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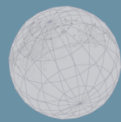
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Citation time windows based on citation frequency profiles of basic recognized work

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Abstract

In order for citation based indicators to be comparable across fields, they need to normalise for two main areas of difference among fields. The first is size differences which include factors such as number of publications and number of references per publication. The second is the time it takes for publications in a field to mature. The first area has been dealt with extensively on a publication level, while the second area has been addressed primarily on the level of fields or journals. Here we investigate the impact maturity time of different fields at the publication level and present a new way of determining an optimal, field specific citation time window. Our work also presents a way to identify 'Sleeping Beauties' and 'Genial Work'.

Introduction

The number of citations received by a publication is frequently used as a proxy for the visibility, quality or impact of the publication. Consequently, it is frequently used in the evaluation of the impact of the research being produced by individuals, departments and institutions. Furthermore, such evaluations are often employed as comparative measures. As such, efforts have been made to devise indicators which normalise for differences among scientific fields. One such indicator is the Mean Normalized Citation Score (*mncs*) introduced by Waltman, van Eck, van Leeuwen, Visser, and van Raan (2011). The Achilles' heel of these indicators however is the citation window, i.e. the period after publication for which citations are counted. When using indicators such as the *mncs* for evaluative purposes there is usually a compromise between a long citation window, which allows for a better assessment of the publications, vs. a shorter window which enables the evaluation of more recent publications. Furthermore, Dorta-González and Dorta-González (2013) pointed out that different fields also have different maturity times and that comparing publications from two fields with vastly different maturity times, based on citations in the same time window is not meaningful.

Errors associated with cross-field journal comparisons were highlighted by Wang (2013), who investigated the rate at which all publications in a journal or field received citations and found ageing differences among fields and journals. They found that the relationship between age and citations change in relation to when the journal is published. In both of these studies, citations were aggregated to the journal or field level, but the *mncs* (and other indicators like it) is used to compare individual publications.

Avramescu (1979) identified the following 5 types of citation life cycles, or citation frequency curves, of individual publications:

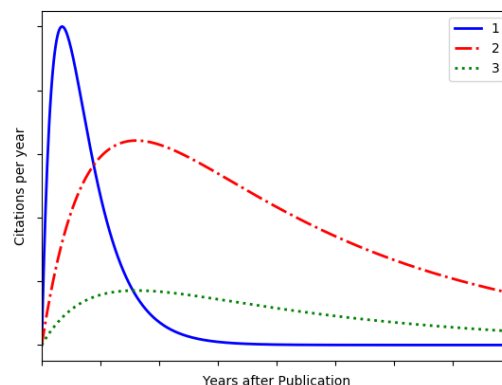
1. Initially much praised work
2. Basic recognized work
3. Scarcely reflected work
4. Well-received but later erroneous qualified work
5. Genial work.

Avramescu (1979) also introduced a mathematical description that could reproduce these citation frequency curves:

$$c(t) = C_0[e^{-at} - e^{-mat}]. \quad (1)$$

As long as $m > 1$, this expression yields a curve with the form shown in Fig. 1. The three curves shown on Fig. 1 represent the first three types of citation life cycles. They all have the same basic shape, but with different heights and decay rates. From here on we will refer to these three types collectively as *Basic Recognized Work*. The last two types have a significantly different shape, but we will not be investigating those life cycles in this paper.

Figure 1 Illustration of the typical shape of Eq. 1, introduced by Avramescu (1979), for types 1 through 3.



Using Eq. 1 Avramescu (1979) was able to categorize publications based on the values of the parameters required to fit the citation frequency curve. We used a similar model to categorise and investigate the properties of the citation frequencies of millions of publications.

When analysing citations aggregated to the journal or field level, such as was done by Wang (2013), the effect of *Genial Work* can overshadow *Basic Recognized Work* since, by definition, they receive many more citations over a longer period of time. We will use our model to do an investigation similar to Wang (2013), but on the publication level, based only on *Basic Recognized Work*.

Methodology

The model

We have two criticisms of Eq. 1. The first is that there is no allowance for publications to lay dormant, so to speak, and ‘wake up’ later and start receiving numerous citations. In principle this problem can be solved through a re-definition of the time axis. Our second criticism is that

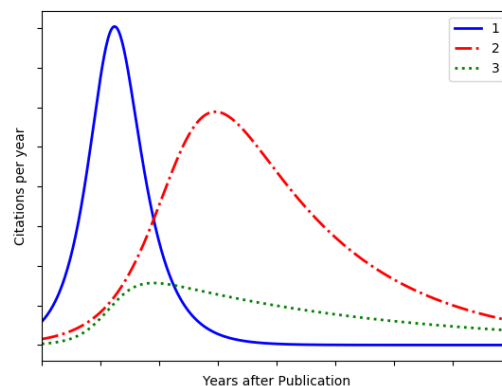
the left hand side of the curve does not exhibit exponential growth¹. This problem can only be solved by considering a different mathematical description altogether. We propose that the profile be described by:

$$P = he^{-r(t-c)} \left(1 - \frac{1}{1 + e^{l(t-c)}} \right), \quad (2)$$

where P is the number of citations received in year t (or other time interval) after publication. c gives an indication of when the publication starts being cited. So called ‘Sleeping Beauties’² will have a large c . l relates to the rate at which the profile increases at first. h relates to the maximum height the profile will reach. Finally r relates to the rate of decrease after the maximum³.

Figure 2 shows what this profile looks like for arbitrary parameters. The curve displays the initial exponential growth followed by exponential decay in citation frequency that we have observed in the data. This model can be fit automatically to the citation data of all publications individually, using a non-linear least squares method, provided that there is citation data for at least 4 time intervals (years) and there is a reasonable number of citations in total.

Figure 2 Illustration of the shape of Eq. 2 that we propose as profiles for types 1 through 3.



Applications

Once we have the mathematical form of the citation profile, we can identify certain points of interest that would be hard to identify on the original data. Figure 3 shows some points of interest. The most obvious is the maximum. While the maximum number of citations that a publication receives in one year in itself is arguably of little importance, the age of the publication when it reaches this maximum is important since it indicates a level of impact maturity. The maximum can be found analytically by finding the point where the gradient is zero. The age at this point is the root of the derivative of the profile equation and is given by:

$$t = \frac{lc + \ln\left(\frac{l-r}{r}\right)}{l}. \quad (3)$$

This root can only be found if $\frac{l-r}{l} > 0$. If this is not the case it indicates one of 3 situations:

¹ This exponential growth is present for curves of type 5, but we are more interested in types 1 to 3, which should also exhibit initial exponential growth.

² Introduced by van Raan (2004).

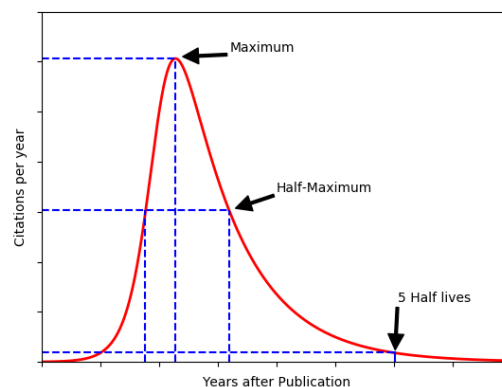
³ While these are the general effects of these parameters, they are inextricably linked and changing just one parameter will affect the entire curve.

1. The citation frequency in the original data is still growing i.e. *Genial Work*.
2. The citation frequency has plateaued i.e. it reached a maximum and receives the same number of citations every year.
3. There are too few citations in total for the profile to be reliable.

Case 3) should be easily avoided by changing the lower limit of total citations required before being profiled. These publications have a negligible effect on large scale citation based bibliometric studies. Case 2) is arguably a variant of case 1). While *Genial Work* is not the focus of this paper, it is clear that the profile can be used to identify such works.

Two further points of interest would be the points of half maximum on either side of the maximum. These are the points on the curve where the number of citations are half of the maximum. Contained between these two points should be a large proportion of the total citations the publication will ever receive. The final point of interest on Fig. 3 is labelled as '5 Half Lives' and indicates the point at which the citations per year has decreased to $\frac{1}{2^5}$ of the maximum. At this point, any further citations will have a negligible effect on the total number of citations that the publication will ever receive. Therefore a comprehensive assessment of the value of a publication, as measured by citations received, can only be done once it has reached this point of '5 Half Lives'. Of course this is usually many years after publication and is therefore impractical when citation analysis is used as a tool to assess the performance of individuals, departments, institutions etc. A good compromise would be the right-hand side Half-Maximum, although even this can be impractical. We propose that a publication should at least have time to mature to the point where its profile reaches its maximum before an assessment of its value be made. We will look at the size of citation windows necessary to ensure that a large proportion of publications in a field have reached this maximum in the Results section.

Figure 3 Citation profile with points of interest indicated.



Goodness of fit

Measuring the 'goodness of fit' of this model is complicated by the fact that it is a non-linear model and the fact that any 'goodness of fit' measure should be scale invariant. Since the profile is used as a proxy for the number of citations received per year, we have decided that the best way to test 'goodness of fit' is to compare the integral of the profile over the period ($\int P$), for which we have data, with the total number of citations actually received ($\sum P$). More precisely, we will use the percentage difference between $\int P$ and $\sum P$ as our 'goodness of fit' measure.

Results

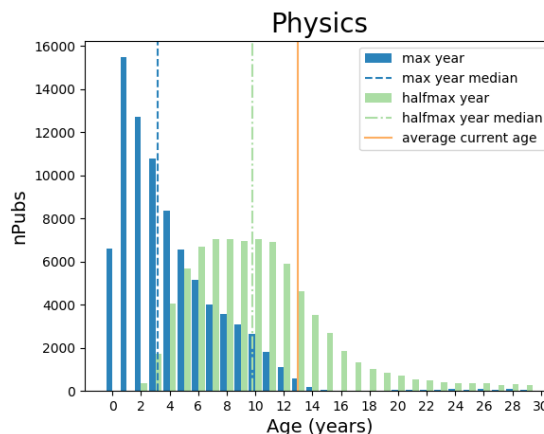
We used citation data from the Web of Science (WoS), counting all citations up to 2016, and we used the WoS field classification system. For this study we have chosen not to exclude self-citations due to the difficulties in accurately identifying them, but this is something we will look at in the future. We fit the profile in Eq. 2 to all publications up to a publication year of 2012.

First we will discuss the results for the field of Physics. Table 1 gives some aggregate information about all the publications in Physics, published between 2001 and 2005, and the citations they received up to 2016. Of the 618 159 publications, the profiles of only 93 942 will be used during the rest of this study. This may seem like a small fraction, but those publications received nearly two thirds of all the citations. For this study we have chosen (somewhat arbitrarily) a maximum percentage difference between $\int P$ and $\sum P$ of 10%. The number of publications listed as ‘Not Good Fit’ are the ones where this difference is more than 10%. Only publications that have received at least 20 citations across 4 years were profiled. Henceforth we shall refer only to profiles instead of publications.

Table 1 Breakdown of publications in Physics, published between 2001 and 2005, showing the numbers of publications whose profiles are used and numbers not used along with their reason. The total numbers of citations received by those publications until 2016 are also shown.

	n Publications	n Citations
Total	618 159	12 481 339
Profile Used	93 942	8 040 628
Not Good Fit	63 815	2 065 341
Too few years	262 685	340 108
Too few citations	197 717	2 035 262

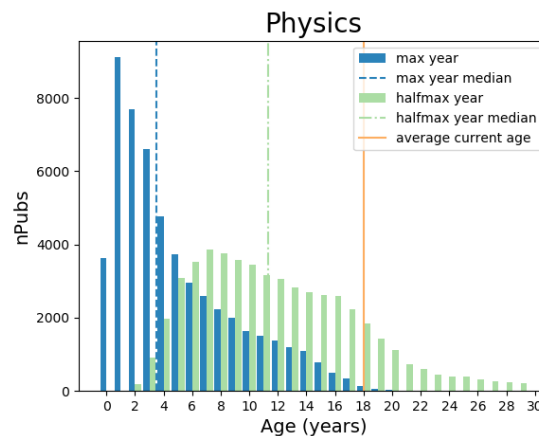
Figure 4 Histogram of the number of profiles that reach their maximum at a specific age, in years, for profiles in Physics with a publication year between 2001 and 2005. The number of profiles reaching their right-hand side half-maximum is also shown. The solid vertical line indicates the average age at the time the data collection is halted. The dashed lines indicate the median age for profiles to reach their maximum and right-hand side half-maximum.



We can now use these profiles to investigate the validity of different lengths of citation windows. Figure 4 shows how quickly profiles in the field of Physics reach their maximum and their right-hand side half-maximum⁴. The most common age for reaching the maximum is at 1 year. After 3 years, half of the profiles have reached their maximum. Understandably it takes longer for the profiles to reach their half-maximum, with most of them reaching it somewhere between 6 and 11 years and the median being at 10 years. While Fig. 4 indicates that some profiles will only reach their half-maximum in the future, this kind of prediction is not the aim of this study and certainly not the purpose of these profiles.

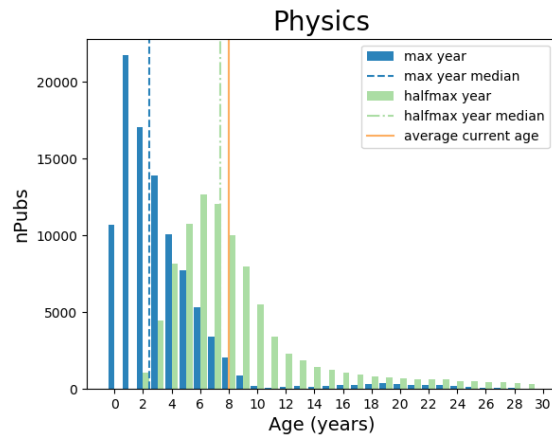
The next question we need to answer is whether the results obtained from the above period of 2001 to 2005 is relevant for any year of publication. Since fields change over time, the citation behaviour may change over time. Figures 5 and 6 show the same results as Fig. 4 but for the 5 years before and after. Figures 5 and 4 look very similar and Fig. 6 looks similar to the others for young ages but it has a faster drop off at later ages. This faster drop off is simply due to the lack of long term data since those publications range between 6 and 11 years of age. From this comparison, we can see that in the field of Physics, the time it takes for profiles to reach their maximum has not changed over this 15 year range. This allows us to use the results of these older publications to inform decisions regarding more recent publications.

Figure 5 Histogram of age at maximum for profiles in Physics between 1996 and 2000.



⁴ While it would be interesting to investigate the profiles based on their parameters instead of points of interest, this is a challenging task and outside the scope of this short paper.

Figure 6 Histogram of age at maximum for profiles in Physics between 2006 and 2010.

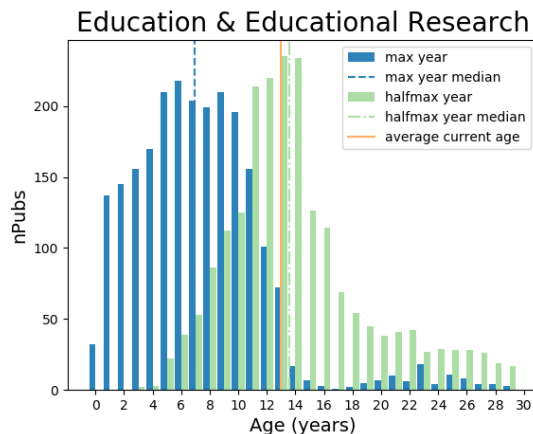


Now we will look at a similar analysis of a much slower moving field, Education & Educational Research. Once again we list the summary of publication and citation numbers in Table 2. In this field, the total citations of the profiles used constitute 256 106 out of the 612 320 received by the field as a whole. Figure 7 shows the histogram of the profile ages at their maximum and half maximum. In this field the age at maximum is much more spread out, peaking at 6 years. It takes 7 years for half the profiles to reach their maximum and 13 years for half of them to reach their half-maximum. In this case using a 2 year citation window would mean that very few profiles have reached their maximum and therefore their value cannot be fairly assessed, much less compared to profiles in Physics that age much faster.

Table 2 Breakdown of publications in Education & Educational Research, published between 2001 and 2005.

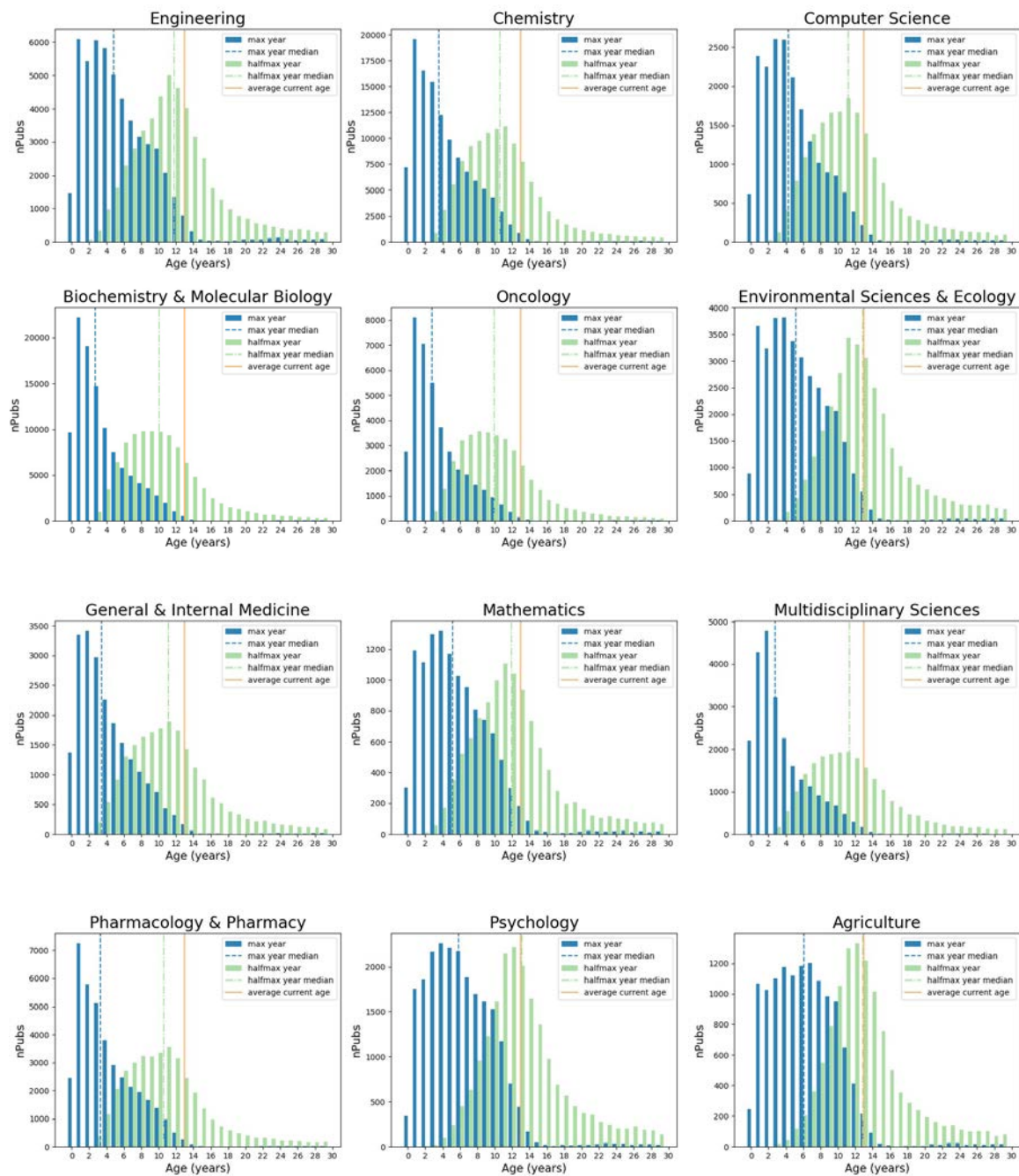
	n Publications	n Citations
Total	59 303	612 320
Profile Used	3 202	256 106
Not Good Fit	5 212	196 992
Too few years	37 214	25 070
Too few citations	13 675	134 152

Figure 7 Histogram of the age at maximum and age at half-maximum for Education & Educational Research between 2001 and 2005.



Finally we present the histograms for a few other fields in Fig. 8.

Figure 8 Age at maximum and right-hand side half-maximum for more fields.



Discussion

In this paper we investigated using the citation profiles of individual publications to draw conclusions on the validity of citation windows, rather than using the citation profile of an entire journal or field. Wang (2013) p.865 shows the citation profile of various large fields in the WoS. Their results for ‘2000 cohort’ should be comparable to our result in Fig. 8.

According to Wang (2013), it takes roughly 10 years for most of the fields to reach their peak, but according to our Fig. 8, most publications reach their own peak earlier. This indicates that, when considering the journal as a whole, the *Genial Works* are overshadowing the *Basic Recognized Work* in the long run. We have found that while a 2-year citation window is

definitely too short for acceptable comparison between publications, even in the fastest ageing fields, it is not quite necessary to wait 10 years. We have also found that the ageing of *Basic Recognized Work* has not changed substantially between 1995 and 2010 in the field of Physics.

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