Five years of S-shaped citation patterns

The growth of citations to published content typically follows an S-shaped curve. We look back at the fairly homogeneous citation-growth patterns — and at the few exceptions to them — for the content that we published in 2017.

Papers rack up citations — first slowly, and then rapidly. Eventually, the growth slows to a trickle. This general trend of how citations to a piece of work accrue can be described by a sigmoid (or logistic) function — that is, an S-shaped curve. In fact, S curves can reasonably describe many natural phenomena, as well as human-driven activities, involving slow–fast–slow patterns (for example, tumour growth, the kinetics of many reactions, a project's progress, the adoption of technology, and the spread of information[1]).

Of course, the rates at which individual articles gather citations over time — and thus the actual shape and height of the corresponding S-shaped curve — can differ significantly. Papers with a larger natural audience — because they are particularly interdisciplinary or because they belong to large or 'hot' fields of research — will accrue citations at faster rates than articles with narrower implications or whose results are mostly relevant to a niche community.

Yet, how heterogeneous are the actual shapes of the citation curves for papers from different disciplines and fields of research? And how big is the fraction of papers with citation records that do not follow the typical sigmoid pattern? According to the brief history of the papers that *Nature Biomedical Engineering* published in its launch year, the answers are unexciting. The growth of citations to articles published in 2017 shows expected variabilities in citation growth (Fig. 1, left; the inset makes the beginning of the expected S-shaped curves visually apparent), and the patterns in annualized growth in citations are, perhaps unexpectedly, rather homogeneous (Fig. 1, right) — for about 80% of them (63 out of

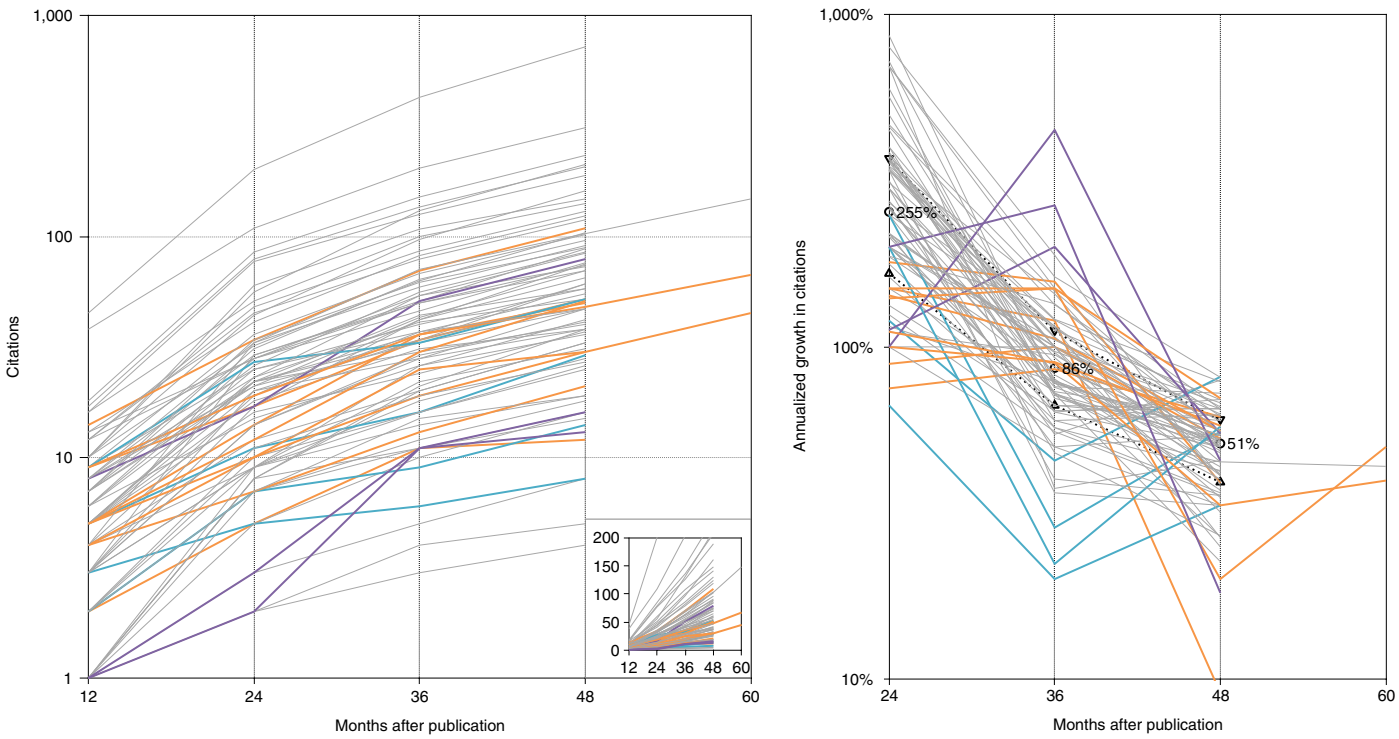

Fig. 1 | Citations, and annualized citation growth rates, to content published in *Nature Biomedical Engineering* in 2017. For every article, citation data are graphed at 12-month intervals after the article's publication (left panel). Sixty-month citation data are only available for the three articles that were published shortly in advance of the journal's launch in January 2017. The inset shows the same data on a linear vertical axis. Citation growth rates (right panel) are annualized — that is, they represent the growth in citations over the previous 12-month time point. Coloured lines highlight articles with atypical citation patterns: purple for articles that accrued citations faster in the second year than in the first year ('sleeping beauties'); orange for articles with similar levels of citation growth in the first two years after publication ('shooting stars'); and blue for articles that accrued citations slower in the second year and for which citation growth picked up in the third year ('late bloomers'). For the data on annualized growth in citations, the circles and triangles (joined by dotted lines as a guide to the eye) indicate the median and interquartile values at months 24, 36 and 48. Citation data were retrieved from Clarivate's Web of Science, and collected on the first day of each month. Individual articles were assigned to the following month if published after the 15th day of the month. Original research articles, Review articles, Perspectives and Comments are included (a total of 79 articles); Editorials and News & Views are not.

79 articles), large annualized growth rates in the second year after publication (with respect to the first year) are followed by smaller growth rates in the third and fourth years.

Looking at the few atypical patterns may be more exciting. Which papers accrued citations faster later than expected (the so-called 'sleeping beauties';[2] purple lines in Fig. 1), which ('shooting star') papers maintained their initial citation growth for longer (orange lines), and which ('late bloomer') articles (blue lines) had an unexpected bounce back from a steeper decline in citation growth rates? We did not find any clear patterns: the 16 articles with atypical citation trends (coloured lines) span disciplines, disease types and research emphases (strictly preclinical, translational, methodological, applicational and performance-based), are of varied content types (original research, commentary and scholarly reviews), and range widely in publication times (from December 2016 to December 2017), article views (from a few thousand to hundreds of thousands) and Altmetric scores (from 16 to over 1,000). Causes for the anomalous patterns may actually be mundane: probably due to chance; also, citations beget more citations; and, for articles that accumulate few citations, citation growth rates can be more prone to fluctuations, owing to variabilities arising from, for instance, publication timings and any errors and delays in the counting of citations.

Also, the five years of accumulated citations are 'early days'. The trends in the data in Fig. 1 suggest that double-digit annualized citation growth rates may persist for many more tens of months. In fact, four years after publication, citations to the articles published in 2017 grew by 51% on median (interquartile range, 39–60%). It may thus take a while for these papers to reach the top of their S-shaped curve of citations.

What can we gather from this analysis? The sigmoidal spread of information can be explained by a model that accounts for fast information flow through established 'long channels' of users of the information and for the slow spread from them to new users[1]. For scientific articles, the 'established users' would mostly correspond to the article's natural readers. We hope that the data in Fig. 1 reflect that the broader audience of *Nature Biomedical Engineering* is helping to diffuse the published interdisciplinary findings farther and wider. ❐

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