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The woman's researcher tale: A Review of Bibliometric Methods and Results for Studying Gender in Science

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1. **Introduction**

Gender self-identification plays a crucial role in shaping the opportunities and choices scholars make throughout their academic careers (Beddoes & Pawley, 2014). Women [1] often perceive their careers as hindered, while the image of the scientist as a man is socially elevated (Boekhout et al., 2021). This situation has led to an increasing demand for "solid quantitative support to what is intuitively known" (Larivière et al., 2013). Although bibliometrics have some limitations, they have become a valuable tool for analyzing the status of women in science, providing insights into patterns, trends and disparities.

Studies on gender inequality are highly politicized and extremely difficult to grasp due to the dynamic nature of the subject. These barriers are overcome in various ways, some more controversial than others. There are instances where gender differences are not acknowledged or are simply denied. A well-known case is the Strumia study, which suggests biological differences as the reason for observed gender gaps (Strumia, 2021; Andersen et al., 2021). The difficulty of generalizing within bibliometric research exacerbates this issue.

Data limitations, an overreliance on descriptive analyses, and contradictory reports based on specific country or field case studies highlight these difficulties (Nygaard et al., 2022b). Most studies focus on Western countries, providing little evidence from other regions (Prozesky & Beaudry, 2019), and there are disciplinary biases, as most studies concentrate on STEM fields. Nonetheless, there is a consensus that gender differences are present in most aspects in academia, though causes behind these differences remain unclear.

There have been targeted literature reviews covering the broad scope of gender and bibliometrics, from approaches that focus on identifying gender and analyzing bibliographic data (Halevi, 2019) to studies on specific elements such as productivity and performance (Nygaard et al., 2022a), funding (Cruz-Castro et al., 2022), and gendered specialties during education (Alers et al., 2014), among other aspects. Some research has also conducted meta-analyses, drawing conclusions from literature on gender in science (Astegiano et al., 2019). The aim of this review is to provide a comprehensive and updated examination of the use of bibliometric methods to study gender differences in science and their results. This review distinguishes itself from previous literature by systematically addressing both the methodological challenges and substantive findings related to gender disparities in scientific research. Our goal is to summarize the main methodological advancements in the study of gender through bibliometric methods, describe their key findings, identify gaps, and propose future research directions.

This narrative review is structured into four sections. The first section examines various methodological approaches used to analyze gender differences in science, including gender identification, units of analysis, and methods employed to address causality. The second section focuses on gender differences in specific research activities, underlying mechanisms behind these differences, and the overall effects of gender inequality, as reported by bibliometric studies. The discussion section provides an overview of the literature review, integrating findings from different studies and highlighting any convergences and divergences in the results. We conclude by discussing the limitations of current methodologies and findings to propose a future research agenda with potential directions to address the identified gaps.

This work offers several novel contributions to the field. First, it examines a wide range of methodological approaches, from traditional bibliometric analyses to more recent techniques such as gender assignment or refined designs for identifying causality. This provides a comprehensive overview of the tools available for studying gender disparities. Second, it offers a global perspective on gender inequality in science by considering studies from diverse regions. Third, it includes a detailed examination of gender disparities across various disciplines, highlighting both the unique challenges faced by women in STEM fields and the commonalities across different research areas.

2. Methodological approaches

Studies on gender inequality face a series of methodological challenges crucial for interpreting their findings, such as gender identification based on metadata, selection of the unit of analysis and methodological design in explanatory studies. This section will delve into how these have been solved in the literature.

2.1. Gender identification

Here we explore two key aspects when identifying gender: the metadata needed from bibliographic records to infer gender, and the algorithmic approaches followed for assigning gender to authors.

2.1.1 Metadata. Data on gender is usually unavailable in bibliographic metadata, thus studies infer them from indirect metadata following basically four different approaches. The most common one consists of using author and affiliation data. Thanks to the inclusion of full names in bibliometric databases, researchers' gender can be estimated, showing the probability that a name corresponds to a particular gender. For instance, Web of Science introduced this linkage in 2007 (searchable since 2011) and Scopus included author full names in May 2022. Other databases commonly used in gender studies include arXiv (Holman et al., 2018), PubMed (Andersen et al., 2020), ProQuest (Liu et al., 2023a), OpenAlex (Song et al., 2024) or Google Scholar (Andersen & Nielsen, 2018).

A second technique uses given names as input to search for pictures in search engines (Kong et al., 2022), or to retrieve individuals' images from their own personal or institutional websites (van den Besselaar & Sandström, 2017). Both approaches assume a relation between names, facial characteristics, and gender. Moreover, they adopt a binary stance of the researcher's gender: man, woman, or unknown if the information is unclear, which might obscure other gender identities leaving no room for self-identification.

To overcome this limitation, a third approach, although less common, is based on pronouns used by authors for self-identification. Pronouns are not available in bibliometric databases but can be found in external data sources such as personal websites or social media (e.g., X, LinkedIn). Maliniak et al. (2013) and Azoulay & Lynn (2020) used this data to assign and validate gender. The fourth kind of approaches are more direct but less common given their time-consuming nature and do not guarantee a complete dataset. Researchers may be surveyed and asked for their gender (Zheng et al., 2022). For example, when the researcher's gender was not clear, Amering et al. (2011) asked colleagues who knew the researchers in question.

2.1.2 Methodological approaches for gender assignment. Most methods for gender identification focus on given names as the primary means of assignment. These methods involve matching names against a pre-existing database containing a comprehensive collection of names associated with assigned genders or probabilities thereof. Refinements to this approach often incorporate geographical information derived from affiliation metadata, allowing for a more nuanced understanding and avoiding overgeneralizations. For example, the name 'Andrea' is generally assigned to women except in Italy, where it is common among men. The inclusion of last names enhances accuracy in some regions, such as Slavic countries, and some algorithms include a temporal dimension, recognizing that gender-name relationships change over time (Blevins & Mullen, 2015).

Many studies use third-party algorithms (like GenderAPI or Genderize.io) and only few develop their own methods for gender assignment. To this aim, they use existing lists of names assigned to men or women in different countries such as the US

Census. While some algorithms provide binary classifications, most offer the probability of a given name being assigned to a given gender. Table 1 shows a non-comprehensive list of the most used gender assignment services and algorithms.

Table 1 *Non-comprehensive list of gender identification services.*

Algorithm	**Information used (type of result)**	**Access**	**Regular Updates (last update)**	**Data sources**	**Size**	**Link**
Gender API	Name (Percentage)	Private	Yes	Publicly available data, governmental data and manual additions/corrections	6,084,389 (190 countries)	https://gender-api.com/
Genderize.io (Ozan Soft)	Name (Percentage)	Private	Yes	Open to the general public government sources	4.079.646 (188 countries)	https://genderapi.io/ http://cran.nexr.com/web/packages/genderizeR/vignettes/tutorial.html
Gender Guesser (NamSor)	Name (Percentage)	Private	?	?	9 billion (249 countries)	https://gender-guesser.com/
Gender-guesser (gender.c)	Name (Unknown, androgynous, female, male, mostly_female, mostly_male)	Public	No (2016)	Nam_dict.txt	44.568 names	https://pypi.org/project/gender-guesser/
NameAPI (Optimaize)	Name (Percentage)	Private	Yes	Phone books, national government publications, websites on the subject, local freelancers	590.000 (55 countries)	https://www.nameapi.org/

Gender-detector (Open Gender Tracking)	Name (Binary)	Public	No (2015)	Social Security Administration (USA) Office of National Statistics (UK) Northern Ireland Statistics and Research Administration (UK) Scotland General Register Office (UK)	125.000 (2 countries)	https://pypi.org/project/gender-detector/
Sexmachine (Python)	Name (Androgynous, male, female, mostly_male, mostly_female)	Public	No (2013)	Nam_dict.txt	44.568 names	https://pypi.org/project/SexMachine/#description
Gender (CRAN)	Nam (Percentage)	Public	No (2011)	First names and dates of birth using historical datasets (U.S. Social Security Administration, the U.S. Census Bureau (via IPUMS USA), and the North Atlantic Population Project)	339,967 (from 1789-1930) 91,210 (from 1930 onwards)	https://cran.r-project.org/web/packages/gender/
Genni + Ethnea for the Author-ity 2009 dataset	Name (two methods: binary and Androgynous, male, female, mostly_male, mostly_female)	Public	No (2018)	Sex-machine data and US Social Security Administration	9,300,183 names	https://databank.illinois.edu/datasets/IDB-9087546

World Gender Name Dictionary	Name	Public	Yes	34 groups of national databases (full detailed list available on their Github)	25,000,000 names (195 countries/territories)	https://github.com/IES-platform/r4r_gender
Wiki-Gendersort	Name (Masculine, Femenine, Unisex, Initials, Unknown)	Public	No (2018)	Wikipedia (English) first names	694 376 names	https://github.com/nicolasberube/Wiki-Gendersort
Genderchecker	Name (Male, Female, Unisex)	Private	No (2011)	2001 and 2011 UK census data.	102,240 names	https://genderchecker.com/
Face++	Face (Binary)	Private	?	?	?	https://www.faceplusplus.com/

2.1.3 Key points and considerations. There are issues with the binary stance most studies assume, as gender is not a binary category (Lindqvist et al., 2021). The She Figures 2021 report highlighted the need to consider non-binary gender data (European Commission, 2021). Over the past decade, researchers have become more aware of how a binary conception of gender can bias their findings and the limitations of gender assignment algorithms (Halevi, 2019).

Some of these approaches do not work well in certain Asian and Sub-Saharan African countries, or Brazil (Andersen et al., 2019; Larivière et al., 2013), potentially biasing the results and creating research gaps in these regions. Gender identification lists are not inherently global. Karimi et al. (2016) suggest using separate gender identification models for each language. Moreover, a researcher`s affiliation may not reflect their country of origin nor origin of their name (Boekhout et al., 2021). Furthermore, names will indicate perceived gender, but will not provide information about legal or self-defined gender.

Many gender assignment algorithms are privately-owned, updated regularly and work relatively well, but they lack transparency and accessibility for many researchers (González-Salmón & Robinson-Garcia, 2024). Alternative and open methods tend to use smaller databanks, centered on English-speaking countries (e.g., Gender-detector, Genderchecker) or end up being abandoned (e.g., OpenGenderTracking Project, SexMachine).

Databases used by algorithms are crucial for measuring their accuracy. For instance, Wikidata information may suffer from biases translated from Wikipedia, which overrepresents men (Tripodi, 2023; Zheng et al., 2023). Although gender self-identification seems the most accurate approach (Van Buskirk et al., 2022) it is also the least exhaustive and most resource intensive. Some authors propose a self-declared gender identification database for each journal (Ribarovska et al., 2021), while others include disclaimers stating that the notion of "gender" used in their research does not refer to the authors' self-identification (Kong et al., 2022).

Finally, efforts have been made to combine different approaches to overcome the inherent limitations of each method (e.g., Chan & Torgler, 2020; El-Ouahi & Larivière, 2023; Ma et al., 2023; Zhao et al., 2023), which may be the most robust way to gain higher precision and exhaustivity in gender assignment (Karimi et al., 2016).

2.2. Unit of analysis

Choices regarding operationalization are crucial because certain publication practices appear to be influenced by gender. Results will vary depending on the unit of analysis observed, which refers to the object or sampling unit described by variables for making inferences (McGrath, 2005, p. 263) or describing. Here, we discuss the main units of analysis used in bibliometric research on gender: publications, authorship, individual researchers, and citations or references.

2.2.1 Publications. Researchers aim to determine how many publications are generated over a certain period by using them as a unit of analysis. But the operationalization of this unit varies across publications (Sugimoto & Larivière, 2023). Some research looks at first authors to create a categorical variable, identifying a paper as written or led by women when they are first authors, and vice versa (Caplar et al., 2017). Variables can also include combinations such as male-male, female-female, male-female, and female-male when two first authors contributed equally (Broderick & Casadevall, 2019). Other approaches count papers multiple times, assigning as many genders to papers as there are authors (Kong et al., 2022), determine a percentage based on the number of men and women in the author byline (Ruggieri et al., 2021), or create a woman-to-man author ratio for each publication (Demaine, 2021).

2.2.2 Authorship. Gender assignment allows researchers to determine authorship, which is basic for constructing indicators. For instance, the Centre for Science and Technology Studies (CWTS) at Leiden University assigns gender to each authorship in their universities ranking, thereby measuring universities' gender diversity and generating different types of indicators: the number of authorships at a university, the number and proportion of authorships belonging to women and men, and the number of authorships whose gender is unknown (Van Eck, 2019). Other studies use this unit of analysis to examine the gender composition of each authorship position (West et al., 2013), sometimes focusing on key positions such as first, last, and corresponding authorship (Bendels et al., 2018b).

2.2.3 Individual researchers. Researcher as unit of analysis implies carrying out an author name disambiguation as to group an individual researcher's outputs and information (Tekles & Bornmann, 2020). For example, Cameron et al. (2016) depart from a list of authors publishing in six journals from ecology and then link them to their Author ID using Scopus. In this way, they assess productivity differences between genders. Spoon et al. (2023) use a different approach, by retrieving individuals' career history from faculty census to study faculty retention in the United States.

By focusing on individuals as the unit of analysis, Holman & Morandin (2019) investigate gender homophily in collaboration patterns. On a similar line, Mihaljevic-Brandt et al. (2016) recreate publication histories of Mathematicians using the zbMATH database and examine differences in collaborations patterns and research topics. Another perspective is followed by Chan & Torgler (2020), who use career-citation metrics (excluding self-citations) to look for gender differences in the academic success for highly cited authors. Conversely, Mishra et al. (2018) study the role of self-citations by gender. They do so by assigning gender to a list of highly productive authors and then computing the share of self-citations they produce. In this case they use a probabilistic disambiguation algorithm applied to publications in PubMed to identify the publication history of authors.

2.2.4 Citations and references. Another way to examine gender differences is to focus on citations as the unit of analysis. Here gender is assigned to papers or authors referenced by a core group of publications. For example, Wang et al., (2021), retrieved publications from 14 communication journals, extracted their list of references and identified the gender of first and last authors of cited publications. This allowed them to investigate gender differences in citation patterns. Dion et al. (2018) followed a similar approach to investigate how the gender composition of fields would affect gender disparities in referencing patterns. That is, whether fields with a higher representation of women would produce a smaller gender citation gap. Another approach is that of Nettasinghe et al. (2021), who use the Microsoft Academic Graph and the list of publications from journals of the American Physical Society to create an author-citation networks to study citation disparities and the role of homophily and preferential attachment within and between genders and authors affiliated to highly ranked institutions in the Shanghai Ranking.

2.2.5 Key points and considerations. The choice of unit of analysis will allow studying different aspects related to gender in academia: differences in citation rates, productivity, career gaps, or differences among groups of authors. Declaring the unit of analysis and comparing findings with papers using the same approach, is key to avoid inconsistent comparisons across the literature. Nygaard et al. (2022b) refer to this as the distinction between the "what" and the "who," emphasizing the importance of avoiding comparisons between fundamentally different entities. Establishing a clear unit of analysis is essential to avoid errors like comparing results on productivity differences with citation patterns which will mislead any conclusion drawn from such analyses (McGrath, 2005). This lack of rigor may partly explain why many studies yield contradictory conclusions (Ceci et al., 2014; Nygaard et al., 2022b).

2.3. Causality, biases and differences

Most bibliometric studies combine both descriptive and causal approaches (e.g., Andersen et al., 2019; Bagues et al., 2014). However, some publications rely more heavily on descriptive analysis (e.g., Bendels et al., 2018a; Mason & Goulden, 2002), while others emphasize causal analysis (e.g., Ceci & Williams, 2011; Squazzoni et al., 2021). Various methodologies are used to analyze gender differences. Among the most common are regression analyses (Aksnes et al., 2019; Brommesson et al., 2022), counterfactual inference (Buchanan et al., 2016; Huang et al., 2020; Sarsons et al., 2021), matching techniques (Andersen et al., 2019; Frandsen et al., 2020), survival analysis (Hart et al., 2019; Kaminski & Geisler, 2012), scientific mapping (e.g., Bagdi et al., 2023), co-citation (e.g., Nguyen et al., 2021), logistic regression (e.g., Sebo et al., 2020), difference in differences (DID) (Liu et al., 2022; Madsen et al., 2022), propensity score matching (Dorantes-Gilardi et al., 2023; Krapf et al., 2017) or cluster analysis (e.g., Sandström, 2009).

While gender differences are influenced by multiple factors (Ceci et al., 2014), studies often focus on specific causes while controlling for other variables. This approach can be problematic because control variables may not be fully independent, limiting the capacity of such analyses to "uncover mechanisms that produce the gender disparities" (West et al., 2013, p. 6), and masking potential mediation effects between different variables (Zheng et al., 2022). The issue is contentious since differences may not always lead to biases or disparities, and not all differences necessarily represent unfairness (Traag & Waltman, 2022). Generally, studies that go beyond descriptive analysis attempt to uncover gender differences related to biases, discrimination, and other factors (Boekhout et al., 2021).

In any case, whether explicitly or not, causality is understood in terms of social structure. Explicit uses of "social structure" can be found in studies by Dong & Li (2023), Sato et al. (2021) and Whittington (2018). But there is no uncontested definition of "social structure". Ritchie (2020) defines it as networks of social relations that, along with individual agency, explain causes for outcomes (Ross, 2024). The scientometric literature on gender assumes that social structure is inherently causal and that each social group experiences a different social structure based on their gender. This constrains individuals and limits their capacity to influence these conditions (Ross, 2024). Hence, changes in the social structure will alter the conditions of the population, and some degree of causality is assumed and accepted.

3. Findings

Having explored the methodological approaches in the previous section, we now turn our attention to the specific findings of gender-focused bibliometric studies. Understanding where and how gender differences manifest in academic authorship, research activities, and professional opportunities is crucial for developing effective strategies to address these disparities. In the following section, we group papers based on the differences they identify, the factors that explain these differences, and the consequences arising from such disparities.

3.1. Gender differences

Firstly, research asks itself where gender differences occur in academia. Most studies reviewed below delve into this issue. Others try to go deeper and after confirming such differences, they try to locate how deep down they are entrenched in academia. Here we find studies looking into differences in the social structure of science, which may influence what we later observe.

3.1.1 Authorship. Authorship order decisions are entangled in social relationships and present gendered characteristics that disadvantage women (e.g., Demaine, 2021; González-Álvarez & Cervera-Crespo, 2017). It is important to consider that disadvantages for women's authorship vary by discipline. For instance, women's position and presence in the byline have not changed significantly despite their increasing presence in fields such as Economics (Boschini & Sjögren, 2007), Pediatrics (Fishman et al., 2017), or Medicine (Jagsi et al., 2006). Conversely, an increase in women in academia correlates with an increase in their overall authorship in other areas, such as Dermatology (Feramisco et al., 2009).

In STEM fields the situation is more pronounced. Ghiasi et al. (2015) found that women constituted 20% of total authorship in Engineering. Mihaljević-Brandt et al. (2016) found that women publish fewer solo-authored publications in Mathematics, a field where single-authored papers are still common. Cavero et al. (2015) showed that women's authorship in Computer Science increased from 3% to 16% over 50 years (1966-2009), but they argued this positive trend might slow down. Bendels et al. (2018b) showed that in the Life Sciences, Multidisciplinary, Earth & Environmental Sciences, and Chemistry categories from the Nature Index, women represented almost 30% of authorships.

Research indicates that overall, women's underrepresentation as first authors has decreased in recent decades (Broderick & Casadevall, 2019; Colwell et al., 2020; Sidhu et al., 2009), though significant differences exist by field. There is an overrepresentation of women in first author positions in medical fields such as Neuroscience, Neurology, or Psychiatry (Marescotti et al., 2022) and an underrepresentation in others such as Entomology (Walker, 2020). Additionally, countries with a higher overall proportion of women as first authors tend to have sharper first-authorship differences between fields, leading to a "gender equality paradox" (Thelwall & Mas-Bleda, 2020). Disadvantages are also observed in corresponding authorship. Even when women are the first authors, they are less likely to be corresponding authors (Chinchilla-Rodríguez et al., 2024; Fox et al., 2018; Morillo et al., 2024). In difficult circumstances, such as the COVID-19 pandemic, men assumed a greater role as corresponding authors than women (Bell & Fong, 2021). However, studies here are limited and tend to be field-specific. This is not the case with last authorship, where there is abundant and uncontested evidence pointing towards a disproportionate number of men over women (Bendels et al., 2018b; González-Alvarez & Sos-Peña, 2020; West et al., 2013).

Authorship position is a critical factor for research career prospects (Milojević et al., 2018). Collaborative papers with mixed authorship tend to be first-authored by men (Broderick & Casadevall, 2019), while the presence of women in the byline increases the likelihood of having a higher number of women co-authors (Aakhus et al., 2018; González-Alvarez & Sos-Peña, 2020; Sugimoto & Larivière, 2023; Zettler et al., 2017). For example, in Ecology and Zoology journals in Latin America, the presence of women in the byline depends strongly on the gender of the last author (Salerno et al., 2019). Women also face further constraints, as they are more likely to experience authorship disagreements, and men are more likely to determine authorship unilaterally (Ni et al., 2021). Additionally, women are less credited than men with authorship for the same type of contributions (Ross et al., 2022), resulting in a higher "time-to-credit payoff" and fewer publications during PhD stages (Feldon et al., 2017). Dissatisfaction with authorship attributions is related to the academic position and gender of authors (Smith et al., 2020). As the motivation to work in research teams may depend on perceived risks and gains (Feng & Kirkley, 2020), this devaluation of women's work creates cumulative disadvantages in scientific careers, especially for early-career researchers (Fleming, 2021).

3.1.2 Productivity. Women are generally less productive than men (Abramo et al., 2009; Astegiano et al., 2019; Campbell & Simberloff, 2022; Ceci et al., 2014; Huang et al., 2020; Nakhaie, 2008; van den Besselaar & Sandström, 2016; Xie & Shauman, 1998). This difference is confirmed across most studies and it is field-specific (Duch et al., 2012). It typically appears from early career stages (Symonds et al., 2006) and across different publication types (Mayer & Rathmann, 2018).

Specialization impacts productivity (Zeng et al., 2019). Women tend to publish in a wider range of topics (Leahey, 2006), exhibit different publication patterns (Mayer & Rathmann, 2018) and perform a broader range of tasks. They engage more in teaching and administrative work than men and volunteer twice as often for non-promotable tasks (Vesterlund et al., 2014), a phenomenon known as "academic housework" (Heijstra et al., 2017). This leads to double discrimination in university recruitment processes (Brommesson et al., 2022), where women are expected to undertake more teaching and administrative tasks, which are then undervalued during evaluations.

3.1.3 Citations. Citations are one of the areas where we find less consensus. Citation differences vary by field and much attention has been paid to citations in STEM disciplines. The analysis by Kuchanskyi et al. (2023) focused mainly on STEM publications and showed that articles predominantly authored by men were cited more than those with more women authors. Additionally, Bendels et al. (2018b) found that articles in certain STEM categories of the Nature Index with key women authorships were cited less than those with key men authors. In Physics, papers authored by women are under-cited, while those authored by men tend to be over-cited (Teich et al., 2022), possibly because men started publishing earlier in their careers (Kong et al., 2022). Similarly, in Astronomy, papers written by women receive fewer citations than if written by men (Caplar et al., 2017).

The situation is unclear in the Life Sciences. Andersen et al. (2019) found almost no gender differences in citations in Medicine when adjusting for other variables. In contrast, Chatterjee & Werner (2021) reported that articles written by women published in high-impact journals were less cited than those by men. Although gender bias in citations is less common among younger scientists, it still contributes to making women's research less visible (Zhou et al., 2024). Less research has been done on Social Sciences, Humanities and Arts. However, there is evidence that women are under-cited in fields such as International Relations (Maliniak et al., 2013) and Communication (Wang et al., 2021).

Citation behavior seems to vary depending on the gender of citing authors, field and journal (Teich et al., 2022), sometimes leading to gender homophily. In the field of Communication in Germany, men cite other men more than women cite women (Potthoff & Zimmermann, 2017). Men's citation practices seem to contribute to the under-citation of women (Dion et al., 2018; Dworkin et al., 2020). This gender homophily in citations has been found in all scientific fields (e.g. Ghiasi et al., 2018), and tends to prevail in every discipline when excluding self-citations and career gaps (Cameron et al., 2016). This could lead to an uninterrupted disparity since men tend to publish more during their careers (Wu, 2024).

Other variables into consideration are geography, productivity and career stage. Thelwall (2020) analyzed gender differences in six English speaking-countries showing that "[i]t is rare for field citation advantages to be dominated by one gender in a country" (p. 610). Chan & Torgler (2020) studied 21 fields in 43 countries, concluding that amongst top scholars, citation inequality was higher than productivity inequality. Regarding elite authors, results are somewhat contradictory: Aksnes et al. (2011) found fewer citation differences among the most productive researchers, while Ioannidis et al., (2023) reported significant citation differences among top-cited authors. Moreover, the role of career stage is closely linked to productivity. Gender citation gaps are smaller at the early career stage and tend to increase with career progression, mirroring productivity between genders (Wu, 2023). Larivière et al. (2011) also noted this trend in Québec University, observing that, after the age of 38, women are disadvantaged in citations.

Research on the role played by self-citations is also contradictory. Some studies found that men self-cite more than women (King et al., 2017) while others claimed the opposite (Caplar et al., 2017). Some reported no differences (Mishra et al., 2018) or have not found a positive impact of self-citations on career outcomes given gender (Azoulay & Lynn, 2020). At the same time, some encourage women to self-cite more (Cameron et al., 2016), while others believe this will not necessarily translate into scholarly gains (King et al., 2017).

3.1.4 Contributions. Research examines author contribution statements to investigate women's roles in research teams (Allen et al., 2019), but contributor role taxonomies are not widely implemented (Hosseini et al., 2023). Macaluso et al. (2016) found that women tend to perform experiments more frequently than men, a trend that remains constant throughout their scientific career. Women are more likely to carry out technical work and write the original draft, while men are more likely to review and edit the manuscript, acquire funding, provide resources and supervise projects (Larivière et al., 2021; Sugimoto & Larivière, 2023).

Gender inequalities among authors who made equal contributions raise concerns about women not receiving proper credit for publications, suggesting a need for journals to clarify the method used to determine author order (Broderick & Casadevall, 2019). Similarly, Paul-Hus et al. (2020) found that women are heavily underrepresented in the acknowledgement sections. These differences in role distribution affect women's career prospects, as they are less likely to be seen as leaders during early and middle career stages, which is crucial for long-term academic success (Robinson-Garcia et al., 2020).

3.1.5 Academic rank and career advancement. It is assumed that gender parity will happen as the number of women in academia increases (Sugimoto & Larivière, 2023). However, the number of women progressing from tenure to full professorship has not "kept pace with their rise in numbers in academia" (Bonawitz & Andel, 2009, p.2). This phenomenon, known as the "leaky pipeline" (Corona-Sobrino et al., 2020; Mihaljević-Brandt et al., 2016; Spoon et al., 2023), sees women dropping out of academia as they progress, with many of them leaving right after graduate school (Mengel et al., 2019) and not reaching seniority (Aramayona et al., 2022). According to Marini &

Meschitti (2018), these differences cannot be explained solely in terms of productivity. In fact, Huang et al. (2020) conclude that higher dropout rates may explain differences found in productivity and impact. Given their striking numbers, most research on dropouts has focused on STEM disciplines (Cech & Blair-Loy, 2019; Cundiff et al., 2013; Jadidi et al., 2018; Mihaljević-Brandt et al., 2016).

Collaborative patterns and evaluative practices in promotion seem to be gendered (Fox, 2020). Collaboration affects men and women's career prospects differently. For women, their co-authors' gender influences their probability of receiving tenure, but it does not affect men equally (Sarsons, 2017). This picture is less clear when discussing evaluative practices: a higher presence of women in evaluation panels has been associated with higher success rates for women applying for full professorships (Zinovyeva & Bagues, 2011). However, Williams & Ceci (2015) found the opposite in men-dominated fields, where women had a greater chance for promotion.

This gender disparity is not only found in higher academic positions, but it is present throughout the entire career of a scientist and is consistent across different countries and disciplines. For instance, although men tend to leave more academia at their early-career stage than at any other stance (Xing et al., 2019), women's dropout rates as early-career scientists are higher (i.e. Jadidi et al., 2018; Isphording & Qendrai, 2019). Research indicates that women may leave academia not only for work-life balance reasons but also due to the work environment, which does not affect men in the same way (Levine et al., 2011; Spoon et al., 2023).

Even before early-career stages, differences exist among doctoral, bachelor's, and master's students. There seems to be a trend where gender parity among doctoral students was reached by the 2010s, but since then, women have become underrepresented again (Sánchez-Jiménez et al., 2023). This trend is particularly striking in STEM fields, where growth of women graduating is slowing down, as seen in Mathematics in Spain (Aramayona et al., 2022) or Computer Science in the United States (Sherman, 2015).

3.1.6 Journals. Gender studies examining journals have followed a twofold objective. Firstly, to look at the (under)representation of women in authorship bylines, and secondly, to analyze women's presence on editorial boards. Following the first approach, research finds that women are underrepresented in high impact journals (Mauleón et al., 2013; Shen et al., 2018), even in fields dominated by women (Squazzoni et al., 2021). This underrepresentation is partly because women often engage in topics that receive less attention from these outlets (Light, 2013) and their work tends to receive less favorable peer review scores (Fox et al., 2018).

Women's representation is also alarmingly low among journal editors, who are key players in the scientific communication system (Kennedy et al., 2001). This low presence extends to editorial boards across many disciplines (Aiston & Jung, 2015; Liu et al., 2023b; Metz & Harzing, 2009). For instance, in most Psychology and Neuroscience journals, more than half of editors were men in 2019 (Palser et al., 2022). In top-ranked medical journals, women comprised around 16% of editors-in-chief (Amrein et al., 2011). Women on editorial boards are less likely to be editor-in-chief, and more likely to perform administrative tasks (Burg et al., 2022). The "leaky pipeline" alone does not explain these differences, as the proportion of women editors is lower than their representation in senior faculty positions (Fishman et al., 2017).

3.1.7 Conferences. Women are underrepresented in scientific conferences and workshops (Santosa et al., 2019), where the presence of the so-called "manels" (all-male panels) is still common. Women do not present their work at conferences as much as their counterparts, regardless of their work being of higher quality (Housri et al., 2008). There has been an improvement in overall parity (Ruzycki et al., 2019), and the presence of women within the organization or in panels increases the proportion of women participants (Casadevall & Handelsman, 2014; Nittrouer et al., 2018; Sardelis & Drew, 2016; Zaza et al., 2021). However, even when there is overall parity, men gather more attention in terms of participation than women: they ask more questions (Carter et al., 2018), take more time during their interventions (Jones et al., 2014), and men's lectures receive higher attendance (Aufenvenne et al., 2021). Furthermore, women prefer presenting posters instead of talks, while men prefer the opposite (Isbell et al., 2012).

3.2 Explicative factors for the gender gap in academia

The literature also seeks to identify factors contributing to these differences. This section is structured around three main aspects. Firstly, we examine gendered behavioral patterns and preferences, which encompass gender homophily and preferences for one gender over another in quality perceptions, collaborative choices, evaluation processes and topic selection. Secondly, we explore gender roles in science, looking into differences in research strategies, workload and work-life balance. Lastly, we focus on gendered impacts of the COVID-19 pandemic.

3.2.1 Gendered preferences. Science shows gendered preferences which manifest either as gender homophily or preference of men over women. These preferences are evident in various aspects such as quality perception, collaboration, evaluative processes or research interests.

Gender homophily is especially noticeable in collaboration choices. Regardless of seniority or the proportion of women in Life Sciences disciplines, men and women often prefer to collaborate with the same gender (Holman & Morandin, 2019). Women may exhibit a stronger gender homophily (Jadidi et al., 2018), but will more often be part of mixed teams, while men have a greater propensity to collaborate in male-only teams (Kwiek & Roszka, 2021). Homophily is also observed in peer review processes. Studies of journals such as eLife (Murray et al., 2018), Frontiers (Helmer et al., 2017) and the American Political Science Review (König & Ropers, 2022) show that both men and women rate more favorably work conducted by colleagues from their own gender. This effect can be minimized in mixed-gender peer review groups (König & Ropers, 2022). In the case of citations, gender homophily may be linked to differences in some research areas (Potthoff & Zimmermann, 2017). Lastly, women's presence at scientific gatherings also reflects gender homophily (see section 3.1.7).

In the absence of gender homophily, men will be preferred over women. This is due to perceptions that men's work is of higher quality and more challenging to produce. For example, women doctoral students are perceived as less committed to their work (Ellemers et al., 2004). Additionally, gender biases lead to women scholars being miss-cited as men significantly more often than the reverse (Krawczyk, 2017). Despite this, research shows that women's work exhibits either higher quality (Housri et al., 2008) or no significant quality difference (Lewison, 2001) with that of their counterparts. In fact, gender-mixed teams often produce better quality science (Campbell et al., 2013; Nielsen, et al., 2017a).

This preference for men over women is also observed in collaboration. For example, Whittington (2018) reported that both, men and women, tended to collaborate more with men in biotechnology patents. Men are seen as more attractive collaborators in male-typed topics, and vice versa (Knobloch-Westerwick et al., 2013). These preferences can vary significantly across disciplines (Yamamoto & Frachtenberg, 2022; Zeng et al., 2016).

Although gender differences are also observed in grant evaluation processes, findings here are inconclusive. Cruz-Castro et al. (2022) reviewed the literature and concluded that the variability in national contexts made a comprehensive global picture elusive. A meta-analysis of 21 studies indicated that men have a 7% higher probability of grant approval than women (Bornmann et al., 2007). However, Marsh et al. (2009), found no significant gender differences using the same data. Country-specific studies reveal mixed outcomes: in Italy, men are more likely to succeed (Bagues et al., 2014; Jappelli et al., 2017), while in Quebec, women over 38 receive less funding than men (Larivière et al., 2011). In Canada, principal investigator women are evaluated less favorably (Witteman et al., 2019). The Netherlands Organization for Scientific Research experiences a 4% loss of women during grant review (Van der Lee & Ellemers, 2015). Larregue & Nielsen (2024) suggest that funding differences may stem from gendered topic selections, with quantitative research often deemed more robust and receiving more funding.

Gender also affects research interests and topic selection. The "people-versus-things" dichotomy (Ceci et al., 2014) shows that women are more likely to study people-related topics like Nursing or Psychology, while men prefer things-related topics like Engineering or Mathematics. This trend takes place across all countries. Charles & Bradly (2009) found that countries with higher economic indicators exhibit larger gender gaps in STEM fields. Similarly, Stoet & Geary (2018) found that democratization of higher education does not correlate with a reduction in gendered discipline choices. Kozlowski et al. (2022) showed that minoritized researchers often study topics related to their gendered or racialized identities. Interdisciplinary research is also gendered, with women more likely to engage in it (Rhoten & Pfirman, 2007; Pinheiro et al., 2022).

3.2.2 Gendered roles and work-life balance. The roles researchers play are gendered, with men and women developing different research strategies. Women are often directed towards teaching and administrative tasks, while men reserve more time for research (Filandri & Pasqua, 2021). Despite these differences, student evaluations tend to favor men (MacNell et al., 2015; Mengel et al., 2019; Miller & Chamberlin, 2000). Furthermore, an overemphasis on publications during evaluations devalues teaching and administrative tasks, thereby hindering women's career progression (Hatch & Curry, 2020; van den Brink & Benschop, 2012). Moreover, women are less likely to attain leadership roles during early and mid-career stages (Robinson-Garcia et al., 2020).

Studies also look into differences in researchers' work-life balance (Kyvik & Teigen, 1996; O'Brien & Hapgood, 2012). Women often undertake more domestic chores and caregiving responsibilities, leaving less time for research (Kalra et al., 2023). This "parenting penalty" (Derrick et al., 2022) affects women's productivity (Hunter & Leahey, 2010). Although the "productivity penalty" is decreasing (Morgan et al., 2021), parenthood still affects women's career prospects more negatively than men's (Zheng et al., 2022). Even when tasks are reportedly divided equally, women researchers often engage more in parenting activities (Derrick et al., 2022). Conversely, some studies suggest that the presence of children can increase productivity for both genders, possibly due to a "positive self-selection effect" where only the most productive women manage both roles effectively (Fox, 2005; Joecks et al., 2014).

This gendered work-life balance affects mobility, with women being less mobile than men (Lubitow & Zippel, 2014; Tower & Latimer, 2016; Jöns, 2011; Sugimoto & Larivière, 2023). Women will move geographically closer to home and to fewer countries (Moguérou, 2004; Zhao et al., 2023). Underrepresentation in international mobility is especially pronounced in Physical Sciences (Momeni et al., 2022), and women often move internationally when their caring responsibilities are lower (Cañibano et al., 2016).

Moving with partners seems more challenging than moving with children (Zippel, 2011) and having a partner may have a stronger impact on women's mobility decisions than men (Rivera, 2017; Uhly et al., 2015). Consequently, there is a call for "gender-aware" policies rather than "gender-neutral" ones (Burch et al., 2023).

This lower international presence impacts collaboration, with men collaborating more internationally than women (Aksnes et al., 2019; González-Álvarez & Cervera-Crespo, 2017). Women rely more on national funds and receive less international funding (Ruggieri et al., 2021). Although Abramo et al. (2019) observed that in Italy, these differences are reduced among highly productive authors.

3.2.3 Gendered impacts of the COVID-19 pandemic. This gendered work-life balance picture is exacerbated by extraordinary events like the COVID-19 pandemic. The pandemic has accentuated existing gender disparities in work-life balance (Andersen et al., 2020; Bell & Fong, 2021; Ribarovska et al., 2021). Some studies suggest there were no significant gender differences in publication rates during the pandemic (Abramo et al., 2022; Jemielniak et al., 2022). But women had a generally lower contribution to COVID-19 research (Vincent-Lamarre et al., 2020), with a noticeable decrease in overall productivity, especially among mid-career women (Kwon et al., 2023). Women's leadership, as indicated by first authored publications, also declined (Liu et al., 2022). Additionally, research on COVID-19 often overrepresented male patients (Salter-Volz et al., 2021).

3.3 Consequences

This review unveils a nuanced landscape with significant negative repercussions, which we categorize into two distinct areas: career diversity within the scientific workforce and balanced and inclusive generation of scientific knowledge. These consequences restrict career prospects and opportunities for women and have detrimental effects on the direction of research, impeding diverse scientific outputs and innovations, and perpetuating gender inequality.

3.3.1. Career diversity and scientific workforce. Every element discussed here creates a vicious circle that negatively affects women's careers (Aiston & Jung, 2015;

Freund et al., 2016; van den Besselaar & Sandström, 2017). This cycle results in fewer opportunities, lower retention rates, and hindered career progression for women, contributing to the accumulation of disadvantages known as Matilda effect (Rossiter, 1993). This leads to different career trajectories, successes and transitions (Filandri & Pasqua, 2021; Jagsi et al., 2011; Lerchenmueller & Sorenson, 2018). Women face more difficulties entering informal networks within the scientific community, with "workplace climate" being one of the top reasons for women leaving academia (Spoon et al., 2023). This is related to the existence of daily "micro-inequities" (Aiston & Fo, 2020).

Women's careers are generally shorter and there are more gaps in their publishing careers compared to men. This can be attributed to diverse career lengths (Huang et al., 2020), although differences in productivity cannot be solely explained by career length or stage, but also by the number of men and women starting careers as researchers (Boekhout et al., 2021). These restraints on gender diversity also affect the scientific workforce as a whole. Diversity – whether gender, ethnic or geographical diversity – leads to more novel research, is better for problem-solving (Nielsen et al., 2017a), generates higher impact (Yang et al., 2022) and receives more citations (Powell, 2018).

3.3.2 Balanced and inclusive generation of scientific knowledge. The literature highlights two main elements related to gender and the generation of new knowledge. First, the lack of gender diversity leads to biased research outcomes and less innovative findings. All-women and mixed teams tend to include variables of sex and gender in their research more than all-men teams (Key & Sumner, 2019). There is a strong positive correlation between women's authorship and the probability of a study including gender and sex analysis (Nielsen et al., 2017b). This is relevant because sex inclusion, analysis and reporting can change the conclusions of an investigation (Sugimoto et al., 2019), and extrapolating data from one sex to another can be dangerous (Klein et al., 2015).

Second, some disciplines and topics are dominated by a specific gender and there tends to be homophily between authors' demographics and the topics they research (Sugimoto & Larivière, 2023). Kozlowski et al. (2022) develop the idea of "privilege of choice", where the choice of a particular topic is influenced by gender and race. In the

US, men tend to study STEM topics, whereas women are more likely to study topics more related to Gender-Based Violence, Families, Learning, LGBT Studies and Nursing (Kozlowski et al., 2022). Stereotypes are considered more impactful than discrimination in some fields, influencing women's absence in certain disciplines because they do not enter them in the first place (Ceci et al., 2014).

Moreover, when women enter fields previously dominated by men, there is often a "reconfiguration" of segregation (Acker, 2006). For instance, in Medicine, women tend to specialize in Pediatrics, Gynecology and General Practice, but not in Surgery, which remains dominated by men (Acker, 2006; Alers et al., 2014).

4. Discussion

This paper provides a comprehensive narrative literature review of gender inequality in science. Unlike other reviews, we focus on research using bibliometric methods, emphasizing two aspects: methodological approaches and findings reported in the literature. Regarding the first aspect, we review the different methods used to identify gender in bibliographic data, the unit of analysis under study, and approaches for identifying causality, biases and differences. As for findings reported in bibliometric studies, we examine the differences reported, the explicative factors identified and the negative consequences such differences may have on the scientific ecosystem.

Regarding methodological aspects, we found a range of techniques for assigning gender to researchers that, while elaborate, are not yet perfected. We also identified various units of analysis, with publications being the most commonly used. Lastly, we addressed issues related to causality. Although establishing causality is challenging, research has attempted to identify possible explanations for gender differences. There is evidence of gender homophily within academia and a general preference for men and their work, exhibited by both genders alike. Literature is also clear on the existence of gender roles within science and its impact in maintaining work-life balance. Furthermore, studies related to the impact of the COVID-19 pandemic in academia warn of the danger of exacerbating these differences in times of difficulty.

Gender differences are found in almost every aspect of academia, reflecting the social inequalities present outside the research world. This is expected, given that science is a social activity. However, research on citations is somewhat contradictory and gender gap evidence on contributorship is still too scarce. These gender disparities have numerous negative consequences that likely extend far beyond our current understanding of the scientific workforce and the generation of new and accepted scientific knowledge. This is why most studies combine bibliometric methods with other interdisciplinary approaches. These consequences mainly relate to career diversity within the scientific workforce and the nature of the scientific knowledge that is produced.

5. Concluding remarks and future agenda

Next, we organize the main gaps observed in this review to propose a novel research agenda for future studies. First, there are methodological issues. Gender identification algorithms often reflect a binary vision of gender and assume that it can be determined from names. Moreover, these processes do not work well for all countries of origin and language, leading to inaccuracies and hindering reproducibility. A collaborative effort is needed to address these challenges, potentially through open approaches or self-declared declared databases. It is essential for all research to acknowledge these limitations and, whenever possible, utilize self-declared gender identification lists.

Another gap is the lack of a global perspective in the research. Studies often focus on specific geographical areas, mainly Europe and North America, in English language and within STEM fields. This results in a patchwork of conclusions that do not allow for a coherent global comparison or holistic understanding of the situation of women in science. What is more, it highlights a Western bias in findings. Future research should address underexplored geographical areas, which will help create a more balanced and inclusive understanding of gender dynamics in the global scientific community. This along with rigorous and transparent methodological designs can help produce literature reviews, and meta-analyses which can provide such overall landscape.

There is also an imbalance in research topics. Most studies focus on authorship, citations, evaluations, and work-life balance, while fewer explore new and diverse topics such as contributorship, interdisciplinarity, networking or impact on the production of scientific knowledge. This situation should be balanced in the future, connecting new insights with existing literature to provide a more comprehensive understanding of gender issues in science.

Lastly, there is a need for greater conceptual clarity. Although research increasingly distinguishes between sex and gender, some bibliometric studies still confuse these concepts or use them interchangeably. Developing clear and systematic guidelines on the correct use of these concepts within bibliometrics is essential. These confusions can mislead readers into believing that differences are biological, natural and definitive. But understanding that gender differences are cultural constructs is key to enable change and foster a more inclusive, sustainable and healthy scientific ecosystem. We acknowledge the challenging nature of this research agenda. Data is often not ideal, and establishing causality is difficult. However, the lack of progress is more due to a lack of imagination in using bibliometrics. Addressing these issues and developing critical reflections on them is crucial to avoid "gender fatigue" (Kelan, 2009) and enable progress. It is a socially responsible act for producing more nuanced and beneficial research.

Policymakers should be aware of the inequalities in the scientific workforce that need to be considered when addressing or proposing scientific agendas and evaluation criteria. The information provided in this review could serve as a baseline for diagnosing the scientific workforce, disentangling mechanisms affecting inequality in science, and reforming research policies at all levels. This includes formulating scientific policies that better align research objectives with evaluation criteria in relation to collaboration and team management in order to develop a sustainable system promoting the use of responsible metrics.

Notes

[1] Throughout this literature review, we use women/men to refer to gender and rather than female/male. Quoted articles are not modified, therefore some of them may not follow this guideline.

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