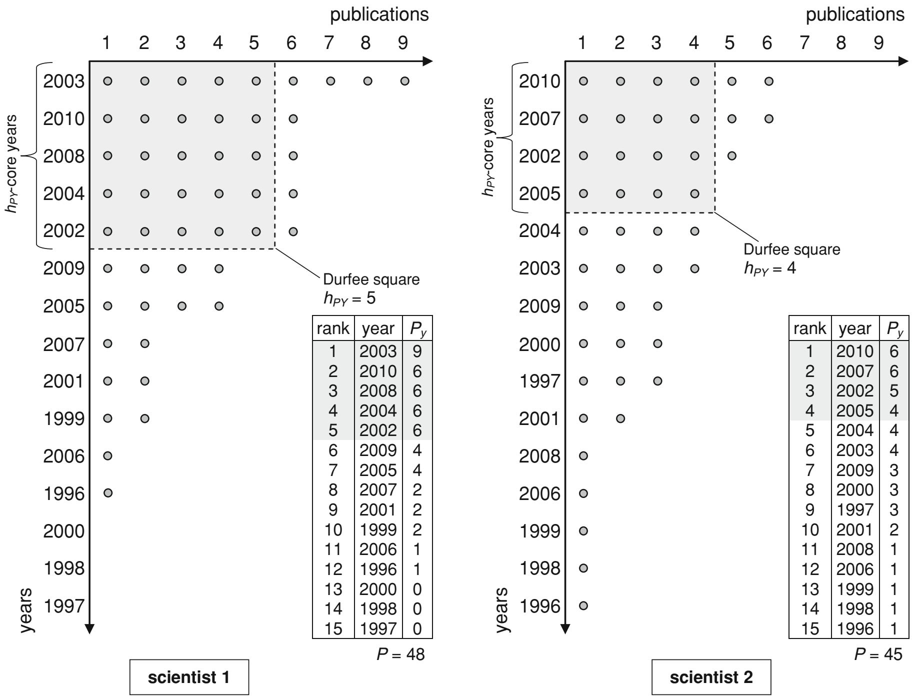


Fig. 3 Ferrers diagrams relating to the P_y distribution (i.e. the yearly distribution of publications) of the two scientists in Fig. 1. P_y values are ranked in descending order and reported in the table on the *right*. The largest completed (*filled in*) square of points in the *upper left* hand corner of a Ferrers diagram is called the Durfee square and it corresponds to h_{PY} (extension of the Hirsch-index) (Egghe 2010a)

of a Ferrers diagram is called the Durfee square (Andrews 1998; Egghe 2010a). The Durfee square side is h_{PY} (for the scientist 1 in the example, $h_{PY} = 5$). Precisely, a scientist has index h_{PY} if h_{PY} of his or her career years have at least h_{PY} publications each and the other years have $\leq h_{PY}$ publications each.

Clearly, h_{PY} is an extension of the classical Hirsch's h-index (Hirsch 2005). For more information on h and the large number of variants and improvements, we refer the reader to the vast literature and extensive reviews (Braun et al. 2006; Bornmann et al. 2008; Rousseau 2008; Alonso et al. 2009; Egghe 2010b).

We remark that the original aggregation criterion of h makes sense when the publications (elements of interest) and the corresponding citations (countable characteristic) are represented by numbers with the same order of magnitude (Franceschini and Maisano 2009). In the case of h_{PY}, the same considerations can be extended to the career years (elements of interest) and the corresponding yearly publications (countable characteristic).

By the Ferrers diagram in Fig. 3, publications can be immediately subdivided into two categories:

1. the series of the h_{PY} most productive years, forming the h_{PY}-core (Kelly and Jennions 2006). They can be classified as "high-production years", that is to say those years with a high number of publications, most of which to the right of the Durfee square;

2. years with relatively few publications (below the Durfee square). They can be classified as "low-production years", i.e. those years with not enough publications to be included within the h_{PY}-core.

The most productive and regular scientists are reasonably those with high h_{PY} values, since they are able to produce a conspicuous quantity of publications that are spread over time (Franceschini and Maisano 2010b). Consistently with the initial definition, a regular scientific output is characterised by a relatively large number of years with substantial quantity of publications.

In general, the fact that h captures only a part of the citation data is usually considered as a drawback. The same issue can be extended to h_{PY}, since it captures only a part of the publication data (Egghe 2006). Both (1) the vast majority of the publications that accompany the high-production years (to the right of the Durfee square) and (2) the low-production years (below the Durfee square) count for nothing in the sense that h_{PY} is not affected by them. Using the Ferrers diagram, the *complete* time distribution of one scientist's publications can be subdivided into three main contributions:

(H_{PY}) publications in the Durfee square. H_{PY} coincides with h_{PY}^2, that is the number of publications for the h_{PY}-core years;
(A_{PY}) publications to the right of the Durfee square ("high-production" years);
(B_{PY}) publications below the Durfee square ("low-production" years).

This triple of indicators—(H_{PY}, A_{PY} and B_{PY}) denominated as publication *triad* and discussed in detail in (Franceschini and Maisano, 2010b)—provides a snapshot of a scientist's publication contributions. An example of calculation is shown in Fig. 4.

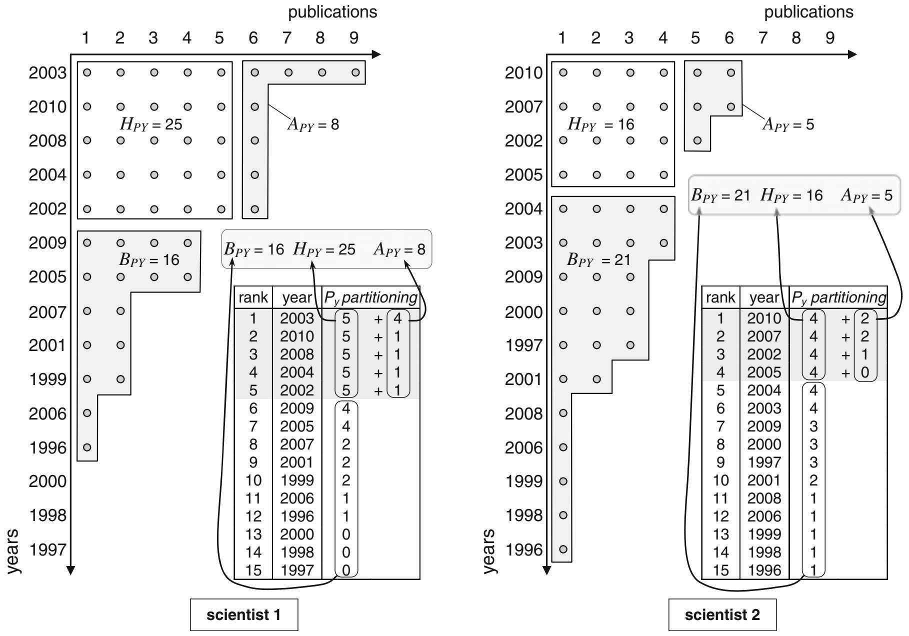
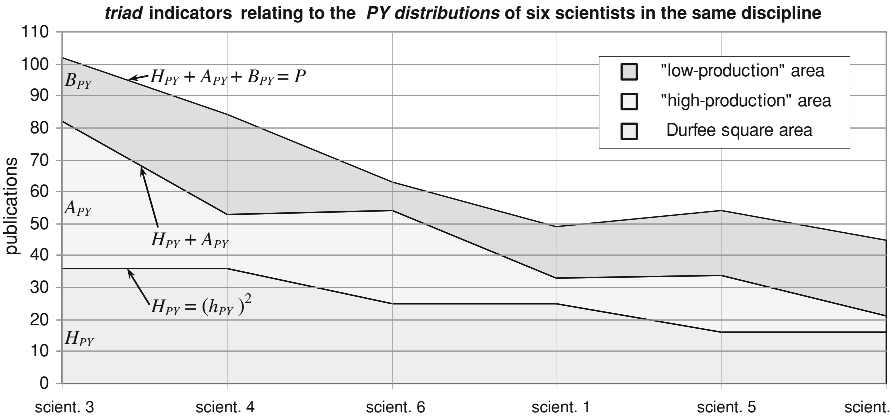


Fig. 4 Calculation of the *triad* indicators (i.e. H_{PY}, A_{PY} and B_{PY})—for the Ferrers diagrams in Fig. 3

Triad's information content is certainly superior than the one given by a single indicator, such as h_{PY} or P. Our proposal is to associate these three indicators to each scientist's publication output. The meaning of *triad* is immediate since each element represents a number of publications: those included in the Durfee square (H_{PY}), in the "high-production" area (A_{PY}) and in the "low-production" area (B_{PY}). In this sense, this tool complements the information of h_{PY} (which is simply referable to H_{PY}), giving an instant overview of a scientist's publication output over time. Another indicator to summarize the contents of a Ferrers diagram is given by the *tapered* h-index, proposed by Anderson et al. (2008). A structured comparison between this indicator and the *triad* indicators is presented in (Franceschini and Maisano 2010b).

An effective way to compare different scientists on the basis of the *triad* indicators is given by the graph in Fig. 5. This chart represents the H_{PY}, $H_{PY} + A_{PY}$ and $H_{PY} + A_{PY} + B_{PY}$ curves of six anonymous scientists in the same discipline (including the two exemplified before). Comparison can be quickly performed on the basis of H_{PY} (lower curve), A_{PY} (distance between the H_{PY} and $H_{PY} + A_{PY}$ curves), B_{PY} (distance between the $H_{PY} + A_{PY}$ and $H_{PY} + A_{PY} + B_{PY} = P$ curves).

Scientists 3 and 4 have the same $h_{PY} = 6$ (indicator of regularity) but scientist 3 has a larger P value, which is mainly due to the contribution of A_{PY} (presence of years with an outstandingly number of publications). It is also interesting to compare scientists 1 and 5: despite the larger overall production, scientist 5 seems to be less regular and has a smaller h_{PY} value.



Complete *PY* distributions

scientist	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	H_{PY}	A_{PY}	B_{PY}	P
1	1	0	0	2	0	2	6	9	6	4	1	2	6	4	6	25	8	16	49
2	1	3	1	1	3	2	5	4	4	4	1	6	1	3	6	16	5	24	45
3	1	1	0	0	5	1	5	4	3	13	9	8	30	16	6	36	46	20	102
4	5	3	0	1	6	1	6	8	4	7	5	9	13	9	7	36	17	31	84
5	0	1	0	2	3	4	1	13	11	6	4	3	4	1	1	16	18	20	54
6	1	6	2	8	0	0	0	12	2	1	14	0	14	2	1	25	29	9	63

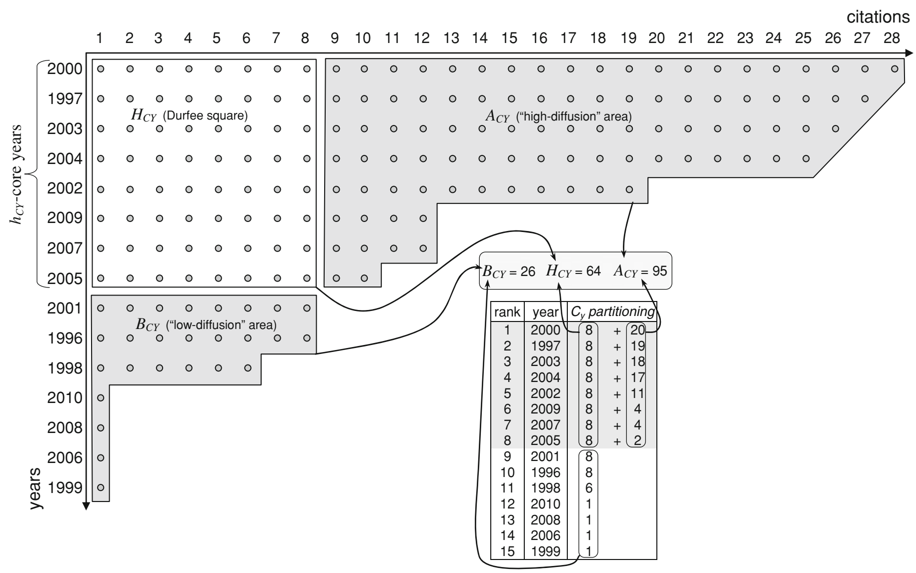
Fig. 5 Chart representing the *triad* indicators relating to the *PY* distributions of six anonymous scientists (including the two exemplified in Fig. 1) in the same discipline. Scientists are reported on the horizontal axis, while publications contributions (H_{PY}, A_{PY} and B_{PY}) on the vertical axis. Conventionally, scientists are ranked in lexicographic order $H_{PY} \rightarrow P$ (sort according to H_{PY} and, in case of equality, according to $P = H_{PY} + A_{PY} + B_{PY}$). The table at the *bottom* of the chart reports the scientists' complete *PY* distribution and the relevant H_{PY}, A_{PY}, B_{PY} and P values

The Ferrers diagram and the *triad* indicators so far constructed take into account only P_y values, which represent the first of the two input data of our analysis (i.e. P_y and C_y statistics). Similar tools could be constructed for evaluating the regularity relating to the diffusion of the scientific output, simply using one scientist's *CY* distribution, instead of *PY* distribution. In a similar way, h_{CY} can be used as indicator of regularity in the scientific output diffusion. Likewise h_{PY}, a scientist has index h_{CY} if h_{CY} of his or her career years have publications with at least h_{CY} total citations (accumulated up to the moment of the analysis) and the other years have publications with $\leq h_{CY}$ total citations each. Then, *triad* indicators (H_{CY}, A_{CY} and B_{CY}) and a chart similar to the one in Fig. 5, but based on C_y-distributions, could be used for complementing h_{CY} and easing comparison among different scientists. For the purpose of example, Fig. 6 reports the citation Ferrers diagram and the corresponding *triad* indicators related to scientist 2.

Consistently with the previous remark on the extension of the *h*-index, this parallelism makes sense only if C_y values (countable characteristic) are not much larger than the number of years analysed (elements of interest). In this sense, the fact that most of the C_y values are likely to be larger than the number of analysed years makes h_{CY} potentially less effective than h_{PY}. This aspect will be investigated in more detail in a future work on the basis of a larger set of empirical data.

Structured comparison of several scientists

Although the tools described provide useful indications on the regularity of the scientific output of a single scientist, they can be further enriched by other methods to facilitate a comparison among several scientists. We now propose a structured comparison among the *PY/CY* distributions of different scientists based on the assumption that the most regular



rank	year	C_y partitioning		
1	2000	8	+	20
2	1997	8	+	19
3	2003	8	+	18
4	2004	8	+	17
5	2002	8	+	11
6	2009	8	+	4
7	2007	8	+	4
8	2005	8	+	2
9	2001	8		
10	1996	8		
11	1998	6		
12	2010	1		
13	2008	1		
14	2006	1		
15	1999	1		

Fig. 6 Ferrers diagram and triad indicators (i.e. H_{CY}, A_{CY} and B_{CY}) relating to the C_y distribution (i.e. the yearly distribution of citations) of scientist 2 (see Figs. 1, 2). C_y values are ranked in descending order and reported in the table on the *bottom*

scientists are the ones who are able to overcome their competitors for most years. This logic is pretty alike to the one of Formula One races, where the world championship is generally the driver who is *regularly* in the top positions for as many competitions as possible during the season, not the one who alternates outstanding with poor performances.

A very simple method for comparing the *PY*/*CY* distributions of different scientists can be the Borda's method (Borda 1781; Saari 1995). Referring to each year, an xth scientist has a rank $r_y(x)$: 1 for the first position, 2 for the second… and n for the last. The Borda score (B) for the xth scientist is the sum of his yearly ranks (see Eq. 1). One supposes that all the years have the same importance.

$$B(x) = \sum_{i=1}^{n} r_i(x)\, x = 1, \ldots, m \qquad (1)$$

m is the number of competitors

The best competitor is the scientist (x^*) with the lowest Borda score (Borda 1781; Saari 1995):

$$B(x^*) = \min_x B(x) \qquad (2)$$

For the purpose of example, Borda's method is applied to the *PY*/*CY* distributions of six anonymous scientists with similar career lengths and involved in the same discipline (see Table 1). This assumption seems realistic, in case of competitive examinations for research positions. Two preliminary rankings, based on P—indicator of overall productivity—and C—indicator of overall diffusion—are reported in the last column to the right of Table 1.

Borda yearly ranks and Borda scores (B) relating to the previous *PY* and *CY* distributions are reported in Table 2. It can be noted that final rankings based on regularity may be different from those based on the overall scientific output (Table 1). For instance, scientist 3—despite having the highest P and C value—is only in second position for both the relevant Borda scores. Also, the *PY* distribution of scientist 6 is considered as the most irregular (highest Borda score) even though, there are three scientists (i.e. 1, 2 and 5) with smaller P values. Again, this is a consequence of the fact that most of publications of scientist 6 are concentrated in relatively few years and in the remaining years productivity is rather low.

Apart from being simple, this comparison on an annual basis makes it possible to "filter out" other generalized trends, which are not necessarily related to the performance of scientists; in particular:

1. the increasing tendency towards publishing and citing, favoured by recently introduced rewards and incentives (Amin and Mabe 2000; Persson et al. 2004; Stephan 2008; Bornmann 2011);
2. the physiological decrease in the C_y values in the most recent years, due to the citation accumulation process.

However, it is important to highlight that this method does not adequately consider the year-by-year "gap" among scientists. For example, considering a specific year, the gap between two scientists with rank positions 4th and 6th is not necessarily coincident to the gap between two groups with rank positions 1st and 3rd. Growing in complexity, we could introduce other more refined methods that could take into account also the magnitude of gaps between rank positions.

The output of the comparison carried out so far consists of two independent rankings, respectively according to the *PY* and the *CY* distribution. The synthesis of these rankings into a single one is an open issue. For example, one could do this by reapplying Borda's

Table 1 *PY* and *CY* distributions of six anonymous scientists, considering 15 consecutive years

	Scientist	‘96	‘97	‘98	‘99	‘00	‘01	‘02	‘03	‘04	‘05	‘06	‘07	‘08	‘09	‘10	$P = \Sigma(P_y)$	Rank
PY distributions	1	1	0	0	2	0	2	6	9	6	4	1	2	6	4	6	49	5th
	2	1	3	1	1	3	2	5	4	4	4	1	6	1	3	6	45	6th
	3	1	1	0	0	5	1	5	4	3	13	9	8	30	16	6	102	1st
	4	5	3	0	1	6	1	6	8	4	7	5	9	13	9	7	84	2nd
	5	0	1	0	2	3	4	1	13	11	6	4	3	4	1	1	54	4th
	6	1	6	2	8	0	0	0	12	2	1	14	0	14	2	1	63	3rd
	Scientist	‘96	‘97	‘98	‘99	‘00	‘01	‘02	‘03	‘04	‘05	‘06	‘07	‘08	‘09	‘10	$C = \Sigma(C_y)$	Rank
CY distributions	1	0	0	0	4	0	0	53	18	0	11	2	3	26	14	4	135	5th
	2	8	27	6	1	28	8	19	26	25	10	1	12	1	12	1	185	4th
	3	0	0	0	0	11	1	30	56	15	78	56	28	83	21	1	380	1th
	4	30	93	0	7	83	36	22	12	2	32	7	14	16	14	2	370	2nd
	5	0	1	0	10	7	3	4	78	52	41	12	2	8	0	0	218	3rd
	6	2	22	15	8	0	0	0	25	22	3	31	0	2	2	0	132	6th

Scientists have similar career lengths and are involved in the same discipline. In the last two columns to the right, scientists are ranked according to *P*—indicator of overall productivity—and *C*—indicator of overall diffusion

Table 2 Borda yearly ranks relating to the *PY* and *CY* distributions in Table 1. Borda scores (*B*) and the relevant rankings—respectively $r_B(P_y)$ and $r_B(P_y)$—are reported in the last two columns to the right

	Scientist	$r_{'96}$	$r_{'97}$	$r_{'98}$	$r_{'99}$	$r_{'00}$	$r_{'01}$	$r_{'02}$	$r_{'03}$	$r_{'04}$	$r_{'05}$	$r_{'06}$	$r_{'07}$	$r_{'08}$	$r_{'09}$	$r_{'10}$	*B* score	$r_B(P_y)$
Borda yearly ranks relating to *PY* distributions	1	2	6	3	2	5	2	1	3	2	4	5	5	4	3	2	49	3rd
	2	2	2	2	4	3	2	3	5	3	4	5	3	6	4	2	50	4th
	3	2	4	3	6	2	4	3	5	5	1	2	2	1	1	2	43	2nd
	4	1	2	3	4	1	4	1	4	3	2	3	1	3	2	1	35	1st
	5	6	4	3	2	3	1	5	1	1	3	4	4	5	6	5	53	5th
	6	2	1	1	1	5	6	6	2	6	6	1	6	2	5	5	55	6th
	Scientist	$r_{'96}$	$r_{'97}$	$r_{'98}$	$r_{'99}$	$r_{'00}$	$r_{'01}$	$r_{'02}$	$r_{'03}$	$r_{'04}$	$r_{'05}$	$r_{'06}$	$r_{'07}$	$r_{'08}$	$r_{'09}$	$r_{'10}$	*B* score	$r_B(C_y)$
Borda yearly ranks relating to *CY* distributions	1	4	5	3	4	5	5	1	5	6	4	5	4	2	2	1	56	5th
	2	2	2	2	5	2	2	4	3	2	5	6	3	6	4	3	51	3rd
	3	4	5	3	6	3	4	2	2	4	1	1	1	1	1	3	41	2nd
	4	1	1	3	3	1	1	3	6	5	3	4	2	3	2	2	40	1st
	5	4	4	3	1	4	3	5	1	1	2	3	5	4	6	5	51	3rd
	6	3	3	1	2	5	5	6	4	3	6	2	6	5	5	5	61	6th

Table 3 Overall Borda score relating to the rankings—i.e. $r_B(P_y)$ and $r_B(P_y)$—in Table 2

Scientist	$r_B(P_y)$	$r_B(C_y)$	*B* score	Final rank
1	3	5	8	4th
2	4	3	7	3rd
3	2	2	4	2nd
4	1	1	2	1st
5	5	4	9	4th
6	6	6	12	6th

The unique resulting ranking is reported in the last column to the right

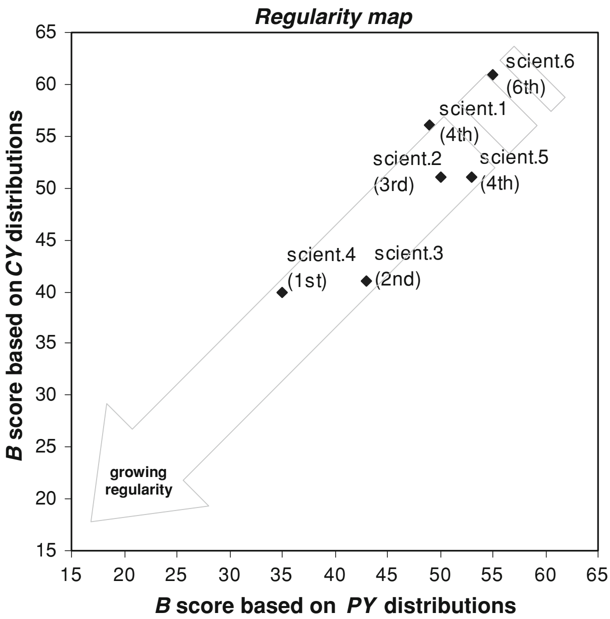


Fig. 7 *Regularity map* representing the Borda scores determined from *PY* and *CY* distributions of six anonymous scientists in the same discipline (see Tables 1 and 2). The final rank positions—obtained by reapplying Borda method (see Table 3)—are reported in the data labels (in *brackets*)

algorithm (see Table 3). However, this entails that regularity in publishing and in the publication diffusion have the same importance.

An alternative way to use the two rankings together, without merging them, is to draw a *regularity map* (see Fig. 7). Such a map illustrates the bibliometric positioning of different scientists, from the point of view of regularity. The most (active) regular scientists are those with low *B* scores (relating to both *PY* and *CY* distributions). They are located near the bottom-left corner. Even if a map is unable to give a final synthesis, it gives a spatial positioning of scientists with reference to regularity. Finally, it is worth noting that the Borda's method can be replaced by other models for comparing *PY*/*CY* distributions of different scientists. Some insights about these approaches can be found in Saari (1995).

Advantages and limitations of the proposed tools

The proposed tools have different pros and cons. Being based on classical bibliometric indicators, such as *P*, *C* and *h*-index—these tools could be subjected to the criticisms made to these indicators themselves, such as:

1. they are insensitive to co-authorship, type of publications, journal quality, self citations, etc.…;
2. they should not be used to compare scientists from different disciplines owing to the different citation rates (Antonakis and Lalive 2008).

Apart from these general features, which are widely discussed in the existing literature (Rousseau 2008; Alonso et al. 2009; Franceschini and Maisano 2010c), the more peculiar advantages and limitations of the proposed tools are summarised in Table 4.

Table 4 Summary of the major pros and cons of the proposed tools

Indicator	Pros	Cons
PY/*CY* diagram	• Easy construction; • Different information on an individual scientist can be deduced from it (e.g. publication activity duration, presence of discontinuities, yearly publications and corresponding diffusion, qualitative indication on the temporal trend).	• This tool is not practical for quantitative comparisons of scientists.
Ferrers diagram and triad indicators	• h_{PY} and h_{CY} provide a rough quantification of the scientific output of a scientist from the regularity viewpoint; • h_{PY} and h_{CY} can be used to identify the most important years for productivity and diffusion; • *Triad* indicators enable a preliminary quantitative comparison among several scientists.	• This tool (as well as *triad* indicators) does not take into account the temporal trend of *PY* and *CY* distributions; • h_{PY} may be not highly discerning when the period of interest (number of years) and yearly number of publications do not have the same order of magnitude. Therefore, analysis time window should embrace 10–15 years at least. The same goes for h_{CY}; • The two bibliometric aspects of productivity and diffusion can be analysed only separately.
Structured comparison of research output of scientists (Borda's ranking)	• This technique provides a quantitative comparison of several scientists on the basis of their regularity in *PY* and *CY* distributions; • Among the possible techniques for comparing *PY*/*CY* distributions, Borda's method is considered for its simplicity; • The comparison on an annual basis makes it possible to "filter out" generalized trends, which are not necessarily related to the performance of scientists (such as the increasing tendency towards publishing and citing, or the physiological decrease in the C_y values in the most recent years); • The two individual rankings (according to regularity in production and diffusion respectively) can be aggregated by means of a *regularity map* or synthesised into a unique final ranking.	• Borda's method introduces some questionable operations; (1) it does not consider the magnitude of gaps between rankings; (2) it gives the same importance to the aggregated sub-ranks. This can be debatable when re-applying the method to synthesize the two individual rankings (relating to regularity in production and diffusion) into a unique one. • Other more refined models can be introduced to replace Borda's method.

Concluding remarks

This paper focused the attention on the problem of evaluating the regularity in the scientific output of individual scientists. In particular, the foundations for a structured analysis have been laid by proposing three practical tools based on two elementary input data: the *PY* and *CY* distributions of a scientist.

1. The *PY*/*CY* diagram provides useful indications on the temporal evolution of a scientist publishing career.
2. Ferrers diagrams provide an alternative and complementary representation. These diagrams make it possible to identify the most important years for publications and for their diffusion, by means of two indicators, specifically h_{PY} and h_{CY}, which are two extensions of the classical Hirsch's *h*-index. In order to ease the comparison of several scientists by means of their Ferrers diagrams, three synthetic indicators—namely *triad* indicators H_{PY}, A_{PY}, B_{PY} and H_{CY}, A_{CY}, B_{CY}—have been introduced. The most significant limitation of Ferrers diagrams is that yearly publications and citations are studied separately.
3. Finally, it was presented a structured technique for comparing several researchers according to their *PY* and *CY* distributions on a yearly basis. The proposed technique, supported by Borda's method, generates two rankings, respectively according to regularity in production and regularity in diffusion of the scientific output. These two rankings can be, in turn, synthesised into a unique final ranking or aggregated by means of a regularity map, which shows the bibliometric positioning of different scientists.

The suggested tools have some limitations. They should be used to compare scientists in the same scientific field and with similar career lengths. Realistically, these conditions seem to be generally respected for scientists involved in examinations for research position/promotion/tenure acquisition.

Regarding the future, the analysis tools will be tested on the basis of a larger amount on empirical data on specific research fields. Moreover a more refined technique to compare and rank scientist according to their *PY* and *CY* distributions will be presented.

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