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Research Paper

A novel indicator h^* to measure research efficiency and identify researchers facing challenges: Application to engineering sciences

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ABSTRACT

The classical h index is a widely used metric to evaluate a researcher's scientific impact by combining productivity and citation counts. However, its main limitation lies in its cumulative nature. Indeed, the h index never decreases, which can mask recent changes in research activity or productivity, especially in late career stages, post retirement or when researchers stop publishing and contributing to scientific work due to administrative responsibilities, a focus on teaching, exclusion from research teams or a deliberate career transition away from research. This can lead to biased comparisons between junior and senior researchers, failing to reflect current research dynamics. To address these issues, this paper proposes a new metric, the h^* index, which extends the classical h index by incorporating temporal elements of a researcher career. The h^* index considers active publication periods and citation rates relative to career length, making it a dynamic and updatable indicator. This allows for early detection of declining productivity, thematic isolation or shifts toward non research duties, providing a more nuanced and fair assessment of scientific performance. Moreover, given that some countries, including France, hesitate to rely solely on traditional bibliometric indices, the h^* index offers a complementary tool designed for continuous career monitoring. By combining robustness and adaptability, this new metric aims to better support research evaluation and management decisions in academic institutions.

Preamble: *The h index values for all the researchers considered in this study were taken from the Scopus website (Elsevier, 2025). Since these values represent the current index h at the time of data collection, only the latest h index was used in the analysis and not its evolution over time (except for some specific cases). The authors can improve the dynamic measurement by including the historical index values h if they have access to it, which would provide a more detailed view of their career path. Most of the researchers considered in this study work in French universities, although there are a few exceptions. For ethical reasons, the names of all researchers are not disclosed to avoid putting individuals in difficulty or in the spotlight. It is also well known that some people try to cheat the metrics by using too many self-citations or by adding their name to publications from research groups without making a real contribution, to artificially increase their h index. This point was also discussed in Gao et al. (2023). However, it would be unfair to dismiss all metric-based evaluations due to such cases. These practices are rare and easy to detect and should not overshadow the usefulness of well-applied dynamic indicators.*

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1. Introduction

The classical h index is widely used to quantify the scientific impact of a researcher over the course of their career. It is defined as the maximum number h in which the researcher has published h papers, each cited at least h times. Starting from zero at the beginning of a career, the h index typically increases or remains stable over time, reflecting cumulative achievements as reported in Liu and Yang (2014). However, as illustrated in Fig. 1, the h index can never decrease once a researcher has reached a certain level, the index remains constant or grows, even if the researcher stops publishing or actively participating in research activities. This characteristic limits the ability of the index h index to reflect changes in research productivity or impact.

The h index was introduced in 2005 by Jorge E. Hirsch (Hirsch, 2005), a physicist at the University of California, San Diego, as a simple but powerful metric to quantify the scientific output and impact of an individual researcher. Hirsch's motivation was to combine both productivity (number of publications) and impact (number of citations) into a single number, thus avoiding the pitfalls of metrics that consider only one dimension. In addition to the classical h index, several platforms provide complementary or alternative metrics to capture different aspects of scientific impact. Google Scholar offers an h index alongside an i10-index, which counts the number of publications with at least ten citations (Scholar, 2025). ResearchGate introduces metrics such as the RG Score, reflecting a combination of publication impact, engagement, and networking (ResearchGate, 2025). The Web of Science calculates an h index limited to indexed journals and provides field normalized indicators such as the Field Weighted Citation Impact (FWCI) (Analytics, 2025). These tools attempt to address some of the limitations of the classical h index limitations by incorporating recent activity, field normalization, or social engagement; however, they do not fully account for the temporal dynamics of a researcher career.

The h index increases over time as more publications and citations accumulate, making it a robust and intuitive indicator for research evaluation. This ease of interpretation led to its rapid adoption across academia, funding agencies and institutional assessments. However, the h index has faced criticism for several intrinsic limitations. It does not consider the career length or age of the researcher, fails to adjust for disciplinary citation practices, ignores the uneven distribution of citations among publications and cannot capture recent changes in research activity or productivity.

Despite these shortcomings, the h index remains one of the most recognized and widely used bibliometric indicators worldwide. Its simplicity and focus on combining productivity and impact continue to make it a useful tool for evaluating scientific careers. The situation becomes paradoxical during retirement, or for researchers who are not publishing and stop scientific activities, since the classical h index remains constant or may even slightly increase over time despite the absence of new publications. This increase occurs when previous work continues to be cited, reflecting the lasting impact of a researcher contributions.

Hence, the h index serves as a measure of recognition of the work of a researcher at the end of their career or even posthumously. However, a major limitation of the classical h index is its inability to take into account the active years of a researcher when comparing individuals. For example, during project evaluations, comparing the h index of a junior researcher with that of a senior researcher inherently favors the latter, even if the junior researcher demonstrates stronger current scientific productivity and momentum. This bias arises because the h index accumulates over time and never decreases as reported in Schreiber (2015), regardless of recent activity or productivity. Relying solely on the h index in such comparisons can therefore lead to misleading or unfair conclusions. The metric lacks objectivity in these contexts, as it does not adequately capture differences in career stage, research dynamics, or recent contributions.This underlines the need for more nuanced indicators that incorporate indexes such as career length, publication activity, and citation rates, providing a clearer and more objective evaluation of scientific impact. In conclusion, several variants of the h index have been proposed to address its limitations, such as ignoring time and publication regularity.

Several previous works have attempted to incorporate temporal aspects into the h-index. The m index (or m quotient), defined as h/n where n represents career years since first publication, was originally proposed by Hirsch (2005) to normalize for career length. Subsequent developments include the contemporary h-index by Sidiropoulos et al. (2007), which weights recent publications more

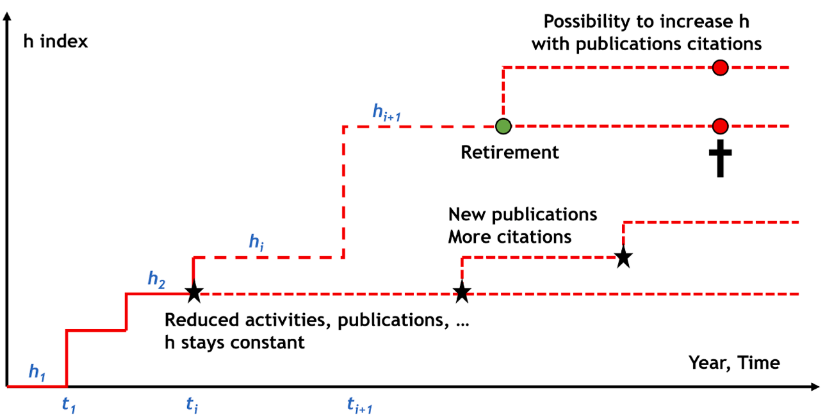


Fig. 1. Possible evolutions of the h index with academic years.

heavily, and the AR index by Jin et al. (2007), which incorporates publication age. Bornmann et al. (2008) systematically compared age-dependent h-index variants, while Burrell (2007) proposed a stochastic model for h-index growth over time. More recently, Bihari et al. (2023) provided a comprehensive review of h index variants, including temporal adaptations. However, these approaches typically focus on single aspects of temporal dynamics either career length, recent impact, or publication age without integrating publication regularity, citation intensity, and career stage simultaneously. This represents a significant gap in the bibliometric literature that the h^* index aims to address through its multi-dimensional temporal framework.

In response to these limitations, the h^* index is proposed as a new indicator designed to measure research efficiency and recent scientific momentum. Unlike the classical h index, which reflects cumulative lifetime achievement, h^* captures the dynamic balance between current productivity, citation impact, and career stage. This provides a more nuanced assessment of a researcher ongoing engagement and trajectory, making it particularly valuable for detecting changes in research activity over time.

Furthermore, the h^* index incorporates citation rates relative to career length, allowing it to reflect not only the quantity but also the quality and current relevance of a researcher output. This makes it a dynamic and updatable tool, capable of serving as an early warning indicator to detect potential challenges such as declining output, thematic isolation, or shifts toward non research responsibilities like administrative or teaching duties. By periodically reviewing h^*, institutions and research teams can quickly identify changes and take some decisions to support researchers with difficulties.

Additionally, the motivation for proposing the h^* index also comes from the fact that some countries, including France, prefer not to rely solely on traditional bibliometric indicators such as the classical h index for research evaluation.

It is important to emphasize that while the French evaluation framework provides a concrete case study with its standardized two-year publication intervals, the h^* index is designed as a universal tool adaptable to any national research system. The French context serves as a standardized test case that enables objective comparison and validation of the method. The parameterized design, particularly through the adjustable coefficients α and β, allows institutions worldwide to calibrate the indicator according to their specific evaluation cultures, publication expectations, and disciplinary norms. This flexibility ensures that the h^* index can be effectively implemented across different research environments while maintaining its core dynamic assessment principles.

This highlights the need for more dynamic and adaptable tools that better reflect how scientific careers change over time. The h^* index is thus intended as a complementary and flexible metric.

1.1. Scopus benchmark integrated in the motivation of the study

Several complementary bibliometric indicators have been proposed in the literature to address some of the limitations of the classical h index, particularly regarding citation distribution, publication impact, and career duration (Alonso et al., 2009; Bihari et al., 2023; Bornmann et al., 2011; dos Santos Rubem & de Moura, 2015; Huang & Chi, 2010; Kaptay, 2020; Norris & Oppenheim, 2010; Schreiber et al., 2012; Tol, 2009). These alternative indicators provide additional perspectives for evaluating scientific activity and may contribute to a more dynamic interpretation of research trajectories.

Among these quantities, the classical h index remains the most widely used cumulative indicator of scientific productivity and citation impact, and is defined as:

$$h = \max\{k : c_k \geq k\}, \tag{1}$$

where c_k denotes the citation count of the kth ranked publication.

Additional indicators may also be considered to complement the interpretation of the h index. For example, the h^2_{upper} component evaluates the proportion of excess citations accumulated within the h-core and is expressed as:

$$h^2_{\text{upper}} = 100\,\frac{C_h - h^2}{C_{\text{tot}}}, \tag{2}$$

where C_h represents the total number of citations inside the h-core and C_{tot} is the total number of citations associated with the considered publication profile. This quantity provides information about citation concentration beyond the minimal h-core threshold.

Another complementary quantity is the Platinum H-index, defined as:

$$PlatinumH = \frac{h}{T} \cdot \frac{C_{\text{tot}}}{N}, \tag{3}$$

where N is the total number of indexed publications and T corresponds to the academic career length expressed in years. This indicator combines cumulative impact, publication productivity, and career duration into a normalized bibliometric quantity. These alternative formulations illustrate the growing interest in developing indicators capable of incorporating temporal evolution, citation intensity, and publication regularity into research evaluation frameworks. In this context, the proposed dynamic indicator h^*, introduced later in Eq. (4), aims to provide a complementary perspective by integrating several of these dynamic aspects within a unified formulation.

2. Proposed dynamic adaptation of the *h* index

2.1. Rationale for the h^* formula

The h^* index is designed to reflect not only cumulative achievement but also recent productivity and impact. Its formulation combines several dimensions:

- **Publication regularity**: The ratio $\frac{P}{R}$ rewards researchers who maintain consistent output over two-year intervals, aligning with evaluation practices that value sustained activity.
- **Citation intensity**: The term $\frac{C}{T}$ normalizes the total citations by career length, emphasizing efficiency rather than mere accumulation.
- **Adjustment of career length**: The factor $\frac{1}{\sqrt{T}}$ introduces a mild penalty for long careers with low recent output, ensuring that senior researchers must maintain activity to maintain high values h^*.
- **Flexibility**: Exponents α and β allow institutions to weight the publication continuity and citation rate according to local priorities, with default values $\alpha = \beta = 1$ providing a balanced approach.

The formula uses multiplication (rather than addition) so that all factors work together. The proposed functional form is motivated by the construction of a composite and interpretable indicator rather than by empirical curve fitting. Each term in h^* represents a distinct and independently meaningful dimension of research activity, namely productivity, citation impact, continuity, and career duration.

The multiplicative structure is intentionally chosen to ensure a balanced interaction between these components, preventing full compensation between dimensions and thereby preserving sensitivity to weaknesses in any single aspect. Such multiplicative aggregation schemes are commonly used in composite performance indicators in scientometrics and related evaluation frameworks, as they provide a coherent way to combine heterogeneous but complementary variables while maintaining interpretability.

2.2. Mathematical definition of the h^* index

The new h index, previously introduced as h^*, is defined as follows, Eq. (4). It enables evaluation of a researcher efficiency and can also detect difficulties discussed previously, issues, or shifts in focus such as increased administrative or pedagogical commitments.

$$h^*(t) = h \times \left(\frac{P}{R}\right)^{\alpha} \times \left(\frac{C}{T}\right)^{\beta} \times \frac{1}{\sqrt{T}} \tag{4}$$

Each component of the formula Eq. (4) reflects an important aspect of the researcher profile:

- h: the classical h-index, which serves as a fundamental measure of scientific impact (Hirsch, 2005),
- C: total cumulative citations, reflecting overall recognition of the researcher's work,
- T: career length in years, providing a temporal framework for the evaluation,
- $R = \left\lfloor \frac{T}{2} \right\rfloor$: total number of two-year intervals within the career,
- P: number of active two-year intervals with at least one publication, capture research continuity (French recommendation),
- α, β: adjustable parameters that allow fine-tuning of the metric's sensitivity to research activity and citation impact,
- $\frac{1}{\sqrt{T}}$: a penalty index accounting for the influence of career duration on productivity and impact.

Although the final value of h^* is the same regardless of the order of publications and citations, the year-by-year trajectory is directly affected by this ordering, highlighting periods of higher or lower research efficiency and providing a temporal perspective that static indices cannot capture, the following picture is reporting the values of h^* by year changing the data order, Fig. 2.

The exponents α and β allow optional calibration to disciplinary norms, making h^* adaptable to differences in typical productivity and citation patterns across fields, while preserving its theoretical grounding, interpretability, and robustness. This formulation combines productivity (P), impact (C), and career length (T) in a multiplicative way, with the concave normalization $1/\sqrt{T}$ ensuring that early-career researchers are not over-penalized while still accounting for career progression, making h^* a robust measure of research efficiency across disciplines and career stages. The comparison between $1/T$ and $1/\sqrt{T}$ is reported in Fig. 3.

2.3. Temporal evolution and derivative of the h^* index

The second equation related to the rate, Eq. (5), must be considered to analyze the researcher career in time. It is important to consider both h^* and its rate of change over time, Eq. (5). The rate of change shows how fast h^* is increasing or decreasing, which helps us to see the trends more clearly. Even small changes are easier to notice by looking at the rate of change than by just looking at the h^* curve. This makes the rate of change a useful tool for understanding if things are getting better or worse.

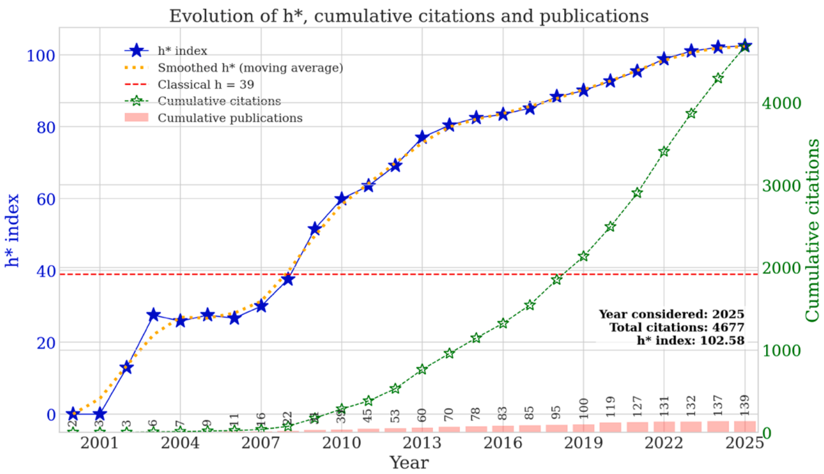
$$\frac{dh^*(t)}{dt} = h^*_{\text{rate}}(t) \tag{5}$$

To calculate the derivative, the following procedure is used. First, the smoothed derivative of h^* is computed by applying a centered moving average over a window of $w = 3$ years to be more representative of the original curve, Eq. (6).

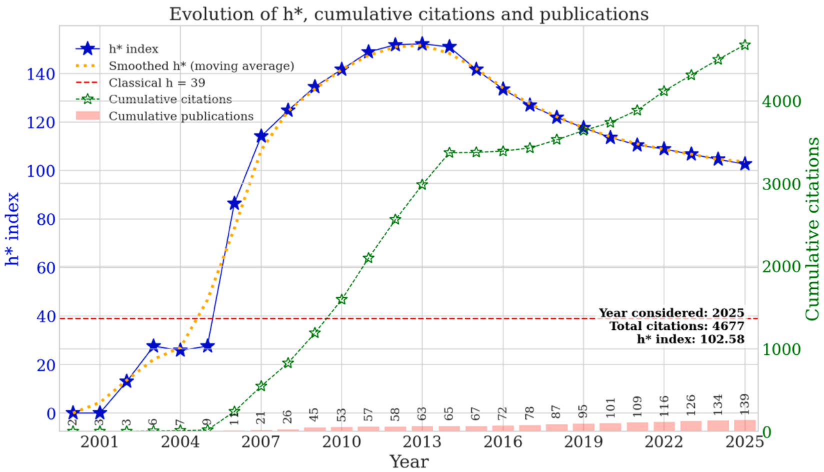
$$h^*_{\text{smooth}}(t) = \frac{h^*(t-1) + h^*(t) + h^*(t+1)}{3} \tag{6}$$

Then, the smoothed derivative is obtained as Eq. (7)

$$\left.\frac{dh^*(t)}{dt}\right|_{\text{smooth}} \approx \frac{h^*_{\text{smooth}}(t) - h^*_{\text{smooth}}(t-1)}{\Delta t} \tag{7}$$



(a)



(b)

Fig. 2. Comparison of h* using the same input data but with different orderings: (a) original data for the considered case; (b) reordered differently, citations and number of papers by year.

where t is expressed in years and $\Delta t = 1$ in our study case.

Several scenarios can be identified and observed (cases 1, 2, and 3), as illustrated in Fig. 4 and dummyTXdummy-: as discussed in Gao et al. (2023) with several interesting points, such as early scientific impact, duration and intensity of scientific production, continuous positive growth throughout a researcher career, and the presence of atypical citation patterns. These observations align well with the relevance of the dynamic h^* indicator. In the first scenario, a researcher publishes consistently and receives steady citations, demonstrating ongoing quality and impact, and in this case the index h^* increases steadily over time. In the second scenario, the researcher continues to publish, but after some years, the h^* index stabilizes. This plateau may indicate fewer publications, a decline in citations, a reduced interest in the research topic, or changes in scientific trends. The final scenario describes an active researcher whose h^* index decreases after an initial rise, possibly due to fewer citations or a shift in focus toward non research activities like teaching or administrative duties, Fig. 4 . Because the h^* index is dynamic and can be updated regularly, early signs of decline provide valuable information. For example, if a researcher is engaged in a challenging or less relevant topic, this early warning allows for timely interventions, such as integrating the researcher into new teams or encouraging the exploration of complementary subjects to regain some activities. A loss of research dynamism may also result from isolation or personal difficulties that call for empathy and tailored support. In contrast, if these warnings are ignored by team leaders, institutional directors, or university presidents, the situation can worsen significantly (noted as problem 2 in Fig. 4, making recovery much harder. The responsibility for addressing such issues lies both with the researcher and with the leadership, highlighting the importance of proactive management.

In general, the h^* index serves not only as a metric but also as a predictive and diagnostic tool, enabling early detection of challenges and fostering a supportive environment for sustained research activity.

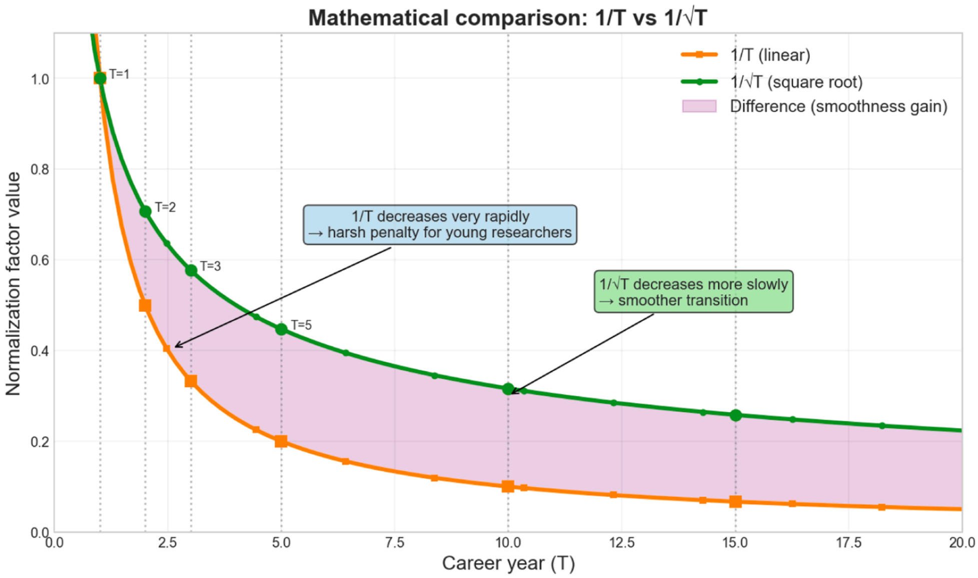


Fig. 3. Effect of $1/T$ and $1/\sqrt{T}$ for h* calculation along the year.

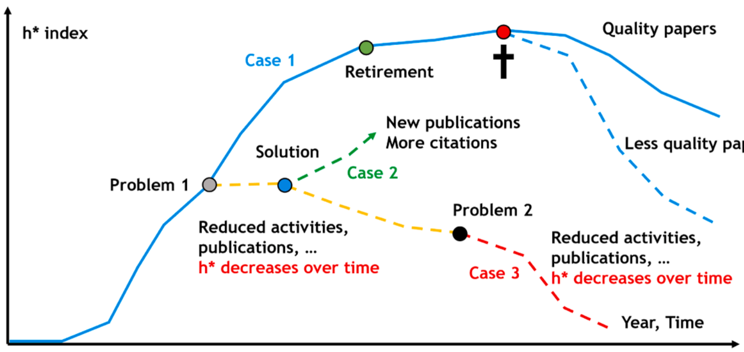


Fig. 4. Possible evolutions of the h^* index with academic years.

Table 1
Interpretation of the h^*/h ratio over time.

Ratio h^*/h	Interpretation
> 1	High efficiency, early productivity or strong impact relative to career length
≈ 1	Performance consistent with the standard h-index
< 1	Lower efficiency, periods of slow productivity or delayed citations

2.4. *Interpretation of the h^*/h ratio*

It is important to note that h^* values are not directly numerically comparable to classical h index values. While h reflects cumulative achievement, h^* measures research efficiency and momentum. Early career researchers in fast moving fields may achieve high h^* values through intensive publishing and rapid citation accumulation, even when their classical h index remains modest.

It should be noted that the ratio h^*/h can be greater than, equal to, or less than one over a research career, as shown in Table 1, reflecting the timing of productive periods and citation accumulation; this point is summarized in Table 1.

The proposed dynamic formulation can now be compared with classical and complementary bibliometric indicators before the detailed case interpretations are presented.

Table 2
Summary of bibliometric indicators used in the comparative framework, year considered 2026.

Profile	Case study reference h^*	N	C_{tot}	h	g	h_N	h^2_{upper} [%]	PlatinumH
Researcher-1	Fig. 6-a	156	5032	41	65	0.263	37.579	50.866
Researcher-2	Fig. 11-a	69	1736	25	40	0.362	45.507	21.689
Researcher-3	Fig. 21	35	676	14	25	0.400	59.320	13.520
Researcher-4	Fig. 14-a	275	5070	36	58	0.131	29.231	16.188
Researcher-5	Fig. 8a	4	48	4	4	1.000	66.667	4.364

Table 3
Comparison of career-length adjusted bibliometric indices.

Indicator	Description	Key characteristic
h/T	h divided by career length T	Static average, smooths all temporal variations
hIa (age-adjusted)	Similar to h/T	Age-normalized, equivalent to h/T in practice
Average h-index	h-index computed on citations per year per paper	Detects early potential but remains a static index
h* (our indicator)	$h^* = h \times \left(\frac{P}{0.5T}\right)^{\alpha} \times \left(\frac{C}{T}\right)^{\beta} \times \frac{1}{\sqrt{T}}$ with α, β adjustable parameters	Dynamic trajectory, sensitive to publication gaps and recovery phases, customizable weighting

3. Comparative analysis of classical and dynamic bibliometric indicators

3.1. Classical and complementary bibliometric indicators

This section provides a comparative analysis of the classical h index, its complementary variants, and the proposed dynamic indicator h^*. The objective is to illustrate how these indicators capture different and complementary aspects of scientific activity when observed through their temporal evolution.

Each indicator captures a different dimension of scientific activity. The classical $h(y)$ index reflects cumulative growth of the h-core over time. The $h^2_{\text{upper}}(y)$ component provides information on citation distribution beyond the h-core threshold. The $PlatinumH(y)$ indicator introduces a normalization with respect to career length and publication volume. Finally, the proposed $h^*(y)$ index integrates temporal and structural dimensions of research activity within a unified dynamic framework.

A compact summary of the corresponding bibliometric quantities is reported in Table 2, which provides a static overview of the different indicators considered in this study.

3.2. Comparison between h, h^2_{upper}, PlatinumH, and h^*

The comparison is based on four bibliometric trajectories corresponding to $h(y)$, $h^2_{\text{upper}}(y)$, $PlatinumH(y)$, and $h^*(y)$, computed using the definitions introduced previously in Eqs. (1)–(3). The associated trajectories are illustrated in Fig. 5, where each panel highlights a different dimension of bibliometric evaluation. The profiles corresponding to Researcher-1, Researcher-3, and Researcher-4 are presented in Figs. 5(a), 7, and 13, respectively. The main advantage of the new proposed approach is that it can be computed at each time instant using only the publications and citations history. Another important feature is its coupling with the first derivative, which allows the detection of instantaneous increases or decreases in research activity, reflecting variations in both publication output and citation recognition. In contrast, the other indicators generally exhibit smoother behaviors, often characterized by monotonic growth or plateau effects, which limits their ability to capture short term variations in research dynamics.

3.3. Positioning of h^* relative to existing career-length adjusted indicators

To clarify the positioning of h^* relative to existing career-length adjusted indicators, Table 3 summarizes the main alternatives and highlights the distinctive features of the proposed index.

Overall, the proposed $h^*(y)$ indicator is not intended to replace existing bibliometric measures, but rather to complement them. This additional $h^*(y)$ perspective enhances the interpretation of research activity by explicitly accounting for its dynamic evolution over time.

4. Analysis of several cases and interpretations

Based on the following description and explanation of the h^* index, several cases will be examined to demonstrate how the h^* index reacts and exhibits different trends. The cases considered come from the field of Engineering Sciences, including Materials Science, which corresponds to section CNU 60 in France. The CNU (Conseil National des Universités) classifies academic disciplines for evaluation and recruitment purposes (Universités, 2025).

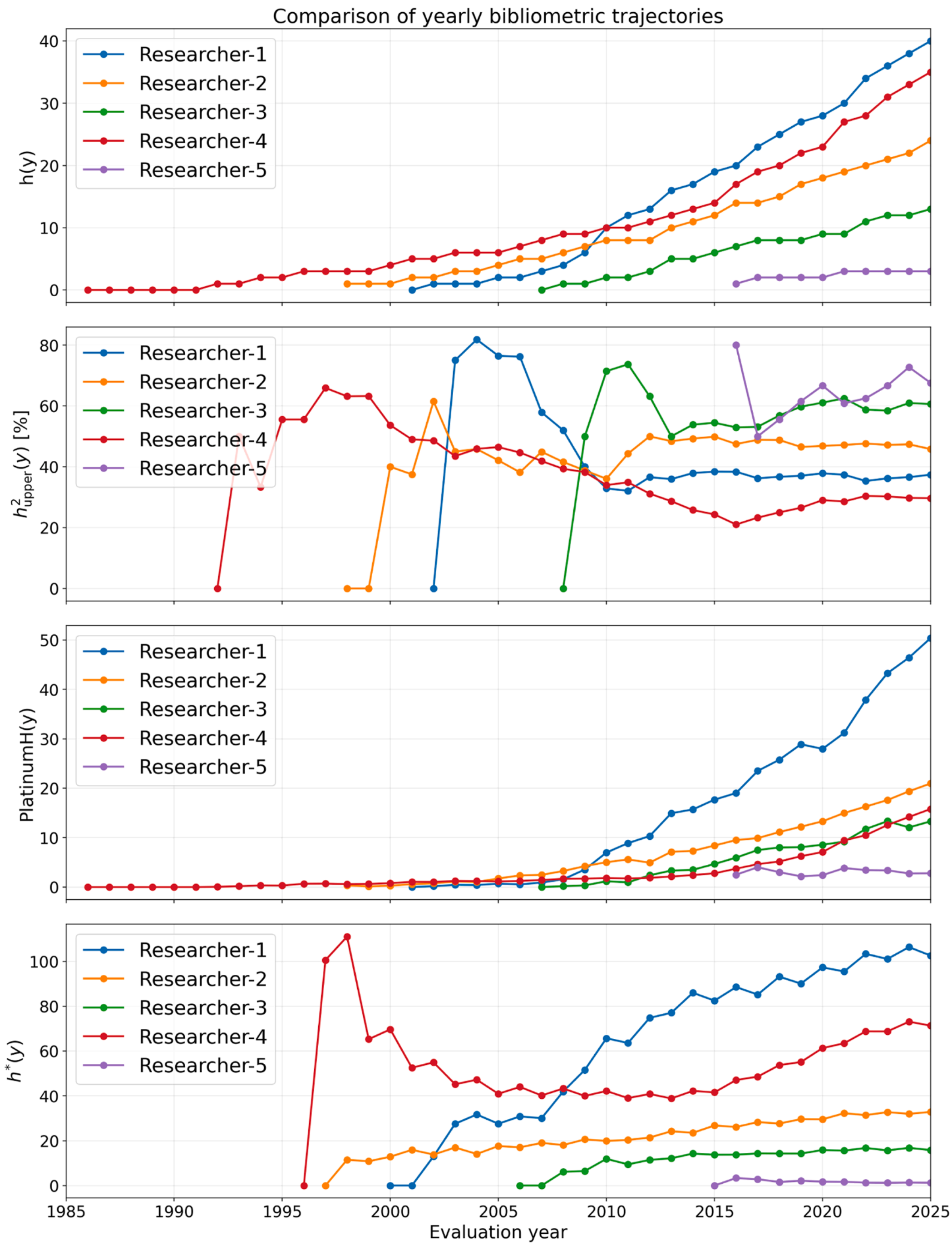


Fig. 5. Comparative evolution of $h(y)$, $h^2_{\text{upper}}(y)$, $PlatinumH(y)$, and $h^*(y)$ over time for the benchmark profiles.

The following cases illustrate how h^* responds to different career patterns in engineering sciences. While not constituting formal validation, these examples demonstrate the indicator sensitivity to changes in publication activity, citation rates, and career transitions

4.1. Interaction between publications and citations

The index h^* is influenced by two main components, the number of publications and the number of citations. These two elements can reinforce each other or compensate for each other over time. When a researcher is fully active, he usually publishes new work and receives citations for recent and past publications, leading to a steady or increasing h^* index. During retirement, the number of new publications often decreases, but citations from previous work may continue to maintain the level h^* for several years. In some cases, a high volume of citations can even compensate for a very low publication rate, Eq. (5), maintaining the h^* index almost constant. In contrast, if both the publication rate and the citation rate drop at the same time, the h^* index will decline more quickly. In the event of sudden discontinuation of publication, such as after the death of the researcher or voluntary end of academic work, the evolution of the h^* index depends entirely on the persistence of citations. If their past work continues to attract attention, the decline can be slow, indicating long term scientific influence. If citations also decrease rapidly, the h^* index will converge quickly to the classical h index, showing that the influence of the researcher was more dependent on the continuous publication activity. It is the same when a researcher artificially increases his h index by self citation. When the researcher stops publishing, the drop in terms of h^* is rapid. It should be noted that a researcher who relies heavily on self citation cannot maintain this strategy for many years, since it requires publishing new papers continuously and in large numbers each year. This decline is not visible with the classical h index, which always keeps its maximum value. Another important index is the total length of the active career. A long career generally allows for a larger publication base, creating more opportunities for citations to continue h^* after activity slows. Thus, h^* captures not only the balance between publications and citations but also how this balance evolves over time according to the length and timing of the career. It is also possible for a younger researcher, for example, at the age of 30 to 35 (in France, the average age to obtain a first permanent academic position as a *maître de conférences* is generally before the age of 33, which corresponds to a hiring age of around 28 to 30 years (Varoquaux, 2020), to have a higher h^* than an older colleague of 50 years. This may occur if the younger researcher publishes intensively in a short period and quickly attracts a high number of citations, especially in fast increase or in highly visible research areas. In contrast, an older researcher with a slower citation rate or publications in a niche field might have a lower h^* despite a longer career. This shows that h^* reflects the efficiency of research and recent impact, rather than only the cumulative output over a lifetime.

4.2. Active researchers with different career lengths

In the first case, Fig. 6-a, the researcher published his first paper in 2000. Naturally, citations were initially non existent and the h^* index was close to zero. However, from 2002, the h^* index began to grow steadily for a few years, followed by a plateau lasting approximately three years. This plateau may reflect a balance between the number of publications and the citations, maintaining a certain equilibrium. After this period, the h^* index resumed continuous growth. From 2007 to 2025, over 15 years, both the number of articles and the number of citations contributed to the increase in value h^*.

If we compare the first profile, Fig. 6-a, with that of a younger researcher who started his career five years later as assistant professor (Post-Doc 2004 to 2005, PhD in 2003), it is clear that the younger researcher demonstrates a much stronger dynamic since the beginning (Initiated during his PhD) and closely follows approximately the trajectory of the first researcher in terms of rate, Eq. (5). The average value dh^*/dt for these three cases is close to 2.5. The faster growth rate, Fig. 6-b, suggests that within the next decade, the younger researcher could reach or even exceed the same level of dynamism in terms of publications and scientific impact. The ten year age difference highlights the role of career stage. The slope of the h^* index appeared much earlier for the younger researcher, a trend clearly visible in the h^* curve. This underlines the importance of considering the researcher age and career starting point when interpreting such indicators. With the h^* index, it is possible to quickly identify strong candidates to reinforce research teams, develop new topics, or strengthen existing groups and teams.

In the last case, the researcher is the oldest and shows a certain dynamic with a nearly constant growth rate. His career started before 1998. It is clear that having such a long scientific career without a decline since 2003 in the h^* index requires a lot of effort and sacrifices. However, the impact and recognition are well established and are likely to continue for many years.

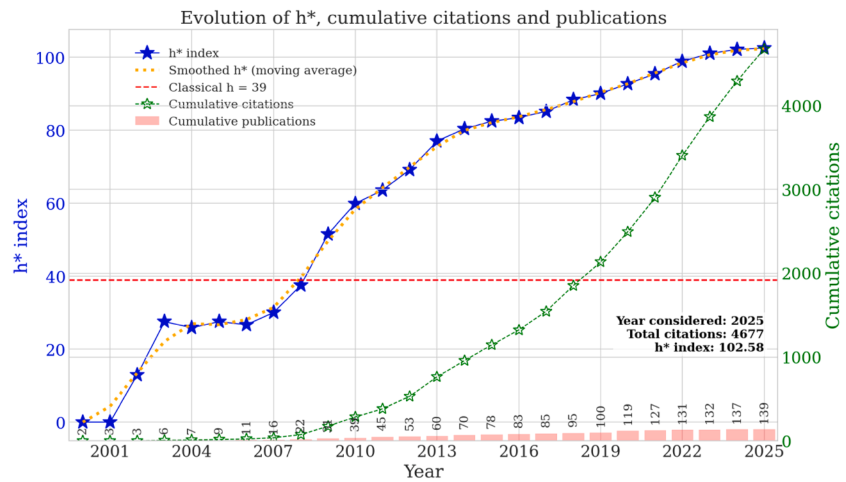
Thus, by having, for example, this reference point in Fig. 6-c, researchers can set clear scientific goals. Using the h^* index, they can monitor their progress and ensure that they are following the right dynamic and growth rate. It is also important to note that the h^* index starts to increase significantly after about 5 years of activity. In some cases, if the researcher has completed a post-doc or published several papers during his PhD, the growth can begin after only 2 years. These observations are consistent with Gao et al. (2023).

If we compare the h index and the h^* index, Fig. 7, for a researcher who publishes regularly and whose articles are cited, both measures h^* and h grow at almost the same rate. However, h^* can detect periods of stagnation or small decreases in dynamics. On average, the two indices remain parallel in their long term evolution, but h^* gives more details about short term variations. The number shown on the curve, Fig. 7-a indicates the year to year increase of the Hirsch h index.

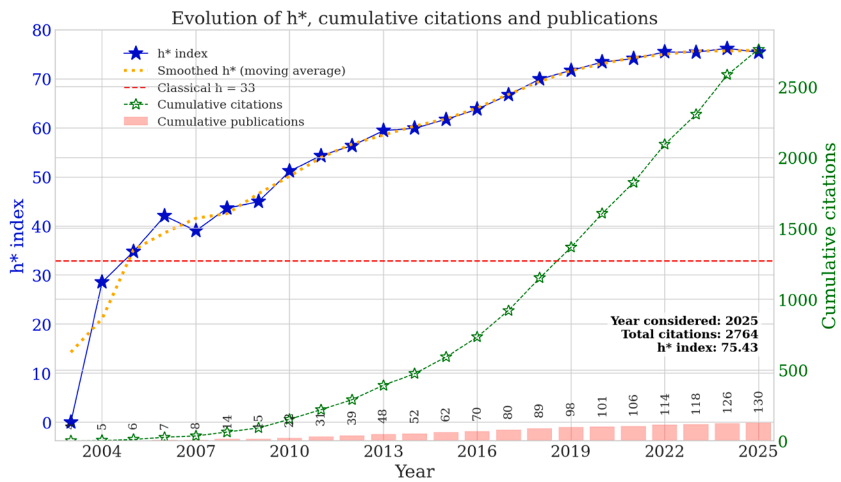
Readers can similarly visualize the yearly evolution of the traditional h-index alongside h* using the provided Python script (File: Extra file to plot h and h-star together with years.py), available as supplementary material, allowing direct comparison of their growth patterns over a researcher career.

4.3. Early stagnation and loss of scientific dynamics

In the following case, Fig. 8, the researcher published his first article in 2015, the index h^* increasing immediately in 2016. However, the coefficient then steadily decreased on average and quickly decreased. This trend indicates difficulties encountered by the researcher and serves as an early warning visible in the curves. Ideally, by 2019 at the latest, it would have been important to identify and address the reasons behind this loss of scientific productivity and recognition. It is likely that no effective action was taken, as the situation appears to have worsened over the following years, with the h^* index diverging sharply from the classical h



(a)



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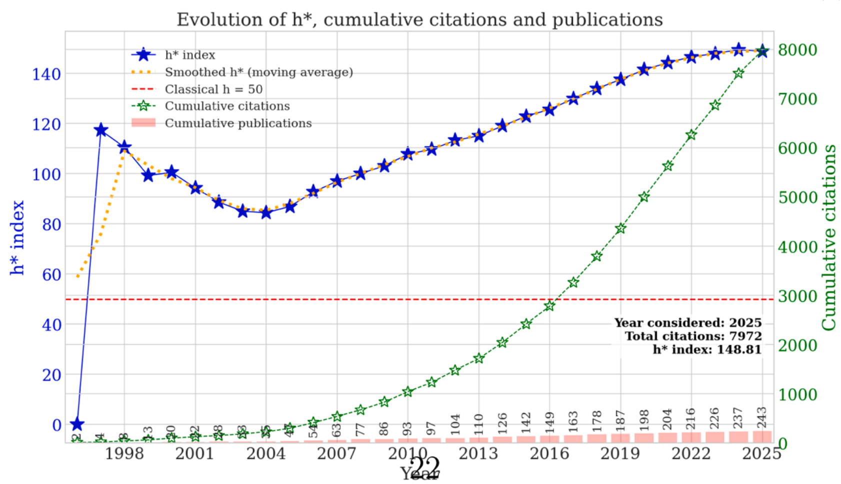

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Fig. 6. Evolution of h^* with academic years, a) Researcher with middle age (54 years old), b) The Youngest researcher considered (45 years old), c) The oldest researcher active (more than 65 years).

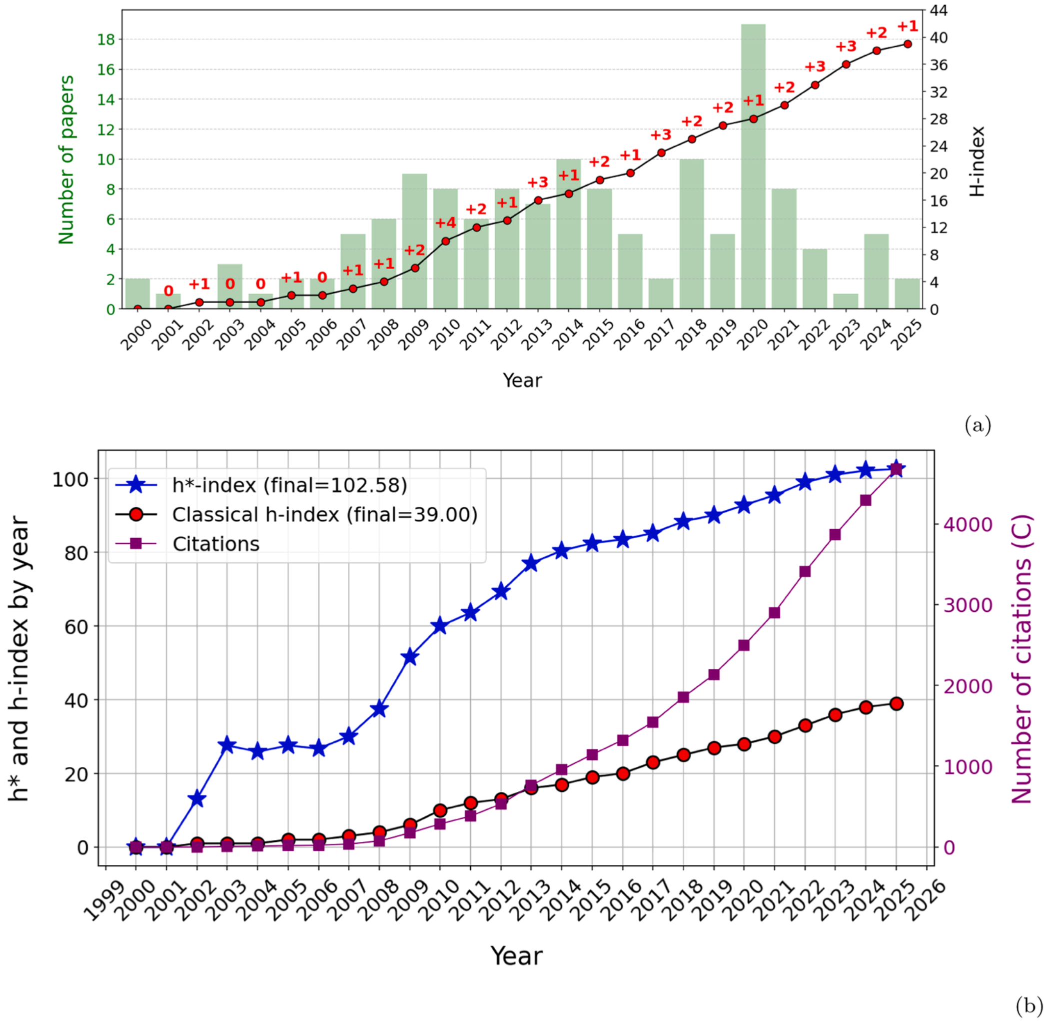


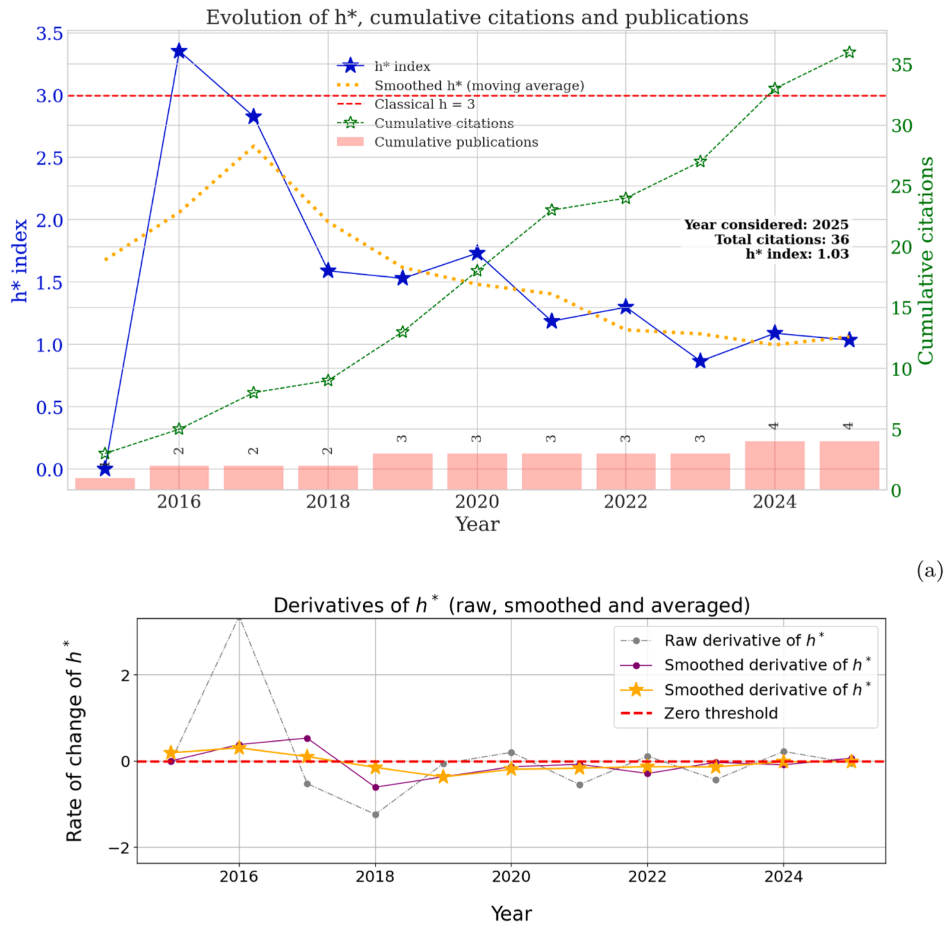
Fig. 7. Comparison of h index and h^* index using Fig. 6-a, curve rebuilt from data scopus, a) Publications by year and h index increase by academic year b) Comparison between h index and h* with years and citations number.

index. This decline is supported not only by the h^* metric, but also by the low number of publications and citations. Indeed, after 10 years of scientific activity, the researcher has only 5 publications, a total of 36 citations, and an h index of 3, indicating a very limited impact on the scientific community. Looking at the publication rate, the decrease in terms of publications and citations can be observed since the rate quickly tends to zero and oscillates around it, Fig. 8-b. Using the h^* index could have helped anticipate this problem earlier and potentially guided corrective actions in collaboration with the researcher. It is clear that drastically changing the situation now seems difficult and may be interpreted as a scientific career wasted.

In Fig. 9, a comparison is reported between the Hirsch index h and h^*. It is observed that even when publications stop, the h index does not go down, it only stays the same or grows. Because of this, the h index cannot show problems or slowdowns in a career. In contrast, h^* is dynamic and can react to changes over time. It can reveal periods of difficulty or lower impact that the h index would hide. Therefore, looking at a single, static indicator like the h index is not enough. A dynamic measure such as h^* gives a clearer and more timely picture of a researcher evolution.

Within this disciplinary framework, values of h^*/h greater than one are generally observed during periods where publication continuity and citation intensity are high relative to career length Fig. 7. Conversely, values below one tend to correspond to phases characterized by reduced publication activity, slower citation growth Fig. 9, or temporary shifts toward non-research responsibilities. Importantly, these ratios do not define normative thresholds, but reflect relative efficiency with respect to time and field-specific expectations.

This illustration demonstrates that, unlike the h index alone, the h^*/h ratio provides a dynamic and temporally sensitive perspective on research activity, allowing changes in efficiency to be identified within a given field without invoking cross-disciplinary comparisons.



(a)

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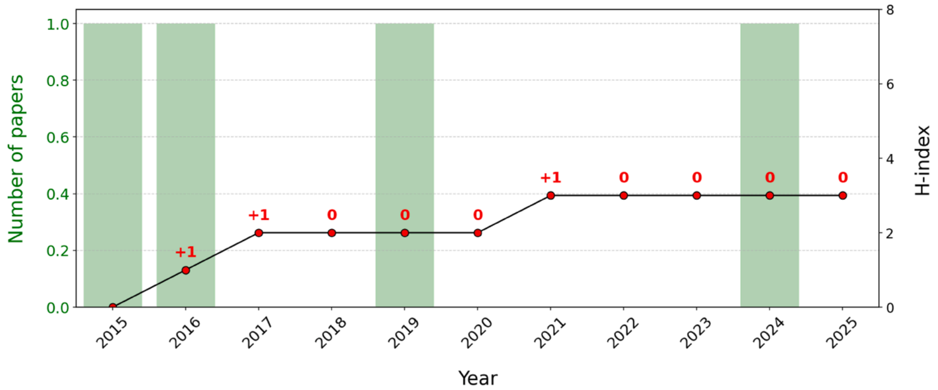
Fig. 8. Evolution of the index with administrative duties, a) Researcher with no publications increase b) Rate of h^* index on time.

4.4. Plateau effects and delayed scientific momentum

In this other case Fig. 10, a different pattern is presented. The researcher has been publishing regularly since 1998. However, a first plateau appears quite early, lasting from 2001 to 2007, followed by a slight increase leading to a second plateau from 2008 to 2015. These plateaus result from a balance between the number of publications and their relatively low impact, which creates an equilibrium in the h^* index. It can be assumed that the work has had a limited impact on the scientific community. Despite this, the researcher has continued his publication efforts, possibly exploring different topics, and then entered a dynamic phase from 2016 to the present, Fig. 10-b. This renewed momentum appears after approximately 18 years, indicating a significant period before the researcher found their stride, possibly due to initial misalignment with their research theme. However, a relatively low citation impact is observed, with a total of approximately 350 citations from 1998 to 2025 corresponding to 27 years (The researcher is certainly approaching the final stage of his academic career).

4.5. Continuous growth and sustained scientific impact

In this last specific case, Fig. 11, a constant growth of the h^* index, Eq. (5), is observed over the years, reflecting a regular and consistent scientific output alongside a proportional increase in citations. This scenario represents an ideal case, where the researcher not only publishes continuously but also maintains a certain scientific impact within the scientific community, Fig. 11-b. Such a profile suggests that the researcher consistently presents original and relevant work that attracts the interest of peers, fulfilling key criteria for both productivity and impact. The dynamic index h^* confirms ongoing influence and vitality in the researcher career. This case can thus be considered exemplary, illustrating how continuous innovation and engagement contribute to sustained scientific recognition. Despite this linear growth, using the time derivative shows a certain slowdown since 2021.



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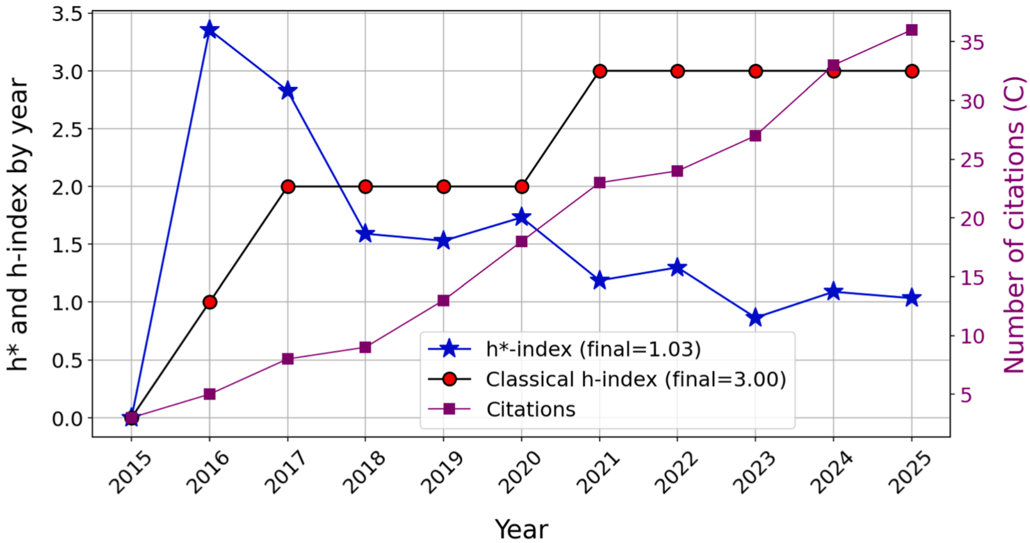

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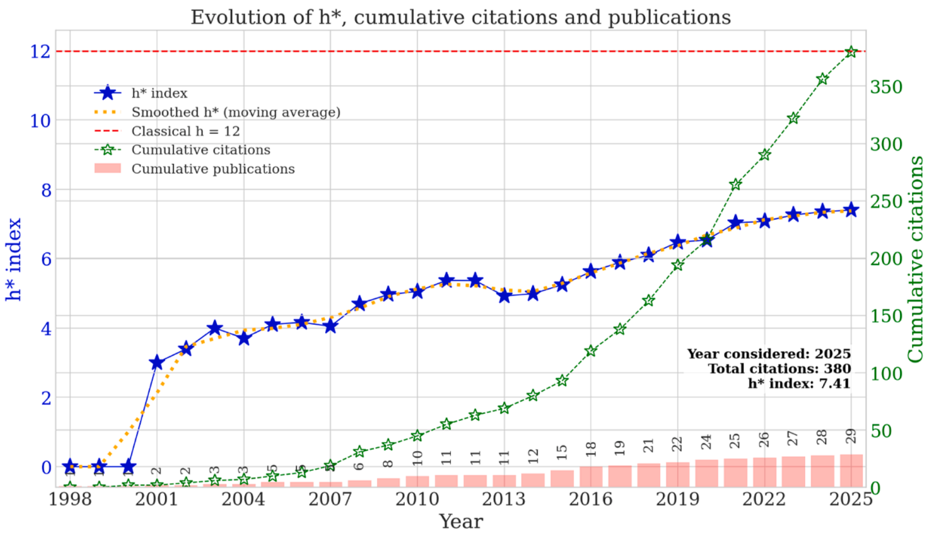
Fig. 9. Comparison of h index and h^* index using Fig. 8, a) Publications by year and h index increase by academic year b) Comparison between h index and h* with years and citations number.

Based on all cases considered, an important aspect of the proposed h^* index is its direct comparability to the classical h index. Since both share the same base unit and meaning, their numerical difference provides immediate insight into the dynamics of a researcher activity.

- $h^* > h$**:** This situation indicates that the researcher recent or actual performance, publication regularity, and citation rate are stronger than what the static h index will suggest. It often reflects an active phase with a consistent flow of impactful publications and a healthy citation rate. Such cases are typical for researchers in a growth phase or working on a timely and influential topic.
- $h^* = h$**:** This case suggests a balance between past and present performance. The researcher is maintaining a steady level of scientific activity and his recent output is in line with their historical trajectory. It may also occur in the early career stages, when the h index itself is still evolving at a rate comparable to h^*.
- $h^* < h$**:** Here, the recent performance is below the long term average represented by the h index. This can arise from a decrease in publication rate, a decline in citation rates or reduced research activity due to thematic shifts, administrative responsibilities, or personal circumstances. In such cases, h^* acts as a sensitive early warning indicator, allowing for timely identification of potential issues.

By providing this dynamic comparison, h^* not only quantifies scientific output but also offers meaningful qualitative information about the current state and trajectory of a researcher's career.



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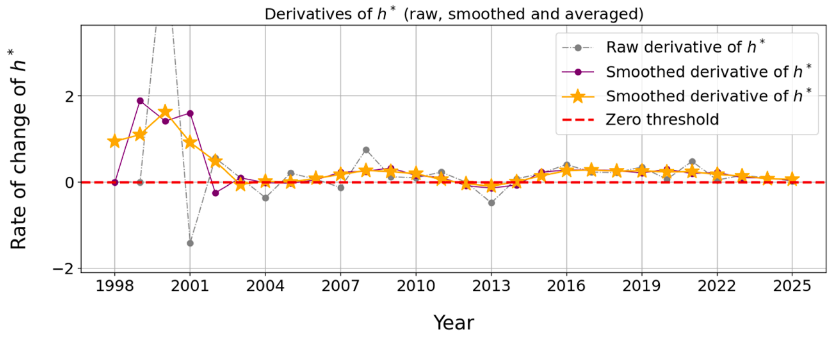


(b)

Fig. 10. Evolution of the index with administrative duties, a) Case of h index with plateau and increase b) Rate of h^* index on time.

4.6. How administrative duties may act on the evolution of the h^* index

Sometimes, as discussed in the previous section, a researcher impact stays low, due to a reduced or no international visibility and his work influence remains modest. This may happen because of a career choice made, perhaps too quickly. It is not useful to judge such a decision, as it is entirely personal, but it can have a direct effect on the h^* index. In such cases, the h^* usually remain lower than the classical h index, Fig. 12. A plateau may appear if administrative responsibilities come in the middle of the career. In some situations, the derivative $\frac{dh^*}{dt}$ can even become quickly negative, meaning that citations no longer compensate for the lower scientific articles publication. This decline, referred as the "dead zone" (blue triangle), reflects a stop in research activity as discussed in the next section. These two cases can be compared to Fig. 6-a, since the researchers were recruited around the same years and initially worked on similar research topics. For the second researcher, Fig. 12-b, an initial alert period was detected very early in the career and lasted for eight years. This was followed by a phase of renewed activity for nine years, before a second alert period with a decreasing trend initiated in 2021, to the present day. Thus, for a 28 year career, these modest activity phases together represent almost half of the total career time. The h^* index clearly reflects this trajectory, showing that, from a purely scientific point of view, the career output was limited. However, the researcher likely had certainly a strong and fulfilling involvement in administrative and managerial roles. This raises an important question, should research positions be sacrificed to take on mainly management and administrative responsibilities?

In the field of administrative effects, opposite situations can also be observed. For example, in the following figure, Fig. 13, a researcher took on an important position, here as Vice-President of a university, yet the h^* continued to grow without any deflection. However, when comparing h^* with a potential candidate or in this case with the candidate CV, it is clear that the constant growth of h^* likely comes from extensive self citations and a large number of publications. The h^* plot shows that the number of publications has doubled since the administrative responsibility began in 2000. In such cases, h^* can help verify the validity of the h index and if the candidate is "honest". Moreover, as h^* is dynamic and constantly changing, academic changes, institutional moves, and administrative responsibilities can be added to the analysis. This researcher is in opposition with the others, Fig. 12.

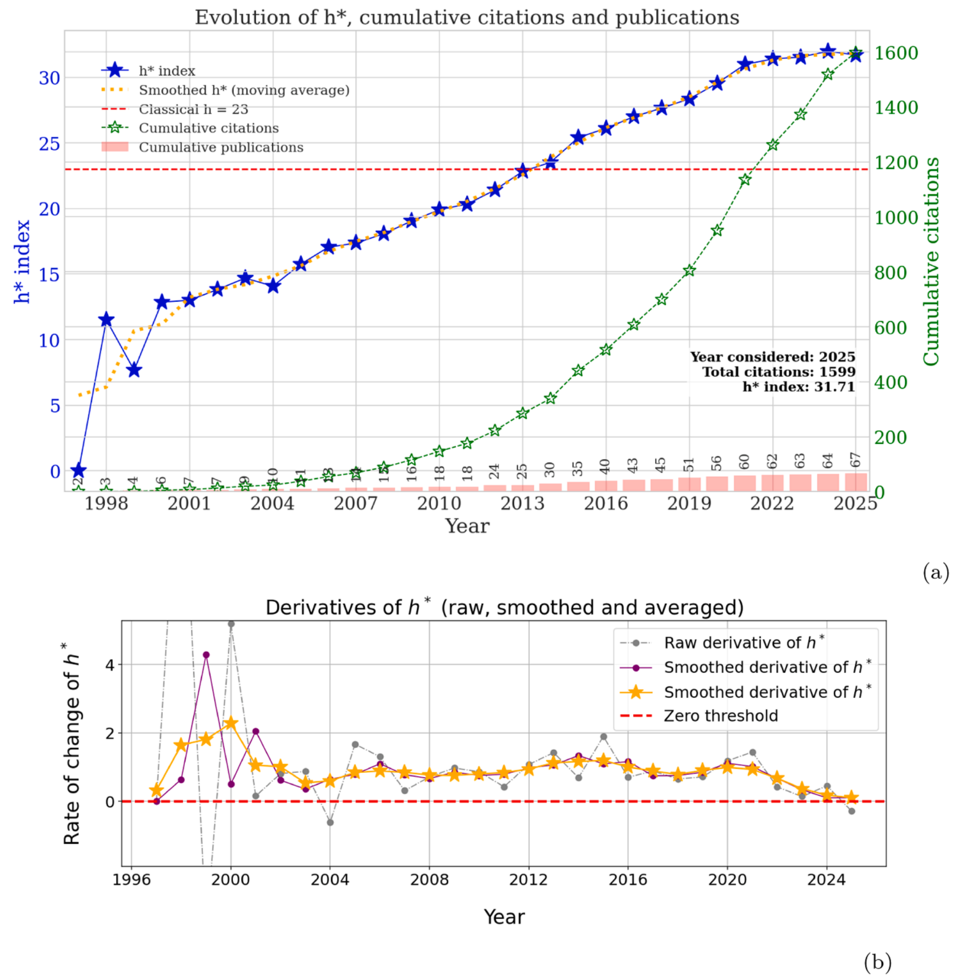


Fig. 11. Evolution of the h^* index with years, a) General trends with citations and number of publications; b) Rate of h^* index on time.

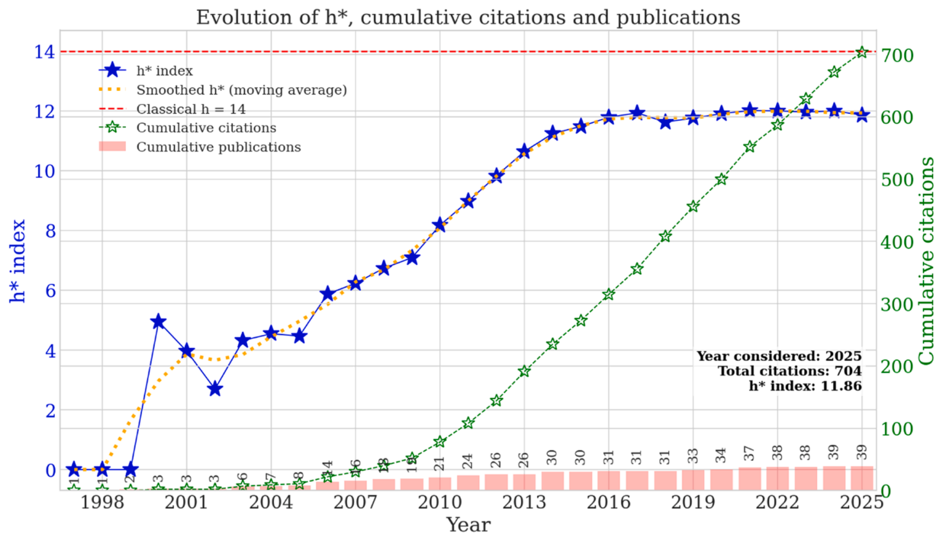
In the following section, the effect of self-citation is studied using a few cases.

4.7. *How self-citation affects the h^* index*

Self-citations can influence the value of the index h^* by artificially inflating the citation numbers, Fig. 14. When authors frequently cite their own previous work, the total number of citations increases, which may increase the value of h^* even if the broader scientific impact remains unchanged. Therefore, it is important to consider and potentially adjust for self citations to obtain a more accurate measure of a researcher influence. It is clear that the published work has a reduced impact, as decreasing the number of publications per year, in this case after 2021, leads to an immediate decrease in derivative $\mathrm{d}h^*/\mathrm{d}t$ for this researcher. It should be noted that keeping an average of 15 papers per year (more than one by month) and using self-citations may be difficult. This artificial trend corresponds to an average of 120 publications over ten years (1 publication per month). On the rate curve, it creates a hill shape, as shown in Fig. 14-b. This detection of self-citation is consistent with Fig. 14-c, showing that self-citation started in an exaggerated way around 2012–2013, with a total difference of about 890 citations in 2025.

Citing previous works is normal and even necessary in a new scientific publication. A reasonable number of self-citations is usually two or three per paper. For a standard production of one or two articles per year, this eventually adds about ten additional citations and maybe changing your h index after ten years about $\Delta h = 1$. However, if self-citations are increased to tens or more per new publication, this becomes extreme, as shown in the following figure, Fig. 15. When hundreds or more self-citations per year are observed, it is reasonable to question the scientific impact of the work. In such cases, the researcher may be more focused on producing a large number of papers than on the quality of the research.

However, it can be seen that keeping self-citation at a reasonable level is difficult. It is then possible to collaborate with other researchers and each cites the others in every new paper. This happens not only in self-citation cases but also when administrative roles are important and maintaining a high publication rate is desired. Some may also used a system called “Paper Mills”, which are



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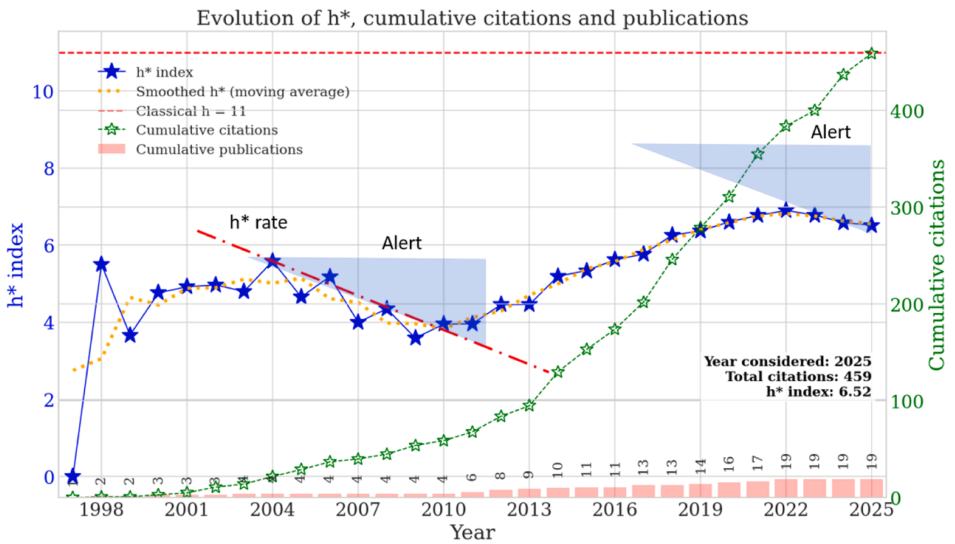


(b)

Fig. 12. Evolution of the index with administrative duties, a) Administrative duties a few years after recruitment b) Early administrative involvement after recruitment.

fraudulent organizations that make money by writing manuscripts and offering authorship slots for sale to academic customers as discussed in Parker et al. (2024).

In the following section, specific cases such as retirement and the rate "blue zone" are described in more detail.

4.8. Evolution of the h^* index following retirement or cessation of scientific activity

When a researcher retires or passes away before retirement as reported in Fig. 16, the classical h index remains constant or may even increase if their past work continues to be cited, Fig. 1. This is because the h index is cumulative and does not decrease over time, reflecting the lasting impact of researcher contributions. However, the h^* index behaves differently in these situations. It can detect the reduction or complete stop of scientific activity, while still measuring the ongoing impact and influence of the researcher work.

After retirement, the h* index differentiates between sustained scientific recognition, reflected by a slow decline driven by continued citations, and the fading impact, characterized by a rapid decrease once the citation flows stagnate.

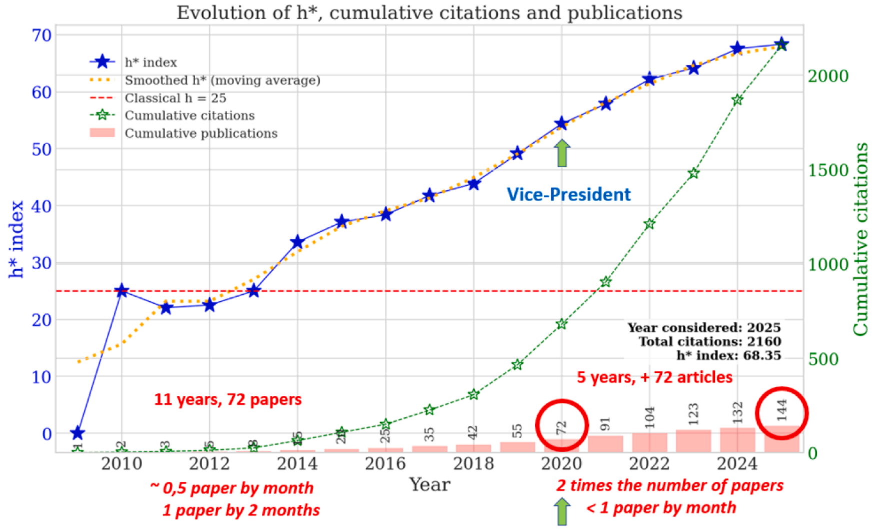


Fig. 13. Evolution of the index with administrative duties, a) Inverse effect, administration boost the researcher .

A rapid decline in the h^* index after the end of active research suggests that the researcher had limited influence during their career and the classical h index may have been artificially inflated, possibly due to self citations or low citation rates. On the other hand, a slow decrease in h^* indicates that the researcher's work continue to be recognized and cited regularly. This steady citation flow can compensate for a reduced or absent publication rate, showing lasting respect and relevance in the scientific community. Therefore, the h^* index is a valuable tool not only during the active academic career but also after it has ended. It provides a dynamic perspective on a researcher scientific impact, distinguishing between ongoing influence and purely historical achievements.

In summary, while the classical h index reflects a static snapshot of achievement, the h^* index offers a more nuanced and time sensitive evaluation. This makes it particularly useful for monitoring the evolution of a researcher influence both during and after their active scientific life.

In these curves, Fig. 17, the rate of the h^* index is plotted. It shows that citations can keep the rate positive or close to zero for few years depending on the impact of the work but without continuing to contribute scientifically by publishing articles, the rate systematical becomes negative and constant. The switch from positive to negative therefore depends strongly on the amount of importance and impact of the work produced during a scientific career.

These curves clearly show that the h^* index reflects the time before retirement, retirement itself, and even after the researcher has passed away. In these three examples, which are about similar research topics, the h^* index decreases in a straight line. In the last example, although the researcher was still publishing and getting citations, the h^* never became higher than the classical h, but close to reach it until his death.The last case is similar to the active researcher shown in Fig. 12-b, but due to administrative duties, the scientific activity declined. Can we conclude that too many administrative responsibilities can be like a "scientific death"? It is also interesting to note that for these three researchers, working on similar topics, quite comparable, retirement or sudden stop of activity leads to a decrease of the h^* index with a very similar decrease rate, corresponding to the blue zone.

5. Visualization and diagnostic use of the h^* index

5.1. Visualizing the impact: a 3D perspective on research performance

Understanding the indices that influence a researcher h^* can be challenging. To make this clearer, we introduce a 3D visualization that shows how h^* evolves with two key elements: the number of active publication periods and the total number of citations. This 3D surface helps deciders, managers, directors of laboratories, president of university to see the combined effect of publishing consistently over time and accumulating citations. It reveals how increasing publications and citations together can boost the research impact. The red point on the graph indicates the current position, helping the researcher track progress and set clear goals. Exploring this 3D surface, allow for a better understanding of what drives scientific success and focus efforts where they matter most. The researcher can see whether you are at the top of the mountain Fig. 18-a or still in the valley Fig. 18-b after few years. By integrating cumulative citations, career length, and publication-adjusted efficiency, the 3D visualization provides an objective, quantitative tool to identify periods of exceptional productivity or declining impact, offering insights that static indices such as h alone cannot reveal.

The difference between the red point (actual situation) and the green star (optimal case), Fig. 18, comes from the rule that requires at least one publication every two years (the French standard). If some periods do not meet this criterion, the intensity of h^* is reduced. Of course, this rule is flexible and can be adapted depending on the recommendations of the laboratory, the country, or the university.

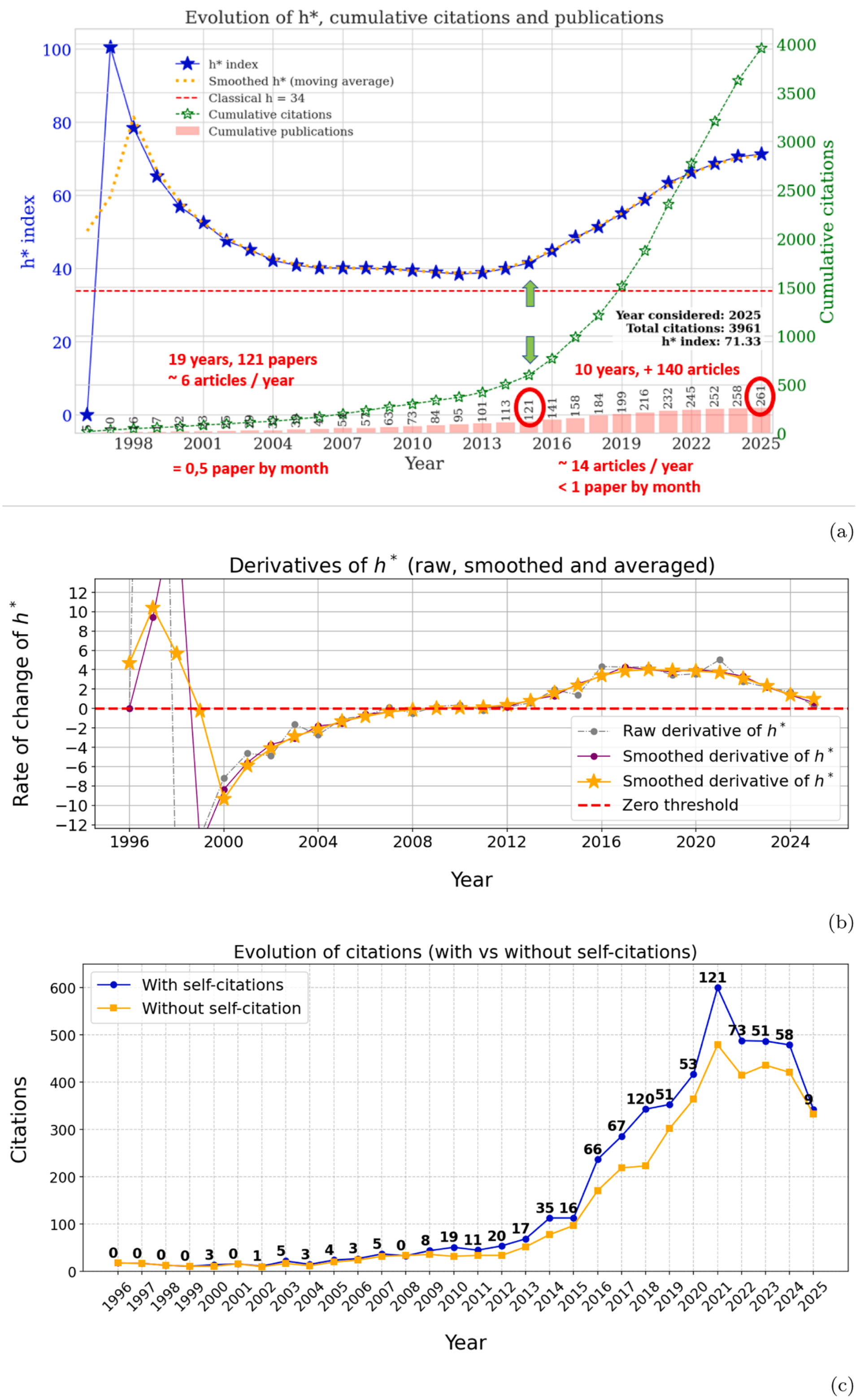


Fig. 14. Evolution of the index with self citation, a) General effect with fast citations increase, b) Rate of the h^* index associated to self citations, c) Citations by year with self-citation and without.

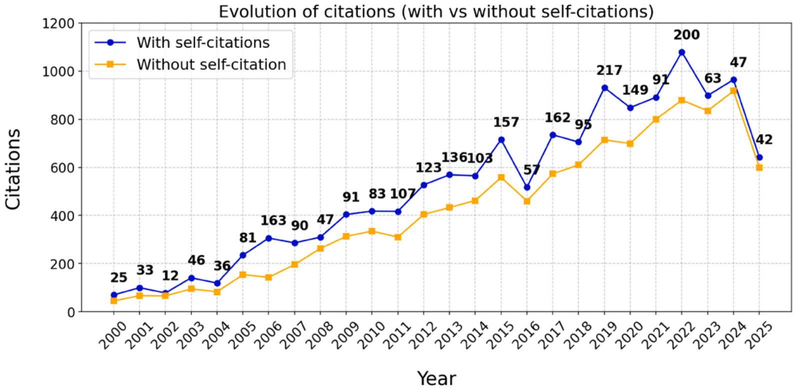


Fig. 15. Example of extreme self-citation reflecting a scientifically dishonest approach. From 2000 to 2025 it corresponding to + 2456 citations and a change of $\Delta h^* = 50$ and $\Delta h = 6$.

5.2. Empty publication periods and distance from the optimal trajectory

In the following graph, Fig. 19, we can clearly see the periods that do not satisfy the imposed criterion.

5.3. Simulation of recovery scenarios

Of course, it is difficult to compensate for long periods of inactivity as discussed earlier and some situations cannot meet the criterion even after many years. However, in certain cases and if the situation is detected very early, solutions can be proposed in agreement with the researcher. For example, Fig. 20, imagine a return to scientific activity with the goal of publishing one impact article per year in order to be cited and recognized by the scientific community. The researcher can then choose the journal and we can estimate how many citations per year would be necessary to reduce the gap between theoretical h^* and actual h^*. In the following figure, the researcher agrees to publish one article per year and it is shown how increasing the number of citations can influence h^*. In this example, after five years, the objective is reached. It is clear that the target can be achieved more quickly with a higher publication rate, Fig. 20-c, which would naturally lead to more citations, without considering extreme cases of self citation as discussed previously, which is not the purpose in this paper. Moreover, self citation is not a real solution. If it is assumed that a new article published has a total of 30 citations, the author may only account for a fraction of these, which limits the increase of h^* through this effect. In this simulation, one article by year is considered after the academic year 2025.

5.4. Discipline-level benchmark surfaces

By considering several researchers in a given discipline, it is possible to plot a 3D map of the covered domain, Fig. 21. We can then define a lower and an upper bound for a certain number of years of scientific career and observe the disparity. In this example, 25 researchers were considered to generate the surface, but it can be extended or redone for another field. One could even imagine one surface per team in a department, one surface per department in a laboratory or one surface per laboratory in a university.

6. Limitations and future directions

To provide a balanced assessment of the h^* index applicability and to guide future developments, several important limitations are described:

The h^* index, like most research metrics, works best within a single research field. For researchers who work across multiple disciplines (interdisciplinary research), the h^* value may appear lower than their actual scientific impact. This happens because different fields have different citation habits some fields cite frequently, while others cite less often. This is a common challenge for all research indicators, not just h^*. While there are methods to adjust for field differences, these require complex calculations and access to large databases that individual research teams typically do not have. The current version of h^* focuses on being easy to calculate and understand. In the future, more advanced versions could include field adjustments, but this would need support from larger research institutions with better data access.

This initial proposal of the h^* index represents a foundational approach that intentionally maintains simplicity while introducing temporal dynamics. Like the classical h index, the current formulation does not account for authorship order or contribution weight. Implementing authorship weighting would require access to large scale data, cross-institutional databases with detailed contribution information, which is beyond the practical scope of individual research teams, laboratories, or even single universities. Such comprehensive authorship analysis is typically only feasible at the scale of major publishing houses or national research databases. Therefore, while authorship weighting represents an interesting direction for future refinement, it was not considered in this initial implementa-

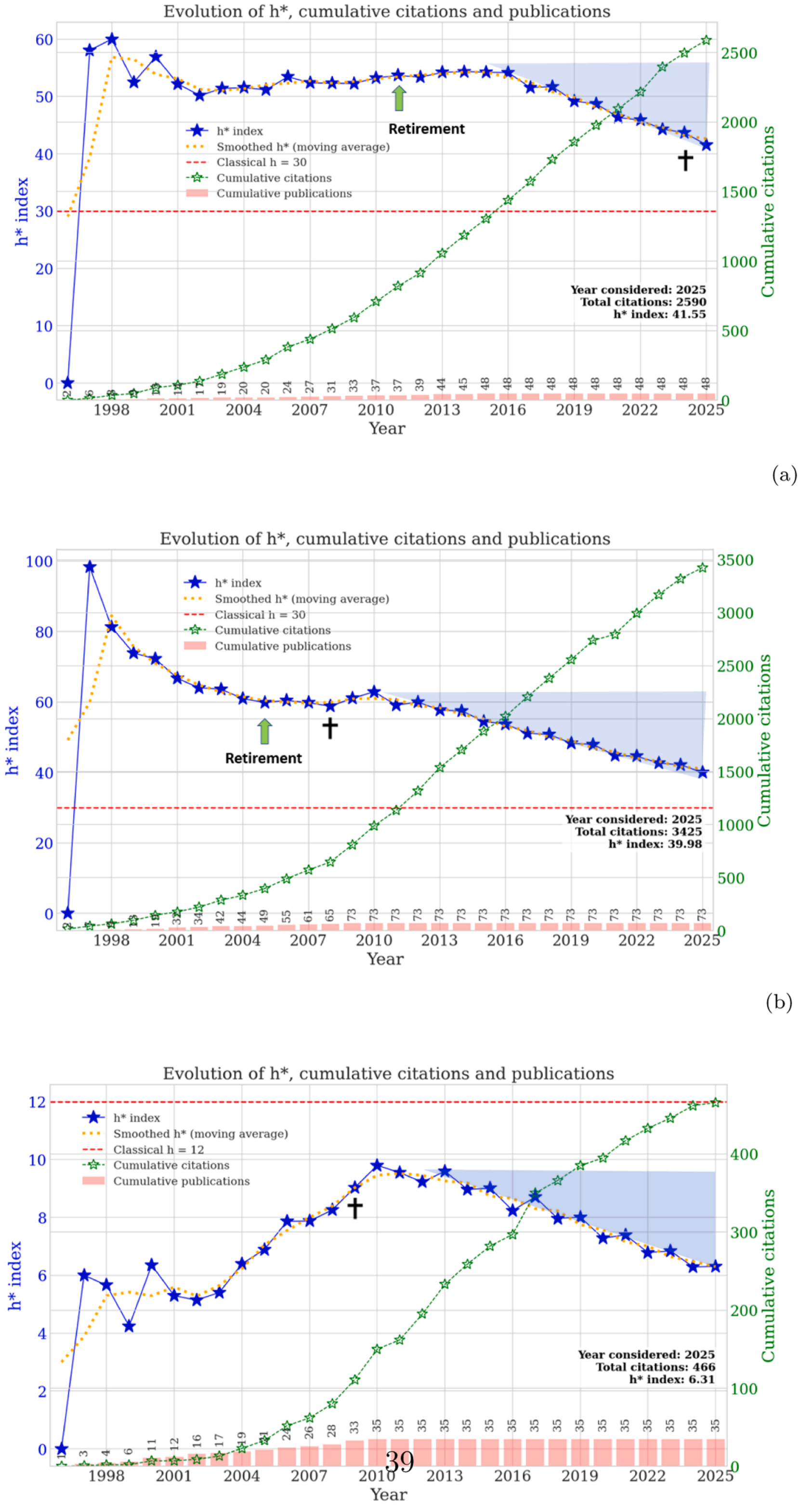
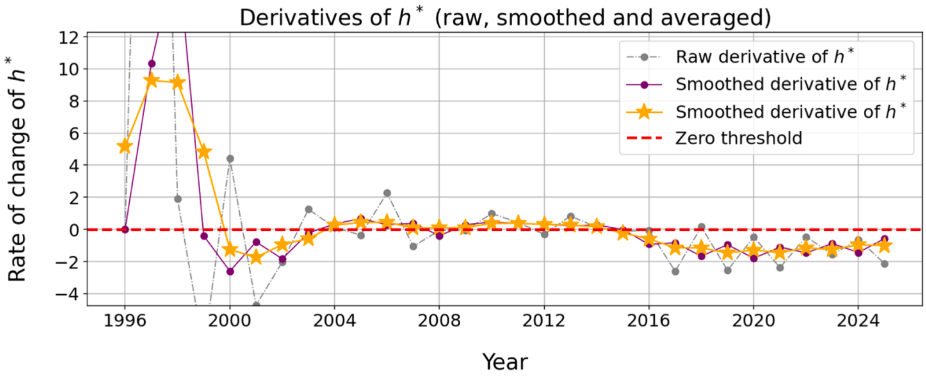


Fig. 16. Evolution of the index after retirement and posthumous period, a) Evolution of the index after 15 years from retirement b) Evolution of the index after 26 years from retirement; c) Evolution of the index without retirement.



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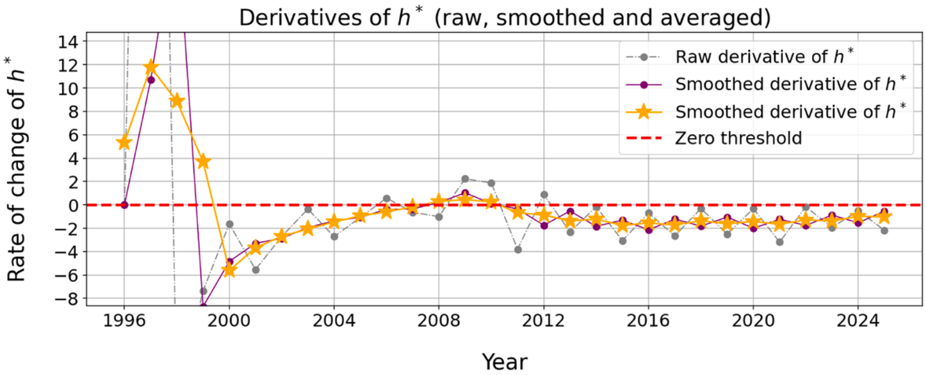

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Fig. 17. Evolution of the rate index after retirement and posthumous period, a) Evolution of the index after retirement, 15 years; b) Evolution of the index after 26 years from retirement.

tion. The current structure focuses on temporal dynamics while maintaining practical calculability, providing a foundation that can be extended by larger research entities with access to the necessary infrastructure and data resources.

1. **Dependence on data quality**: The accuracy of h^* calculations is inherently tied to the completeness and reliability of publication and citation data in source databases like Scopus. Missing publications or incomplete citation records may affect the indicator validity, particularly for early career researchers or those working in interdisciplinary fields.
2. **Field-specific variations**: The h^* index, like most bibliometric indicators, is influenced by disciplinary citation practices. Researchers in mathematics or engineering may show different h^* trajectories compared to those in life sciences, even with similar research impact. Future work could explore field normalization approaches, though this would require access to comprehensive cross disciplinary databases.
3. **Authorship considerations**: The current formulation does not account for authorship order or contribution weight. In fields where multi author papers are common, this may affect the indicator precision. However, this limitation also applies to the classical h-index and most bibliometric indicators. Future adaptations could incorporate fractional counting or contribution weighting, though this would require more complex data processing.
4. **Parameter sensitivity**: The values of α and β parameters influence the relative weight given to publication regularity versus citation impact. While we recommend default values of $\alpha = \beta = 1$ for general use, institutions may need to calibrate these parameters based on their specific evaluation criteria and disciplinary contexts.
5. **Interdisciplinary challenges**: Researchers working across multiple fields may show apparently lower h^* values due to fragmented citation patterns across different research communities. This reflects a fundamental challenge in bibliometrics that affects all existing indicators.
6. **Practical implementation**: Large scale adoption would require integration with existing research information systems and training for evaluators. The Python script provided as complementary material in this paper represents a first step toward accessibility, but institutional deployment would need more robust software solutions.

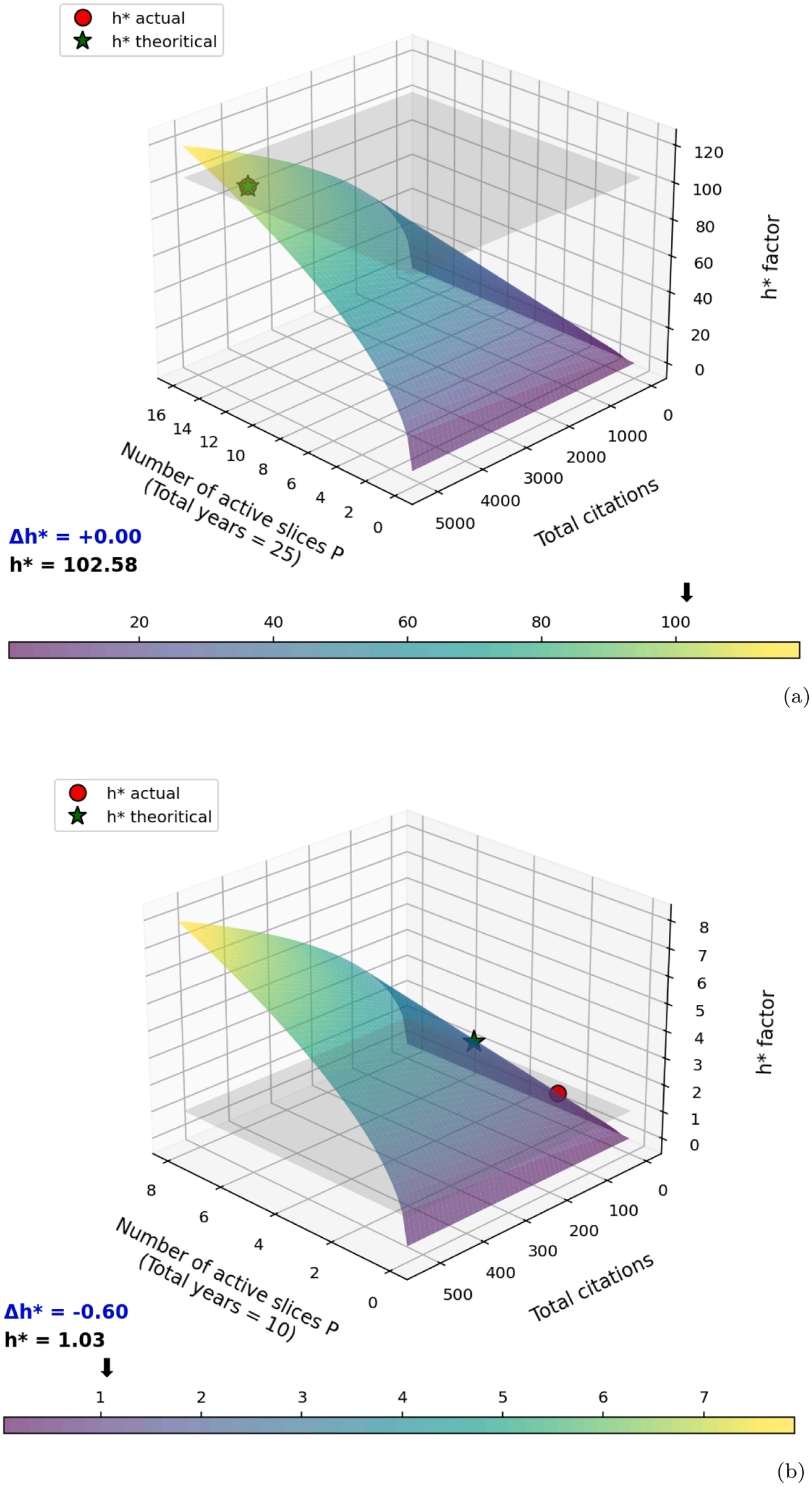


Fig. 18. Definition of the actual position of a researcher in 3D space, a) With no empty years in term of publications, respecting the criteria of 1 publication by 2 years b) Considering case Fig. 8.

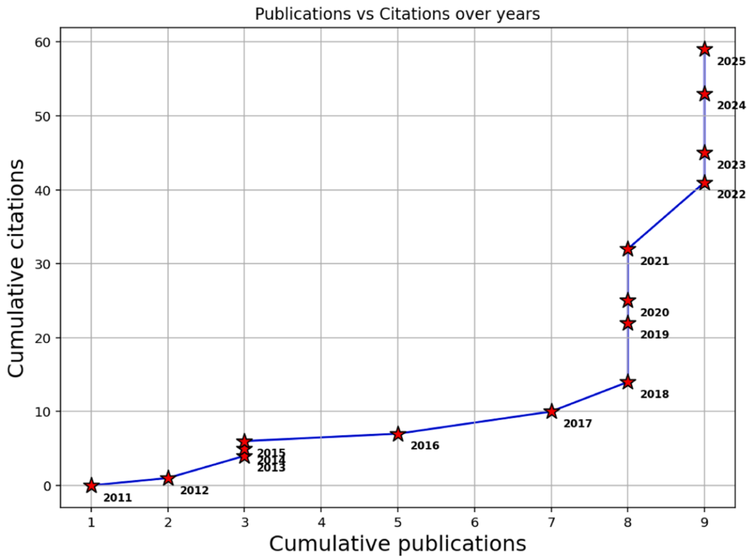


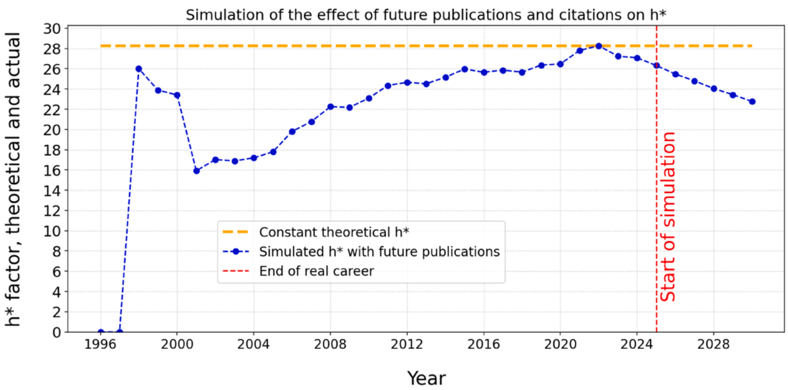
Fig. 19. Description of the periods that do not respect the publication criterion and affects the value of h^*.

Table 4
Final comparisons between h and h^* and comments.

Criteria	h index	h^* index	Comment
Definition	Number h such that h papers have at least h citations	h adjusted by regularity of publications, growth of citations and penalties for empty years	h* is a generalization of h
Evolution	Can only increase or stay constant	Can go up or down depending on activity	h* shows recent dynamics better
Time sensitivity	Ignores career breaks (value stays high)	Decreases if publications or citations stop	h* reflects inactivity more clearly
Regularity of work	Not considered	Penalizes long publication gaps (empty years)	h* rewards consistent work
Comparing researchers	Simple, widely used, but favors long careers	More fair, balances young and senior researchers	h* helps in dynamic evaluation
Complexity	Very easy to calculate	Needs yearly data and parameters (α, β)	h is simpler, h* is more complex

7. Like all bibliometric indicators, the h* index can be affected by structural career interruptions, including those related to parental leave; therefore, it should be interpreted as a diagnostic measure within a broader qualitative evaluation framework, rather than being used on its own or as a normative criterion.

Despite these limitations, the h^* index provides a valuable foundation for dynamic research assessment. Future directions include large scale validation studies across different disciplines, development of field normalized versions.



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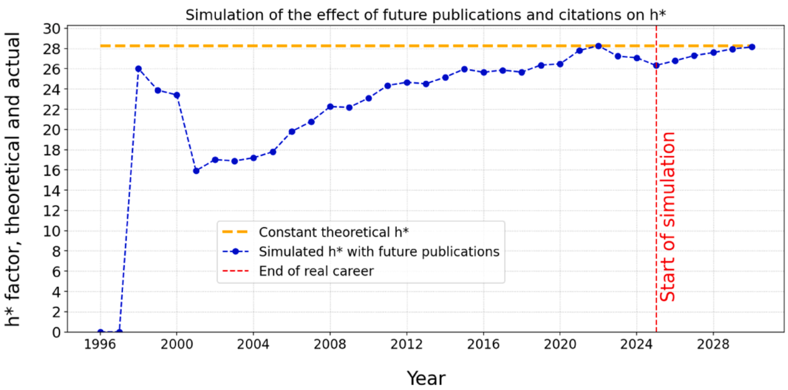

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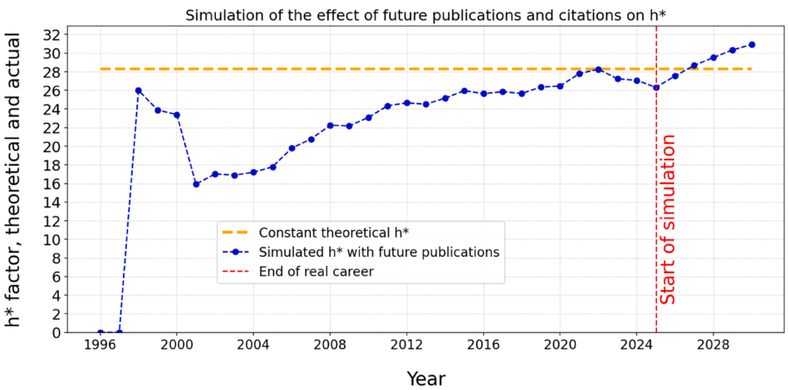

(c)

Fig. 20. Simulation to define the solution to reach the theoretical h* index, a) Just publishing one paper by year after 2026 and keeping a similar citations number close to 2025 b) Same condition and 50 extra citations by year, b) Same condition and 80 extra citations by year.

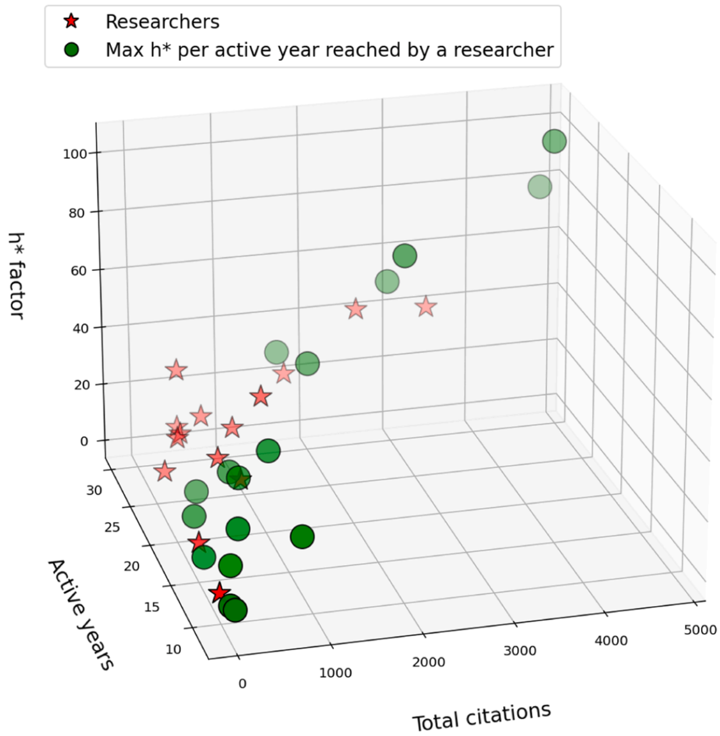

Fig. 21. 3D surface representing the scientific domain of more than 25 researchers. Observation of the lower and upper values for a given career length, showing the disparity.

7. Conclusions

In this study, we have explored how the h^* index evolves during important phases of a researcher career, including retirement and even after their passing. Unlike the classical h index, which remains constant once the researcher stops publishing, the h^* index is dynamic and can reveal more about the ongoing influence of a researcher work over time.

Our analysis shows that the h^* index gradually decreases after activity stops, reflecting how the impact of a researcher fades or persists depending on how frequently their work continues to be cited. This dynamic behavior provides useful information that static metrics cannot capture.

It is important to recognize that no single indicator can fully describe the scientific contribution of a researcher. However, when used with care, dynamic indicators such as the index h^* can help to understand changes in scientific influence and the evolution of research impact more clearly. It also helps to define objectives on a given time scale to correct a decreasing trajectory. The productivity component of the h* index could be generalized through a field-dependent reference parameter reflecting discipline-specific publication norms, and its empirical calibration across fields constitutes a natural extension of the present framework.

These tools can be valuable not only for evaluating past performance, but also for predicting future trends and supporting decisions in academic policy and funding.

In general, this work highlights the importance of adopting flexible and evolving metrics that better reflect the realities of scientific careers and the progress over time. The following table, Table 4, summarizes the description of the h and h^* index along with the advantages and disadvantages of both metrics.

This simple observation about the h^* index makes it natural to end with a “citation” that describes the meaning of a researcher work and its lasting impact.

> *“Un indicateur ne dit pas qui vous êtes, il dit ce que les autres ont retenu de vous. Le h ou h* facteur ne mesure pas la vérité, il mesure combien de fois une idée a su traverser le temps sans tomber dans l’oubli”*

> *“An indicator does not say who you are, it says what others have remembered about you. The h or h* index does not measure the truth, it measures how many times an idea has managed to survive through time without fading into oblivion”*

> *“Wskaźnik nie mówi, kim jesteś mówi, co inni o tobie zapamiętali. Czynnik h czy h* nie sprawdza prawdziwości, lecz pokazuje, ile razy dana myśl zdołała utrzymać się w obiegu, zamiast zniknąć w zapomnieniu.”*

Prof. Alexis Rusinek

Prof. Tomasz Jankowiak (Polish translation)

CRediT authorship contribution statement

Alexis Rusinek: Writing – review & editing, Writing – original draft, Validation, Supervision, Software, Investigation, Formal analysis, Conceptualization; **Tomasz Jankowiak:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization; **Aurélien Besnard:** Writing – review & editing.

Declarations of competing interest

The authors declare no conflicts of interest.

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