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Article

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Meeting evaluation criteria based on authorship positions by gender, academic age, and research field: the Spanish case

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Abstract

This study aims to provide an overview of the distribution of the Spanish scientific workforce focusing on differences in authorship position by gender, academic age, number of authors, and research field. The results show some degree of parity in younger age cohorts and areas such as biomedicine, but little participation of females in the oldest age cohort and areas such as mathematics. In addition, the presence of women undergoes significant changes in certain areas and decreases in oldest age cohorts. This circumstance leads to a low probability of finding women or junior researchers in relevant authorship positions. Policymakers should know that inequalities in the scientific workforce must be considered when addressing/proposing scientific evaluation criteria.

Keywords: author's position; gender; academic age; evaluation criteria; Coalition for Advancing Research Assessment (CoARA); Spain.

1. Introduction

The European Commission included the mandate to reform the research assessment system in its European Research Area Policy Agenda of 2021, to improve the quality of research while respecting the principles of diversity, inclusiveness, and openness. This collaboration culminated in the Agreement on the Reform of Research Assessment in July 2022 and the Coalition for Advancing Research Assessment (CoARA) creation in December 2022. The main goal is to implementation of reforms in assessment research, researchers, and research organizations. In Spain, the Ministry of Science recently published a proposal for a draft law to modify Law 14/2011, of June 1, on Science, Technology, and Innovation.[1] The main goal of this new law is to design a sustainable research career model, acknowledging that the current system has proven to be 'inefficient given the many years that those who dedicate themselves to public research must invest to achieve a stabilized employment situation, concatenating successive employment contracts temporarily'. This national and European framework allows exploring whether certain (often well-intended) evaluation criteria established by agencies—such as the position of authors in the byline of publications—might backfire on the road to a responsible research assessment framework, perpetuating inequalities in science (e.g. gender imbalances). In this context, authorship positions in co-authored publications are established by research groups and conform to a critical part of research evaluation criteria.

Spain's *Agencia Nacional de Evaluación y Acreditación* (ANECA[2]) is responsible for conducting evaluation, certification, and accreditation of the Spanish Higher Education system. Three programs focus on the individual level: PEP[3] evaluates the CV of applicants for university professorial positions; ACADEMIA[4] evaluates CVs for university positions; and the CNEAI[5] Program is dedicated to the research incentive system or recognition of research quality (*sexenios*). One explicit criterion used by these programs to estimate the leadership role of a researcher is that at least half of the applicant's publications must be as the first or corresponding author, as well as the principal investigator of a project. Therefore, these authorship positions in co-authored publications are better rated/rewarded than middle positions in publication byline. However, while the *Estrategia Española de Ciencia y Tecnología y de Innovación (EECT) 2021–27*[6] encourages collaboration to achieve national scientific objectives and facilitate scientific advancement in the country, stiff competition lies at the heart of these programs. In other words, what matters in terms of scientific knowledge may not be important for one's scientific career advancement. Collaboration can be costly under current evaluation criteria, as researchers are assessed individually, meaning rewards and incentives collide with collaborative strategies at all levels of aggregation (Robinson-Garcia and Amat 2018).

Although collaboration 'is a mantra in most research agendas, few studies at the national level depict the Spanish scientific workforce disaggregated by gender, academic age, and authorship position. Some reports analyze the situation of women in science in Spain, such as 'Científicas en cifras[7]' and 'Mujeres e innovación[8]' by the Ministerio de Ciencia e Innovación, or 'Informe Mujeres Investigadoras[9]' by the Consejo Superior de Investigaciones Científicas. The Fundación Conocimiento y Desarrollo (CyD) publishes a report on the situation of universities in Spain, although it does not focus specifically on gender. These reports share the desire to document the situation of women's research institutions and universities and their relationship with funding and public research policies. They examine the number and percentages of female and male researchers within research levels and disciplines.

This background provides the main motivation for our study. An approach centered on demographics might prove relevant in the context of competition and collaboration in science, offering an overview of the distribution of the Spanish workforce in co-authorship and the probability of occupying relevant authorship positions in the byline of publications. This overview will consider the number of authors, academic age, and different research fields. Such information could serve as a baseline for a diagnosis of the scientific workforce, disentangling another of the many mechanisms affecting inequality in science—authorship practices in research groups-, and for proposing revisions/changes at different levels: in the formulation of scientific policies (better alignment between research objectives and evaluation criteria related to collaborative activities), and in the management and strategies of research groups to further the development of a sustainable system promoting the use of responsible metrics.

2. Objectives

The main goal of this study is to ascertain the discrepancies in authorship position (first, last, middle, and corresponding authorship) as a function of academic age, gender, and the number of authors These positions are analyzed to investigate the distribution of roles (namely, leading and supporting authors). The following questions are addressed: How is the workforce distributed in terms of gender and academic age in each field? To what extent do these demographic features show differences in the probability of meeting evaluation criteria and the position of authors in publications? In which areas (if any) can be found the greatest gender divergences? What conclusions and/or recommendations can be derived from these results and prove useful for science policymakers?

This paper reflects on gender differences in the Spanish scientific workforce, going beyond parity of representation and adding a perspective that takes into account the positions occupied by authors in the byline of scientific publications. Our research also examines how the researcher's gender and academic age may affect the probability of meeting institutional evaluation criteria. With a more comprehensive view of the situation of women in Spanish science, more thoughtful and effective public policy responses can be expected. We consider this information essential for proposing actions and/or measures in designing responsible evaluation research frameworks (CoARA 2022[10]) and for the mechanisms behind the selection of authorship positions in collaborative publications for research groups.

3. Related works

Authorship is the mechanism by which researchers are acknowledged for their research activities (Tscharntke et al. 2007), and it is at least as important as the number of publications when it comes to hiring, promotion, or tenure (Wren et al. 2007). Therefore, if researchers do not receive the credit and visibility they deserve for their work, they face major problems in consolidating their careers, especially at early career stages and women researchers (Robinson-García et al. 2020).

The last decades have witnessed a trend toward more co-authorship and a higher frequency of cross-institutional collaborations (Wuchty et al. 2007; Larivière et al. 2015; Wang and Barabási 2020), which calls into question the equal treatment of all authors on the byline, as the relevant author positions become more pronounced (Hu, Rousseau and Chen 2010; Larivière et al. 2016; Bu et al. 2020). Although the traditions of some countries and research fields still influence authorship order (Liu and Fang 2014), in general, the most important positions are those of the first and last author (Costas and Bordons 2011), which are highly correlated with academic age and experience (Costas and Bordons 2011; Escabias and Robinson-Garcia 2022). The first authors are more likely to be found in academically younger scholars who did the most work (Wren et al. 2007; Larivière et al. 2016; Sekara et al. 2018; He et al. 2020). The last authors, in turn, tend to be senior researchers who are associated with 'advising', contributing to the design and writing the draft, or the provision of scientific resources (Tscharntke et al. 2007), and not doing data collection or other more technical tasks. These patterns hold for the vast majority of publications (especially in the biomedical and natural sciences) (Dance 2012). Besides, there is another position on the authorship list, the corresponding author. The corresponding author tends to be responsible for corresponding with editors and coordinating collaboration among all co-authors involved (Chinchilla-Rodríguez et al. 2024). While there is no consensus about the status and significance of the corresponding author, lately the corresponding authorship has become an indication of a major contribution for the author rather than a particular set of responsibilities (Willems and Plume 2021), and this position is better rewarded in the Spanish academic system (ANECA 2021).

Previous studies report some dynamics influencing relevant roles. Corresponding authors are more likely to appear first in the byline, as provided in the ICMJE guidelines, although there are differences depending on the number of authors and the country of origin (Mattsson, Sundberg and Laget 2011; Moya-Anegon et al. 2013). The likelihood that women are first or corresponding authors during early career stages is affected by a lower involvement of men in support tasks (Larivière et al. 2016). Huang et al. (2020) found that each year women are more likely to interrupt their scientific careers than their male colleagues, and that differences in the distribution of roles by gender might explain the higher drop-out rates for women (Haeussler and Sauermann 2020; Lamarre, Sugimoto and Larivière 2020). The main reason behind such imbalances might be the different proportion of men and women who publish works at the beginning of their careers. Even though divergences appear to decrease over time, some gender differences persist in career paths, with men publishing more and being more likely to reach high academic positions than their female colleagues (Boekhout, van der Weijden and Waltman 2021).

In a competitive environment, committing to collaboration can pose a risk in terms of the balance of transaction costs and collaborative benefits. The motivation for researchers to participate in collaboration may depend substantially on the perceived risks and rewards (Feng and Kirkley 2020). Furthermore, authorship disputes in collaborative articles influence motivation. Young researchers and female researchers are more likely to experience authorship conflicts when their contributions are underestimated (Fleming 2021). The dissatisfaction that researchers perceive about co-authorship bears relation to the academic rank and gender of the authors. Such dissatisfaction can be linked to homogeneity in the estimation and assessment of scientific careers, with an emphasis on individual achievement and the understanding that scientists must undertake numerous research activities on their own (Gómez-Ferri, González-Alcaide and LLopis-Goig 2019; Smith et al. 2020).

The set of normative criteria followed by some national funding agencies, which evaluate and recognize merits for the promotion and tenure (P&T) process, tend to push for publication counts without rewarding the structure of collaboration. Or they prioritize academic leadership in the byline of publications, disregarding other profiles (Ancaiani et al. 2015; Robinson-Garcia and Amat 2018). In this evaluative framework, collaborative research is relatively institutionalized. However, there is a lack of comprehensive and explicit criteria for appraising individual contributions to collaborative work-based research. Individuals may therefore face a double handicap in research assessment exercises. Their work is typically judged according to discipline-based standards (e.g. journal's impact factor), and their contributions are under-valued if they are not the first authors of papers or principal investigators with a grant, i.e. 'leading' research (Cabezas-Clavijo et al. 2013; Klein and Falk-Krzensinski 2017).

Then, if research assessment approaches do not consider individual characteristics of researchers such as gender or academic age, and they do not encourage collaboration, specific policies should intervene to avoid negative feedback within academic institutions and research groups, with the unintended consequence of reinforcing inequalities on science (Jappelli, Nappi and Torrini 2017). Current initiatives on evaluation reform appeal to the necessity of considering diversity and inclusivity when research assessments are carried out by funding and academic organizations (CoARA 2022). From a policy perspective, a deeper understanding of patterns of authorship practices is critical for addressing/assessing inequality in science.

4. Data and methods

Data were provided by the CWTS using its in-house version of Web of Science. The data were collected in August 2019 for the period 2015–17, and include documents in all fields by authors with a Spanish address (a total of 176,753). Articles, chapters, conference papers, and reviews are considered.

This dataset is composed of several indicators plus the identification of authors (Caron and Van Eck 2014; D'Angelo and Van Eck 2020), gender (Boekhout, van der Weijden and Waltman 2021), and academic age (Nane, Larivière and Costas 2017). The individual author, rather than the individual article, is the unit of analysis, i.e. we use publications to identify the presence of researchers. In all scientific fields, there are a total of 201,580 authors with a Spanish address, 14% of whose gender is not clearly identified and who are therefore excluded from the analysis. Of the set of authors identified by gender, 81,179 are females (46%) 95,574 are males (54%), and both are involved in the authorship of 165,649 documents.

As women and men are spread unevenly throughout the scientific workforce both horizontally (e.g. by scientific field) and vertically (e.g. by academic age), it is important to disaggregate the population by similar characteristics (Nygaard et al. 2022). Here, we are interested in cohorts of scientists who have the same academic age. Then, the entire temporal span of the database was used to establish the starting and ending years (until 2018) of the publishing activity of each author as a proxy of academic age. This operationalization of the academic age of researchers represents the length of an author's active engagement within a scientific community (Milojević 2012). Accordingly, we allocated researchers to four age cohorts (mutually exclusive) based on the number of years of academic publishing or publication length: (1) a cohort of authors with publications in the interval [0–10 years]; (2) interval [>10–20]; (3) interval [>20–30]; (4) interval [>30]. In the figures, these four cohorts are denoted by 0, 10, 20, and 30. This breakdown allows us to study gender differences acting as a starting point to stratify the workforce.

We determine an 'individual publication portfolio' for every author. To do so, we link authors to thematic fields following the classification used in the Leiden Ranking,[11] which considers five main fields: Biomedical and Health Sciences (BIO), Life and Earth Sciences (LIF), Mathematics and Computer Science (MAT), Physics and Engineering (PHY), and Social Sciences and Humanities (SSH). Authors with a highly multidisciplinary profile can be assigned to more than one field. Using individual researchers as the unit of analysis, we calculate the number of authors for each published paper and consider author positions in the byline of all co-authored publications. These positions include first, middle, last, and corresponding author (a leadership proxy), as well as their combinations (e.g. first, middle, or last author as corresponding author).

To study differences in authorship positions by age, gender, and discipline, we considered the articles published by one, two, and more than two authors. In the case of publication by two authors, we identified cases where the author appeared only as the first author, as the first and corresponding author, or as the last and corresponding author. For publications with three or more authors, the following positions were considered: the author appears only as first author, only as last author, only as an intermediate author, as the first and corresponding author, as last and corresponding author, or as intermediate and corresponding author.

Our analysis relied on a logit model of multiple nominal responses (Valderrama et al. 2018) that models these positions given age, gender, and number of authors in the byline of the publication, and allows for estimation of the probability that a given author would occupy one of these positions (Annex 1). The estimation of the model and calculation of probabilities were performed with Software R (R Core Team 2021) using the nnet library (Venables and Ripley 2002). Because each area of knowledge presents different distributions for age, gender, number of authors, and authorship position, the analysis was carried out separately for each discipline involved.

5. Results

5.1 Demographic characterization by gender, academic age, and research field

Overall, our sample shows an unequal presence of female (46%) and male (54%) scientific authors by age and scientific field. Considering academic ages, two distinct perspectives

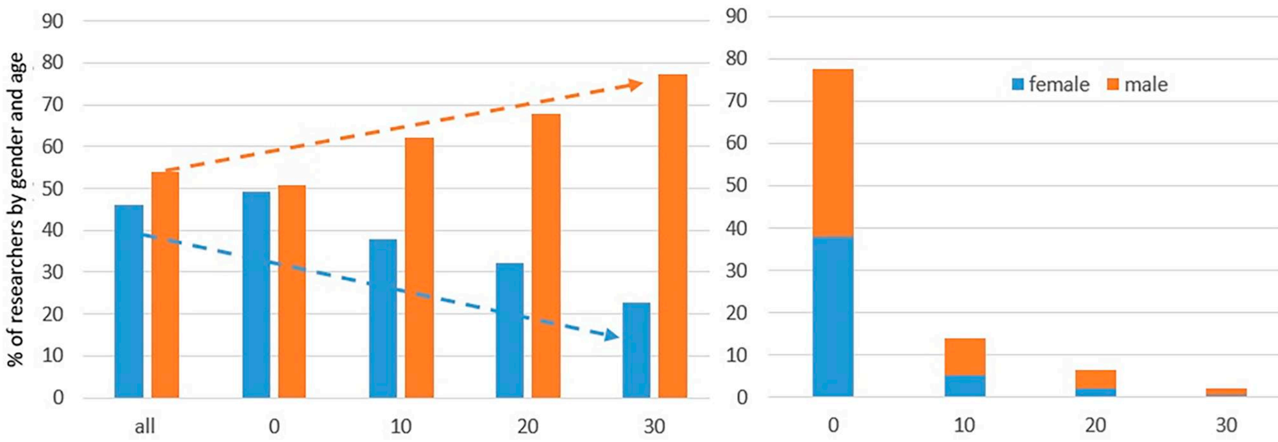

Figure 1. Percentages of researchers by gender and academic age. The *y*-axis shows the percentage of researchers, and the *x*-axis shows the academic age.

are reflected in Fig. 1. In the left panel, we see that for young cohorts the difference in the proportions of authors by gender is minimal. The most obvious shift occurs in researchers with more than 10, 20, and 30 years of publications in their respective fields, with less female presence (38%, 32%, and 23% respectively) (Fig. 1—left).

And if we zoom in on the actual proportion of researchers by academic age? The panel on the right shows the distribution of gender in each cohort. The most relevant finding is that over three-quarters are junior researchers (38% women and 40% men), in contrast to the low percentages of researchers with more than 10 years of academic publishing (14% of total researchers: 5% women and 9% men), with more than 20 years of publishing records (6.4% of total: 2% women and 4% men) or with more than 30 years (2.2% of total researchers: 0.5% women and 1.7% men). We hold this finding to be of great importance for future human resource strategies and/or policies in gender parity within Spain's scientific system.

When looking at the number of scientists by research field (Fig. 2—left), women appear in a slightly higher proportion than men do (52% and 48% respectively) in BIO (55% of the total Spanish active researchers). This field is followed at a distance by LIF (20%), wherein 55% of the total are men; and by PHY (19%), with a clearer predominance of men (65%).

Meanwhile, SSH represents 12% of the scientific pool, having 46% female and 54% male presence. In turn, MAT has the lowest number of active researchers (8%), and women are under-represented (21%) in comparison with men (79%); indeed, the ratio is nearly 10 men per woman for authors with more than 30 years of publication (Fig. 2—right). The higher proportions of researchers are concentrated in young cohorts in SSH and BIO (83% and 78%), and only 0.6% and 2.3% of active researchers are in the oldest cohorts (Fig. 2—center).

Now, we compare the distribution of researchers in each cohort to determine whether there are differences by gender. As the sample sizes are large, we assume normality and perform a parametric test H0: _M = _F (M = Male, F = Female).

Figure 3 shows basic statistics per cohort. Differences by gender are always significant in all fields. There are more junior women in SSH and BIO and more senior men in LIF, MAT, and PHY.

Figure 4 presents the percentages of women and men who publish co-authored papers in each cohort. In BIO, women account for a higher percentage than men in the first cohort (55%). Yet this proportion falls by more than half in the oldest cohort (24%). Similar patterns for junior researchers, albeit with lesser female presence, can be detected in LIF, and SSH (∼49%). In the latter case, there is moreover a very marked decrease in women's presence in the oldest cohort (<14% of women and 86% of men). In MAT, the numbers show a clear male prevalence in the first cohort (78%), rising to 91% in the last cohort.

In PHY, the proportion of men virtually doubles that of women in the first cohort (62% vs 38%), and these differences increase among researchers with more than 10 years of publication activity (70% males-30% females). The proportion of men in the last cohort is over 79%.

5.2 Authorship position

We explore the distribution of researchers by research field in co-authored papers per cohort. For the latter objective, relevant author positions were analyzed, namely first, last, and corresponding author, for the total of females and the total of men respectively (Fig. 5). In all research fields men prevail in relevant positions, especially in the last positions in which there are three men for every woman listed as the last author in the publication byline. In the remaining relevant positions, differences are smaller, though women are consistently less represented than their male counterparts.

Figure 6 presents the percentages of authors in co-authored papers according to their position in the byline of publications (axe y), academic age (axe x), and research field. Overall (in all fields and cohorts) the predominant position is middle authorship, with the last position having a stable or increasing presence in contrast to the first position, which tends to decrease in the oldest cohorts (20, 30). In all fields, BIO accounts for more than 78% of junior researchers. Around 28% of these authors publish at some point as first authors, 11% as last authors, and 15% as corresponding authors (regardless of position). Among the older cohorts (<9% of the total workforce in this field), 60% appear in the last position.

In LIF, 46% of researchers in cohort A appear as first authors and only 16% as last authors, while ∼71% of researchers in the two oldest cohorts (20, 30) publish as

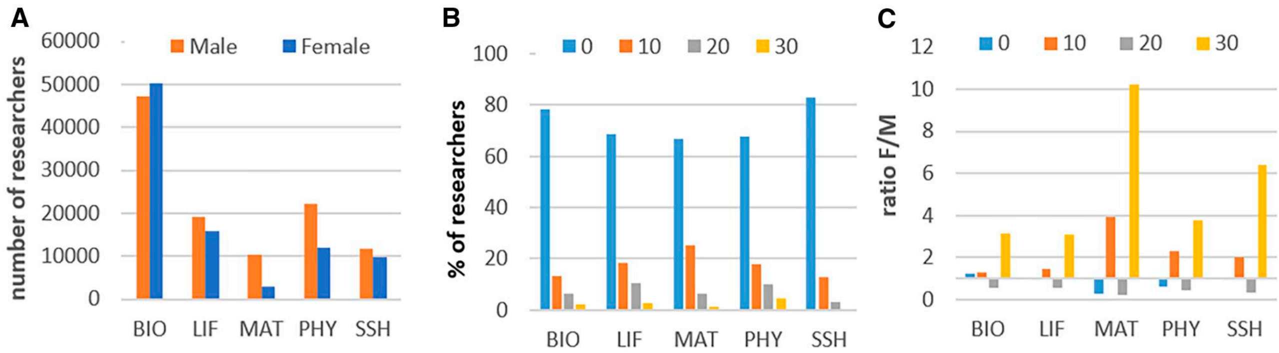

Figure 2. Characterization of research fields by (A) the number of male and female researchers, (B) the percentage of researchers by academic age, and (C) the ratio of female/male by academic age. Biomedical and Health Sciences (BIO), Life and Earth Sciences (LIF), Mathematics and Computer Science (MAT), Physics and Engineering (PHY), and Social Sciences and Humanities (SSH). Academic age is denoted by 0, 10, 20, and 30.

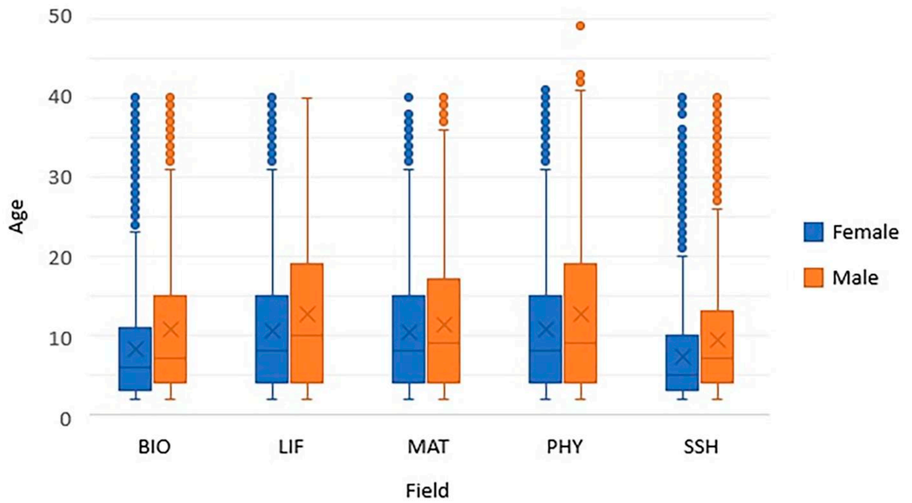

Figure 3. Differences by gender, academic age, and research field. Biomedical and Health Sciences (BIO), Life and Earth Sciences (LIF), Mathematics and Computer Science (MAT), Physics and Engineering (PHY), and Social Sciences and Humanities (SSH).

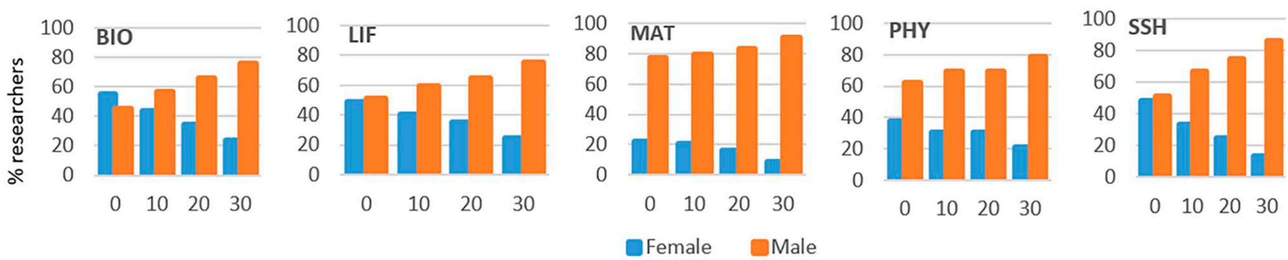

Figure 4. Gender distribution by academic age and scientific field. Biomedical and Health Sciences (BIO), Life and Earth Sciences (LIF), Mathematics and Computer Science (MAT), Physics and Engineering (PHY), and Social Sciences and Humanities (SSH). Academic age is denoted by 0, 10, 20, and 30.

last authors. Corresponding authorship in this field is assigned to 27% of young researchers, and it is evenly distributed among the rest of the cohorts (52%, 57%, and 53%, respectively). MAT disciplines are the least populated (only 8% of Spain's scientific workforce). This field presents a similar pattern in terms of the prevalence of last positions in the oldest cohorts, while first authorship slightly increases for researchers in the second cohort (20), then remains relatively stable for the last two cohorts (20, 30). The major difference to other fields is that the corresponding authorship is more likely to be assumed by almost half of the researchers across cohorts.

In PHY (19% of the whole workforce), authorship patterns are similar to BIO and LIF, with few possibilities to publish as the last author for the younger cohort (18%), and more as the corresponding author (28%). Around 12% of researchers publish in SSH and more than 83% of them are junior researchers. In this area, the first or corresponding authorship is distributed quite evenly across cohorts, while the last authorship is reserved for the last two cohorts (20,30), ranging from 64% to 72% of researchers appearing in this position (Fig. 6).

Furthermore, we examined gender disparity in author position by scientific field. Figure 7 gives the ratio of females and

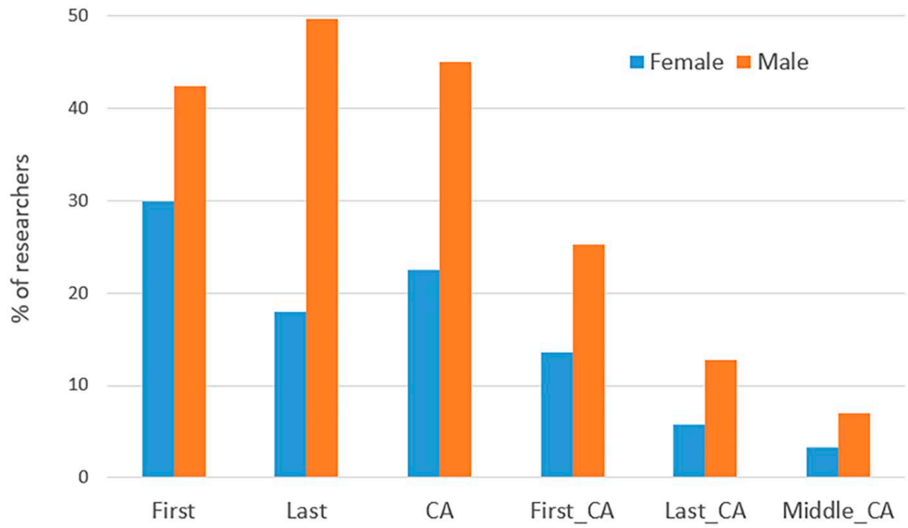

Figure 5. Percentage of researchers by gender and author position in co-authored publications. First: first author; Last: last author; CA: corresponding author; First_CA: first author as corresponding author; Last_CA: last author as corresponding author; Middle_CA: middle author as corresponding author.

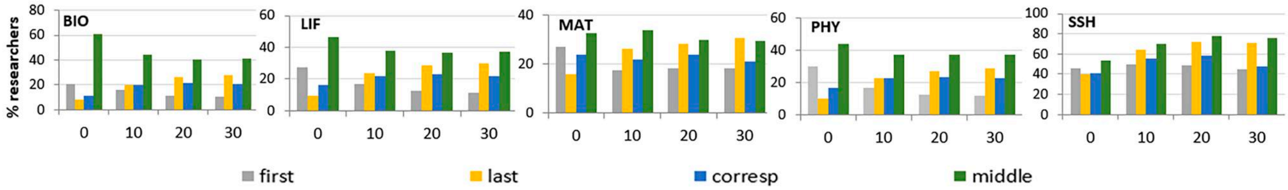

Figure 6. Distribution of researchers' authorship position by academic age and research field. First: first author; Last: last author; Corresp: corresponding author; middle: middle author. Academic age is denoted by 0, 10, 20, and 30.

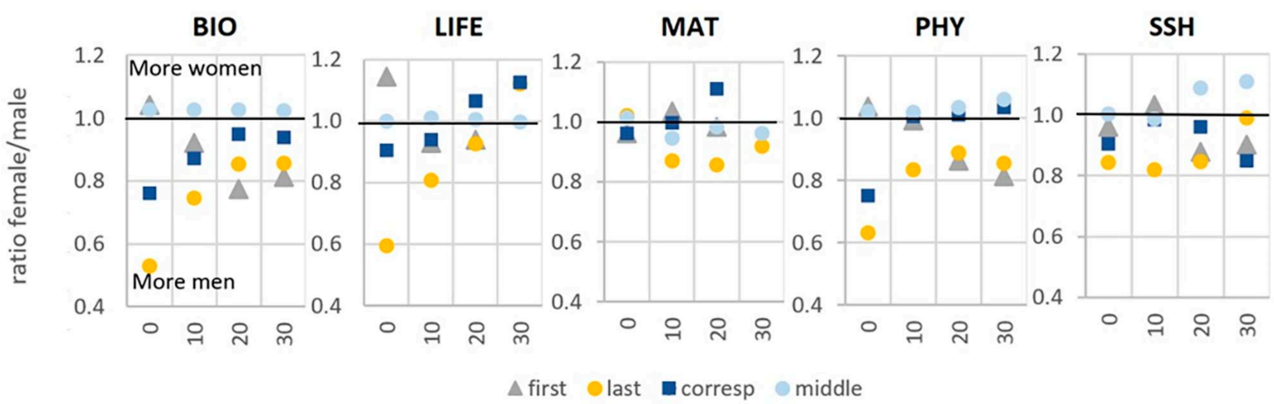

Figure 7. Gender disparities by author position, academic age, and research field. First: first author; Last: last author; Corresp: corresponding author; middle: middle author. Academic age is denoted by 0, 10, 20, and 30.

males in the byline position in co-authored documents per cohort. Values >1 on the vertical axes show a female advantage in a given field, while lower results indicate a male advantage, and 1 indicates gender parity. Females are above men as first authors in BIO in the first cohort—though just slightly, the respective proportions being 28.7% and 27.5%. Likewise, there is a higher proportion of young women as first authors in LIF. Notwithstanding, this is the only advantage for women in relevant positions; middle positions are more significant for women than for men in all fields and cohorts. There is no parity at all in the way women appear as first, last, or corresponding authors in comparison with men.

5.2.1 *Authorship patterns—probability to occupy relevant positions*

We investigate whether single and co-authored publications are more likely to be produced by females or males (Fig. 8). For all areas, the single-author publication occurs more among males than among females, with smaller differences in the SSH area and greater in PHY. In these fields, solo publication takes place in the younger cohort for the SSH area and in the oldest cohort for PHY. In the oldest cohort, men are more likely than women to publish alone. In co-authored publications, women are more represented in BIO and SSH and less so in MAT and PHY. In all research fields, women

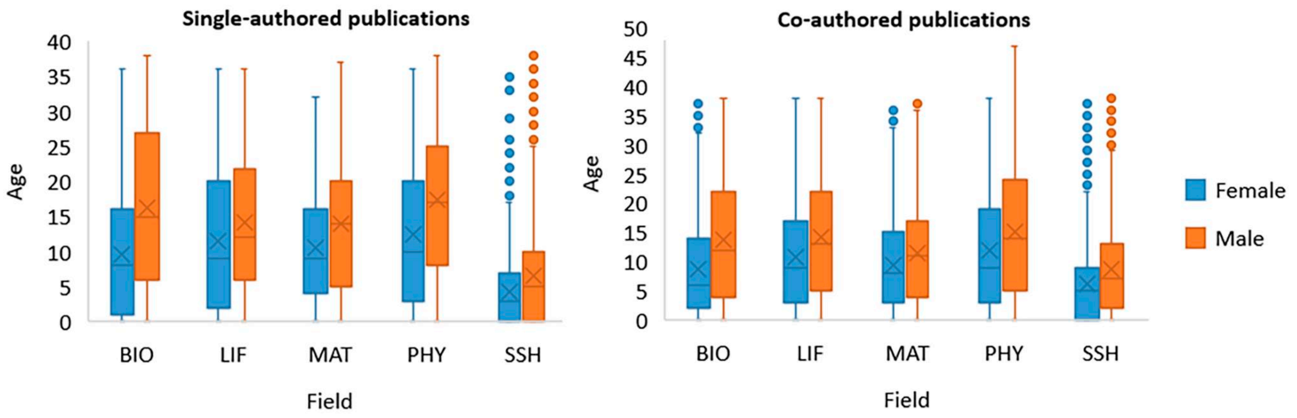

Figure 8. Distribution of researchers by gender, academic age, and research field in single and co-authored publications. The y-axe shows the field, and the x-axe shows academic age.

are more likely than men to participate in co-authored publications in the first cohort, but their presence in the oldest cohorts appears to be significantly lower than that of their male counterparts

The probability of females and males appearing in a relevant position in co-authored publications is analyzed (Fig. 9). To this end, a multiple-response model was applied to fields in which gender and academic age are used as explanatory variables (see Annex). Probabilities values range from 0 to 1 denoting the percentage of women and men in each position by field. For example, in BIO (the model correctly classifies 37.04% of the cases), the probability of female presence is greater in the first position, (40% of females vs. 30% of males), except when also being the corresponding author, although the differences decrease in oldest cohorts. For the last position as the corresponding author, the probabilities are slightly higher for females, increasing in the second, third, and last cohorts (10, 20, 30). In LIF (the model correctly classifies 45.65% of the cases), the probability of female presence is greater in the first position, except for the oldest cohorts, and only higher for young men as corresponding authors. In the last position, the probability is higher for males than females, contrasting with the last authorship as the corresponding author where females are more likely to appear in the oldest cohorts.

In MAT (this model correctly classifies 42.22% of the cases), it is striking that, except when being only the first author and not a corresponding author, the gender differences do not vary across cohorts. In PHY (42.52% of the cases classified correctly), as in LIF, although the differences are smaller, the probabilities of the last authorship position and first authorship as the corresponding author are higher for males than for females, while females are more likely to appear as first authors and last author as corresponding author. For SSH (44.28% of the cases are classified correctly), the probability predicted by the model shows that, only in the last author position, the probability is higher for males than females.

6. Discussion

Our study indicates that over three-quarters of the Spanish scientific workforce corresponds to young researchers (78%) while the rest of the cohorts concentrated the remaining 22% of active researchers (14%, 6%, and 2%, respectively). These results suggest that only a small proportion of researchers have a long publication record, indicating a stable position within the Spanish

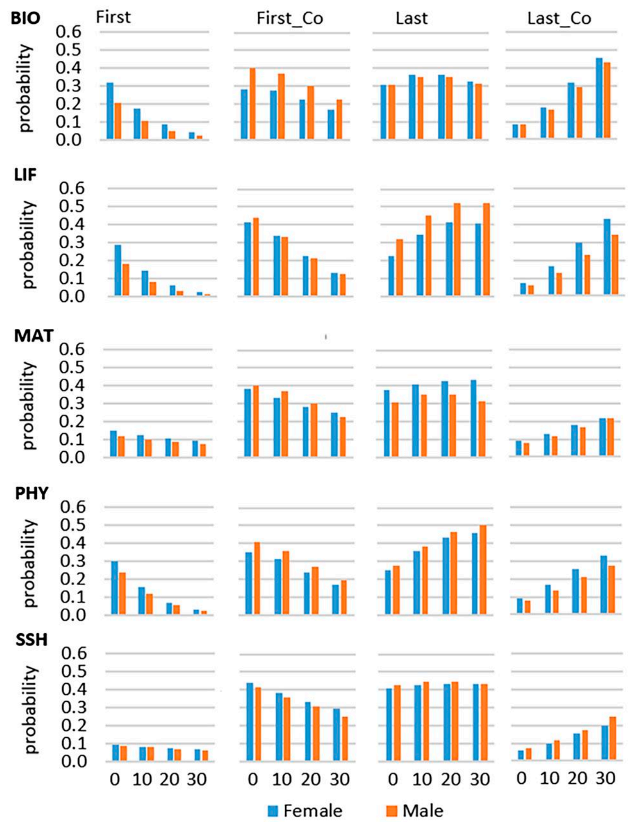

Figure 9. Probability of appearing in a particular position in the byline of publications. First: first author in co-authored papers; First_Co: first authors as corresponding authors in co-authored papers; Last: last author in co-authored papers; Last_Co: last authors as corresponding authors in co-authored papers. Academic age is denoted by 0, 10, 20, and 30.

scientific system, while a high percentage of researchers are transient authors (publishing once and never again). In this regard, since women publish less than men do, we study all authors with at least one publication to avoid the under-representation of women as authors in publications (West et al. 2013). As the disambiguation algorithms might create 'fake' researchers with one or very few publications, in this study, we performed a test to know whether results change excluding researchers with one publication, two publications, and less than three publications. However, no significant differences have been found (see Annex, Table 1).

The CSIC Women Researchers Report (2021) affirmed that the gender gap exists in Spaiń s major research institutions. At the national level, there is a generally unequal presence of women (46%) and men (54%). In the Spanish scientific system, the relative female presence shows important variations not only by age cohorts but also according to the research publication field. Women have a greater presence than men in BIO alone, while in LIF and SSH, they lag somewhat behind parity. In PHY and MAT, their presence is far more limited, publishing little over a fifth of the documents in the latter field. Meanwhile, women's presence is less likely to appear in the oldest cohorts than their male counterparts. Among the oldest cohorts within BIO, LIF, and PHY, we found just one woman per every three males (Fig. 3). In SSH, the ratio is even greater: for each woman, there are six males. Moreover, MAT is known to be a male-dominated field for the oldest cohort (just one woman per 10 males). This finding aligns with, among others, those of Mihaljević-Brandt, Santamaría and Tullney (2016) and Aramayona et al. (2023). They report significant gender differences that tend to place women at a disadvantage in this field.

The low female presence in the oldest cohort is significantly greater for SSH and lower for PHY. Despite the equity statement issued for science policy, the leaky pipeline is still rife. Women amount to just 32% of researchers between those with more than 20 years of publication records, and an even lower percentage for the oldest cohorts (22%). Recently, Spain's government approved the *First Gender Equality Plan 2021–23*[12] aimed at identifying needs and implementing measures to promote equality between women and men in R&D funding activities. So, these statistics might serve to shed light on Spain's scientific workforce distribution by gender and age cohorts and be used on institutional strategies, and/or investments in gender-diversity schemes in science.

In addition, female scientists do not occupy relevant positions. Our study shows that men predominate not only as corresponding authors but also as first and last authors, except for a greater presence of young females. West et al. (2013) likewise found that women are historically under-represented in the first author position, and are currently under-represented in the last author position. According to our findings, in co-authored publications, men occupy the last position in nearly 12% more papers than women, 8% more as corresponding authors, and 6% more as corresponding authors in the first position. The lack of a more relevant position among women might affect research assessments based on authorship. At the national level, these inequalities in the scientific workforce provide evidence of the gender inequalities in the Spanish scientific system.

At the global level, though recent decades have introduced significant reforms aimed at improving gender parity in science (European Commission 2021b; Colwell, Bear and Helman 2020), gender inequality persists (Larivière et al. 2013; Jappelli, Nappi and Torrini 2017) and has been classified in multiple dimensions (Kwiek and Roszka 2021). For example, women are under-represented in publication rates and faculty positions (Huang et al. 2020); in promotion and tenure (Marini and Meschitti 2018; Filandri and Pasqua 2021); and funding (van der Lee and Ellemers 2015; Andersson, Hagberg and Hägg 2021). Women receive lower salaries (Freund et al. 2016); they are significantly less likely to succeed as entrepreneurs (Guzman and Kacperczyk 2019); tend to be less cited (Knobloch-Westerwick, Glynn and Huge 2013; Caplar, Tacchella and Birrer 2017; Potthoff and Zimmermann 2017; Thelwall 2020); and the first position in co-authored publications is not equitable across gender (Colwell, Bear and Helman 2020). Women in science furthermore have a different portfolio than men—who tend toward more research but fewer teaching and administration tasks than women—which leads to double discrimination in universities' recruitment processes (Brommesson et al. 2021). This background could also lead to consequences for the knowledge created (Sugimoto et al. 2019; Koning, Samila and Ferguson 2021; Kozlowski et al. 2022). All these aspects open up potential for further studies focused on the Spanish scientific workforce.

Though the merit-based system of hiring, promotion, and funding aims to select the best talent to lead scientific endeavors with high social, economic, and innovative impact, something is failing along the way, and it may be gender equality (Broderick and Casadevall 2019; Colwell, Bear and Helman 2020). To minimize the persistent gender gap, specific policies are needed to generate specific changes at several levels based on empirical pieces of evidence, as shown in the aforementioned literature.

6.1 Policy implications

The findings of this study contain potential policy advice and could be interpreted by stakeholders in more than one direction. This information might play different roles at various points in the policy cycle (defining and setting research agendas, policy recommendations and/or interventions, their implementation, and eventual research evaluation) and at different aggregation levels (research groups, institutions, countries/regions).

First, scientific societies and universities are in prime positions to develop guidelines surrounding the distribution of authorship (Ni et al. 2021). Journals and publishers can adopt contributorship statements, wherein scientists are not associated with a scientific product, though their contributions are delineated (Allen, O'Connell and Kiermer 2019). In dealing with potential disputes, one may establish clear conditions at the onset of work, or raise complaints at some point to avoid further problems (Academy of Medical Sciences 2016). Given the competition for academic positions, it is important to establish clear authorship rules that will persist and prevail. Indeed, young researchers (as well as women in general) may see their professional prospects jeopardized by being relegated from publication in favor of other researchers (Fleming 2021). The findings of our study might serve to encourage a cultural shift in the management of research groups and in assigning authorship positions for publications. Some available guidelines—e.g. those defined by the International Committee of Medical Journal Editors (ICMJE) or the Recommendations for Group-Author Articles in Scientific Journals and Bibliometric Databases, published by the Council of Science Editors (CSE)—should be more widely known and discussed by the research community in general, and by policy-makers involved in the definition of evaluation criteria.

Second, our study offers a bibliometric perspective for research assessment. Although the study of authorship positions in the byline of publications is not the only variable to be considered when appraising criteria (Sugimoto and Lariviére 2023), it is a valid method for comparing and contrasting various practices. This enhances our understanding of inequality, helping to mitigate the myriad negative impacts on academic careers (Ni et al. 2021). The bibliometric lens through which research evaluation criteria view equity in science is very narrow (González-Salmón, Chinchilla-Rodríguez and Robinson-Garcia 2024a), and seeds a critical eye on how agencies appraise them in the light of tenure, promotion, or funding (Molas-Gallart and Ràfols 2018). Recognition of gender disparities as a persistent problem will no doubt contribute to a fair evaluation of women in hiring decisions. The so-called 'leaky pipeline problem' of disregarding women's contributions to science further undermines the meritocratic ideals of science and lends itself to a significant underuse of the skills present in the pool of doctoral trainees (Sheltzer and Smith 2014). Given the importance of academic publishing in the scientific 'reward' system, any under-representation of women as authors or more prestigious authorship positions undoubtedly affects the representation of women in academia (West et al. 2013). This implies that subtle biases continue to hinder the role of females in science (National Academy of Sciences 2007). For example, Cruz-Castro and Sanz-Menéndez (2021) investigate preferences for evaluation criteria regarding tenure and promotion (reported by female and male academics in Spanish universities). They find that female academics are underrated as opposed to men using bibliometric indicators, except when considering higher positions. In Italy, however, evaluation based on quantitative indicators proves to be more favorable to women than peer review evaluation (Jappelli, Nappi and Torrini 2017). Thus, the validity and reliability of bibliometric indicators in the assessment of institutions and individuals ought to be revisited along with the expert's opinion for evaluation purposes (Weingart 2005). They should examine the respective impacts of academic age, field, authorship position, and type of institution (Kwiek and Roszka 2022).

Third, the current definition of a career does not necessarily follow a reasonable pattern. The increase in the number of PhD degrees is not visibly accompanied by an expansion in the number of academic positions, only by an increase in the temporary workforce in scientific careers. In terms of human resources, when a growing number of scientists enter the system to contribute to the 'leadership' of others, they eventually act only as supporting authors in publications (Milojevic, Radicchi and Walsh 2018). Such trends do not only depend on the size of the teams but also on the division of labor, which assigns specific roles to the researchers involved (Robinson-García et al. 2020). The large proportion of young researchers who are tempted to leave the scientific system, the lack of opportunities for new talent, and the consequent aging of the scientific workforce should urge administrators to rethink academic careers and promote discussions about the need for policy interventions to address a dire problem (Georghiou et al. 2013; Ni et al. 2021).

6.2 Limitations and further studies

This study requires further analysis to overcome certain limitations. First, inequalities in the distribution of the scientific workforce and relevant authors' positions may be due to the historical overrepresentation of men in senior positions (leaky pipeline). Therefore, some predictive models may prove interesting for future analyses to see what contributes to gender parity in science (González-Salmón et al. 2024b), and how the situation could evolve when currently young researchers become senior researchers in terms of the length of an author's active publishing. Second, we analyze disciplinary differences among broad scientific fields, but there are significant differences in authorship practices within, e.g. economics as compared to sociology. Therefore, case studies focused on particular disciplines are necessary. Third, to examine the roles and functions that authors play in the construction of knowledge and the relationship between these roles and authorship order, it would be interesting to explore contributorship analysis as an alternative/complementary approach (Allen, O'Connell and Kiermer 2019). However, given the limited availability of data regarding disciplinary trends in contributorship, this approach is put aside for future case studies. Fourth, the classification of age cohorts only focuses on a specific outcome of scientific activities, the publications. However, it should consider a wide range of knowledge outputs beyond scientific publications, such as mentoring, knowledge transfer, etc (Robinson-Garcia et al. 2023). For the operationalization of age cohorts in further research, we will introduce a more comprehensive and systematic view of the expertise of scholars based on a more diverse kind of scientific-technology-innovation knowledge outputs as in Kwiek and Roszka (2022) and Cortés et al. (2024). It will allow us to extend the understanding of the diverse expertise of the scientific Spanish workforce. Fifth, the author disambiguation algorithm used in this study is exhaustive, meaning that all authorships are assigned to an author which can lead to distortions as one author may be split into several author identifiers. Although the methodology for author identification (Caron and van Eck 2014) produces the best results in comparison with other unsupervised approaches (Tekles and Bornmann 2020), and achieves high precision and recall, there is still room for improvement (D'Angelo and van Eck 2020). Besides, the gender inference algorithm has high precision for both genders (Boekhout, van der Weijden and Waltman 2021) but only considers gender-disaggregated data for men and women. It would also be important to consider non-binary gender for data collection, as the She Figures 2021 Report suggested. Still, we know the limited capacity to gather and process this information.

Finally, whereas the present study is nationally oriented, this approach could likewise be extended to other geographical/institutional domains by tracking changes in the demographics of the workforce in further studies.

7. Conclusions

This paper contributes to an overall reflection on inequalities in science to allow more thoughtful, inclusive, and effective research management and public policy responses. It provides insights into authorship practices within the Spanish scientific workforce, specifically addressing the challenge of fulfilling one specific evaluation criterion: relevant authors' positions in the byline of collaborative publications. Our results indicate less presence of females in the oldest age cohorts plus a disparity between the evaluation criteria and the probability of women and younger researchers reaching these criteria. We believe that this technical study could prove highly relevant in discussions about how current evaluation criteria are related to responsible metrics as declared by CoARA and the necessity of a framework for guiding the development, diversity, and inclusiveness of the Spanish research ecosystem. Therefore, such studies mark a starting point for informed debate and discussion among interested policymakers, stakeholders, and research group leaders. We hope this work sparks awareness of the subtle ways in which gender continues to play a role in shaping the careers of young scientists. The findings may contextualize current research assessment and ultimately contribute to the design and development of new frameworks for scientific evaluation [e.g. the First Spanish Gender Equality Plan 2021–23, the draft of Law 14/2011, of June 1, on Science, Technology, and Innovation, the Agreement on the Reform of Research Assessment (CoARA)].

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Notes

1. https://www.ciencia.gob.es/Noticias/2020/importadasVINETTE/noviembre/El-Ministerio-de-Ciencia-e-Innovacion-abre-consulta-publica-para-promover-una-carrera-investigadora-estable-en-la-ley-de-la-Ciencia.html
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2. http://www.aneca.es/ANECA
3. http://www.aneca.es/Programas-de-evaluacion/Evaluacion-de-profesorado/PEP
4. http://www.aneca.es/Programas-de-evaluacion/Evaluacion-de-profesorado/ACADEMIA
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6. https://www.ciencia.gob.es/Estrategias-y-Planes/Estrategias/Estrategia-Espanola-de-Ciencia-Tecnologia-e-Innovacion-2021-2027.html
7. https://www.ciencia.gob.es/Secc-Servicios/Igualdad/cientificas-en-cifras
8. https://www.ciencia.gob.es/Secc-Servicios/Igualdad/Mujeres-e-Innovacion.html
9. https://icp.csic.es/wp-content/uploads/2021/06/informe_mujeres_investigadores_cmyc-2021_0.pdf
10. https://coara.eu/
11. A detailed description of the assignment of publications to fields is provided here: https://www.leidenranking.com/information/fields. It is important to note here that humanities journal publications are removed from the Leiden Ranking publication set.
12. http://www.aei.gob.es/stfls/MICINN/AEI/ficheros/I_GENDER_EQUALITY_PLAN.pdf

Annex—Multinomial response logit model: formulation and interpretation

Multinomial response models are regression models for the case of a categorical response variable involving more than two categories. Given a polytomic response variable Y that may adopt $S > 2$ categories $Y_1, Y_2, \ldots, Y_S$ the probability of each one of the response categories may by modeled in terms of the observations of the explicative variables $X_1, X_2, \ldots, X_k$, in a generic way as $\pi_s(x) = f_s(x) \forall s = 1, \ldots, S$, so that $\pi_s(x) = P[Y = Y_s | X = x]$ for each vector x of values observed for the explaining variables. The model comes from considering the multinomial distribution for the response with probabilities $\pi_s(x)$: $(Y|X = x) \to M(1; \pi_1(x), \ldots, \pi_S(x))$, verifying that $\sum_{s=1}^{S} \pi_s(x) = 1$.

For the formulation of the model in terms of the explicative variables $X_1, \ldots, X_k$, for each vector of values observed for the explaining variables $x = (x_0, x_1, \ldots, x_k)^T$ with $x_0 = 1$, and $\beta_s = (\beta_{0s}, \beta_{1s}, \ldots, \beta_{ks})'$ the vector of parameters associated with the category Y_s, the model can be expressed in terms of the probabilities of response

$$\pi_s(x) = \frac{\exp(\sum_{j=0}^{k} \beta_{js} x_j)}{\sum_{s=1}^{S} \exp(\sum_{j=0}^{k} \beta_{js} x_j)} \forall s = 1, \ldots, S,$$

with $\beta_{jS} = 0$ (Agresti 2013)

The estimation method of the parameters of the multiple response model is that of maximum reliability, derived from the multinomial distribution. The estimator's properties of the $S-1$ vectors of the parameters are inherited from the maximum reliable estimation: Asymptotic unbiased; Asymptotic normal distribution; Minimal variance. Therefore, all the inference methods regarding the model parameters are either based on the asymptotic properties of the parameters or the distribution of the Wilks' likelihood ratio.

Table 1. Distribution of researchers by gender and age according to the number of papers

	Authors with one paper				Authors with two papers			
Age	female Counts	male Counts	female Percentage	male Percentage	female Counts	male Counts	female Percentage	male Percentage
[0,10]	39818	39982	49.90	50.10	22044	22236	49.78	50.22
(10,20]	2488	3771	39.75	60.25	3053	4588	39.96	60.04
(20,30]	673	1416	32.22	67.78	1033	1849	35.84	64.16
(30,47]	219	675	24.50	75.50	248	693	26.35	73.65
	Authors with more than two papers				**All cases**			
Age	female Counts	male Counts	female Percentage	male Percentage	female Counts	male Counts	female Percentage	male Percentage
[0,10]	84252	103466	44.88	55.12	146114	165684	46.86	53.14
(10,20]	44108	88110	33.36	66.64	49649	96469	33.98	66.02
(20,30]	24963	65088	27.72	72.28	26669	68353	28.07	71.93
(30,47]	6424	29760	17.75	82.25	6891	31128	18.13	81.87

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Research Evaluation, 2025, 34, 1–13
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