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Research Paper

Analysis of the distribution of authorship by gender in scientific output: A global perspective

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ABSTRACT

This study presents a thorough examination of gendered scholarly contributions and impact from 2003 to 2023, encompassing details on 212,631,585 authorships indexed in Scopus. The analysis unveils promising advancements towards gender equity, demonstrating an increase in contributions from both genders, which indicates the trend towards a progressive and inclusive environment. These findings challenge an initial perception of male prolificacy. The positive trends extend to female-led research teams, highlighting a correlation between gender balance and leadership. This evolving landscape is reflected in the convergence of male and female authorship participation over time. A decline in citable papers suggests a narrowing of the productivity gap, which challenges gender disparities in impact metrics and emphasizes the multifaceted nature of scholarly excellence across genders. Our data and gender classification method also enables us to look into the country level in order to characterize gender distribution locally. Contrary to conventional assumptions, developing countries are exhibiting a pronounced evolution in female authorship rates. In summary, the study underscores the positive trends towards gender equity, advocating for sustained efforts to promote diversity and foster nuanced understanding in academia.

1. Introduction

Gender gaps in scientific productivity have been a persistent and concerning phenomenon which has drawn attention to the disparities between male and female researchers in academia. A growing body of research underscores the existence of notable gender imbalances in the production and dissemination of scientific knowledge, encompassing publication rates, citation metrics, and research funding. Several studies, dating back to the 1970s, have consistently revealed significant disparities and inequities in the gender distribution within STEM fields. These studies predominantly highlight the disproportionate male representation in authorships, citations, and grant allocations in comparison to females (Lewin & Duchan, 1971; Marwell et al., 1979).

Since the 1980s, there has been a significant surge in interest and discussion surrounding gender disparities in academia, encompassing academic participation, publications, and impact. The substantial volume of research in this domain has greatly

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contributed to a thorough comprehension of the factors that influence gender inequalities in science and technology. Research in this area has included comparisons of scientific productivity between males and females. This body of literature frequently entailed comparing the contributions of male and female researchers across diverse disciplines and global regions, offering insights into the prevailing trends (Abramo et al., 2009; Bendels et al., 2018; Bordons et al., 2003; Davarpanah & Moghadam, 2012; Gander, 1999; Holman et al., 2018; Larivière et al., 2013; Mauleón et al., 2014; Paul-Hus et al., 2014; Requena et al., 2016; Sánchez-Jiménez et al., 2023; Söderlund & Madison, 2015; Sugimoto, 2016; Webster, 2001).

These evaluations commonly characterize productivity as the aggregate number of publications generated by a scientist, providing a simple metric for the assessment of male and female contributions. Although this measure may be deemed simplistic, it proves effective in scrutinizing specific scientific domains.

Another aspect of gender studies in the context of scientific endeavour is scientific impact. In the realm of performance studies, researchers have delved into gender differences in citation rates. A prevalent approach in these studies involves analysing the number of citations received by female-authored publications and comparing them to their male-authored counterparts. However, definitive conclusions about citation rates remain elusive. Some studies suggest there is no significant differences between males and females in terms of citation rates (Maliniak et al., 2013; Mitchell et al., 2013; Slyder et al., 2011; Turner & Mairesse, 2005). The gender disparity observed in scientific output can be attributed to the underrepresentation of females in particular scientific fields (Brück, 2023; Larivière et al., 2013; Lewison, 2001; Lewison & Markusova, 2011; Sharkey et al., 2016), delayed career starts for women, disadvantages during their early career years coinciding with major life events, and a tendency for females to focus on teaching and service rather than research (Lerchenmueller & Sorenson, 2018; Sax et al., 2002; Van den Besselaar & Sandström, 2017; Ward & Wolf-Wendel, 2004). The latter may be influenced by closed academic networks and inherent roadblocks (Chan, 2022; Holman et al., 2018; Nazli & Noman, 2023).

While the analysis of gender representation in academic publications at the country level is still in its early stages, this paper seeks to contribute to the existing body of research in this area. By examining the gender dynamics within publications at the national level, this study aims to shed light on the current landscape of gender representation in academia. Country-specific variations further contribute to the complexity of understanding gender gaps in scientific productivity. Research indicates that the magnitude of these gaps varies between different nations, suggesting that cultural, institutional, and systemic factors play pivotal roles in shaping gender dynamics within the scientific workforce.

The Global Leadership and Organizational Behavior Effectiveness project (GLOBE) introduced a cultural dimension called gender egalitarianism, measuring the influence of biological sex on societal roles in workplaces, homes, and communities (House et al., 2004). In societies with low gender egalitarianism, traditional gender roles are emphasized, while high egalitarian societies emphasize similarities in men's and women's involvement in various life domains. GLOBE's model suggests that societal practices and values impact organizational cultures. Lyness and Judiesch (2014) found that work-life balance ratings by supervisors varied based on their country context and gender, with women in low egalitarian cultures facing stricter standards.

In such societies, in the STEM fields, overcoming biases is challenging for women. Additionally, culture affects education and career choices, influencing gender disparities from an early stage. Han's (2016) study on STEM occupational expectations across countries highlighted significant variations in gender disparities based on the secondary education systems. Some countries with stratified systems exhibit more pronounced gender gaps compared to those with standardized education systems (Han, 2016). Consequently, a comprehensive exploration of gender gaps requires an examination of these variations, considering the unique contexts and challenges faced by female researchers in different countries. Some key contributors to these disparities and the differences between countries could include: (1) Cultural Influences – societal expectations and stereotypes about gender roles that can impact women's participation and recognition in scientific fields, in particular, cultures that perpetuate traditional gender norms may inadvertently discourage women from pursuing academic careers or hinder their advancement (El-Hout et al., 2021; Nazli & Noman, 2023; Soylu Yalcinkaya & Adams, 2020); (2) Access to Education – unequal educational opportunities may limit the number of women pursuing advanced degrees and subsequently contributing to scientific publications(Chan & Torgler, 2020; Han, 2016; Tandrayen-Ragoobur & Gokulsing, 2022); (3) Legal and Policy Frameworks - Legal and policy frameworks related to gender equality and women's rights can vary between regions and impact women's opportunities in academia and research. In regions with strong legal protections and policies promoting gender equality, women may have greater opportunities for advancement and representation in scholarly publications (Llorens et al., 2021; O'Connor, 2020). (4) Socio-economic Factors - Socio-economic factors, such as income inequality, access to healthcare, and employment opportunities, can influence women's participation in academia and research. In regions with high levels of socio-economic inequality, women from marginalized backgrounds may face additional barriers to publishing their work and achieving recognition in their field (Caro et al., 2009; Farid et al., 2014; Mahmood & Saleem, 2020; Morgan et al., 2022).

Transformations in society and culture typically unfold gradually and encounter resistance, making the pursuit of gender equality a challenging endeavour. Without sustained awareness and action, progress toward gender parity remains elusive. The quest for solutions to address gender bias presents formidable challenges, as some approaches may prove more viable in specific contexts than others. Nonetheless, persistent efforts and diverse strategies are essential to advancing gender equality and fostering inclusive societies.

This study endeavours to contribute to the existing body of research on gender authorship in academia by providing a comprehensive and current analysis of gender distribution in authorships. Spanning nearly two decades from 2003 to 2022, the study examines a substantial dataset comprising 212,631,585 authorships. By including gender distribution between males and females across different countries, the aim is to offer insights into the general trends and patterns of authorship within academic publications. Through this extensive examination, the study seeks to enhance our understanding of the disparities and variations in gender representation across various regions and contexts, thereby adding valuable country-level perspectives to the discourse on gender

authorship in academia.

1.1. Research questions

1. How have gendered scholarly contributions evolved from 2003 to 2023, and what factors have influenced these changes?
2. What specific trends in gender balance and leadership within research teams have been observed over the study period?
3. What implications do the findings have for addressing gender disparities in scholarly impact metrics, particularly in relation to citable papers?
4. How do the trends in gendered scholarly contributions vary across different regions and countries, particularly in developing nations?

2. Methods and data

Algorithmically assigning gender to individuals disregards their self-defined gender and how they want to be perceived by others. Gender, a concept scrutinized by various authors, will be approached with a deliberately neutral and less exhaustive definition. Lindqvist et al. (2021) highlights four facets: (a) physiological aspects (sex); (b) self-defined gender; (c) legal gender; and (d) social gender in terms of norm-related behaviour and expressions. This discussion focuses on an approximation to the fourth facet to consistently describe the gender assignment process, acknowledging that it may not capture its full meaning in all instances.

The most prevalent method to infer the gender of the authors of scientific papers is by using given names. While alternative approaches involving gender-indicative pronouns or authors' portraits in profiles have been explored (Young et al., 2018), these are typically limited to verification processes for result validation. The challenges inherent in automating such methods likely contribute to their restricted use. Associating an author with their profile poses difficulties, as self-descriptions or photographs may not always be available.

This complexity arises from the interplay between how individuals define themselves and how they are perceived, making this a nuanced matter. Simultaneously, names play a social role in influencing gender, though this interaction only partially aligns with other layers of gender determination. When validating algorithmic gender assignment with information provided by researchers, we acknowledge the importance of considering how individuals define themselves, as this perspective becomes relevant at that stage.

To determine authors' gender, we employed a method relying on given names, grounded in "cultural consensus theory" (Van Buskirk et al., 2023). This approach utilizes a contextual evaluation of each source's "competence" to assign weight to responses, offering a more accurate estimate of the consensus. It assesses a source's overall agreement with the existing consensus to determine its competence. Thus, the CCT-based method simultaneously infers a culturally constructed consensus and each source's alignment with that consensus (i.e., its competence). The Python package implementing these principles, "nomquamgender" (NQG), is freely available at https://github.com/ianvanbuskirk/nomquamgender. This tool utilizes data of 150 countries from 36 publicly accessible sources, providing diverse and extensive coverage suitable for identifying genders, especially in the case of less conventional scientific authors.

Various publicly available methods exist for this task, some of which have been applied in notable gender research in science. Van Buskirk, Clauset & Larremore (2023) compared four of these methods with their own and found that NQG achieved a 95.4 % accuracy, slightly outperforming the others (ranging from 93.8 % to 94.9 %) based on the classification of 97.0 % of names, albeit classifying fewer names, as the other methods classified from 97.5 % to 100 %. Recognizing the risks associated with attempting gender assignment with insufficient or no data, we aim to address this concern by incorporating additional performance measures when evaluating the CCT method.

Spoon et al. (2023) applied this approach to assign gender to US faculty in their study on gender retention patterns. They validated the method's accuracy by comparing it with self-reported genders from a previous survey on staff with diverse disciplinary backgrounds in the US (Morgan et al., 2022), yielding a 97 % correspondence rate. Lin et al. (2023) also adopted this system to assign gender to authorship records in their large-scale science-of-science database, although they did not provide a means of validation. Lockhart et al. (2023) caution researchers about information-theoretic limits on the cultural consensus approach, emphasizing that name-based gender/ethnicity tools estimate cultural consensus rather than the non-existent "ground truth" of a person's name's gender or race (which does not exist).

We will refrain from attempting to identify other non-binary genders based on names, recognizing that this largely falls within the realm of how individuals define themselves and extends beyond the social dimension. Employing a frequentist approach to distinguish this aspect would be severely constrained. Names exhibiting weak genderization do not necessarily indicate a non-binary gender; rather, they may result from the overlap of different combinations that locally possess strong (yet opposing) genderization or from situations where names are used interchangeably, unrelated to a non-binary perspective. All names with very weak genderization will be categorized as unknown, acknowledging that some may lead to errors in gender assignment, a challenge that is inherently difficult to circumvent.

Our dataset encompasses information on scientific papers published between 2003 and 2022 indexed in Scopus, with some impact indicator analyses excluding the last two years. This dataset comprises details on 212,631,585 authorships. Scopus data also provides information on authors' affiliations, which enables country attribution, as well as unique author ID numbers, which facilitates better researcher identification and benefits from an internal normalization procedure by the data provider (Baas et al., 2020). While other databases such as arXiv or PubMed have been successfully utilized (Holman et al., 2018), reporting gender assignment rates above 92 %, Scopus emerges as a preferable choice for a global study on the subject.

Ensuring a high level of recall and meaningful results relies heavily on the quality of the dataset. Previous authors have highlighted

issues related to given names, which present challenges in their processing. A particularly noteworthy problem involves records where authorship is denoted by a sequence of initials and surnames, posing a significant hurdle. Huang et al. (2020) encountered difficulties and where only able to process the first names of 2.1 million out of the 7.8 million single authors in their WoS dataset, primarily due to the scarcity of full given names before 2006. Larivière et al. (2013) found that 31 % of the given names information for distinct authors provided by WoS consisted solely of initials. Although this problem exists in Scopus data, it seems less prominent. In our set, 29 273 692 authorships (13.37 %) included only initials as the author's given name. This percentage increased slightly to 13.41 % when narrowing our analysis to authors with three or more papers. The degree of importance of this phenomenon also varies significantly among countries, and although major science producers show very reasonable rates (table S1 in the supplementary information) there is still room for local improvement.

As the coverage of our study is greater than other studies that report on the CCT method's performance and we have added some surname heuristics for Slavic names to complement the original method, we have conducted a separate test using a sample of 1,043 authors. While the average precision in detecting both female and male genders is very high, it falls slightly below other reported results (see table S2 in supplementary information). However, the percentages of authors for whom gender assignment can be determined are significantly higher than those reported by other authors. We think that accounting simultaneously for both precision and recall is important for the use case, and thus have used the F1 score. Scores for our procedure based on the CCT classifier, Larivière et al. (2013) and Boekhout et al. (2021) are respectively 96.9 %, 71 % and 81.9 %. Based on these results, we are confident in the accuracy of our data.

The indicators used to characterize scientific production were the following:

- **Ndocc**: Number of citable documents (articles, reviews, conference papers, and short surveys) published in scientific journals included in the Scopus database.
- **%International Collaboration**: Percentage of documents in whose byline appear authors from different countries.
- **Normalized Impact (NI)**: Average normalized citation received by each document, understanding this to be the ratio between the citations received by the document and the average citations of documents of the same type, year, and Category (Rehn & Kronman, 2008).
- **Excellence10**: Number of documents that are among the 10 % most cited of the same year, type, and Category (Bornmann et al., 2012).
- **%Q1**: Percentage of papers published in journals that are within the first quartile in their scientific categories in the year of the publication of the paper according to the SJR indicator. This indicator reflects the effort made by the countries to disseminate their scientific results.
- **Evolution (Ev.)**: To show the annual percentage evolution of an indicator throughout the period, we calculated the slope of the trend line (least squares), multiplied by one hundred and divided by the average of the indicator throughout the period.

The counting methods used were the following:

- **Full Counting** (also known as the whole counting method): a document co-authored is assigned to the aggregates of the author with a full weight of one regardless of the number of aggregate authors participating. Documents with a single author were considered.
- **Fractional Counting**: a document co-authored by n authors is assigned to each researcher with a weight of $1/n$. If m authors of an aggregate participate, m/n is assigned to that aggregate. Documents with a single author were considered.
- **Complete Counting**: a document co-authored is assigned to each researcher with a full weight of one. If m authors of an aggregate participate, m is assigned to that aggregate. Documents with a single author were considered.
- **First Counting**: a document co-authored is assigned only to the first researcher with a full weight of one. Documents with a single author were not considered.

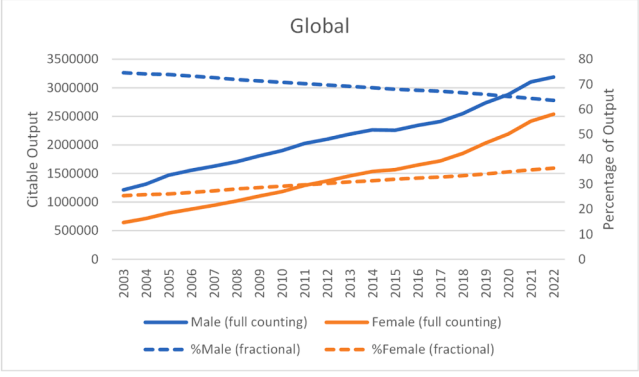

Fig. 1. Global citable output categorized by gender using full counting and presented as a percentage through fractional counting.

- **Last Counting**: a document co-authored is assigned only to the last researcher with a full weight of one. Documents with a single author were not considered.
- **Research Guarantor** (RG): a document co-authored is assigned only to the corresponding author with a full weight of one (Moya-Anegón et al., 2013). Documents with a single author were not considered.
- **Unique**: Only documents with a single author were considered.

3. Findings

Over the specified period covered in this study (2003–2022), the production of both genders has undergone significant growth, marking an upward trajectory in scholarly contributions. When adopting the fractional counting method, the percentage of female gender representation displays a notable trend towards achieving parity, approaching the 50 % mark. This observation underscores a positive shift in gender balance within the context of scholarly output (see Fig. 1).

The convergence trend towards gender equality is further highlighted in Table 1, where various types of counts provide a comprehensive overview of the evolving landscape of gender representation in academic production.

The observed increase in both male and female scholarly contributions suggests a progressive environment that encourages diverse participation in academic endeavours. The trend towards a more balanced representation, particularly as reflected in the fractional counting method, not only signifies positive strides in gender inclusivity but also emphasizes the potential for a more equitable and diverse scholarly community.

If we compare the percentage of authors with that of production, an initial inference might suggest that men are more prolific. This contrast becomes more pronounced, especially in the context of single-author documents or Research Guarantor documents, particularly for the last author. The least disparity is noted in the case of the first author. However, the trend significantly favours female production across all counts.

A parallel pattern emerges in Table 2 concerning impact indicators. Notably, there is a more substantial variance in positions of responsibility. It should be noted that production data in this Table is accumulated up to 2020, as the metrics for the last two years are too volatile for reliable citation analysis.

Table 3 reveals a comparable trend in international collaboration, showcasing a higher level of global involvement in male production. While female production demonstrates better outcomes in terms of the Q1 percentage, a shift occurs when examining more significant roles such as Research Guarantor and Last authorship. In these instances, the tables are turned, suggesting variations in % Q1 based on gender and the specific roles within scholarly contributions (see Table 3).

Fig. 2 illustrates a variation in gender assortativity in scientific collaboration. Assortativity is the degree to which nodes with similar attributes (such as degree, age, gender, etc.) are more likely to be connected to each other within a network. Positive assortativity indicates that nodes tend to connect with others that have similar attributes, while negative assortativity suggests the opposite, where nodes preferentially connect with dissimilar nodes.

The black line represents the percentage of female authorships each year, reflecting the average within research teams. As expected, research teams generating female-authored research consistently show a higher proportion of female members, surpassing the 50 % mark and displaying a slight upward trend. Conversely, in male-produced research teams, the initial percentages start below 20 % but demonstrate a noticeable upward trajectory, notably, with teams with female authors in prominent positions, such as Research Guarantor (RG), First, and Last authorship, tend to exhibit a higher representation of female members compared to the overall average. Conversely, teams led by males seem to show the opposite effect, as depicted in Fig. 2.

Until now, the attention has been on the scientific output itself and the years of publication. Moving forward, focus should shift to researchers, examining their cumulative scientific production spanning from 2003 to 2022, with the year of publishing their first paper serving as the entry point into the system. This approach allows one to compare the production of both men and women who entered research during the same period. To ensure accuracy in author profiles, we have restricted the analysis to individuals who have published more than two papers. Consequently, the inclusion of very few authors in the last three years may result in variations in the trends of the time series for those years. It is important to note that such variations have been omitted from our interpretation of the trends.

Fig. 3 illustrates the progression of author counts based on the year of publication of their initial paper, which signifies their entry into the system. To ensure accuracy and avoid the inclusion of erroneously created profiles, only authors with a minimum of three

Table 1
Global citable outputs using various counting methods.

	Ndocc		%Ndocc		Ev. Ndocc		Ev.%Ndocc	
	Male	Female	%Male	%Female	Male	Female	%Male	%Female
Full Counting	42,638,443	28,911,189			4.49	6.43		
Fractional Counting	29,021,900	13,318,737	68.54	31.46	3.82	6.35	−0.82	1.87
Research Guarantor	25,499,903	11,157,157	69.56	30.44	4.57	7.05	−0.82	1.96
Unique	4,109,250	1,806,586	69.46	30.54	−0.98	1.70	−0.85	1.92
First	23,573,020	12,850,095	64.72	35.28	4.44	7.06	−0.98	1.89
Last	26,952,094	9,613,992	73.71	26.29	4.65	7.38	−0.76	2.23
Authors	49,236,729	30,027,019	62.12	37.88	5.69	7.82	−0.87	1.50

Table 2
Normalized impact and %Excellence 2003–2020.

	NI		Ev. NI		Exc10		Ev. Exc10	
	Male	Female	Male	Female	Male	Female	Male	Female
Complete Counting	1.36	1.28	0.81	0.81	16.08	15.70	0.76	0.51
Fractional Counting	1.05	0.98	−0.15	−0.02	12.81	12.32	0.19	0.13
Research Guarantor	1.15	1.02	−0.47	−0.35	14.14	12.83	−0.16	−0.34
Unique	0.62	0.57	−0.98	−0.10	6.93	6.72	−0.47	0.05
First	1.14	1.05	−0.43	−0.47	13.90	13.41	−0.14	−0.39
Last	1.14	1.02	−0.48	−0.28	14.08	12.84	−0.25	−0.15

Table 3
%International Collaboration and %Q1 2003–2022.

	%Int		Ev.%Int		%Q1		Ev.%Q1	
	Male	Female	Male	Female	Male	Female	Male	Female
Complete Counting	26.95	24.02	2.51	2.54	48.14	50.44	0.67	0.61
Fractional Counting	19.48	16.44	2.87	2.97	40.41	41.62	0.65	0.66
Research Guarantor	22.36	19.21	2.08	2.16	43.77	42.86	0.16	0.43
Unique					26.58	25.39	1.26	1.73
First	22.08	20.00	2.09	2.06	42.11	45.85	0.27	0.08
Last	22.70	17.95	2.06	2.46	44.01	42.07	0.14	0.56

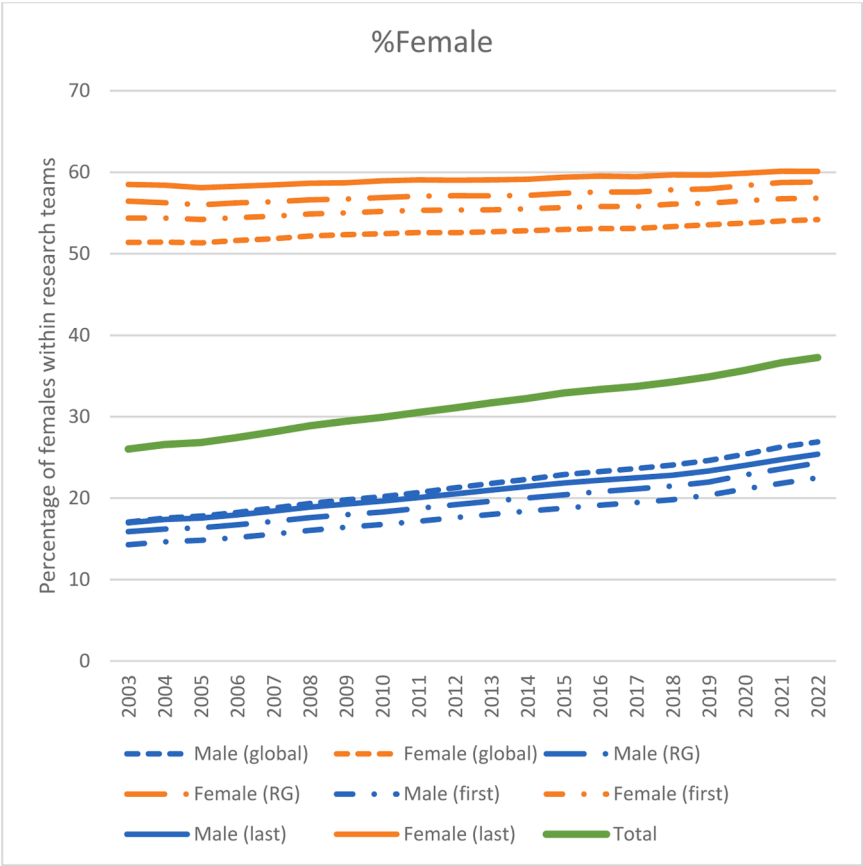

Fig. 2. The average proportion of females within research teams across scientific productions of both genders employing various counting methods.

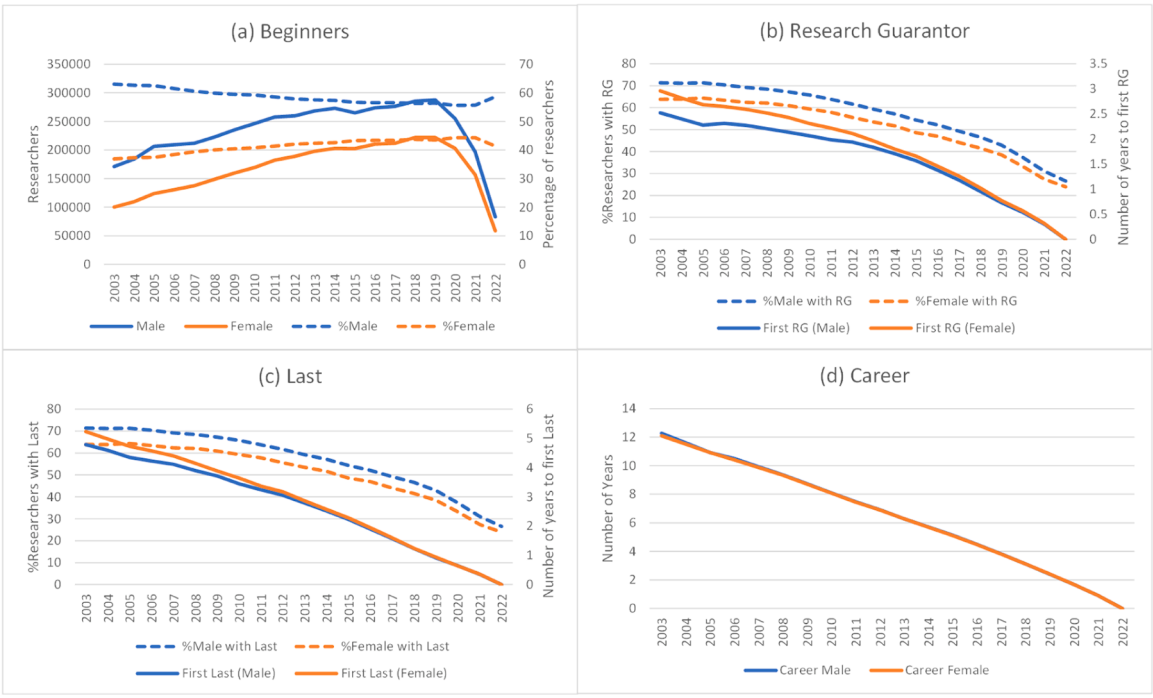

Fig. 3. The progression of author counts based on the year of publication of their initial paper: (a) the progression of author counts, encompassing those who have published a minimum of three papers, contingent on the year of their initial publication as the year of incorporation; (b) the percentage of authors with papers as Research Guarantor (RG); (c) the percentage of authors with papers as the last author; and (d) the average number of years from the first paper to the last paper.

published papers have been tallied. It is essential to note that this counting restriction has affected the last three years, as per our imposed limitation.

Fig. 3(a) suggests that, while initially more male authors are entering the system, a noticeable pattern is emerging over time that indicates a convergence in the participation of male and female authors. In other words, the gap between the numbers of male and female authors appears to be narrowing as time progresses. This trend could be indicative of changes in the field, such as increasing opportunities or a greater emphasis on inclusivity, that are leading to a more balanced representation of genders in authorship. It highlights a positive shift in the landscape, showcasing a move towards greater gender equity among authors, as evidenced by the diminishing disparity in the influx of male and female contributors over the years.

The data presented in Fig. 3(b) reveal that there is a greater proportion of male authors who have papers published under the designation of Research Guarantor (RG). Additionally, these male authors exhibit a somewhat shorter timeframe in producing their initial RG paper compared to their female counterparts. However, despite this initial disparity, the overall trend is towards a steady reduction in these gender-based differences over time. In essence, while there may be an initial discrepancy in the percentage of male authors in RG roles and the time it takes for them to produce their first RG paper, the observed trend indicates a positive trajectory towards a more equitable distribution and a diminishing gender gap in the Research Guarantor category.

A similar pattern is observed in Fig. 3(c) concerning papers as the last author, and the data presented in Fig. 3(d) provide insight into the average career duration of authors, delineated as the mean number of years spanning from the publication of their initial paper to their most recent paper. Notably, the data illustrate a noteworthy similarity in the average career duration across the observed years. This suggests that, on average, authors irrespective of gender or other factors tend to have a consistent span of years between their debut in publishing and their most recent contribution throughout the period analysed. The stability in this metric implies a certain uniformity in the longevity of the authors' careers, offering a valuable perspective on the temporal aspect of scholarly contributions and the enduring nature of authors' engagement in academic endeavours.

The trends presented in Fig. 4 indicate a decrease in the accumulated count of citable papers across all counting methods, reflecting the lower publication output of researchers who joined the field more recently and have had less time to publish. While there remains a noticeable lower productivity among women in all the counting categories, there is a diminishing gap from their male counterparts in addition to a reduction in the percentage gap. The distinction is less pronounced in single author papers but becomes more substantial in papers as Research Guarantor (RG) and Last Author, reaffirming the earlier observation that women encounter greater challenges in reaching positions of responsibility within scholarly contributions.

Table 4 provides a comprehensive overview of the average normalized impact and excellence (top 10 %) along with their trajectories, employing diverse counting methods. Similar to the approach in Table 2, the data considered extends only up to the year 2020. This limitation is imposed due to the variability in recent citations, especially considering that many authors may have a limited

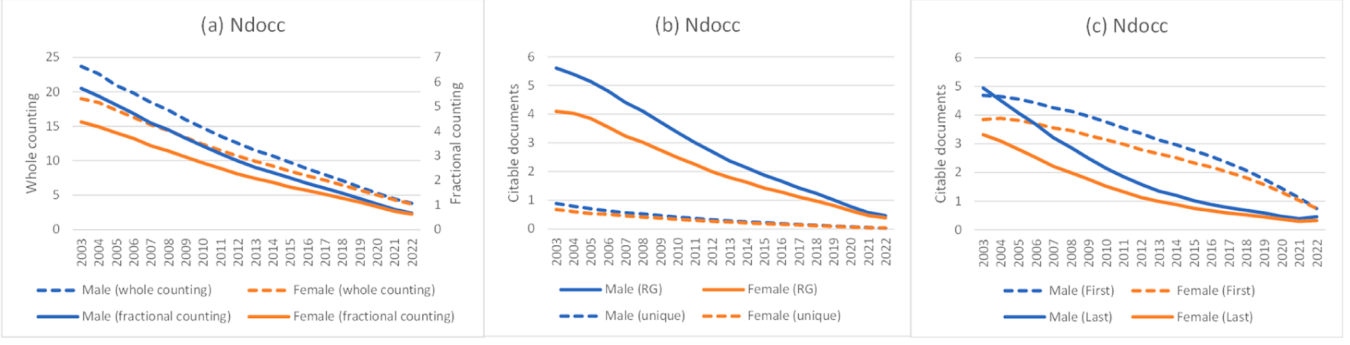

Fig. 4. The average number of citable documents per author categorized by the year of publication of their first paper, employing various counting methods. Authors included in the analysis have published more than two papers.

Table 4
Average normalized impact and percentage of excellence of authors with more than 2 published documents and their evolution, 2003/2020.

	NI		Ev. NI		Exc10		Ev. Exc10	
	Male	Female	Male	Female	Male	Female	Male	Female
Complete Counting	1.16	1.21	1.15	0.98	12.86	13.92	1.18	0.54
Fractional Counting	1.00	1.02	1.30	0.92	11.56	12.49	1.48	0.80
Research Guarantor	0.50	0.42	−2.64	−3.11	5.35	4.83	−3.29	−3.71
Unique	0.07	0.06	−8.51	−8.24	0.77	0.74	−8.55	−8.73
First	0.72	0.69	−0.09	−0.40	8.54	8.54	0.18	−0.28
Last	0.40	0.34	−4.77	−5.19	4.44	3.99	−4.74	−5.32

number of papers, rendering the citation metrics still more volatile.

In contrast to the findings presented in Table 2, which indicated a lower impact of scientific production involving women, Table 4 reveals a distinct pattern. Specifically, when comparing the cumulative production over a given period for men and women who entered scientific publication the same year, women demonstrate higher values in both normalized impact and excellence (top 10 %). This shift in results implies that the impact differences highlighted in Table 2 are primarily influenced by the variance in seniority between the male and female researcher populations.

While there is still a discernible gap when focusing solely on papers where authors hold prominent roles (Research Guarantor, single, first, and last), this nuanced insight underscores the significance of employing diverse counting methods to capture the multifaceted nature of scholarly impact and excellence. It provides a more nuanced perspective on gender dynamics in academic achievements.

Table 5 reveals similar trends in examining the percentages of international papers and Q1 publications, except for cases involving Research Guarantor (RG) and Last Authors. In these specific instances, the data show that males exhibit consistently higher values than females. Despite this exception in roles with greater responsibility such as RG and Last Author, the overarching pattern demonstrates that, in general, females consistently contribute to a greater percentage of international papers and publications in Q1 journals than their male counterparts.

Similar to Fig. 2, Fig. 5 depicts gender assortativity within research teams, illustrating the gap observed and offering a clear view of the underlying dynamics (depicted in black, the percentage of female authors from each year until the end of the period). Unlike Fig. 2 however, there is a less apparent upward trend in male cases over time, suggesting that this temporal evolution may not be solely attributable to the age of the researchers. Essentially, this implies that the observed disparity in male and female representation in Fig. 5 does not necessarily stem from a consistent increase in male authors entering the system. Instead, it may be influenced by changes in the scholarly landscape over the considered timespan. This nuanced interpretation emphasizes the importance of considering both temporal and demographic factors to comprehend the patterns of authorship and research contributions in academic settings.

The trends observed in Table 6, depicting the progression of female authorship rates across countries, do not conform to the positive correlation identified. Notably, what stands out is the intriguing observation that several countries demonstrating a more pronounced evolution in terms of increased female authorship rates also tend to possess intermediate or even low Human Development Index (HDI) rates. This unexpected pattern challenges conventional assumptions that higher levels of development are necessarily associated with greater strides in gender equity within scientific authorship.

This observation is further accentuated in Fig. 6 depicting the relationship between Human Development Index (HDI) and female authorships. While it is generally evident that high HDI countries tend to exhibit higher percentages of female authorships, the figure also reveals intriguing exceptions. Specifically, certain developing countries with relatively low HDI values showcase notably high percentages of female authorships, deviating from the expected correlation. The figure provides a nuanced visual representation of the complex interplay between HDI and female authorship percentages, emphasizing that the relationship is not strictly linear. The exceptions observed suggest that factors beyond overall development, such as cultural, educational, or policy-driven influences, play a significant role in shaping gender dynamics within scientific authorship. This nuanced perspective challenges a simplistic understanding of the correlation between development indices and gender equity, underscoring the need for a more comprehensive exploration of diverse factors influencing female participation in scientific research across the different countries.

Table 5
Average percentage of internationalization and percentage of Q1 of the authors with more than two published documents, as well as their evolution 2003/2023.

	%Int		Ev.%Int		%Q1		Ev.%Q1	
	Male	Female	Male	Female	Male	Female	Male	Female
Complete Counting	22.03	22.41	0.85	0.63	42.35	48.65	1.28	0.58
Fraqtional Counting	18.99	19.21	1.42	1.21	40.49	46.53	1.42	0.70
Research Guarantor	10.01	8.59	−2.92	−3.09	17.13	17.58	−3.99	−4.19
Unique					2.77	2.54	−8.56	−8.30
First	13.91	13.76	−0.63	−0.79	28.87	32.26	−0.38	−0.91
Last	7.69	5.72	−5.10	−5.44	13.57	12.75	−5.38	−6.11

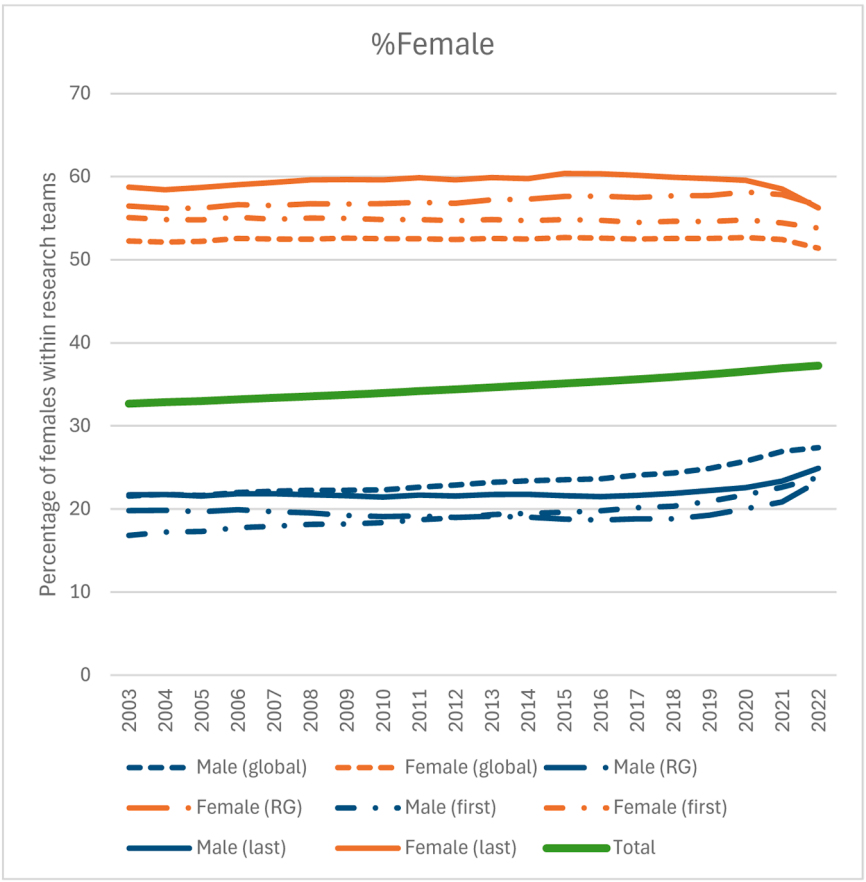

Fig. 5. Average female percentage in research teams, of researchers of both genders using different types of counts by debut year. Authors with more than two published papers.

Once the two countries with the highest percentages of authors of undefined gender, namely Thailand (49.35 %) and Indonesia (38.32 %), are excluded, a noteworthy and statistically significant positive correlation of 0.48 emerges at a 0.01 significance level (p-value is 0.00006). This correlation, contrary to expectations, stands in contrast to the evolution depicted in Table 6. In Table 6, the progression of female authorship rates across countries does not align with this positive correlation. Interestingly, many of the countries that have undergone a more pronounced evolution in terms of female authorship rates tend to have an intermediate or even low Human Development Index (HDI). It is particularly intriguing that there is a significant negative correlation of -0.40 (at p-value 0.001) between HDI and the evolution of female authorship rates. This suggests that, contrary to what might be anticipated, many developing countries are rapidly closing the gender gap in science, as evidenced by the increasing incorporation of women into scientific endeavours. This nuanced observation challenges preconceived notions about the association between a country's level of development and its progress in achieving gender equity in scientific authorship.

4. Discussion

Over the period studied from 2003 to 2022, there has been substantial growth in the scholarly contributions of both genders, with a positive trend towards achieving gender parity, particularly notable when using the fractional counting method. The difference between the number of female and male scholars has significantly declined over time. This agrees with Ioannidis et al. (2023), including their observation that data varies significantly from country to country. This shift signifies positive strides in gender inclusivity and points towards a more equitable and diverse scholarly community. Despite an initial perception that men may be more prolific when comparing the percentage of authors to production, the trend consistently favours female production across all counts, emphasizing a positive trajectory towards gender balance.

We observed that the duration of the careers for both female and male researchers is quite similar, with minimal distinctions during the initial years. This marks a noteworthy departure from the scenario outlined by Huang et al. (2020) who documented substantial variations in career length, suggesting a potential influence on productivity and impact. In contrast, our findings align more closely with those of Boekhout et al. (2021), indicating that female careers seemed shorter in earlier periods (individuals commencing research in 2000) but converged in duration during subsequent periods.

Table 6
Authors with more than two papers by country, Human Development Index and percentage of authors of undefined gender.

Country	Authors					Evolution Authors				HDI
	Authors	Male	Female	%Male	%Female	Male	Female	%Male	%Female	
China	1,859,293	988,548	674,608	59.44	40.56	7.19	8.91	−0.65	0.99	0.768
United States	1,201,597	606,794	487,617	55.44	44.56	0.52	2.16	−0.63	0.79	0.921
Germany	309,611	165,641	103,297	61.59	38.41	2.38	4.07	−0.72	1.15	0.942
Japan	297,884	199,158	70,140	73.95	26.05	−1.61	0.58	−0.31	0.88	0.925
United Kingdom	273,380	128,038	104,631	55.03	44.97	1.63	2.92	−0.40	0.49	0.929
Brazil	231,028	102,900	104,065	49.72	50.28	3.44	4.92	−0.47	0.48	0.754
India	230,542	103,580	56,014	64.90	35.10	5.88	8.27	−0.88	1.66	0.633
South Korea	199,549	114,027	60,479	65.34	34.66	2.29	4.57	−0.69	1.32	0.925
Spain	194,412	80,941	82,665	49.47	50.53	0.68	2.45	−0.58	0.58	0.905
Italy	185,385	71,422	88,177	44.75	55.25	1.18	1.66	−0.10	0.09	0.895
France	169,096	77,521	60,513	56.16	43.84	0.20	2.10	−0.52	0.68	0.903
Canada	164,478	78,923	68,598	53.50	46.50	0.76	2.39	−0.65	0.75	0.936
Russian Federation	121,107	51,507	49,424	51.03	48.97	8.03	9.85	−0.73	0.79	0.822
Australia	119,453	53,809	52,371	50.68	49.32	2.58	3.87	−0.31	0.32	0.951
Iran	118,814	63,679	39,735	61.58	38.42	4.05	9.43	−2.08	3.57	0.774
Taiwan	95,279	55,455	33,424	62.39	37.61	−1.00	−0.18	−0.26	0.44	
Netherlands	80,981	34,622	32,911	51.27	48.73	1.23	4.06	−0.99	1.06	0.941
Turkey	77,174	39,591	30,512	56.48	43.52	−1.47	1.51	−1.56	1.95	0.838
Poland	69,820	30,880	32,778	48.51	51.49	1.91	4.41	−1.66	1.54	0.876
Mexico	58,046	29,309	19,569	59.96	40.04	2.90	4.07	−0.33	0.50	0.758
Switzerland	55,512	27,745	19,869	58.27	41.73	1.79	5.00	−1.13	1.59	0.962
Malaysia	55,009	25,700	16,781	60.50	39.50	8.45	10.29	−0.69	1.08	0.803
Sweden	51,365	23,858	22,660	51.29	48.71	0.20	0.96	−0.04	0.04	0.947
Indonesia	46,177	15,712	12,769	55.17	44.83	20.53	21.81	−0.91	1.28	0.705
Belgium	44,156	20,967	17,248	54.87	45.13	1.95	3.47	−0.57	0.70	0.937
Egypt	41,174	20,548	15,627	56.80	43.20	6.67	8.87	−0.87	1.21	0.731
Portugal	40,307	16,701	18,833	47.00	53.00	3.03	4.66	−0.60	0.54	0.866
Pakistan	36,826	21,399	11,604	64.84	35.16	6.83	10.82	−1.44	2.88	0.544
Czech Republic	36,157	18,095	13,788	56.75	43.25	2.25	4.13	−1.11	1.45	0.889
Denmark	34,580	16,442	15,114	52.10	47.90	3.51	6.23	−0.89	1.01	0.948
Austria	34,460	18,036	12,372	59.31	40.69	1.96	4.09	−0.82	1.21	0.916
Israel	33,925	18,000	13,233	57.63	42.37	0.87	0.92	0.02	−0.02	0.919
Greece	32,475	16,268	11,571	58.44	41.56	−1.77	1.29	−0.82	1.16	0.887
Singapore	31,582	16,898	10,765	61.09	38.91	2.53	4.73	−0.55	0.88	0.939
Hong Kong	31,375	16,458	10,992	59.96	40.04	3.15	4.27	−0.28	0.43	0.952
Argentina	31,280	12,486	14,744	45.85	54.15	1.92	2.13	0.07	−0.05	0.842
Thailand	30,805	6877	8725	44.08	55.92	3.43	3.36	0.06	−0.05	0.8
South Africa	30,253	12,132	10,284	54.12	45.88	5.44	5.26	−0.01	0.02	0.713
Finland	30,029	13,264	13,986	48.68	51.32	0.16	1.11	−0.29	0.28	0.94
Romania	27,140	11,291	12,748	46.97	53.03	2.12	3.65	−1.28	1.12	0.821
Colombia	25,802	14,243	8837	61.71	38.29	7.84	9.04	−0.36	0.58	0.752
Chile	24,842	13,530	8359	61.81	38.19	4.62	5.82	−0.45	0.74	0.855
Ukraine	21,675	8029	7092	53.10	46.90	5.74	8.52	−1.24	1.47	0.773
Hungary	19,693	9955	7824	55.99	44.01	0.88	2.76	−0.51	0.66	0.846
Norway	19,531	8462	9301	47.64	52.36	1.28	3.33	−0.78	0.72	0.961
Ireland	19,010	8916	7611	53.95	46.05	0.98	3.53	−0.65	0.78	0.945
Nigeria	18,807	9813	3911	71.50	28.50	3.86	5.20	−0.55	1.41	0.535
New Zealand	18,271	8368	7748	51.92	48.08	1.29	2.68	−0.56	0.61	0.937
Algeria	16,535	7756	4816	61.69	38.31	5.31	7.20	−0.86	1.41	0.745
Morocco	16,169	7667	4858	61.21	38.79	11.42	14.59	−1.34	2.31	0.683
Bangladesh	16,168	9792	3305	74.77	25.23	9.31	11.31	−0.47	1.48	0.661
Saudi Arabia	15,629	9821	3887	71.64	28.36	10.34	14.34	−1.53	4.50	0.875
Tunisia	15,220	5271	7622	40.88	59.12	2.72	9.97	−3.84	2.86	0.731
Slovakia	13,653	6201	5923	51.15	48.85	4.46	5.74	−0.51	0.54	0.848
Iraq	13,231	7253	4291	62.83	37.17	20.36	24.30	−1.46	3.20	0.686
Serbia	12,212	5107	6176	45.26	54.74	2.44	4.19	−1.55	1.23	0.802
Croatia	10,597	4316	5557	43.72	56.28	−1.51	0.81	−1.45	1.11	0.858
Viet Nam	10,037	6566	2908	69.31	30.69	12.33	14.63	−0.77	1.89	0.703
Lithuania	7692	3263	3588	47.63	52.37	−2.53	−0.01	−2.29	1.95	0.875
Slovenia	7671	3607	3479	50.90	49.10	−1.38	1.57	−1.33	1.37	0.918
Bulgaria	7618	3692	3781	49.40	50.60	−0.08	−0.47	0.20	−0.18	0.795
Cuba	7186	3219	2839	53.14	46.86	−3.81	−3.96	0.35	−0.40	0.764
Peru	7131	4139	2262	64.66	35.34	8.69	8.27	−0.32	0.60	0.762
Philippines	7072	3373	2762	54.98	45.02	11.08	9.80	0.99	−1.18	0.699
Jordan	6734	4144	2068	66.71	33.29	3.46	11.06	−2.24	4.95	0.72
Ethiopia	5816	3766	689	84.53	15.47	12.77	15.56	−0.71	4.54	0.498
Ecuador	5469	3230	1855	63.52	36.48	21.91	21.77	−0.72	1.30	0.74

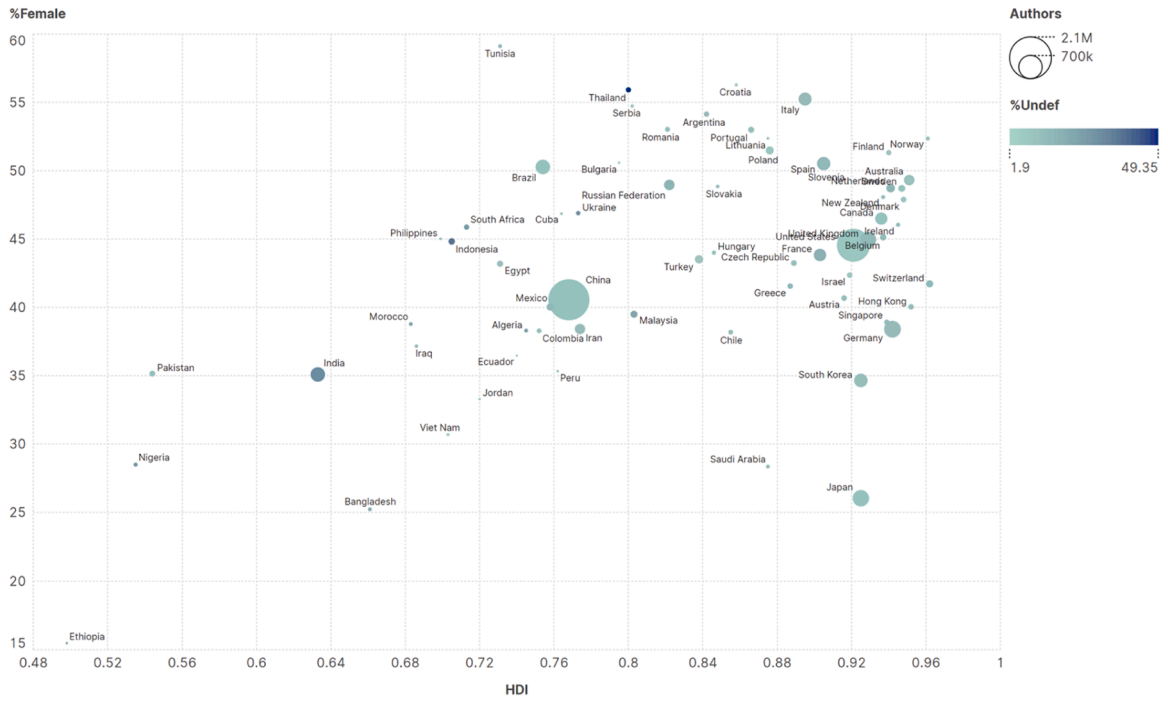

Fig. 6. Country scatter plot, %Female authors vs Human Development Index 2021. The thickness of the nodes is proportional to the number of authors and the colour to the percentage of authors of undefined gender.

Gender assortativity is notable within research teams, particularly in those generating female-authored research, where a higher proportion of female members is observed, especially when women hold significant positions such as Research Guarantor (RG), or First or Last Author. Illustrated in Fig. 3, there is an evident convergence in the inclusion of both male and female authors over time, signifying a diminishing gender gap in authorship. This trend suggests positive changes in the academic landscape, fostering inclusivity and promoting gender equity.

While initial disparities exist in roles such as Research Guarantor (RG) and Last Author, the observed trends in Figs. 3(b) and (c) indicate a steady reduction in gender-based differences over time. The data in Fig. 4 show a decrease in the accumulated count of citable papers, mainly influenced by researchers joining the field more recently. Despite lower productivity among women in all counting categories, the gap with their male counterparts is declining.

Table 4 reveals nuanced insights into the impact and excellence of scholarly contributions. Women show higher values in both normalized impact and excellence (top 10 %) when considering all positions, which challenges previous gender disparities in impact metrics. The scenario changes when only prominent positions are considered, with the results being lower in terms of impact and excellence. Table 5 indicates that, excluding roles such as RG and Last Author, females consistently contribute to a greater percentage of international papers and publications in Q1 journals, which would imply better publication habits.

Table 6 and Fig. 6 present unexpected patterns, highlighting that countries with intermediate or low Human Development Index (HDI) rates can exhibit pronounced evolution in female authorship rates. This challenges conventional assumptions about the correlation between development levels and gender equity in scientific authorship. The findings underscore the need for a comprehensive exploration of diverse factors influencing female participation in scientific research across different countries.

The study yields several implications, including:

Theoretical Implications:

- The observed positive trend towards achieving gender parity in scholarly contributions over the studied period suggests a shift towards a more equitable and diverse scholarly community. This aligns with theoretical frameworks emphasizing the importance of promoting inclusivity and diversity in academia for enhancing research quality and innovation.
- The convergence in career duration between female and male researchers challenges previous notions of substantial variations in career length and its potential influence on productivity and impact. This underscores the need for further theoretical exploration into the factors shaping career trajectories and their implications for gender equality in research.

Practical Implications:

- The diminishing gender gap in authorship and the higher proportion of female members in research teams generating female-authored research indicate positive changes in the academic landscape towards fostering inclusivity and promoting gender equity. Practically, this suggests the importance of creating supportive environments and policies that facilitate gender-balanced research teams and promote equitable opportunities for all researchers.
- The observed reduction in gender-based differences in roles such as Research Guarantor and Last Author over time highlights the effectiveness of efforts aimed at addressing gender disparities in academic leadership positions. Practically, this underscores the importance of implementing policies and initiatives that promote gender diversity in leadership roles within academia.

Policy Implications:

- The unexpected patterns in female authorship rates across countries with varying levels of Human Development Index challenge conventional assumptions about the correlation between development levels and gender equity in scientific authorship. This calls for policy interventions aimed at addressing gender disparities in research participation across diverse socio-economic contexts. Policymakers need to consider the nuanced factors influencing female participation in scientific research and tailor interventions accordingly to promote gender equity in academia globally.
- The higher values of normalized impact and excellence among women in scholarly contributions challenge previous gender disparities in impact metrics. Policymakers should consider incorporating gender-sensitive evaluation criteria and metrics in research assessment frameworks to ensure equitable recognition and advancement opportunities for female researchers.

Overall, the findings presented in the study have theoretical, practical, and policy implications that contribute to advancing our understanding of gender dynamics in academia and inform efforts aimed at promoting gender equality and diversity in research.

5. Conclusions

In this study, we have noted a slightly lower productivity among females, but with increased international collaboration, a greater percentage in the top quartile (%Q1), and a greater overall impact. Additionally, the study indicates a slightly less favourable performance by females in leadership roles. Lastly, a significant gender assortativity is observed within research teams. While assortativity has decreased over time when considering the entire dataset, it remains higher and decreases at a slower rate around leadership figures.

In conclusion, the comprehensive analysis of scholarly contributions from 2003 to 2022 reveals encouraging trends towards gender equity and diversity in academic authorship. The adoption of the fractional counting method highlights a positive shift, drawing closer to a balanced gender representation, emphasizing the evolving landscape of scholarly output. The increasing scholarly contributions from both genders signify a progressive environment fostering diverse participation, showcasing the potential for a more equitable and inclusive scholarly community.

Despite an initial impression of male prolificacy when comparing authors to production percentages, the consistent favouring of female production across various counts indicates a significant positive trajectory towards gender balance. This pattern extends to research teams, where teams with female authors in prominent positions exhibit higher female representation, underlining a positive correlation between gender balance and leadership roles.

This study has shown that the convergence in male and female authorship participation over time is changing the academic landscape, prioritizing inclusivity. Disparities in roles such as Research Guarantor (RG) or Last Author diminish over time, reflecting positive trends in gender-based differences. The decrease in the accumulated count of citable papers, particularly influenced by recently joined researchers, indicates a narrowing gap in productivity between genders.

Noteworthily, this study challenges previous gender disparities in impact metrics, indicating that when considering all authors, women demonstrate higher impact and excellence (top 10 %), and it highlights consistent female contributions to international papers and Q1 publications except in roles such as RG and Last Author. This nuanced understanding emphasizes the multifaceted nature of scholarly impact and excellence across genders.

Surprisingly, this study also challenges conventional assumptions about the association between a country's Human Development Index (HDI) and progress in achieving gender equity in scientific authorship. Developing countries with intermediate or low HDI rates demonstrate pronounced evolution in female authorship rates, suggesting the influence of diverse factors beyond just overall development.

In summary, the study indicates positive trends towards gender equity in scholarly contributions, which might indicate changing academic landscapes and more inclusive practices. The findings call for continued efforts to foster diversity, challenge assumptions, and explore multifaceted factors influencing gender dynamics in scientific research across different countries. The nuanced approach presented here encourages a comprehensive understanding of gender participation in academia for informed policy and practice.

5.1. Study limitations

The study relies heavily on the availability of information on given names, and the ability to infer gender from these. The coverage of given name data in some of the countries is improvable, and some countries were left out of the study for this reason. Main science

producers are nevertheless above the limits that other authors have considered acceptable. Other possible limitation stems from the difficulty of assigning gender to names from some Asian countries. This might affect the accuracy of gender detection locally, which has been reported in detail by Nakajima et al. (2023) in a recent study. Although our tests did include a representative number of Asian names and the results are nevertheless good, it's an issue that we will try to improve in the future.

5.2. Further study

A promising avenue for future research involves investigating the extent to which disruption and novelty vary across genders in academia and technology. Understanding how different genders contribute to disruptive innovations and novel advancements can provide valuable insights into the dynamics of gender representation and innovation in these fields. In academia, exploring the role of gender in driving disruptive research paradigms and groundbreaking discoveries can shed light on potential gender biases and barriers to innovation. Research could delve into the extent to which female and male researchers engage in disruptive research practices, the types of innovations they produce, and the impact of gender diversity on research outcomes. Similarly, in the technology sector, investigating gender differences in disruptive technologies and novel technological advancements is crucial for understanding the factors shaping innovation and entrepreneurship. Research could explore the representation of women in tech startups, their involvement in disruptive technologies, and the barriers they face in accessing funding and resources for innovation. Additionally, examining the impact of gender diversity on the development and adoption of disruptive technologies can provide valuable insights into the role of diversity in driving technological innovation. By examining disruption and novelty through a gender lens, future studies can contribute to a more nuanced understanding of gender dynamics in academia and technology and inform efforts to promote gender equality and foster innovation in these fields. This research has the potential to identify strategies for increasing the participation of women in disruptive research and technology entrepreneurship, ultimately leading to more inclusive and innovative academic and technological landscapes.

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CRediT authorship contribution statement

Rodrigo Sánchez-Jiménez: Writing – review & editing, Software, Methodology. **Pablo Guerrero-Castillo:** Software, Data curation. **Vicente P. Guerrero-Bote:** Visualization, Software, Methodology, Funding acquisition, Conceptualization. **Gali Halevi:** Writing – review & editing. **Félix De-Moya-Anegón:** Supervision, Funding acquisition, Conceptualization.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.joi.2024.101556.

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