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The lengthening of papers' life expectancy: a diachronous analysis

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Abstract The aging of scientific has generally been studied using synchronous approaches, i.e., based on references made by papers. This paper uses a diachronous model based on citations received by papers to study the changes in the life expectancy of three corpus of papers: papers from G6 and BRICS countries, papers published in Science, Nature, Physical Review and the Lancet and all papers divided into four broad fields: medical sciences, natural sciences and engineering, social sciences and arts and humanities. It shows that that: (i) life expectancy is extensively different from a corpus to another and may be either finite or infinite, meaning that the corpus would never be obsolete from a mathematical perspective; (ii) life expectancy for scientific literature has lengthened over the 1980–2000 period; (iii) life expectancy of developed countries' (G6) literature is on average shorter than that of emerging countries (BRICS).

Keywords Aging · Obsolescence · Life expectancy · Life-time · Citation distribution · Diachronous · Synchronous · Journals · Countries · Fields

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Introduction

The rate at which scientific literature age or becomes obsolete has been studied extensively by information scientists, going as far as the seminal paper by Gross and Gross (1927), who analysed age distribution of journals cited by the Journal of the American Chemical Society. Although these first studies were typically made in the context of managing collections and shelf-space—which are less an issue with digital libraries—, contemporary studies on the topic provide key insight for the compilation of bibliometric indicators, especially in terms of the optimal citations window one should use.[1] One of the most commonly used concept in obsolescence studies is the famous half-life, inspired from nuclear physics, derived from the model originally proposed by Burton and Kebler (1960). Even if the term half-life has been incorrectly attributed to Burton and Kebler (Szava-Kovats 2002), it remains a reference expressing citation distributions or obsolescence in exponential terms.

In spite of their similar curves and symmetry (Nakamoto 1988), the synchronous and diachronous distributions fundamentally designate and refer to completely different characteristics of scientific literature aging. The first considers references (papers) cited by a publication of a particular year and then analyzes retrospectively the distribution of their ages (Fig. 1). This approach has been called *retrospective citation* approach (Barnett et al. 1989; Burrell 2002; Glänzel 2004). Conversely, the diachronous approach consists of analysing the distribution of citations gained over time to a publication published in a given year by subsequent literature (Fig. 1). This has been called *prospective citation* approach (Burrell 2002; Glänzel 2004). A few studies have compared the two approaches. For instance, using literature of human and medical genetics, Stinson and Lancaster (1987) have found that the results of a diachronous study of obsolescence over a 19-year period were significantly different from those of a synchronous study.

Some models proposed in the literature for citation distributions use the cumulative citations (Burton and Kebler 1960; Rousseau 1994; Yu and Li 2007). These models only make a sense mathematically in a synchronous approach, as papers' cited references are *de facto* known, no matter how old they are. Cumulative citations are initially known and so is the total number of these citations. These models are, however, almost senseless in a diachronous approach, as citations received are only partially known and additional citations are expected to be gained in the future years.

As a consequence, the concept of papers' life-time has a different sense depending on the approach. In a synchronous approach, life-time T corresponds to the time period during which the currently active set of documents (or cited references) was published. Meaning all the cited references are aged not more than T past years. However, the life-time in a diachronous approach should mean the time period T following the literature publication year during which this literature would be cited. Hence, the latter refers more naturally to *life expectancy* than life-time, which is more appropriate for a synchronous approach.

Life expectancy is defined by The American Heritage Medical Dictionary as the *The number of years that one is expected to live as determined by statistics* (The American Heritage® Medical Dictionary Copyright © 2007, 2004 by Houghton Mifflin Company). Furthermore, according to the OECD's statistical glossary terms, *'Life expectancy at birth and ages 40, 60, 65 and 80 is the average number of years that a person at that age can be expected to live, assuming that age-specific mortality levels remain constant'* (Glossary of

[1] An extensive discussion of the topic can be found in Line (1993) and Line and Sandison (1974).

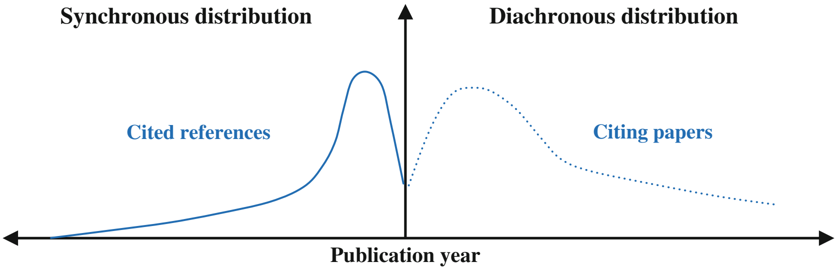


Fig. 1 Schematic representation of diachronous and synchronous citation distributions

Statistical Terms, accessed 12 October 2012).[2] By analogy, in diachronous citation analysis, one could refer to 'at birth' as 'at publication date' and 'number of years a person [...] is expected to live' as 'number of years a publication [...] is expected to be cited'. And, as for the human life expectancy, which can be predicted for the ages of 40, 60, 65 or 80 years, the life expectancy of papers can be predicted after a given age of publication. This simply means that one tracks citations to a body of literature over a given period of time after its publication (birth) which designates the 'age' and then predicts the remaining years of life beyond this to obtain its life expectancy.

The model recently proposed by Bouabid (2011) fits well the observed citations distribution in a diachronous approach. Moreover, the life expectancy, which was called 'lifetime', has been predicted using this model based on a sample of data covering a set of countries and other corpuses of publication.

In this article, the model is applied to a wider and diverse set of countries, journals, scientific fields and publication years, with a focus on the evolution of papers' life expectancy. More specifically, previous research has shown that (Larivière et al. 2008; Egghe 2010; Yang et al. 2010) the age of cited references was increasing, i.e., that, since the 1960s, researchers are citing material that is increasingly old. These studies were, however, made using synchronous analyses performed at different years. In this paper, we apply the model developed by Bouabid (2011) to assess the changes in papers' life expectancy, and to see if any differences can be observed across countries (developed and emerging), journals and disciplines.

Model and methodology

It is well known that the number of citations $c(t)$ increases starting from the publication year to reach a peak value of citations (or maximum) c_0 at a time t_p (peak time) and then decreases progressively to a lower value c_∞ (Fig. 2). This last characteristic has been called *residual citations* (Bouabid 2011) which has been found not vanish to zero in some cases meaning that the corpus of publications does not cease to earn more citations in longer term. In this case, life expectancy can be considered as infinite.

Time period from Fig. 2 could be divided into two stages. The first one before peak time, that is when $t \in \lfloor 0, t_\mathrm{p} \lfloor$ and the second one when $t \in \lfloor t_\mathrm{p}, \infty \lfloor$. It has been argued that the most interesting stage is the second one. Indeed, the two stages are not systematically linked. Each one is governed by rather different social behaviours of citing communities.

[2] http://stats.oecd.org/glossary/detail.asp?ID=1530.

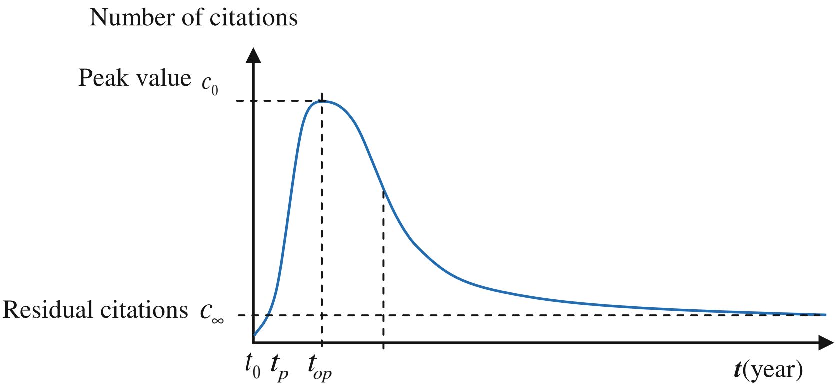


Fig. 2 Schematic curve of citation distribution

The first stage is impulsed rather by scientists' reaction to recent advances and knowledge which results in a high increase in citing. Such a phenomenon results in a lower rate of citations to older publications. In addition, we note in recent years that papers can gain citations even during the year of their publication. Thus, the first stage becomes narrower over time and consequently the peak time becomes closer to the publication year whereas the length of the second stage increases. This distinction is supported by other researchers (Egghe and Rousseau 2000) who describe citation distributions as composed of two functions: a growth and a decay.

The proposed model focuses on the second stage. The number of citations $c(t)$ at a time t starting from the peak year is given (Bouabid 2011) as:

$$c(t) = c_0 - \alpha \frac{t^p}{t^p + \beta}$$

where α and β are constants and $p > 1$ are characteristics of the corpus. Its polynomial form makes it simple to implement for bibliometric and scientometric purposes.

Two major indicators are derived from this model. The first one is the *Optimum-time* t_{op}:

$$t_{\mathrm{op}} = \sqrt[p]{\frac{\beta(p-1)}{(p+1)}}$$

as the inflexion time-point corresponding to the maximum rate of decline in citations gained by this corpus after peak time (Fig. 2). The second indicator is the *speed of withdrawal* as the speed (or the rate of decline) in citations at the optimum time point. This indicator allows dynamic analysis of citations distributions.

For a long time t is greater ($t \to \infty$), then $c(t) \approx c_0 - \alpha$. Three cases are mathematically possible:

Case 1 $c_0 > \alpha$: the life expectancy is infinite and $c(t) = c_0\left(1 - \gamma \frac{t^p}{t^p + \beta}\right)$, where $(1 - \gamma)$ gives the percentage of remaining citations compared to those at peak time, namely $1 - \gamma = \frac{c_\infty}{c_0}$;

Case 2 $c_0 = \alpha$: meaning $\gamma = 1$ and t-axis is the asymptote of the curve. c_∞ is equal to zero but the distribution does not completely vanish;

Case 3 $c_0 < \alpha$: the total number of citations vanishes to zero within a finite time t_v calculated by setting $c(t_v) = 0$ (Bouabid 2011) since the number of citations $c(t)$ is never negative. The life expectancy is then $t_v = \sqrt[p]{\frac{\beta}{(\gamma-1)}}$ with $\gamma > 1$.

The three cases are not just mathematical consequences of the model but reflects the observed types of citations distributions over time. The case 2 is the only one described by previous and existing models of citations distributions.

Data used in this article are taken from Thomson Reuters' Web of Knowledge and considers research articles published in 1980, 1985, 1990, 1995 and 2000. Citations to these articles are counted for each year following publication (including the year of publication) under the same citation window of 12 years, which serves as 'age' as discussed above. The countries' dataset is composed of two subsets: developed countries (G6) and emerging countries (BRICS). The G6 countries are USA, England, Japan, France, Italy and Germany. Emerging countries, often known as BRICS, are Brazil, Russia, India, China and South Africa. Citations distributions are also compiled for the four broad domains of scholarship: medicine (MED), natural sciences and engineering (NSE), social science (SS) and arts and humanities (AH). Finally, a smaller dataset of citations received by a few general and specialized journals, well-known among the scientific community is inclusively considered in this article. These journals are: Nature, Science, the Lancet and Physical Review. The citations counts for all these corpuses are given in Appendix 1. On the whole, 190 million citations received by 3.3 million papers are analyzed in this article. A citation window of 12 years following publication year was used in this analysis as 'age' termed previously and referred to by the OECD Glossary.

The diversity of fields, countries, journals, time-series, is believed to offer a rich sample to confirm the findings and conclusions. Further, the R^2 values are given in Appendix 2 to comfort once again the accuracy of the model, the findings and conclusions put forward in this article.

Results and discussion

Countries

Figure 3 shows that life expectancy is infinite (in mathematical terms) for USA's articles published between 1980 and 2000. As a consequence, these articles are expected to remain of interest for the scientific community for a long period. Indeed, articles from the USA in 1980 would succeed to maintain for a long time 35.2 % of citations earned at peak, whereas those published in 1995 would enjoy much longer life, since residual citations after a long period of time are predicted to represent 85.5 % of citations collected at peak (Appendix 3). Moreover, the peak time for articles published in 2000 is reached at the 9th year after publication, which is more extended than before (4th year in 1980, 1985 and 1995 and 6th year in 1990).

While it is expected that Japanese papers published in 1980 will be completely forgotten by the scientific community in less than half a century (49 years) after publication, articles of the same country in 2000 would keep almost 50 % of the citations gained at peak for infinite time. Citation distributions of England exhibit a similar profile. In fact, on one hand, the life expectancy is infinite for its articles published between 1980 and 2000, and it

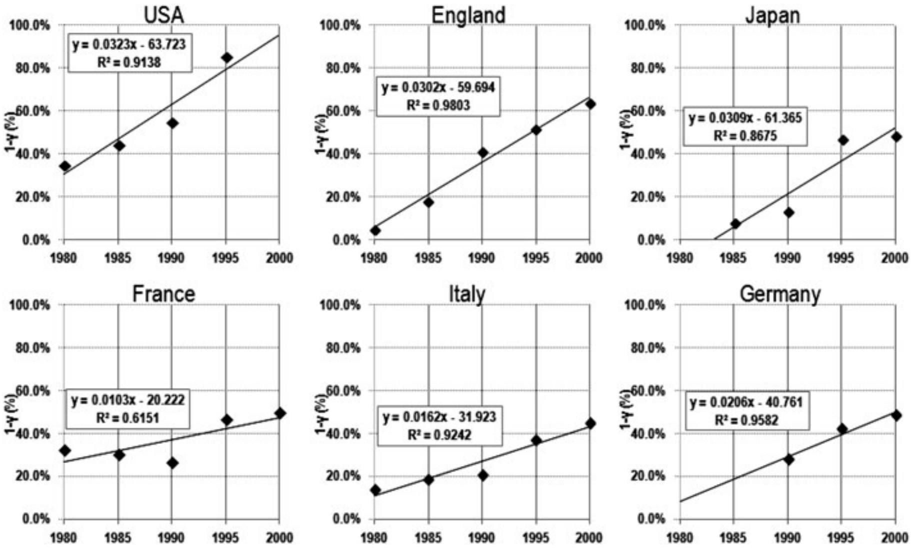


Fig. 3 Life expectancy increase with time for USA, England, Japan, France, Italy and Germany, model results (*diamond*) and trend (*line*)

is steadily increasing with time. The percentage of residual citations c_∞ to total citations at peak c_0 (which is equal to $1 - \gamma$) climbed from 5.4 % for articles published in 1980 to 64 % for those of 2000 (Fig. 3). Given the political situation of Germany before 1989 and its reunification since then, the analysis of its citations distributions is limited to 1990 onward. Despite this, the evolution of its papers' life expectancy is similar to that of other countries and has continued to increase from 1990 to 2000 with a rate greater than that of France and Italy but smaller than that of USA, England and Japan. Italian articles, on their end, would experience an increase of the ratio of residual citations to citations at peak from 14 % in 1980–45 % in 2000 (Appendix 3). Finally, as Fig. 3 shows, France is the only G6 country which articles do not show noticeable expansion of the life expectancy over the period 1980–2000.

Among emerging countries, Brazilian articles' life expectancy has increased from a finite period of 68 years for those published in 1980 to an infinite one for those of 1995 (Appendix 2). Indeed, articles of 1995 would succeed in maintaining for a long period of time 64 % of citations gained at peak (Fig. 4). Life expectancy will be extended for articles published in 2000 because the peak time is not reached until 2009. For Russia, the distributions of citations are given only for 1990 onwards (after the collapse of the USSR). Since 1990, articles published by Russian researchers have enjoyed an increasingly long life expectancy. On the other hand, the growth of life expectancy of South African articles over the period from 1980 to 2000 remains the lesser among the BRICS countries (Fig. 4). This smaller rate of growth is partially related to its smaller scientific production compared to other BRICS countries. If we exclude Russia for which citations distributions are not plotted from 1980 to 1990, China is the leader in increasing life expectancy of its articles over the period from 1980 to 2000. Chinese articles are more and more cited with time. As a result, their life expectancy is increasing between 1980 and 2000. This obviously implies that Chinese articles attracts and would continue

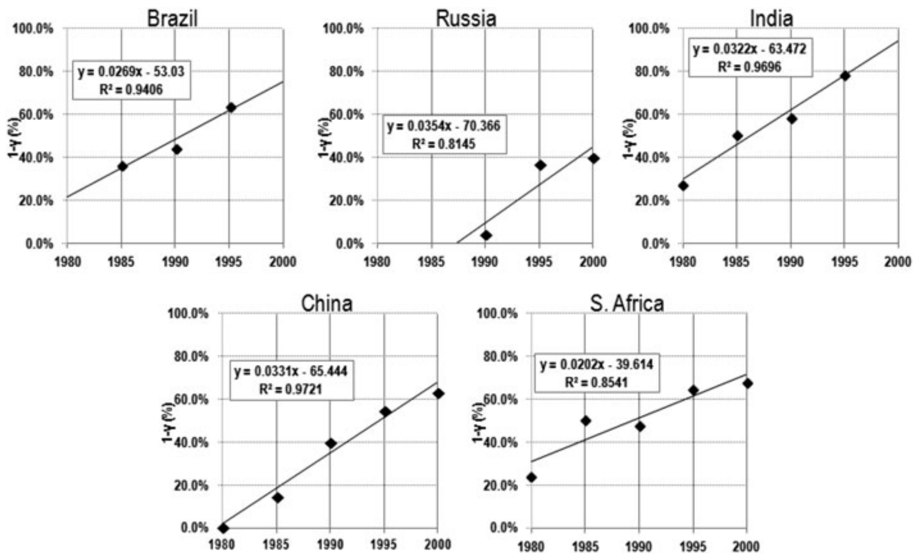


Fig. 4 Life expectancy increase with time for BRICS countries, model results (*diamond*) and trend (*line*)

to attract more interest worldwide (including for Chinese scientists), for recent as much as for older articles.

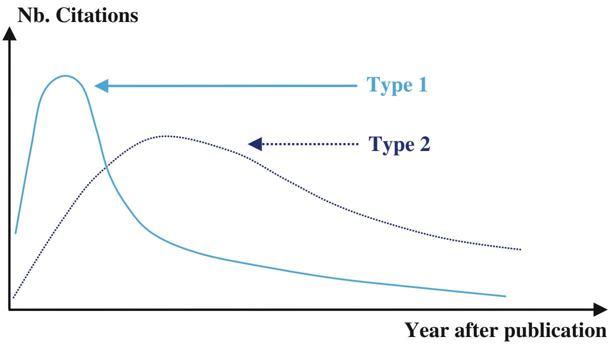
The increase of life expectancy for China is supported by the findings of Zhou and Leydesdorff (2006), who noted that the ratio of citations per publication for Chinese literature has an exponential growth between 1993 and 2004 (using a time window of 10 years). Furthermore, China is, according to these authors, the fourth country in terms of the growth of its percentage of world share in citations during the period of 1997–2001 compared to 1993–1997.

Finally, the comparison of Figs. 3 and 4 shows that the life expectancy of emerging countries' articles is on average greater than that of developed countries, with respect to the growth rate of residual citations to citations at peak ratio. Even if the number of citations for developed countries (more than 60,000 citations at peak in 2000) is greater than emerging countries (less than 30,000 citations at peak in 2000), their life expectancy is seemingly longer than that of developed countries over the two decades starting in 1980. Should the citation patterns of countries remain unchanged, these different profiles in terms of life expectancy would continue to increase further in the future.

More specifically, citations distribution of developed countries follows broadly the curve of type 1 plotted in Fig. 5, where the diffusion of scientific results is very rapid and, consequently, the speed of withdrawal (decline after peak) is sharper. On the other hand, the curve of citation distributions of emerging countries (BRICS) is flatter and fit more type 2 with a slow growth in diffusion process associated with a slower speed of withdrawal, which is likely related to their lower citation rates. These two types of citations were found by Cano and Lind (1991) to be the distinctive two curves to represent life cycle of ten 'citations classics' with time.

Figures 6 and 7 illustrate this characteristic dichotomy. We choose, for the G6 group, the country with the lowest number of citations at peak (Italy) to compare with the BRICS

Fig. 5 Different observed types of citations distribution with time



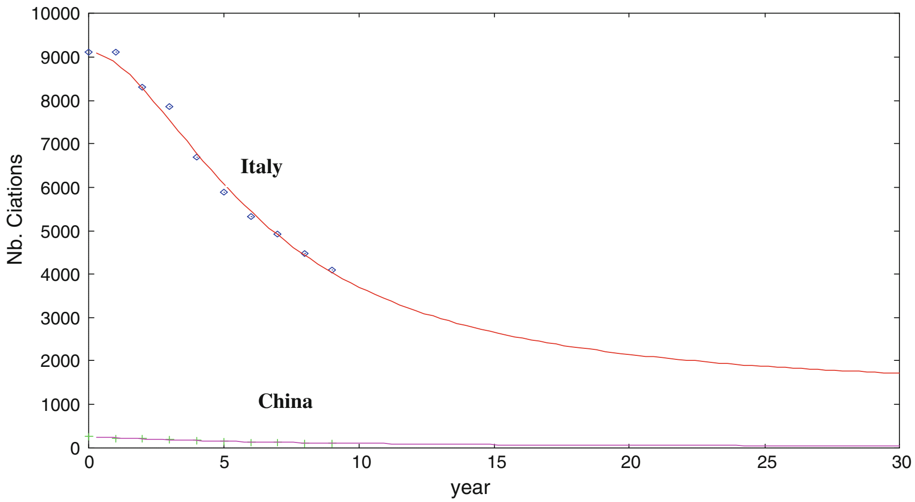


Fig. 6 Diachronous distribution of citations for Italy and China to articles published in 1980, observed (*diamond* and *plus*) and model (*line*)

country having the highest number of citations at peak (China).These two figures plot both the model and observed data for 1980 (Fig. 6) and 2000 (Fig. 7).

These emerging countries have seemingly built up domestic research systems of internationally comparable standards in the previous decades and have apparently been moving forward to internationally quality standards and recognition worldwide. This positive progression could be seen as a real mutation from a scientific developing country toward a developed one, because developing a science system might be characterized by its growth without necessarily meant an achievement of quality standards (Sotudeh 2012).

Journals

Since its creation by Eugene Garfield, the Impact Factor has been widely used by the scientific community in assessing journals impact and 'quality' and has been used and misused by scientists, managers and policy-makers to evaluate other entities such as researchers, research groups, institutions, countries, networks, etc. In spite of its

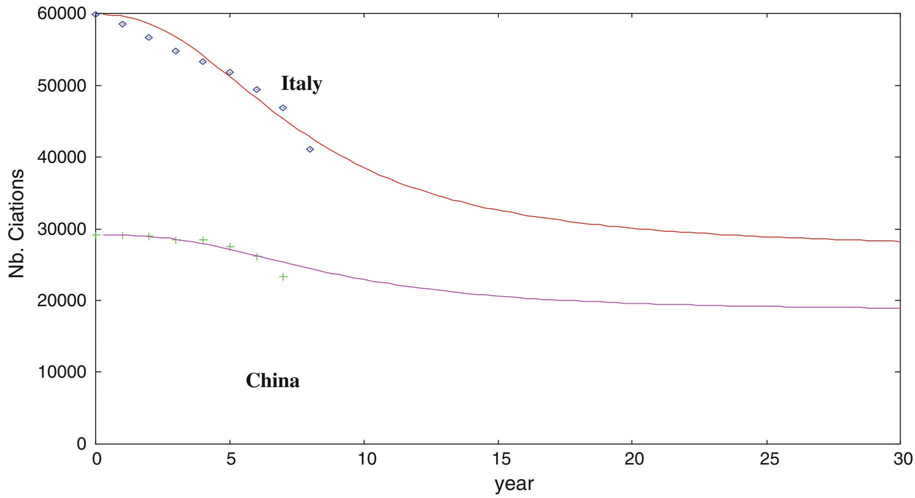


Fig. 7 Diachronous distribution of citations for Italy and China to articles published in 2000, observed (*diamond* and *plus*) and model (*line*)

widespread utilization, the Impact Factor has been continuously criticized (Archambault and Larivière, 2009; Vanclay 2012). Another criticism one could add is that the Impact Factor remains static (time window of 2 or 5 years) and does not offer any dynamic view on the evolution of gained citations over time or on their perspective in the future. The model is used here to portray the citations distributions of journals from 1980 to 2000 in order to analyze how life expectancy of journals evolves over time. It is aimed also to derive dynamically a prospective analysis of citations, instead of static and cumulative citations over a fixed period of time.

Figure 8 shows that, in a manner similar to that of countries, journal articles citations' are increasing their life expectancy. On the whole, articles published in these journals in 2000 would continue to receive citations for a longer time than those published in 1980. The residual citations of the publications in 2000 are more than 34 % of the citations gained at peak-time while this ratio is much less for articles published in 1980. It does not exceed 12 % for *Nature* and reaches 31 % for *Physical Review* (Appendix 4). *Science* exhibits the highest lengthening of its life expectancy: *Science* articles published in 1980 have kept 14 % of citations received at peak and those published in 2000 would succeed in keeping 43 %.

The growth of residual citations to citations at peak ratio as almost identical for *Science* (0.015) and *Physical Review* (0.014), even though *Science* is a general journal, which publishes papers across all disciplines, and *Physical Review* publishes exclusively basic research papers in physics, which remain cited for a longer time. Figures 9 and 10 illustrate this similarity in spite of the fact that citations at peak for *Science* are smaller than for *Physical Review*.

The life expectancy for *Lancet* in 1985 and 1995 is finite, meaning that Lancet articles published in these two years would be completely obsolete within respectively 69 and 38 years after publication (Appendix 4). It is worth mentioning that *Lancet* presents the lowest numbers of citations at peak among the journals set. The ratio of residual citations to citations peak for Lancet has only slightly changed from 1980 to 2000, which might be due to the fact that articles in medical sciences are generally cited immediately after

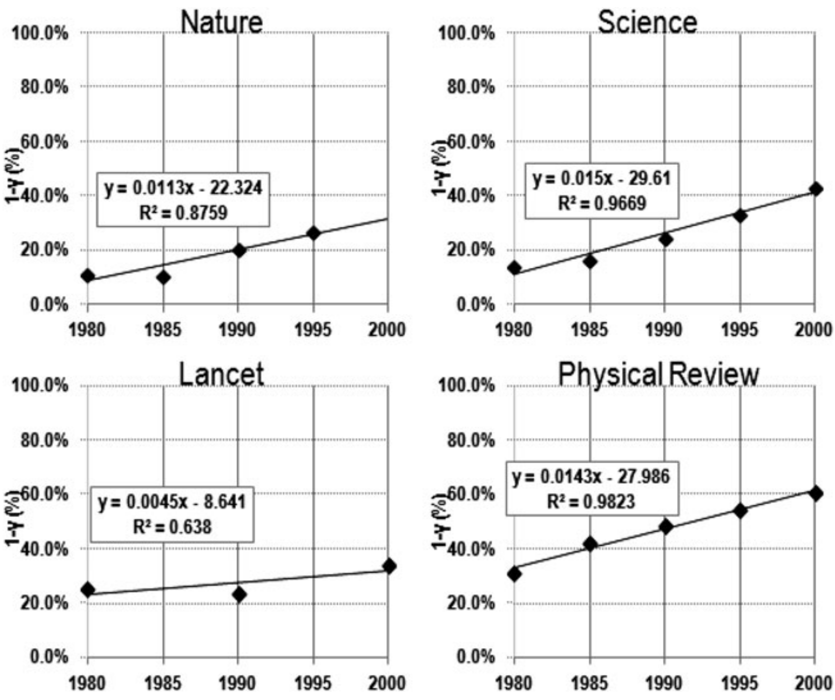


Fig. 8 Life expectancy increase with time for journals, model results (*diamond*) and trend (*line*)

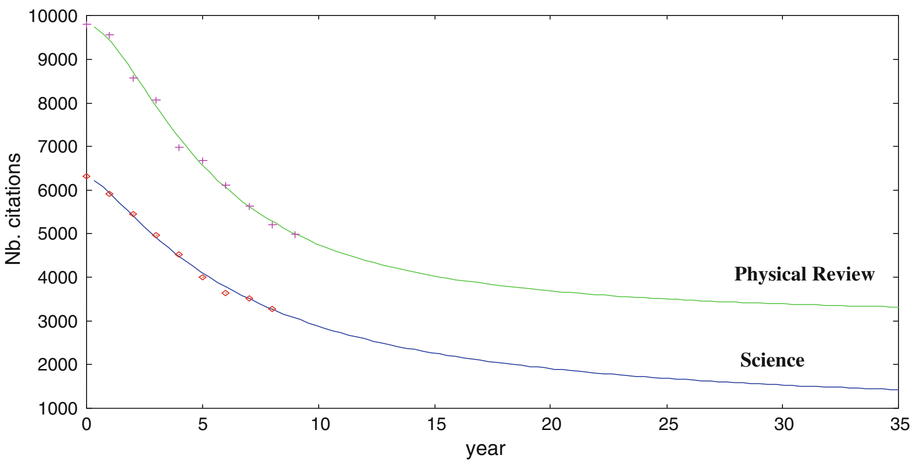


Fig. 9 Diachronous distribution of citations of for *Science* and *Physical Review* articles published in 1980, observed (*diamond* and *plus*) and model (*line*)

publication (high process of diffusion) and are then less likely to be cited to the same extent far later in time. As a consequence, high effect is on immediate citations change and very little effect is on citations on long term and, hence, on residual citations. To the

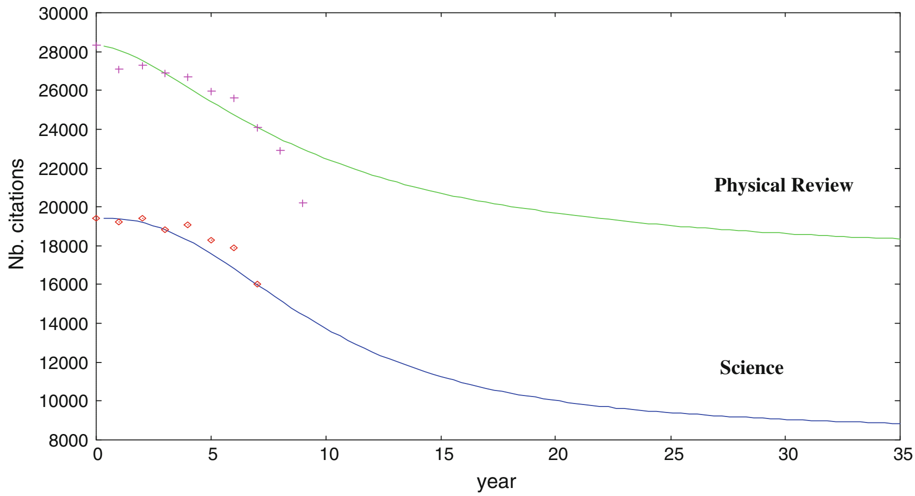


Fig. 10 Diachronous distribution of citations of for *Science* and *Physical Review* articles published in 2000, observed (*diamond* and *plus*) and model (*line*)

opposite, the life expectancy of 1980 articles published in *Physical Review* is initially extended with a ratio of residual citations to citations at peak of 31.2 %, compared to the other journals of the set. Life expectancy has since gradually increased to reach almost 61 % in 2000. Citations to *Physical Review* articles are much higher than for other journals even after longer time, because they generally are basic research findings that remains up-to-date knowledge which continues to be cited 'indefinitely'. In summary, Fig. 8 confirms once again the expansion of life expectancy of scientific literature correlated to a slowing down of its obsolescence with time.

Fields

Figure 11 shows the lengthening of papers' life expectancy with time for scientific fields. In MED, NSE and AH, articles are likely to be cited for a longer period than before, and unlikely to be quickly out of date. However, the structure of the distributions is different across fields. The diffusion process occurs more rapidly in MED, since more recent articles are highly cited and the time period to reach the peak is shorter. The obsolescence is then as quick as the diffusion process. Indeed, Fig. 11 shows the acceleration of life expectancy expansion for MED literature, which indicates that their citation behavior is about to change and that articles would continue to earn citations for a longer time after their publication than before. This interesting characteristic is in its priming stage. For MED, life expectancy has significantly moved from a finite period for articles published in 1980 to an infinite one for those of 1995 for which the residual citations to citations at peak is almost 75 % (Appendix 5). In fact, MED research papers exhibit the highest growth in life expectancy. This tendency, corollary of a slowing obsolescence, is expected to continue in the future when we know that the citations peak is reached 9 years after publication. The evolving of the obsolescence in SS and AH with time shows that, on the whole, life expectancy has increased since 1980. The percentage of residual citations to citations at peak of AH have grown from 2.1 % for articles published in 1980 to 69.4 % for articles

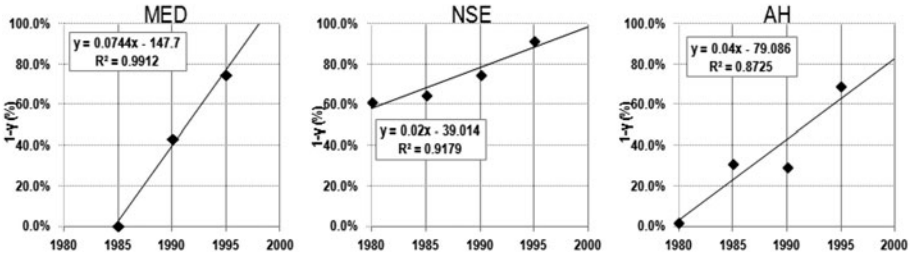


Fig. 11 Life expectancy increase with time for scientific fields, model results (*diamond*) and trend (*line*)

published in 1995. The lengthening of the life expectancy would continue over the next years. Indeed, the maximum of citations for articles published in 2000 is reached after the 11th year.

Despite the noticeable expansion of life expectancy with time, AH citations distribution is flatter than that of NSE and is more similar to the curve of type 2 in Fig. 5. Moreover, the maximum number of citations has not significantly increased from 1980 to 2000. Hence, the citations at peak have hardly moved from 1,659 for articles published in 1980–2011 for articles published in 2000 (Appendix 5).

In the social sciences, citation distributions follows a sawtooth curve (Fig. 12). Citation distributions are plotted for each year following publication over a citation-window of more than 20 years. This time period is used here just to reflect the irregularities of the curves and yet the change occurring on the distribution of citations from 1980 to 2000 adversely to the adopted time-window of 12 years throughout this article.

Barnett et al. (1989), in their synchronous analysis of citations distributions of the scientific fields [natural, medical sciences & engineering (NME), social sciences (SS) and

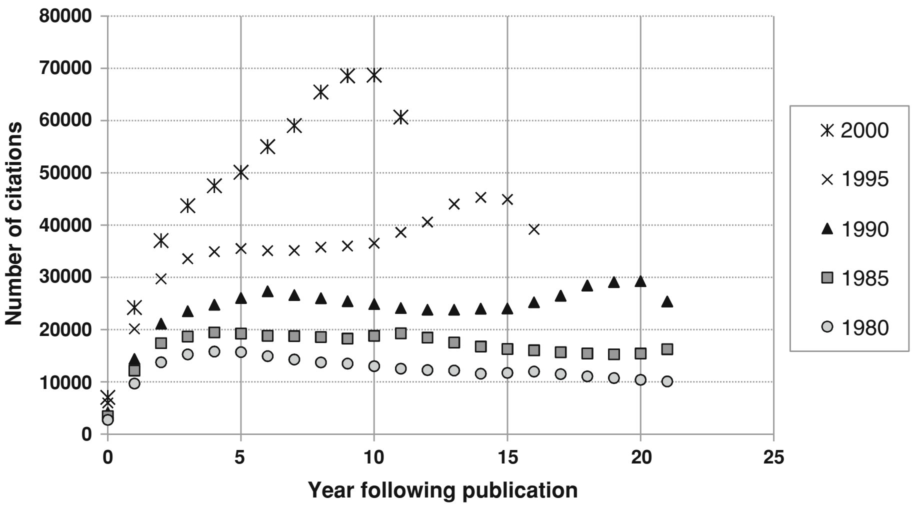


Fig. 12 Citation distributions of articles published respectively in 1980, 1985, 1990, 1995 and 2000

humanities & art (HA)], have found that the diffusion process—and decline later—is much less rapid for SS than NME and consequently articles in SS are likely to be cited for longer than those in NME. Similarly, Rafsnider (1975) pointed out not just the utilization of recent literature as a reason for lower citations profile and citations far backward but also weak internal interdisciplinary between social science sub-fields which results in a few diffusion of new knowledge and low rate of citations conversely to natural science. Later, Small and Crane (1979), when examining the structure of science and social science fields using citation indexes, have suggested that this citation characteristic might be due to new knowledge being created less rapidly in the social sciences than in the natural sciences. They have invoked existing specialty in physics (as an example) versus external interdisciplinary in social sciences. But they added that knowledge is developing in parts of the social science disciplines in a manner similar to the natural sciences. Leydesdorff (2003) also noticed this development on 1998–1999 data, mainly due to specialty formation within sub-fields of social science, which are important mechanisms for intensive citation profile. Along these lines, Fig. 12 suggests that the field of SS is being under changeable publication-citation practices and behaviors. A transition from type 2 to type 1 distributions (as presented in Fig. 5) is seen forward. Citations distributions are flatter at the beginning (1980 and 1985) with an irregular form and are of type 2 in Fig. 5. They have recently evolved to higher number of citations at peak and sharper increase over citations distributions of 1995 and 2000 similar to type 1 in Fig. 5.

The increase of the age of scientific references overtime has been shown by several authors using a synchronous approach (Larivière et al. 2008; Egghe 2010; Yang et al. 2010). This paper proves that an analogous phenomenon can also be observed using distinctively a diachronous approach, and for several levels of aggregation: countries, journals and fields. The consequence of the two results is that the expansion of the life expectancy is an intrinsic characteristic of scientific literature and the expansion is expected to continue in the future assuming that age specific citations factors remains constant. From a diachronous perspective, scientific literature is getting increasingly a longer life than before and will continue to do so due to electronic papers, digitizing scientific old resources far backward, development of several public-access databases, widespread of high-speed information technology use among larger scientific community.

Egghe et al. (1995; 2000) points out the steady growth of literature the last few decades as a reason for the increase of citations. Assuming an increasing exponential function for production and a decreasing one for aging, he has found that on a diachronous basis, the larger the increase in production, the smaller the obsolescence rate. He concluded, however, that growth can influence aging but that it does not cause aging (Egghe and Rousseau 2000). On another hand, the constant dynamic and rapid change of scientific outputs in developed countries causes lower interest in older scientific literature. Scientists are on the whole already at the frontier science and technology. As a result, citations decrease sharply after longer time. In emerging countries scientists tend to cite older scientific literature because they are not under the same constant dynamics and rapid changes of scientific outputs and also because they are in general working on common and conventional fields. Not being able to attend very known, unavoidable and specialized conferences, considered as crucial meetings in which latest results and advances are released, scientists from developing countries are unlikely to be 'updated' among their community and consequently, to orient their research works toward advanced and in frontier science and technology. This situation is however progressively changing (Kay and Shapira 2009; Bouabid and Martin 2009).

Conclusion

This paper used a diachronous model and firstly argues why suggested *life expectancy* is best appropriate for diachronous distribution instead of life-time useful in synchronous distribution. Three datasets are used for the years 1980, 1985, 1990, 1995 and 2000: (1) papers from G6 and BRICS countries, (2) papers published in Science, Nature, Physical Review and the Lancet and (3) all papers, divided into four broad fields: medical sciences, natural sciences and engineering, social sciences and arts and humanities. It puts forward that life expectancy varies widely from a corpus to another. When life expectancy is infinite it assumes that the corpus would continue to attract scientific community' interest for a very long time.

It shows that the life expectancy of scientific papers is lengthening with time. The lengthening (expansion) of the life expectancy is intrinsically a characteristic of scientific literature and scientific community behavior since the expansion has been found to be independent of countries, journals, fields, times. Mostly, this expansion, proved in a prospective manner, is highly expected to continue in the future assuming that citation patterns remain unchanged.

Finally, life expectancy for developed countries literature is on average shorter than that of emerging ones. Scientific literature produced by the latter has been likely to enjoy longer life and become obsolete less faster than the literature produced by the former. The characteristics of literature in these two categories of countries are such that for developed ones it is relying on very recent and very advanced science (or technology) but is at the end getting very rapidly obsolete. As a result, the immediate citations increase is very high to reach the peak and so is the decline afterward. On the other hand, literature in developing countries is likely relying more on aged (or older) science but is at the end enjoying longer life. The cumulative citations at peak time for emerging countries are fewer than those of developed countries but the decrease of citations after peak time is slower than that of developed countries.

Appendix

See Tables 1, 2, 3, 4 and 5

Table 1 Citations distributions of countries, journals and fields for the time series: 1980, 1985, 1990 and 2000

Year	USA					England					Japan				
	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
0	30,650	40,439	47,974	60,533	72,032	7,334	9,368	10,899	15,952	21,265	4,668	6,459	8,345	11,491	16,579
1	112,430	138,169	170,965	215,477	243,093	27,723	35,124	44,186	66,238	84,053	17,297	24,736	36,387	52,585	71,543
2	153,566	184,327	228,487	289,197	329,178	38,951	49,036	62,115	91,719	117,338	23,200	33,056	49,726	72,942	99,122
3	161,287	192,755	245,337	307,265	359,859	40,572	49,850	65,900	95,223	124,891	22,740	33,161	50,257	74,692	103,281
4	162,535	193,743	252,566	310,890	378,565	38,944	47,415	65,664	91,768	126,353	21,408	31,221	49,842	71,984	103,223
5	162,431	190,720	254,901	307,308	388,399	37,767	45,461	63,482	86,707	125,862	20,495	28,617	46,944	67,444	100,131
6	149,208	186,932	262,480	295,609	399,075	33,938	42,182	63,400	80,279	125,559	18,035	27,194	45,350	61,361	98,279
7	142,348	181,240	251,306	290,803	403,097	31,409	39,907	57,762	76,574	124,129	16,499	25,295	41,571	58,077	94,965
8	134,607	174,938	237,368	286,604	412,466	28,620	37,070	53,364	72,849	124,633	15,175	23,508	37,979	54,524	93,397
9	129,060	169,930	224,859	283,240	408,251	26,639	35,237	48,671	69,822	121,570	14,072	22,127	34,689	51,909	89,029
10	122,638	165,403	214,431	278,889	402,384	25,120	33,349	44,761	66,479	117,586	13,198	20,587	32,190	49,061	84,594
11	116,995	166,621	200,914	276,167	363,116	23,120	33,333	40,800	64,695	104,339	12,276	19,904	28,916	47,062	75,254
Year	France					Italy					Germany				
	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
0	3,895	5,195	6,705	9,822	14,424	1,499	2,215	3,242	5,999	9,043			9,429	13,833	20,613
1	16,294	21,690	30,253	47,393	61,813	6,535	9,597	15,364	29,077	40,989			39,444	61,030	84,932
2	22,566	29,784	41,845	66,759	86,459	9,119	13,448	21,867	40,755	57,960			54,304	83,993	116,280
3	22,279	29,994	43,374	66,997	90,191	9,115	13,479	22,253	41,389	59,895			55,648	84,841	120,958
4	21,160	27,861	42,354	64,205	89,293	8,311	12,563	21,720	39,376	58,568			54,807	81,249	120,625
5	19,640	25,462	39,636	59,271	86,995	7,853	11,524	19,946	36,482	56,653			51,954	75,476	118,010
6	17,241	23,703	38,888	54,276	85,768	6,693	10,537	19,931	33,262	54,784			50,869	68,343	114,615
7	15,632	22,090	35,332	50,645	83,334	5,891	9,708	17,894	31,178	53,345			46,301	64,353	111,323
8	14,350	20,645	31,886	48,188	82,348	5,332	9,061	16,073	29,144	51,838			42,204	60,248	109,173
9	13,001	19,146	29,096	45,595	78,343	4,918	8,254	14,918	27,540	49,451			37,984	56,887	105,416
10	11,922	17,959	26,541	43,364	75,309	4,478	8,041	13,574	26,182	46,874			34,646	53,322	100,438
11	11,100	17,870	23,784	41,405	65,800	4,091	7,910	12,369	24,567	41,039			31,590	51,278	88,936

Table 1 continued

Year	Brazil					Russia					India				
	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
0	155	254	402	921	1,878			104	2,712	3,409	828	805	928	1,252	1,904
1	823	1,091	1,860	4,343	8,402			489	11,718	14,624	3,293	3,416	4,113	6,112	9,371
2	1,137	1,498	2,635	6,116	12,684			562	15,278	18,956	4,534	4,420	5,573	8,316	14,072
3	1,231	1,436	2,647	6,315	12,987			527	14,710	18,268	4,378	4,208	5,732	8,692	14,614
4	1,070	1,393	2,417	6,177	13,400			410	13,221	17,831	3,994	3,960	5,488	8,176	14,774
5	1,003	1,323	2,400	5,795	13,208			372	12,066	16,785	3,658	3,479	5,271	7,898	15,041
6	860	1,174	2,359	5,426	13,516			339	10,624	16,020	3,040	3,444	5,391	7,108	15,266
7	796	1,204	2,322	5,357	13,474			312	9,969	15,112	2,725	3,183	5,015	7,409	15,632
8	718	1,026	2,098	5,134	13,710			254	9,072	14,795	2,446	2,923	4,602	7,133	16,109
9	685	965	1,935	5,058	13,450			244	8,654	13,915	2,254	2,899	4,431	7,072	15,950
10	630	951	1,914	4,730	13,014			215	8,005	13,245	2,008	2,708	4,148	7,020	15,728
11	528	950	1,723	4,747	11,312			191	7,701	11,265	1,905	2,772	4,020	6,969	13,900

Year	China					S. Africa				
	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
0	37	311	756	1,090	3,466	328	431	439	583	846
1	160	1,107	2,903	5,628	17,701	1,192	1,577	1,801	2,396	3,236
2	259	1,642	3,809	8,138	26,288	1,830	2,164	2,625	3,424	4,696
3	212	1,521	3,884	8,105	28,308	1,728	2,094	2,614	3,517	4,930
4	215	1,498	3,640	7,742	29,150	1,650	1,932	2,608	3,489	4,907
5	198	1,398	3,483	7,115	29,067	1,629	1,913	2,594	3,275	4,916
6	167	1,217	3,398	6,788	28,994	1,442	1,737	2,644	3,031	4,939
7	145	1,171	3,233	6,632	28,525	1,324	1,511	2,335	2,888	5,003
8	144	1,062	2,919	6,359	28,407	1,126	1,411	2,171	2,763	4,903
9	134	1,083	2,726	6,196	27,554	1,089	1,395	2,079	2,601	4,889
10	101	1,001	2,590	5,966	26,243	1,047	1,332	1,798	2,533	4,656
11	102	996	2,477	6,000	23,312	954	1,319	1,786	2,501	4,283

Table 1 continued

Years	Nature					Science				
	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
0	1,704	2,226	2,584	3,466	4,227	1,039	1,361	1,874	3,293	3,593
1	7,587	9,800	12,408	15,177	18,289	4,618	6,962	10,330	16,113	14,104
2	10,350	12,649	16,663	18,477	24,148	6,253	9,287	13,892	20,551	18,552
3	10,252	12,844	17,605	18,864	24,712	6,327	9,386	14,255	21,019	18,820
4	9,944	12,491	17,251	17,935	25,572	5,914	9,301	14,103	20,490	19,434
5	9,201	11,590	16,354	17,076	25,114	5,458	9,031	12,976	19,157	19,223
6	8,343	10,995	15,657	15,550	25,127	4,975	8,494	12,369	17,615	19,420
7	7,454	10,166	14,087	14,249	24,995	4,531	7,632	11,225	16,648	18,824
8	6,969	9,468	12,824	13,423	24,842	3,996	7,276	9,905	15,753	19,074
9	6,236	8,484	11,558	12,871	23,930	3,630	6,609	8,903	14,848	18,280
10	5,949	7,640	10,327	11,734	23,855	3,524	6,031	8,124	14,172	17,882
11	5,262	7,087	9,367	11,077	21,151	3,269	5,775	7,366	13,328	16,001
Years	Lancet					Physical				
	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
0	458	617	426	639	1,421	2,125	3,860	4,392	5,666	6,824
1	1,857	2,650	2,820	3,627	5,335	8,663	11,514	14,985	20,789	23,440
2	2,513	3,365	4,209	5,273	7,572	9,808	13,539	17,664	24,429	28,356
3	2,584	3,517	4,185	4,967	7,845	9,564	12,703	17,853	23,491	27,099
4	2,501	3,047	4,038	4,757	7,595	8,578	11,636	17,231	22,126	27,288
5	2,510	2,905	3,870	4,332	7,171	8,070	10,453	15,873	21,466	26,891
6	2,095	2,547	3,872	3,859	6,835	6,987	10,034	15,499	19,843	26,730
7	1,829	2,450	3,392	3,815	6,728	6,686	9,450	14,228	19,177	25,987
8	1,582	2,233	2,985	3,631	6,504	6,107	9,318	12,881	17,527	25,649
9	1,426	1,937	2,674	3,389	6,116	5,640	8,585	11,833	17,319	24,103
10	1,350	1,692	2,444	3,041	5,699	5,211	8,177	11,221	17,055	22,929
11	1,216	1,827	2,217	2,822	4,789	4,988	8,029	10,682	16,576	20,224

Table 1 continued

Years	MED					NSE				
	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
0	30,953	39,148	45,583	59,049	74,585	28,414	35,523	38,397	47,810	56,179
1	100,770	124,672	151,294	200,372	234,601	82,886	97,264	118,139	154,793	181,654
2	134,233	159,611	195,430	256,470	301,495	102,097	121,106	148,313	198,961	240,652
3	139,895	167,010	207,952	272,648	325,902	103,918	120,965	154,364	204,105	259,979
4	141,354	167,990	214,804	276,574	339,935	101,523	118,016	156,095	202,325	274,503
5	144,937	167,063	218,864	274,215	350,474	98,610	114,029	155,400	197,229	281,993
6	132,335	163,269	229,802	264,725	360,301	89,807	111,540	157,653	190,436	291,453
7	126,577	159,472	221,720	261,407	370,628	85,684	107,687	151,156	188,860	292,398
8	119,738	153,250	211,887	257,352	380,073	81,333	105,495	143,700	188,407	296,905
9	114,203	148,618	201,203	253,853	377,007	77,816	103,520	136,691	188,756	296,819
10	109,219	143,369	191,815	250,019	373,786	75,043	102,631	131,229	188,690	291,333
11	102,770	146,411	178,608	245,092	339,022	72,469	103,212	125,765	190,513	266,147

Years	SS					AH				
	1980	1985	1990	1995	2000	1980	1985	1990	1995	2000
0	2,737	3,467	4,104	5,986	7,040	383	488	346	477	483
1	9,689	12,175	14,386	20,151	24,235	1,114	1,401	1,261	1,219	1,148
2	13,761	17,419	21,145	29,728	37,045	1,473	1,779	1,743	1,772	1,702
3	15,266	18,688	23,516	33,562	43,718	1,659	1,765	1,685	1,786	1,718
4	15,810	19,467	24,783	34,924	47,529	1,576	1,690	1,584	1,720	1,794
5	15,707	19,253	26,066	35,518	50,115	1,491	1,562	1,516	1,653	1,795
6	14,937	18,833	27,345	35,113	55,026	1,375	1,455	1,517	1,531	1,811
7	14,291	18,759	26,639	35,141	59,058	1,279	1,301	1,393	1,443	1,860
8	13,734	18,586	26,027	35,780	65,466	1,162	1,224	1,308	1,397	1,985
9	13,506	18,286	25,462	35,997	68,563	1,091	1,187	1,188	1,359	1,967
10	13,016	18,811	24,897	36,545	68,711	977	1,163	1,130	1,342	2,011
11	12,540	19,305	24,152	38,622	60,668	938	1,089	1,041	1,310	1,537

Table 2 R^2 of the model to the observed data of SCI for countries for journals and fields

Country	R^2 (%)
USA_80	99.15
USA_85	98.38
USA_90	99.82
USA_95	98.46
USA_00	–
England_80	99.51
England_85	99.74
England_90	99.46
England_95	99.83
England_00	99.98
Japan_80	98.96
Japan_85	99.72
Japan_90	99.73
Japan_95	99.79
Japan_00	99.99
France_80	99.90
France_85	99.57
France_90	99.69
France_95	99.84
France_00	99.98
Italy_80	99.13
Italy_85	99.25
Italy_90	99.50
Italy_95	99.87
Italy_00	92.65
Germany_90	99.77
Germany_95	99.81
Germany_00	99.99
Brazil_80	98.70
Brazil_85	96.80
Brazil_90	98.54
Brazil_95	97.62
Brazil_00	–
Russia_90	97.95
Russia_95	99.79
Russia_00	95.20
India_80	99.70
India_85	98.06
India_90	97.25
India_95	88.91
India_00	–
China_80	95.87
China_85	97.31
China_90	98.47

Table 2 continued

Country	R^2 (%)
China_95	97.77
China_00	99.98
S. Africa_80	97.71
S. Africa_85	97.8
S. Africa_90	99.09
S. Africa_95	99.52
S. Africa_00	99.43

Journal	R^2 (%)	Field	R^2 (%)
Nature_80	99.44	MED_80	99.16
Nature_85	99.65	MED_85	98.56
Nature_90	99.81	MED_90	99.86
Nature_95	99.48	MED_95	98.03
Nature_00	99.98	MED_00	–
Science_80	99.67	NSE_80	99.43
Science_85	99.68	NSE_85	96.13
Science_90	99.83	NSE_90	99.56
Science_95	99.73	NSE_95	85.44
Science_00	99.98	NSE_00	–
Lancet_80	99.10	SS_80	99.18
Lancet_85	96.02	AH_80	99.72
Lancet_90	98.74	AH_85	98.08
Lancet_95	98.29	AH_90	98.52
Lancet_00	99.88	AH_95	99.44
Physical_80	99.39	AH_00	–
Physical_85	98.95		
Physical_90	98.82		
Physical_95	98.58		
Physical_00	99.94		

Table 3 Parameters results of the model for countries

Country	α	p	β	c_0	t_v or $(1-\gamma)$
USA_80	105310.6	1.01	8.29	162535	35.2 %
USA_85	107580.7	2.27	162.89	193743	44.5 %
USA_90	117051.3	1.48	10.37	262480	55.4 %
USA_95	45197.1	1.59	7.29	310890	85.5 %
USA_00	Maximum reached at 9th year after publication				
England_80	38366.5	1.39	21.89	40572	5.4 %
England_85	40704.4	1.31	18.53	49850	18.3 %
England_90	38319.5	2.9	221.29	65900	41.9 %
England_95	45697.0	1.53	11.91	95223	52.0 %
England_00	45419.5	1.85	95.69	126353	64.1 %

Table 3 continued

Country	α	p	β	c_0	t_v or $(1-\gamma)$
Japan_80	26033.7	1.44	31.46	23200	49
Japan_85	30481.2	1.15	13.85	33161	8.1 %
Japan_90	43409.3	1.93	58.03	50257	13.6 %
Japan_95	39562.2	1.62	12.82	74692	47.0 %
Japan_00	53168.5	1.95	82.03	103281	48.5 %
France_80	15330.8	2.22	44.45	22566	32.1 %
France_85	20913.1	1.24	8.85	29994	30.3 %
France_90	31859.9	2.05	48.47	43374	26.5 %
France_95	35660.8	1.56	10.56	66997	46.8 %
France_00	45380.7	1.87	65.45	90191	49.7 %
Italy_80	7862.7	1.81	29.17	9119	13.8 %
Italy_85	10980.4	1.21	10.45	13479	18.5 %
Italy_90	17617.4	1.85	37.82	22253	20.8 %
Italy_95	26114.6	1.43	11.33	41389	36.9 %
Italy_00	32920.1	2.37	126.75	59895	45.0 %
Germany_90	40063.3	2.24	71.98	55648	28.0 %
Germany_95	49163.2	1.56	11.93	84841	42.1 %
Germany_00	62129.1	1.83	71.37	120958	48.6 %
Country (cont.)	α	p	β	c_0	t_v or $(1-\gamma)$
Brazil_80	1379.0	1.04	9.2	1231	68
Brazil_85	940.5	1.58	20.52	1498	37.2 %
Brazil_90	1460.9	2.06	47.44	2647	44.8 %
Brazil_95	2266.5	1.5	9.92	6315	64.1 %
Brazil_00	Maximum reached at 9th year after publication				
Russia_90	535.5	1.29	7.93	562	4.7 %
Russia_95	9618.3	1.77	13.31	15278	37.0 %
Russia_00	11351.6	1.96	48.42	18956	40.1 %
India_80	3270.4	2.07	22.97	4534	27.9 %
India_85	2149.0	1.67	10.09	4420	51.4 %
India_90	2329.5	2.17	37.36	5732	59.4 %
India_95	1834.8	1.75	2.96	8692	78.9 %
India_00	Maximum reached at 9th year after publication				
China_80	256.7	1.11	8.25	259	0.9 %
China_85	1394.8	1.17	13.75	1642	15.1 %
China_90	2309.7	1.53	16.59	3884	40.5 %
China_95	3643.5	1.52	16.56	8138	55.2 %
China_00	10655.7	2.59	276.18	29150	63.4 %
S. Africa_80	1377.0	1.81	30.25	1830	24.8 %
S. Africa_85	1056.9	2.16	24.42	2164	51.2 %
S. Africa_90	1357.1	3.11	557.96	2625	48.3 %
S. Africa_95	1224.9	2.2	19.07	3517	65.2 %
S. Africa_00	1569.6	2.52	637.32	4930	68.2 %

Table 4 parameters results of the model for journals

Journal	α	p	β	c_0	t_v or (1 − γ)
Nature_80	9182.4	1.74	40.28	10350	11.3 %
Nature_85	11488.6	1.92	48.7	12844	10.6 %
Nature_90	13978.0	2.06	52.46	17605	20.6 %
Nature_95	13809.0	1.44	15.84	18864	26.8 %
Nature_00	11418.5	2.92	464.63	25572	55.3 %
Science_80	5440.0	1.33	12.34	6327	14.0 %
Science_85	7839.2	2.14	85.8	9386	16.5 %
Science_90	10775.7	2.04	40.21	14255	24.4 %
Science_95	13959.3	1.46	16.99	21019	33.6 %
Science_00	11078.4	2.41	242.33	19434	43.0 %
Lancet_80	1938.5	2.23	37.82	2584	25.0 %
Lancet_85	4032.6	1.01	10.11	3517	69
Lancet_90	3215.0	2.23	100.49	4209	23.6 %
Lancet_95	8086.4	1.08	25.51	5273	38
Lancet_00	5182.2	1.24	15.79	7845	33.9 %
Physical_80	6750.4	1.7	16.81	9808	31.2 %
Physical_85	7864.1	1.29	7.4	13539	41.9 %
Physical_90	9153.7	2.02	21.46	17853	48.7 %
Physical_95	11187.6	1.59	13.18	24429	54.2 %
Physical_00	11120.1	1.66	40.83	28356	60.8 %

Table 5 Parameters results of the model for scientific fields

Field	α	p	β	c_0	t_v or (1 − γ)
MED_80	167735.0	1.01	17.91	144937	109
MED_85	166198.8	1.67	97.53	167063	0.5 %
MED_90	129153.9	1.49	17.58	229802	43.8 %
MED_95	69321.1	1.25	14.56	276574	74.9 %
MED_00	Maximum reached at 9th year after publication				
NSE_80	39631.0	2.07	20.66	103918	61.9 %
NSE_85	42361.1	1.51	28.13	121106	65.0 %
NSE_90	38620.5	3.74	414.93	156095	75.3 %
NSE_95	16770.4	3.14	10.52	204105	91.8 %
NSE_00	Maximum reached at 9th year after publication				
SS_80	5010.4	1.75	17.19	15810	68.3 %
AH_80	1623.7	1.39	21.71	1659	2.1 %
AH_85	1216.2	1.58	24.4	1779	31.6 %
AH_90	1224.8	1.67	32.12	1743	29.7 %
AH_95	547.2	2.02	10.68	1786	69.4 %
AH_00	Maximum reached at 11th year after publication				

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