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Are Female Scientists Less Inclined to Publish Alone? The Gender Solo Research Gap

Abstract

Solo research is a result of individual authorship decisions which accumulate over time, accompanying academic careers. This research is the first to comprehensively study the "gender solo research gap" within a whole national system: We examine the gap through "individual publication portfolios" constructed for each internationally visible Polish university professor. Solo research is a special case of academic publishing where scientists compete individually, sending clear signals about their research ability. Solo research has been expected to disappear for half a century, but it continues to exist. Our focus is on how male and female scientists of various biological ages, age groups, academic positions, institutions, and institutional types make use of, and benefit from, solo publishing. We tested the hypothesis that male and female scientists differ in their use of solo publishing, and we termed this difference "the gender solo research gap". The highest share of solo research for both genders is noted for middle-aged scientists working as associate professors rather than for young scientists as in previous studies. The low journal prestige level of female solo publications may suggest women's propensity to choose less competitive publication outlets. In our unique biographical, administrative, publication, and citation database ("Polish Science Observatory"), we have metadata on all Polish scientists present in Scopus (N = 25,463) and on their 158,743 Scopus-indexed articles published in 2009–2018, including 18,900 solo articles.

1. Introduction

In the highly competitive global science, publications are a major determinant of successful academic careers (Stephan 2012). However, publications represent various types of authorship, with the major distinction between solo and team research. Single-authored publications, characterized as being doomed to extinction for the past three decades in research literature (spanning scientometrics, sociology of science, economics of science, and higher education research) but still continuing to exist, ask for analytical attention as a special mode of academic knowledge production (Kuld and Hagan 2018). Our interest here is in what we term "the gender solo research gap," or differences in male and female scientists making use of solo publishing, and its impact on academic careers. Solo publications reflect the traditional vision of knowledge in which individual scientists, rather than their teams, contribute to scientific discoveries. Although this perspective has been changing, with ever greater emphasis on team research, solo research continues to exist, albeit with different roles in different disciplines (West et al. 2013).

In the early 20th century, the publication author was simply the single author. However, individual science gradually changed into team science over the century (Larivière et al. 2015; Wuchty et al. 2007), with exponential growth of co-authored publications accompanied by expectations that solo research would disappear (Price 1963). The most characteristic tendency in publishing in the 21st century is the "intensifying scientific collaboration" (Gläznel 2002: 461). Currently, in a "collaborative era in science" (Wagner 2018), assigning credit to, and receiving recognition from, collaborative research is still an unresolved problem; this has been highlighted extensively in the past three decades (Bridgstock 1991; Endersby 1996; Allen et al. 2014; Sarsons 2017). Current thinking about science and its progress—deeply rooted as it is in the history of science, with the sole author on the science pedestal for centuries (Shapin 1990)—has not caught up with daily practices in science in which team publishing predominates; in such daily practice, there is an increasing share of collaborative research in global science, and the average team size is increasing both in natural (Huang 2015) and social sciences (Henriksen 2016). Consequently, with the increasing division of labor, specialization, and hierarchy in larger teams, it is difficult to clearly identify who should be given credit as the main "authors" of the paper (Jabbehdari and Walsh 2017: 2).

Solo research is the only publishing mode in which there seems to be no ambiguity in credit allocation, no errors in signals about scientists' research abilities, and no "biased credit attribution" (Sarsons et al. 2020: 31). In solo research, signals are not "noisy": Men and women are treated similarly as sole authors and "receive the same amount of credit" (Sarsons et al. 2020: 32). Thus, solo research is a special case of credit allocation in science; the credit goes to a single author in an unambiguous manner.

Our focus is on gender differences in solo research from the macro-level perspective of a single national system. Our dataset comprises all scientists with doctoral degrees employed full time in the research-involved university sector and all their publications, including all solo publications (from Scopus), in all academic disciplines. Our focus is on how male and female scientists of various biological ages, academic positions, institutions, and institutional types make use of, and benefit from, solo publishing.

Solo publishing, including gender differences in solo publishing, has not been studied comprehensively in terms of whole national systems, all age groups, academic positions, and disciplines. (However, Kuld and O'Hagan 2017 examined 175,000 articles in 255 top journals in economics; Vafeas 2010 studied 25 accounting and finance journals over a five-year period; Nabout et al. 2014 studied four sub-areas of biology; and Ghiasi et al. 2019 studied 1.18 million solo articles published in 2008–2017 and indexed in the Web of Science). Generally, solo research has appeared in the margins of the studies of multi-authored papers. The sub-issues related to the gender solo research gap can be characterized as follows: (1) solo research and career stages (e.g., early career, mid-career, and established scientists); (2) solo research and disciplines (or cross-disciplinary differences); (3) solo research and institutions/institutional types (or cross-institutional differences); (4) solo research and academic rewards (e.g., tenure, research grants, and academic recognition); and finally, (5) solo research and disciplinary, institutional, and national academic cultures (and their changes over time). However, our focus is limited by our data because we do not have the data on research grants and on changes in academic cultures over time.

In this study, gender has been unambiguously defined for all scientists, and all solo articles produced in a national system in 2009–2018 have been gender classified. Using our newly constructed "Polish Science Observatory" database (see Kwiek and Roszka 2020b), we examined all male and female scientists with their biographical and administrative histories, including their biological age and clearly defined academic positions, as well as locations of their institutions and their dominant disciplines; we then investigated all their research articles, whether published solo or in teams. Based on previous research literature, we assume gender differences in solo research to be significant, and we examine them through "individual publication portfolios" constructed for each scientist ($N = 25{,}463$ scientists, all with doctorates, with 158,743 articles published in 2009–2018, including 18,900 solo articles; in our sample, 2,887 female scientists authored 6,119 solo articles, and 4,871 male scientists authored 12,781 solo articles). For contextual purposes, we also examined our parallel "OECD Science Observatory" database of all (gender-defined) scientists and all (gender-classified) articles indexed in Scopus from 1,674 research-involved institutions from 40 OECD economies in the same period (2009–2018), encompassing 4.2 million scientists and 18.0 million articles.

2. Key Literature

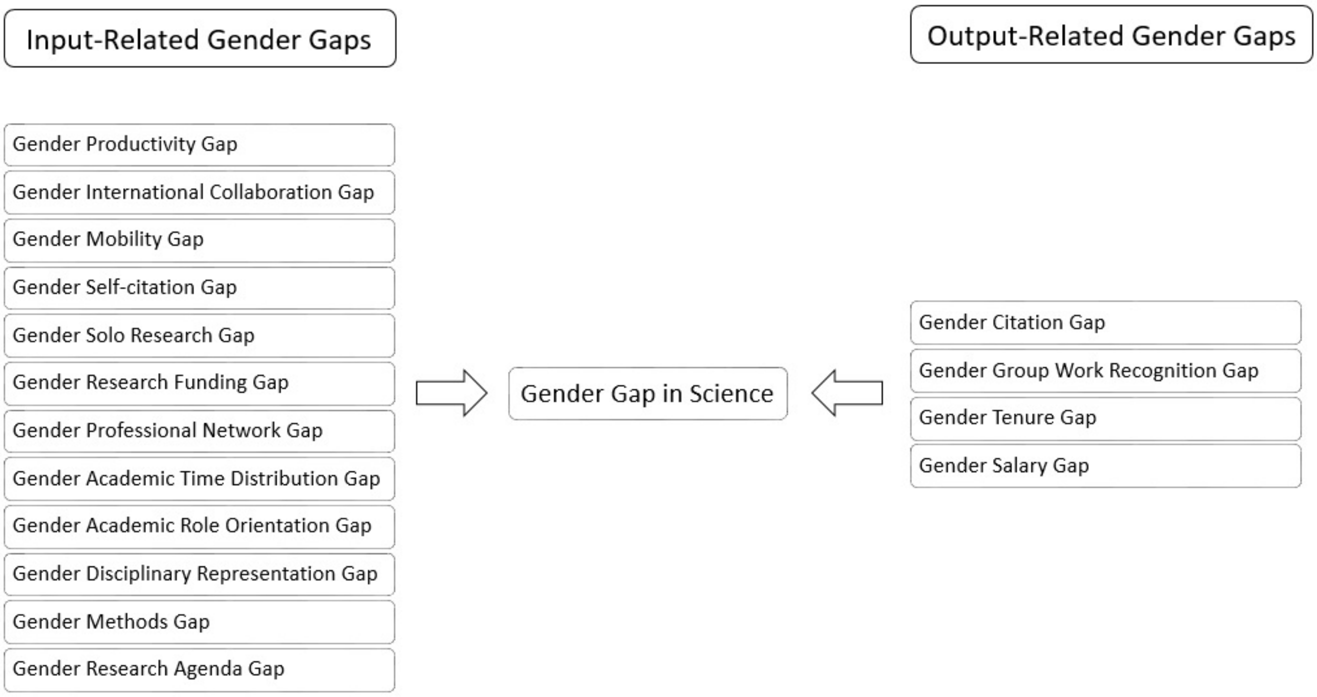
2.1. The Context: The Gender Gaps in Science

The gender solo research gap accompanies other gender gaps in science. Systematically reviewing research literature on male–female differences in science, we have identified specific gender gaps in 16 areas; these are productivity, citations, international collaboration, mobility, professional networks, research funding, academic time distribution, academic role orientation, disciplines, methods, research agendas, and self-citations (defined as "input-related gender gaps"), as well as citations, group work recognition, tenure, and salaries (defined as "output-related gender gaps"; see Figure 1).

Input-related gaps accompany the process of research production; output-related gaps, in contrast, accompany the processes of assessment and reward in science (and assessment and rewarding of scientists, its producers). Among the rewards in science, we identify differences in how male and female scientists are cited, how their role in collaboration is assessed, how they obtain their tenure, and what salaries they receive. Good examples of input- and output-related gender gaps are self-citations for the former gap class and citations for the latter. Female scientists tend to self-cite less (King et al. 2017; Maliniak et al. 2013) on the input side, but they also tend to be cited less (Ghiasi et al. 2018; Potthof and Zimmermann 2017) on the output side. Instead of providing a wide panorama of gender gaps in science and how they operate, a list of the 16 gender gaps with a few representative studies is presented in Table 1. However, on top of that, gender gaps in science function within much larger gender socioeconomic gaps, with the former being clearly linked to the latter; for instance, gender relations in universities cannot be easily disassociated from gender relations in societies at large (including balancing work and family roles, the role of religion and patriarchy in societies, etc.; see a comprehensive account in Lindsay 2011).

Females are massively involved in research, but gender gaps continue to exist, possibly widening in some areas. (Polish females constituted 41.50% of university professors of all ranks, with at least a doctoral degree in our sample and 47.00% of the entire full-time academic workforce in 2019; Statistics Poland 2020: 181). A mechanism that may contribute to widening rather than closing gender gaps in science is "cumulative disadvantage" (Kwiek 2019), or the "accumulation of failures" (Cole 1979: 78), representing the reverse of Merton's (1968) "cumulative advantage." Processes of accumulative advantage for male scientists may be accompanied by processes of accumulative disadvantage for female scientists in which the negative impact of some or all gender gaps combined build up over time (with the "self-reinforcing dynamic" ever stronger; van den Besselaar and Sandström 2017: 14). As the rich (in citations, publications, international collaboration, mobility, funding, professional networks, research time, tenure, recognition, etc.) become richer, the poor—here, female scientists embedded in gender gap–ridden academic environment—become relatively poorer.

Figure 1. Gender gaps in science: a classification.



2.2. Solo Research and the Individual Authorship Decision

Research literature tends to show the future of solo research in dramatic terms; while the "decline" of solo publications has been discussed for several decades, more recently, the "extinction of the single-authored paper" has appeared "imminent" (in ecological research; Barlow et al. 2018). Moreover, "the demise of the 'lone star'" as the author of solo research is discussed, even though the results from research indicate "relative decline" (in economics; Kuld and O'Hagan 2017); new alternatives of "publish together or perish" (in neurology and psychiatry; Baethge 2008: 380) and "publish (in a group) or perish (alone)" emerge (in biology; Nabout et. al. 2015). Solo research is conceptualized as a "vanishing breed," particularly in life sciences (Allen et al. 2014), and the "demise of single-authored publications" is reported in computer science (Ryu 2020). The "death throes" of solo research is reported for ecology research (MacNeil 2019); its "extinction" is expected in four sub-areas of biology (Nabout et al. 2015), and its "decline" is expected in mathematics, chemistry, and physics (Huang 2015). A sharp decline in solo research has also been reported for social sciences and humanities (in Flanders in 2000–2010; Ossenblok et al. 2014). Apart from a long list of factors explaining why solo research is disappearing, two technical factors are important to highlight as follows: the tendency of supervisors to co-author with their students and doctoral students and a shift from informal to formal collaboration in which scientists are making sure that their contributions are visible (Henriksen 2016). As a paper on Austrian life science postdocs summarizes its qualitative findings, "nearly every act of technical or epistemic support constitutes an implicit exchange relationship; publication credits are received for the time and knowledge invested" (Fochler et al. 2016: 193).

Table 1. Gender gaps in science: brief literature review.

Type	Simple explanation	Selected literature
Gender *productivity* gap	Female scientists are less productive than male scientists are.	Larivière et al. 2011; Larivière et al. 2013; Nielsen 2016; van den Besselaar and Sandström 2016; Mihaljević-Brandt et al. 2016; van den Besselaar and Sandström 2017; Maddi et al. 2019; Abramo et al. 2019; Huang et al. 2020; Madison and Fahlman 2020.
Gender *collaboration* gap	Female scientists are less involved in (especially international) research collaboration than male scientists are.	Bozeman et al. 2012; Larivière et al. 2013; Abramo et al. 2013; Vabø et al. 2014; Fell and König 2016; Nielsen 2016; Fox et al. 2017; Aksnes et al. 2019; Maddi et al. 2019; Kwiek 2020b; Kwiek and Roszka 2020a; Fox 2020.
Gender *mobility* gap	Female scientists are less involved in (especially international) mobility than male scientists are.	Ackers 2008; Frehill and Zippel 2010; Jöns 2011; Zippel 2017; Uhly et al. 2017.
Gender *self-citation* gap	Female scientists cite themselves less often than male scientists do.	Hutson 2006; Maliniak et al. 2013; King et al. 2017; Mishra et al. 2018.
Gender *solo research* gap	Female scientists are less involved in publishing alone than male scientists are.	West et al. 2013; Walker 2019; Sarsons et al. 2020.
Gender *research funding* gap	Female scientists are awarded smaller research grants or receive them less often compared with male scientists.	Larivière et al. 2011; van den Besselaar and Sandström 2015; van den Besselaar and Sandström 2017; Cruz-Castro and Sanz-Menéndez 2019. Opposing evidence: Marsh et al. 2009.
Gender *professional network* gap	Female scientists have narrower (and less international) formal and informal networks of collaborators than male scientists do.	Feeney and Bernal 2010; Van den Brink and Benschop 2013; Kegen 2013; Clauset et al. 2015; Greguletz 2018; Halevi 2019; Heffernan 2020.
Gender *academic time distribution* gap	Female scientists spend more time on teaching and male scientists more time on research.	Toutkoushian and Bellas 1999; Cummings and Finkelstein 2012; Leišytė and Hosch-Dayican 2017; Goastellec and Vaira 2017; Kwiek 2019.
Gender *academic role orientation* gap	Female scientists are less research-oriented and more teaching-oriented than male scientists are.	Miller and Chamberlin 2000; Cummings and Finkelstein 2012; Leišytė and Hosch-Dayican 2017; Goastellec and Vaira 2017; Kwiek 2019.
Gender *disciplinary*	Female scientists are underrepresented	Ceci and Williams 2011; Shapiro and Williams 2011; Ceci et al. 2014; Avolio et

representation gap	in large parts of STEM fields compared with male scientists.	al. 2020.
Gender *methods* gap	Female scientists use quantitative methods less often and qualitative methods more often than male scientists do.	Thelwall et al. 2019; Key and Sumner 2019.
Gender *research agenda* gap	Female scientists study different research topics than male scientists do.	Key and Sumner 2019; Thelwall et al. 2019; Santos et al. 2020.
Gender *citation* gap	Female scientists are less cited than male scientists are.	Aksnes et al. 2011; Maliniak et al. 2013; Ghiasi et al. 2015; Abramo et al. 2015; Potthof and Zimmermann 2017; van den Besselaar and Sandström 2017; Ghiasi et al. 2018; Lerchenmueller et al. 2019; Maddi et al. 2019; Huang et al. 2020; Madison and Fahlman 2020; Thelwall 2020.
Gender *group work recognition* gap	Female scientists receive less recognition (or less credit) for their collaborative publications than male scientists do.	Heffner 1979; Sarsons 2017; Sarsons et al. 2020.
Gender *tenure* gap	Female scientists are less often promoted to tenure than male scientists are.	McDowell and Smith 1992; Abramo et al. 2015; Fell and König 2016; Weisshaar 2017; Rivera 2017; Diezmann and Grieshaber 2019; Sarsons et al. 2020. Opposing evidence: Madison and Fahlman 2020.
Gender *salary* gap	Female scientists have lower salaries in academia than male scientists do.	Fox 1985; Barbezat and Hughes 2005; Ward and Sloane 2000; Ceci et al. 2014; Kwiek 2018a.

In practical terms, solo research stems from voluntarily making individual authorship decisions. Individual scientists make consequential authorship decisions about how to follow in their research, and choosing solo publications is one of the options (as is choosing same-sex or mixed-sex collaborators; McDowell et al. 2006; on the gender-based homophily in research, or men collaborating with men and women collaborating with women, see Kwiek and Roszka 2020b). The authorship decision is important because "it is likely to affect the project's quality, efficiency of execution, and exposure, as well as the amount of credit an author receives following its eventual publication" (Vafeas 2010: 332). The results of many individual authorship decisions accumulate over time, accompanying lifetime academic careers.

Authorship decisions may bear on the availability of external research grants from national research councils. Major research funding agencies may favor not only publications in top international journals but also publications written in international collaboration, following the global and European "internationalization imperative" (Ackers 2008) in research policies and a generally assumed link between research internationalization and productivity (Abramo et al. 2011; Kwiek 2015; Kwiek 2020b; a global exception to a positive role of research internationalization in promotion, tenure, salaries, and research grants being the United States, see Cummings and Finkelstein 2012). Therefore, authorship decisions need to be "intelligent" (Vafeas 2010: 333) and "strategic" (Jeong et al. 2011: 968). The major discrete choice among the collaboration modes is between solo research and team research and then between the various types of team research. Women are reported to be significantly underrepresented not only as first and last authors of publications (Walker 2019) but also as authors of solo research (West et al. 2013; Walker 2019; Sarsons et al. 2020).

Individual authorship decisions may be critical for individual academic careers; however, the implications go far beyond individual scientists and reach the aggregated levels of institutions, disciplines, and national systems (such that Poland has the lowest level of international collaboration in research among all 27 European Union countries and the second highest levels in solo publishing, Kwiek 2020a, at 36.0% and 12.1%, respectively; Scopus 2021). The publishing patterns at aggregated levels, such as those for an institution or a country, depend entirely on individual decisions of thousands of scientists who are willing to publish solo or in institutional, national, or international collaboration. Collaboration, as opposed to solo publishing, involves compromise and tends to reduce risk taking (Hudson 1996: 157; Kuld and O'Hagan 2017: 1221). However, collaboration can result in information overload, unclear responsibilities, and communication issues—collectively known as "coordination costs" (Olechnicka et al. 2019: 111). Scientists make consequential decisions not only about where to publish (within a steep hierarchical order of academic journals; see the "prestige-maximization" role of top journals in Kwiek 2020c) but also about whether to publish solo or to collaborate based on the available resources, research environment, and trade-offs among alternative modes of collaboration (Jeong et al. 2014: 521).

2.3. Solo Research and Academic Disciplines

Solo research is differently distributed across disciplines, which exhibit distinct dominant collaborative practices; consequently, one might not expect a direct comparison between the team size of papers in mathematics versus physics and astronomy (Huang 2015), the former being a low-author field and the latter a high-author field on average. Average team size is highly differentiated across disciplines (Larivière et al. 2015), and in disciplines that are heavily solo research dominated, such as some in the arts and humanities and in social sciences, authorship credit is usually attributed to a single creator (Endersby 1996: 381). As reported for Canada, "in the humanities and literature, formal collaboration based on co-authorship is a marginal phenomenon" (Larivière et al. 2006: 531).

As demonstrated for seven major academic institutions in Israel, the more theoretical the research, the higher the probability of the paper being single authored (Farber 2005: 65). There are also significant cross-institutional differences in the numbers and shares of solo publications, with mathematics identified as a discipline with a remarkably higher number of single-authored papers across all seven Israeli institutions (Farber 2005: 64).

While the general opposition between solo and team research is analytically useful, it does not allow telling the whole story, especially the story of ongoing evolution in dominant authorship types by discipline. In some disciplines, the historical change in the past quarter of a century is away from solo and toward team publications, while in others, it is away from two-author and toward three-author publications. The trends for two-author and three-author publications may not be the same, and the trends for two-author and 10-author publications, both being generally team publications, may differ substantially. “Small-group collaborations” may have different dynamics by discipline and over time than “large-group collaborations” do. Consequently, “small-group collaborations” in basic sciences as stochastic processes differ from “large-group collaborations” as staggered plateaus (Huang 2015: 2141–2146). In different disciplines, there are different authorship types dominating at one time, and research collaboration in different disciplines may go through the same stages, but with a delay, at different times (Huang 2015: 2146).

2.4. Solo Research and Academic Reputation

Academic reputation comes almost exclusively from publications (Stephan 2012), just as social stratification in science is largely publication based (Kwiek 2019). It seems to be closely linked not only to team publications but also to solo publications. The disciplines studied in the literature in the context of solo research include accounting (Rutledge and Karim 2009), mathematics (Mihaljević-Brandt et al. 2016), social sciences and humanities (Larivière et al. 2006), political sciences (Fisher et al. 1998), and life sciences (Fochler et al. 2016; Müller 2012; Müller and Kenney 2014). Specifically, the link between academic reputation and solo research pertains to highly prolific and highly cited authors (Vafeas 2010): A certain minimum amount of solo publications may be needed to belong to the global research elite (Kwiek 2016), and solo publications for this specific layer of top scientists may be strategically located in highly prestigious journals (Kwiek 2020c).

As a study of accounting shows, prolific authors in accounting literature become more productive and produce longer articles using extensive collaboration. However, such prolific authors “appear to decrease the number of co-authors on their higher quality publications, possibly to increase the quality of their reputation” (Rutledge and Karim 2009: 130). Interestingly for our research, regression results suggest that productive authors’ publications that use fewer co-authors are more likely to appear in journals with a greater impact on the literature (Rutledge and Karim 2009: 133). Scientists are reported to be more likely to publish solo research if they are affiliated with universities located higher in rankings, when the expected amount of work (proxied by the article’s length) is small, and if the article is conceptual rather than empirical (Vafeas 2010: 340–341). The university rank is significantly related to the likelihood of single authorship, with authors from highly ranked institutions “having the training and resources to be more self-sufficient in conducting their research” (Vafeas 2010: 341). There may be a tendency of highly cited scientists to publish their solo research, rare as it is, in top journals in their disciplines.

2.5. Solo Research, Age, and Academic Positions

Solo research emerges from literature as strongly related to age and academic seniority. Junior faculty are reported to show a higher propensity to publish solo research than senior faculty are, with two independent explanations for this phenomenon: First, junior faculty use single authorship as signals about their ability to perform independent research; and second, junior faculty are sole authors in papers coming out of their doctoral theses (Vafeas 2010: 341), in the Polish case, when they are about 30–35 years old. As Kuld and O'Hagan (2018) have shown for journals in economics, younger scientists publish significantly more solo-authored papers than older scientists do. In economics, over 20% of all articles in top journals are solo authored, and in many cases, solo-authored articles have citation counts as high as or higher than citations for papers with multiple authors (Kuld and O'Hagan 2018: 1223). Solo research may also suggest a higher degree of research independence and credibility, and it may be useful in the academic job marketplace at the postdoctoral level.

2.6. Solo Research and Competition in Science

Solo research may be linked to competition in science and how male and female scientists approach it. Global research is highly competitive (Stephan 2012; Wagner 2018): Teams compete against teams, and individual scientists compete against individual scientists institutionally, nationally, and globally in search of recognition and funding for further research (Fochler et al. 2016; Latour and Woolgar 1986). Within-team collaboration (and competition) is accompanied by between-team collaboration (and competition). However, solo research may be viewed as riskier than team research is because it is more vulnerable to criticism (Hudson 1996; Kuld and O'Hagan 2017). Female scientists have been found to be generally less inclined to enter into direct criticism of others (Wu et al. 2020) and possibly to enter into direct competition with others, as they are seen as less "combative in science" (Sonnert and Holton 1996).

Solo research, especially research published in prestigious journals, can be viewed as more competitive than team research in which all responsibilities, including responsibilities for possible failures and errors, are shared between multiple scientists. In solo research, responsibility rests with the sole author, and female scientists may be deterred from both competition (including prestigious grant applications; Cruz-Castro and Sanz-Menéndez 2019) and sole responsibility more than male scientists are. Experimental and personnel economics show that women may be deterred by competition in science (and in workplaces; Dargnies 2012; Flory et al. 2015). Such shying away from competition and risk aversion could have implications for team formation in research collaboration, including lower levels of self-selection into solo publishing versus team publishing.

Women might shy away from competition and men might embrace it, with gender implications for publishing patterns (Sonnert and Holton 1996). Gender differences in the general propensity to choose competitive environments (possibly choosing solo research in academic publishing) are reported to be driven by gender differences in confidence and preferences for entering and performing in a competition (Niederle and Vesterlund 2007: 1098–1100). Gender differences in choices over competition may be driven partly by men preferring competitive to noncompetitive settings (Flory et al. 2015). Not surprisingly, male scientists overcite (King et al. 2017; Maliniak et al. 2013), are better represented in top journals, and have higher visibility in science (Maddi et al. 2019). In addition, social norms or expectations of conventional behavior in science may matter: There may be different common social practices for men and women, particularly in male-dominated disciplines, regarding solo publishing. Moreover, social norms may hold women scientists up to more scrutiny than men (Gupta et al. 2011: 16). Women scientists might be seen as socialized to be less competitive, often feeling they are "under the magnifying glass" (Sonnert and Holton 1996: 69), with possible implications for a different distribution of solo publications for male and female scientists. Females may be less likely to submit their work to journals (choosing, e.g., edited volumes) and to submit to top journals in particular because they do not believe that their work "will be published" (Key and Sumner 2019: 663). A survey of 2,440 American Political Science Association members shows that female academics prefer not to submit manuscripts to certain journals, believing that their chances to get published are lower: a gender submission gap is accompanied by a gender perception gap (Brown et al. 2020).

2.7. Solo Research, Credit Allocation, and Authorship Claims

Solo research avoids problems in credit allocation for publication (Sarsons 2017; Sarsons et al. 2020), and it may reduce possible conflicts about authorship (Barlow et al. 2017). Academic publications are key to the individual futures of young scientists, especially when large cohorts of postdoctoral researchers seek permanent jobs (confirming the role of "cohort effects"; Stephan 2012: 174–176). Young scientists fight for academic survival in a rapidly changing academic world in which doctoral students are already expected to publish, and postdocs are expected to publish extensively; such expectations were lower in the late 20th century. High-quality research performance matters because, as Stephan (2012) comments, "no output, no funding" (149). However, cohort also matters: In this case, what is important is the current global abundance of postdoctoral researchers and the scarcity of academic employment opportunities for them. The supply of highly able doctorates exceeds the demand for postdoctoral opportunities, not to mention permanent jobs (see two edited volumes on postdocs and young faculty in the US and globally: Jaeger and Dinin 2018 and Yudkevich et al. 2015). A series of studies based on in-depth analyses of interviews with postdocs in life science about their academic career rationales (Fochler et al. 2016; Müller 2012; Müller and Kenney 2014) highlight growing tensions related to the choice of preferred working style and publishing pattern in their day-to-day practices. In a hypercompetitive academic environment in which the supply of postdocs in life sciences (as in other disciplines) is much higher than the demand for candidates for full-time academic jobs, young scientists with doctorates have to ensure first authorship (or solo authorship) for their publications if they want to send clear signals to the academic labor market about their outstanding research abilities.

Publication, and hence, the question of authorship, is pivotal in negotiations about collaboration in ongoing research. The postdoc's choice is often to work individually to avoid possible authorship conflicts; postdocs are reported to use those collaborative opportunities that "do not pose a threat to individual authorship claims" (Müller 2012: 291). In fast-growing, highly internationalized, and highly competitive research fields—in which science is expected to be highly collaborative—young scientists, paradoxically, may choose individualized modes of working and publishing. The reason is simple: In solo (or, to some extent, first-author papers), it is clear where credits for publication go. Strategic thinking may involve considering solo research more strongly in one's 30s than in one's 40s—although certainly not in all disciplines. In Europe, with its highly prestigious, multibillion-euro European Research Council financing thousands of scientists, publications co-authored with dissertation supervisors tend not to count in competitions for early career researchers.

In our research, we assume that the attractiveness of solo research will last as long as the issues of recognition, including formal and informal credit for co-authorships, remain unresolved (Allen et al. 2014). Such resolution may not happen in the foreseeable future. While publishing in co-authorships is safer (the risk of openly hostile criticism is reduced, and the responsibility for errors is divided between all co-authors), it may not suffice to obtain a permanent job, or in some systems, to keep it. In most disciplines, first-author publications are as powerful signals of individual research ability as solo publications are. Although Price (1963) expected that "by 1980 the single-author paper will be extinct," Abt (2007: 358) was right when he claimed that single-authored papers would not disappear soon because "there are some projects that do not require teams and some authors who prefer to work individually."

2.8. Research Questions and Hypotheses

Our six research questions and hypotheses are shown in Table 2, together with support received in the Results section of the paper.

Table 2. Research hypotheses and results (summary).

Research Question	Hypothesis	Support
RQ1. What is the relationship between publishing solo, gender, and disciplinary gender representation?	**H1: Gender and disciplinary representation:** We expect that women scientists will exhibit lower individual publishing solo rates in male-dominated disciplines than in female-dominated disciplines.	Supported
RQ2. What is the relationship between publishing solo, gender, and institutional research intensity?	**H2: Gender and institutional research intensity:** We expect that female scientists will exhibit higher individual publishing solo rates in research-intensive institutions than in institutions less involved in research.	Supported
RQ3. What is the relationship between publishing solo, gender, and journal prestige?	**H3: Gender and journal prestige:** We expect that female solo articles are published in less prestigious journals than male solo articles are.	Supported
RQ4. What is the relationship between publishing solo, gender, and biological age?	**H4: Gender and biological age:** We expect that younger male and female scientists publish significantly more solo-authored papers than older male and female scientists do (that individual publishing solo rates in their individual publication portfolios are significantly higher).	Not supported
RQ5. What is the relationship between publishing solo, gender, and academic position?	**H5: Gender and academic position:** We expect that male and female scientists lower in academic ranks will publish significantly more solo-authored papers than male and female scientists higher in academic ranks do (that individual publishing solo rates in their individual publication portfolios is significantly higher).	Not supported
RQ6. What is the relationship between the propensity to publish solo and gender?	**H6: Gender and solo publication propensity:** We expect that being a female scientist decreases the propensity to conduct solo research or the individual publishing solo rate (in fractional logit regression models).	Mixed results: marginal influence of gender

3. Data and Methods

3.1. Dataset

We used the "Polish Science Observatory" database, in which two large databases of different natures were merged: Database I was an official national administrative and biographical register of all Polish academic scientists; Database II was the Scopus database (a detailed description of the integrated database is presented in Kwiek and Roszka 2020b). Database I comprised 99,535 scientists employed in the Polish science sector as of November 21, 2017. Only scientists with at least a doctoral degree (70,272) and employed in the higher education sector were selected for further analysis (54,448). The data used were both demographic (gender and date of birth) and professional (the highest degree awarded; and institutional affiliation), with each scientist identified by a unique ID. Database II included 169,775 names from 85 institutions, where the publications for the decade analyzed (2009–2018) were included in the database and the metadata on 384,736 Scopus-indexed publications. Scopus uses an author-matching algorithm to identify publications by the same author; however, gender is not captured in the Scopus Author Profiles (Elsevier 2020: 119). We have identified scientists with their different individual IDs in the two databases and provided them with a new ID in the new "Observatory" database. Probabilistic methods of data integration were used (Enamorado et al. 2019; Fellegi and Sunter 1969; Herzog et al. 2007). The computation was made using the fastLink R package (version 0.6.0). From among 384,736 publications included in Database II, 377,886 publications had up to 100 authors, and 230,007 were written by the authors included in Database I (we used deterministic record linkage at this stage of data integration). Subsequently, only journal articles were selected for further analysis (158,743 articles). Finally, our dataset had 7,758 solo authors (i.e., authors with at least a single solo article, 4,871 male and 2,887 female scientists) and 19,252 solo articles. In the "Observatory" database, every Polish academic scientist with a doctoral degree is characterized by the dominant discipline (one of 27 ASJC general disciplines, ASJC is All Science Journal Classification is Scopus). Consequently, we have a clearly defined gender, biological age, and dominant discipline for every scientist, along with all their solo and team publications, as well as the distribution of female and male scientists in every discipline. The dominant disciplines, individual publication portfolios, gender composition of disciplines, and average publication prestige were constructed for the decade of 2009–2018.

3.2. Methods

Table 3 provides a short description of variables used in the analysis ("Observatory" refers to the Polish Science Observatory and "Ministry" means the Polish Ministry of Education and Science).

Table 3. Variables used in the analysis.

No.	Variable	Description	Source
1.	Biological age	Numerical variable. Biological age as provided by the national registry of scientists (*N* = 99,935). Age in full years as of 2017 is used.	Observatory
2.	Age group	Categorical variable. Three major age groups are used: young (39 and younger; *N* = 8,400), middle-aged (40–54; *N* = 11,014), and older (55 and older; *N* = 6,049) scientists.	Observatory
3.	Gender	Binary variable, male or female, as provided by the national registry of scientists (*N* = 99,935). No other options are possible in the registry.	Observatory
4.	Academic position	Categorical variable. Three Polish degrees were used as proxies of academic positions: doctoral degree only (assistant professor; *N* = 14,271), habilitation degree (associate professor; *N* = 7,418), and professorship title (full professor; *N* = 3,774). All scientists without doctoral degrees and from outside of the higher education sector were removed from the analysis.	Observatory
5.	Discipline	Categorical variable. All scientists ascribed to one of 27 Scopus ASJC (All Science Journal Classification) disciplines. Dominant disciplines were used (*N* = 25,463).	Scopus

No.	Variable	Description	Source
6.	STEM disciplines	Categorical variable. STEM disciplines: AGRI, agricultural and biological sciences; BIO, biochemistry, genetics, and molecular biology; CHEMENG, chemical engineering; CHEM, chemistry; COMP, computer science; DEC, decision science; EARTH, earth and planetary sciences; ENER, energy; ENG, engineering; ENVIR, environmental science; GEN, biochemistry, genetics, and molecular biology; IMMU, immunology and microbiology; MATER, materials science; MATH, mathematics; NEURO, neuroscience; NURS, nursing; PHARM, pharmacology, toxicology, and pharmaceutics; and PHYS, physics and astronomy. GEN, NEURO, and NURS were omitted from the analysis as they did not meet an arbitrary minimum threshold of 50 scientists per discipline.	Scopus
7.	Non-STEM disciplines	Categorical variable. Non-STEM disciplines: BUS, business, management, and accounting; DENT, dentistry; ECON, economics, econometrics, and finance; HEALTH, health professions; HUM, arts and humanities; MED, medicine; PSYCH, psychology; SOC, social sciences; and VET, veterinary.	Scopus
8.	Male- and female-dominated disciplines	Binary variable. Male-dominated disciplines are those in which the percentage of male scientists exceeds or equals 50% (N = 12,786 scientists). Female-dominated disciplines are those in which the percentage of female scientists exceeds 50% (N = 12,677 scientists).	Observatory
9.	Mean publication prestige (percentile rank)	Numerical variable. Mean prestige represents the median prestige value for all publications written by a scientist in the study period of 2009–2018. For journals for which the Scopus database did not ascribe a percentile rank, we have ascribed the percentile rank of 0; Scopus ascribes percentiles to journals in the 25th to 99th percentile range, with the highest rank being the 99th percentile.	Scopus
10.	Research-intensive institution	Binary variable. The 10 institutions (from among 85 examined) are the IDUB (or "Excellence Initiative–Research University") institutions selected in 2019.	Ministry

The key methodological step was to determine what we termed an "individual publication portfolio" for every internationally visible Polish scientist (for the decade of 2009–2018—an approach already used in Kwiek and Roszka 2020a, in a study of gender differences in international research collaboration, and Kwiek and Roszka 2020b, in a study of gender homophily in academic publishing). Next, using an individual scientist as the unit of analysis, we calculated the proportion of solo articles among all articles within the individual publication portfolio of every Polish scientist in the sample. Thus, for all scientists, male and female, we constructed what we termed the individual publishing solo rate (for scientists publishing all their articles alone, the rate is 1) as a numerical variable. Analogously, a rate of 0 is equivalent to conducting no solo research—the scientist collaborates with others in all publications, that is, there are only collaborative articles in the portfolio. For the vast majority of authors (10,015 or 67.3% of all males and 7,690 females or 72.7% of all females; 17,705 in total), the individual publishing solo rate was zero, meaning they had not had a solo article published in the decade studied.

The major difference between approaching solo research via individual publication portfolios and via aggregated percentages of solo research in the Polish science system as a whole is the role of publishing outliers, or highly productive scientists (see Kwiek 2016). Their role is reduced in the first method, whereas they may play an excessive role in the second method, leading to distortions (see Abramo et al. 2013; and the role of outliers in altering research conclusions in Aguinis et al. 2013), especially in view of previous research showing a highly skewed distribution of productivity in Polish science (in which 10% of scientists produce about 50% of publications; Kwiek 2018b). In the first method, each scientist has a clearly defined individual publication portfolio, with a specific individual publishing solo rate ranging from 0 to 1. The impact on the average male and female rates in Poland of scientists with 100 publications equals the impact of those with 10 publications.

3.3. Sample

The sample ($N = 25{,}463$) consists of 14,886 male scientists and 10,577 female scientists (58.5% and 41.5%, respectively). Based on our dataset of 99,935 scientists, it contains all scientists who had at least a single article indexed in the Scopus database in the period of 2009–2018 and who had at least a doctoral degree. Thus, the sample includes all internationally visible Polish academic scientists. In terms of the age distribution, about half of them are middle-aged (or in the 40–54 age bracket; 49.7%), and in terms of academic positions, over half of them are assistant professors (56.0%). Table 10 in the Data Appendices shows column percentages, which enable the analysis of the gender distribution by major age groups, academic positions, and disciplines (by type: STEM and non-STEM, female-dominated and male-dominated), and it shows row percentages, which enable the analysis of how male and female scientists are distributed according to a given feature. About half the scientists work in female-dominated disciplines and about half in male-dominated disciplines (49.8% and 50.2%). All assistant professors hold doctoral degrees, all associate professors hold habilitations, and all full professors hold professorship titles.

3.4. Limitations

Our research is affected by a selection bias as a result of the database construction: We select only internationally visible authors, that is, authors with Scopus-indexed publications, and we select only authors with at least doctorates. There are also five simplifying assumptions (as in Kwiek and Roszka 2020b), which are as follows: (1) We examine a decade of individual publishing output, although the actual publishing period may be shorter for younger scientists; (2) Scopus-provided journal percentile ranks are deemed stable, although they may fluctuate over the period studied; (3) we assume that scientists did not change institutions in the decade studied; (4) we regard scientists who were assistant, associate, and full professors on the date of reference (November 21, 2017) as keeping these positions for the decade studied, while these positions are the highest ranks achieved in the study period; and (5) for the purpose of international comparability in the results, we refer to three categories of academic positions (assistant, associate, and full professor), although in practice, two Polish academic degrees (doctorate and habilitation) and a Polish academic title (professorship) are used. Thus, academic positions are useful proxies for Polish academic degrees and titles. While the administrative and biographical variables of biological age, academic position, employment type, and institution were defined as of November 21, 2017, the publication and citation variables derived from the Scopus database were constructed to show mean values for the decade of 2009–2018 (and they may have differed from year to year). Therefore, another limitation is that the values for 2017 for some variables and the mean values for the decade of 2009–2018 are used in the same analysis.

4. Results

4.1. Solo Research and Academic Discipline by Gender

H1: Gender and disciplinary representation: We expect that women scientists will exhibit lower individual publishing solo rates in male-dominated disciplines than in female-dominated disciplines (hypothesis supported).

We use two approaches to individual publishing solo rates (the rate being the proportion of solo articles among all articles within the individual publication portfolio), examining rates (ranging from 0 to 1 for no solo articles and all solo articles in individual publication portfolios, respectively) by gender for all authors and for solo authors only. The former approach highlights the distribution of the rate among all authors by gender and discipline (left panel in Table 4), the rate being as low as 0.013–0.016 in BIO (or less than 2%) and as high as 0.50–0.53 in SOC and 0.76 in HUM, depending on gender. The latter approach highlights the intensity of publishing solo, or the individual publishing solo rate for solo authors only by discipline (right panel in Table 4).

To take a generally high-collaboration discipline of chemistry (CHEM) and a generally low-collaboration discipline of arts and humanities (HUM), it can be observed that, in the former, 3.2–3.4% of publications in the individual publication portfolios of male and female scientists are published solo; in the latter, the percentage is about 76%. However, for solo authors only, or the authors who published at least one solo article in the decade studied, for CHEM, the intensity is 15–16%, and for HUM, it is 92–93%. In CHEM, solo authors publish solo occasionally, compared with HUM, where solo authors publish almost all their articles solo. In other words, in HUM, three-quarters of authors publish solo, and for those who publish solo, the pattern of solo publishing is intense—more than 90% of their articles are solo articles.

On average, across all disciplines, the rate is slightly higher for men (0.1429) than for women (0.1301, $p < 0.001$; we used the Mann–Whitney test). In addition, male solo scientists show a lower intensity of publishing solo (0.4366) than female solo scientists do (0.4767), and the difference is also statistically significant ($p = 0.000$). Overall, the differences within disciplines by gender are smaller than expected and statistically significant only in several selected disciplines. (The rate is higher for women in 6 out of 10 female-dominated disciplines and in 6 out of 14 male-dominated disciplines). Cross-gender differences are more visible in the intensity of solo publishing by discipline. The rate for solo authors is higher for women in 13 disciplines.

To conclude, women scientists across disciplines publish solo only slightly less often than men do; however, when they do, they publish solo with higher intensity in both heavily male-dominated disciplines (e.g., physics and astronomy, with 16.6% of females publishing solo; see the gender distribution of scientists across 14 male-dominated and 10 female-dominated disciplines in Table 10 in the Data Appendices; Earth and planetary sciences, with 33.4% of females publishing solo) and female-dominated disciplines (e.g., pharmacology, toxicology, and pharmaceutics, with 66.5% of females publishing solo; medicine, with 53.7% of females publishing solo). Additionally, 67.3% of males and 72.7% of females had not had a solo article published in the decade studied (their individual publishing solo rate was zero). The distribution of the rate for all authors (top panel) and solo authors (bottom panel) by gender and discipline is shown in boxplots in Figure 5. In principle, in the case of all authors, the level and variability of the rate by gender within disciplines are similar. In contrast, in the case of solo authors, the level and the variability differ substantially in selected disciplines, especially female-dominated ones (e.g., IMMU, MED, and PHARM).

Table 4. Mean individual publishing solo rates by discipline and gender: for all authors (left panel) and for solo authors only (right panel; shading: from the highest rate in dark blue to the lowest rate in light blue).

	Male	Female	Total	*Z*	*p*	Male	Female	Total	*Z*	*p*
AGRI	0.0455	0.0434	0.0444	−0.478	0.633	0.2373	0.2340	0.2356	−0.705	0.481
BIO	0.0159	0.0133	0.0143	−0.325	0.745	0.2639	0.2057	0.2280	−0.883	0.377
BUS	0.2779	0.2553	0.2661	−0.425	0.671	0.6787	0.6248	0.6507	−1.427	0.153
CHEM	0.0320	0.0335	0.0328	−1.298	0.194	0.1632	0.1536	0.1580	−1.948	0.051
CHEMENG	0.0988	0.0467	0.0788	−2.175	0.030	0.3750	0.2468	0.3353	−2.252	0.024
COMP	0.1568	0.1530	0.1562	−0.258	0.796	0.4282	0.4334	0.4290	−0.244	0.807
DEC	0.4297	0.3264	0.3838	−1.016	0.310	0.7161	0.8704	0.7675	−1.506	0.132
DENT	0.0051	0.0052	0.0052	−0.032	0.975	0.0909	0.0995	0.0973	−0.447	0.655
EARTH	0.1597	0.1778	0.1658	−0.397	0.691	0.3768	0.4306	0.3945	−2.437	0.015
ECON	0.3635	0.3577	0.3606	−0.001	0.999	0.6877	0.6587	0.6733	−0.649	0.516
ENER	0.1538	0.1638	0.1565	−0.509	0.611	0.4816	0.6105	0.5131	−1.645	0.100
ENG	0.1502	0.1650	0.1524	−1.068	0.286	0.3770	0.3954	0.3799	−1.056	0.291
ENVIR	0.0713	0.0804	0.0759	−2.783	0.005	0.2810	0.2506	0.2638	−1.044	0.296
HEALTH	0.0792	0.1783	0.1132	−0.983	0.326	0.5810	0.8200	0.6897	−1.344	0.179
HUM	0.7583	0.7601	0.7592	−0.233	0.816	0.9193	0.9316	0.9254	−0.930	0.352
IMMU	0.0126	0.0315	0.0269	−0.024	0.981	0.1217	0.3149	0.2666	−0.466	0.642
MATER	0.0502	0.0469	0.0491	−0.036	0.971	0.1903	0.1757	0.1853	−0.475	0.635
MATH	0.2786	0.2483	0.2709	−1.468	0.142	0.4414	0.4287	0.4384	−0.372	0.710
MED	0.0174	0.0240	0.0210	−0.486	0.627	0.1911	0.2827	0.2387	−3.516	0.000
PHARM	0.0094	0.0189	0.0157	−0.147	0.883	0.0892	0.1998	0.1600	−2.180	0.029
PHYS	0.0710	0.0670	0.0704	−0.709	0.478	0.2133	0.2302	0.2158	−1.689	0.091
PSYCH	0.1800	0.1682	0.1725	−0.026	0.979	0.4714	0.4533	0.4600	−0.579	0.563
SOC	0.5292	0.4962	0.5128	−1.140	0.254	0.7867	0.7636	0.7754	−0.956	0.339
VET	0.0113	0.0198	0.0150	−0.804	0.421	0.0998	0.2414	0.1513	−2.041	0.041
Total	0.1429	0.1301	0.1376	−8.227	<0.001	0.4366	0.4767	0.4515	−3.968	0.000

Figure 4. Mean individual publishing solo rates for all authors (left panel) and for solo authors (right panel) by gender and discipline (in descending order).

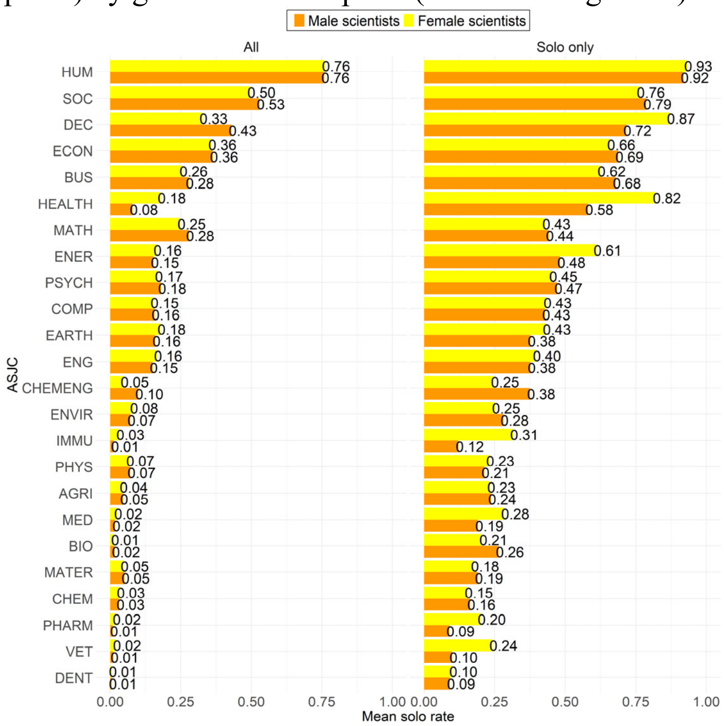
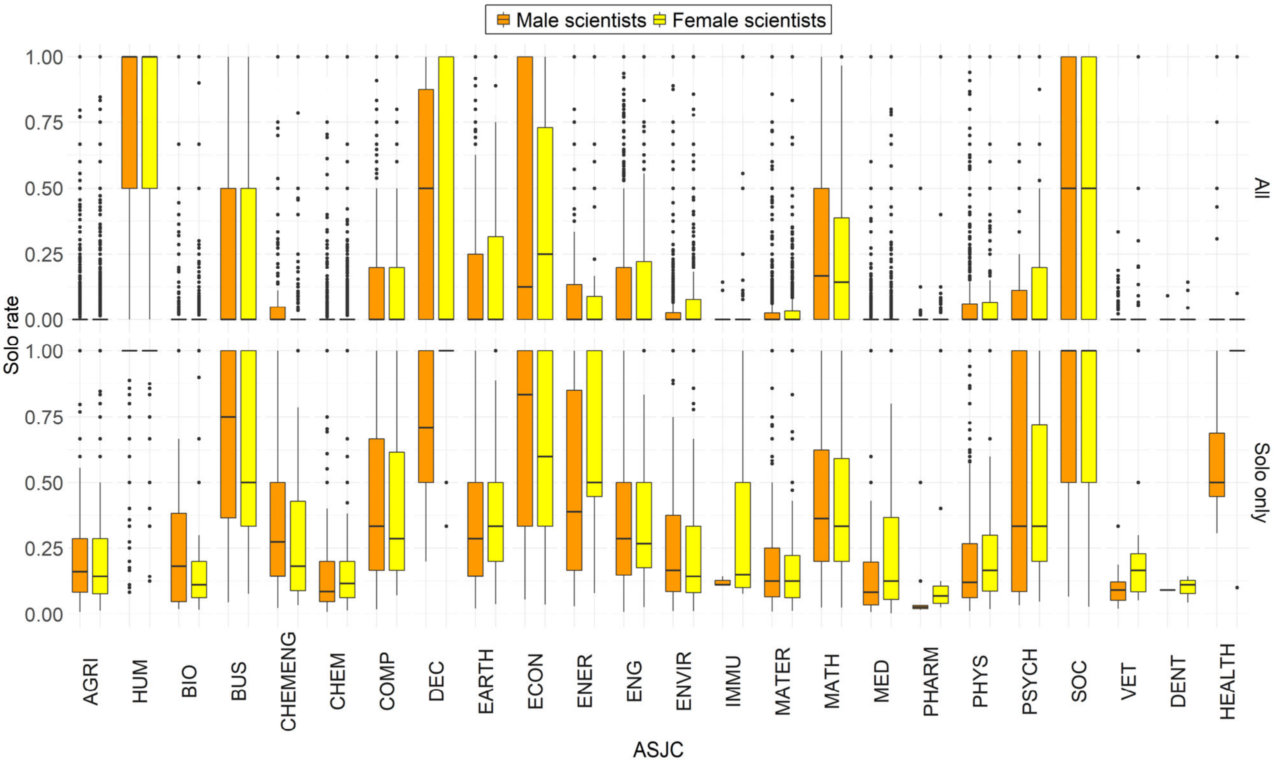


Figure 5. Distribution of the individual publishing solo rate for all authors (top panel) and solo authors (bottom panel) by gender and discipline.



4.2. Solo Research and Institutional Type by Gender

H2: Gender and institutional research intensity: We expect that female scientists will exhibit higher individual publishing solo rates in research-intensive institutions than in institutions less involved in research (hypothesis supported).

Previous literature indicates differences in publishing solo by institutional type: The more research focused an institution, the higher the involvement in publishing solo among faculty (e.g., Vafeas 2010: 340). Therefore, we test whether the individual rate differs by institutional type. We contrast 10 research-intensive institutions with 75 other research-involved institutions. The 10 institutions are the IDUB (or "Excellence Initiative–Research University") institutions, which were selected for additional research funding for the 2020–2026 period. The IDUB institutions include both top Polish universities and polytechnic institutes, and they were the top 10 Polish institutions in terms of total publications output in 2009–2018 (articles only).

While the rate for all authors for all institutions and for the rest of the institutions is higher for men (Table 5, upper panel), for research-intensive institutions (IDUB), it is higher for women (lower panel). The intensity of solo publishing (shown through the rate for solo authors only) is substantially higher for research-intensive institutions: the rate for women is higher by almost 10 percentage points. It is also higher for all institutions combined (see especially the graphic difference in Figure 6 between rates for women in IDUB institutions versus the remaining institutions; women seem much more prone to be publishing solo, in accordance with previous literature). All differences are statistically significant.

Table 5. Individual publishing solo rate by institutional type and gender. The Mann–Whitney test was used.

		Female	Male	*Z*	*p*
All authors	IDUB	0.1540	0.1502	3.920	<0.001
	Rest	0.1211	0.1388	6.311	<0.001
	Total	0.1301	0.1429	8.277	<0.001
Solo authors only	IDUB	0.5030	0.4093	6.262	<0.001
	Rest	0.4651	0.4549	0.157	0.875
	Total	0.4767	0.4366	3.968	<0.001

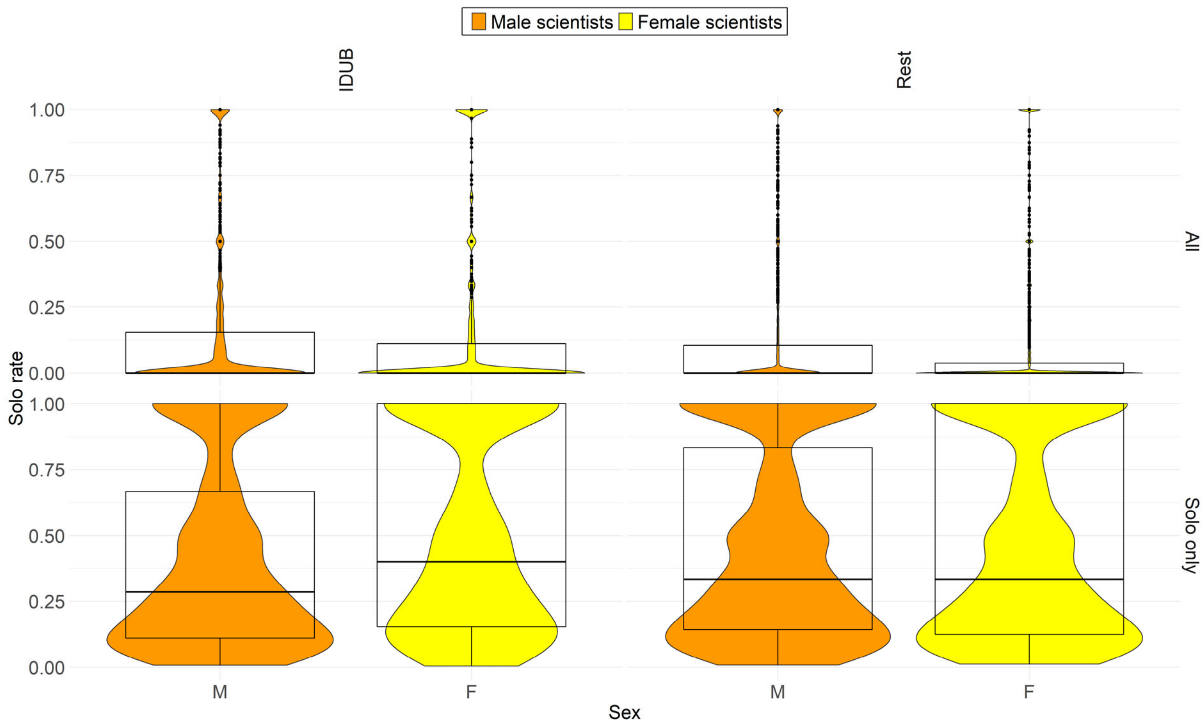


Figure 6. Individual publishing solo rate: the distribution by institutional type and gender (boxplots and violin plots combined; "research-intensive institutions" or "IDUB institutions" vs. "rest").

4.3. Solo Research and Journal Prestige by Gender

H3: Gender and journal prestige: We expect that female solo articles will be published in less prestigious journals than male solo articles are (hypothesis supported).

The literature indicates that gender differences in team composition are reflected in an article's citation levels, leading to a citation gap in science (Abramo et al. 2015; Huang et al. 2020; Madison and Fahlman 2020; Potthof and Zimmermann 2017; Maddi et al. 2019; Thelwall 2020). In this section, we seek to show how differently gender-classified articles authored by male and female scientists are located in the prestige hierarchy of academic journals expressed in one of Scopus prestige ranks—percentile ranks within about 42,000 journals. The literature highlights that, generally, it is more difficult to publish solo articles than team articles in highly prestigious journals unless by eminent scientists; we test the hypothesis about gender and journal prestige and examine whether female solo articles are located in less prestigious journals on average than male solo articles are. The reasons for this may be gender-related and may relate to the authors themselves (the journal type they target, Key and Sumner 2019; Brown et al. 2020), editors and reviewers as gatekeepers in science (the journals and how their gatekeepers view solo male and solo female submissions,), the institutional culture and norms in which the authors are located, and other factors. With our data, we are unable to open the black boxes of institutional culture and norms and gatekeepers in journals, including submission rates and submission success or time from submission to acceptance (as in Hartley 2005; Walker 2019); however, we are able to examine where gender-classified articles are finally published, perhaps after rounds of rejections and resubmissions.

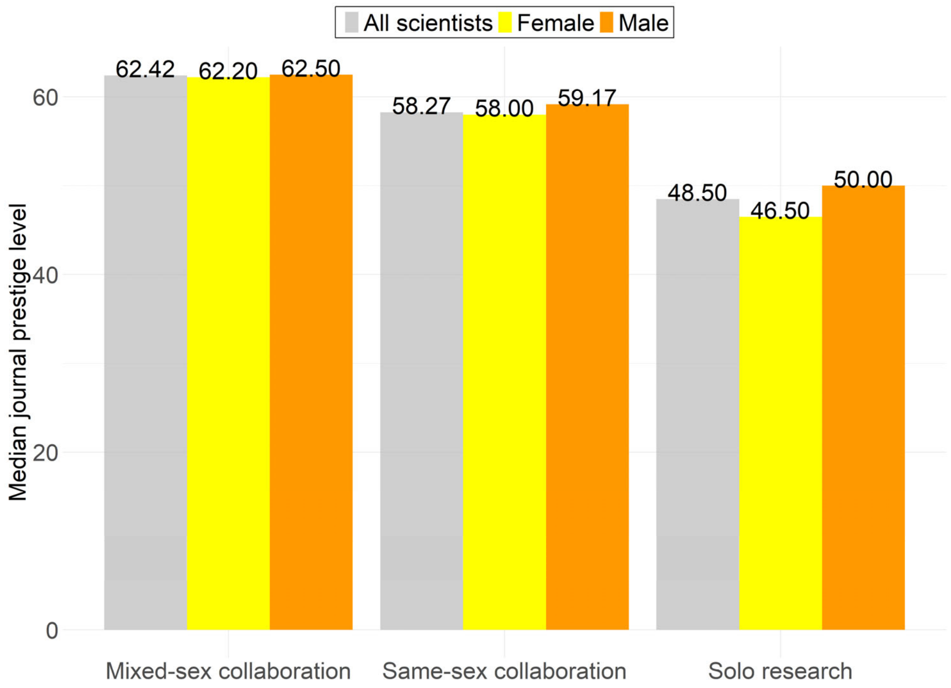
Our 158,743 articles (including 18,900 solo articles) are published in journals of different Scopus CiteScore percentile ranks. Percentile ranks of journals are used here as proxies of journal prestige: Highly prestigious journals tend to have high percentile ranks in their disciplines, while less prestigious journals have lower percentile ranks. Scopus annually ascribes percentile ranks to each academic journal within its ASJC discipline. Scientists in our sample have unique individual publication portfolios with all their publications, translatable into average individual journal prestige via Scopus CiteScore citation metrics. The prestige of each article in this portfolio is derived from the prestige of the journal in which it was published.

We used the measure of average prestige, which represents the median prestige value for all publications written by a given scientist in the study period of 2009–2018. For journals for which the Scopus database did not ascribe a percentile rank, we have ascribed the percentile rank of 0; Scopus ascribes percentiles to journals in the 25th to 99th percentile range, with the highest rank being the 99th percentile. Respecting gender team composition, we classified all articles into five types: solo male, solo female, all-male, all-female (shown under "same-sex collaboration" for men and women), and mixed-sex articles.

The median prestige level for all publications written in same-sex collaboration by gender does not differ much (Figure 7). The median values for all-male publications and all-female publications by gender are almost identical. In addition, the median value for mixed-sex collaborations does not differ significantly by gender. Articles written by men in mixed-sex collaboration, on average, are published in more prestigious journals than those written by men in all-male collaborations; the same pattern holds for women.

Most importantly, solo articles are published in far less prestigious journals, with solo articles authored by women published in the least prestigious journals (the median prestige level: 46.50 in the scale of CiteScore journal percentile ranks of 0-99). Solo research by males is located in more prestigious journals (50.00) than solo research by females (46.50), but the difference compared with the location of publications written in mixed-sex collaborations is striking: For women, it is almost 15 percentage points. All gender differences for same-sex collaboration and for solo research are statistically significant ($p < 0.001$), and for mixed-sex collaboration, they are not (all hypotheses were tested using the Mann–Whitney test). Gender-related journal prestige differences by publishing type are consequential for academic careers, especially in more metrics-focused science systems.

Figure 7. Median prestige level distribution (by journal percentile from 0–99, with the 99th percentile being the highest) of publications by major gender collaboration type and gender.



4.4. Solo Research, Biological Age, and Career Stage by Gender

H4: Gender and biological age: We expect that younger male and female scientists will publish significantly more solo-authored papers than older male and female scientists will (that individual publishing solo rates in their individual publication portfolios is significantly higher) (hypothesis not supported).

H5: Gender and academic position: We expect that male and female scientists lower in academic ranks will publish significantly more solo-authored papers than male and female scientists higher in academic ranks do (that individual publishing solo rates in their individual publication portfolios is significantly higher) (hypothesis not supported).

There are two unique variables available for each observation in our study—academic position (reflecting career stages) and biological age (sometimes aggregated to age groups; see Table 3 with variables). The two variables are not available in large-scale national or global studies (except for Italy and Norway; see Abramo et al. 2020; "academic age" based on the year of the first globally-indexed publication is sometimes used as a proxy of age or career stage, e.g., Robinson-Garcia et al. 2020, who used four stages of academic life in their study of task specializations: junior, early career, mid-career, and late-career stages). The total number of solo articles in the study period is 18,900, where 12,781 (or 67.6%) were published by men and 6,119 (or 32.4%) by women. The total number of solo authors is 7,758, of which the majority are men (Table 6).

Table 6. Distribution of Polish scientists by publication type (solo authors, non-solo authors) by gender.

	Female Scientists			Male Scientists			Total		
	N	Row %	Col %	*N*	Row %	Col %	*N*	Row %	Col %
Solo authors	2,887	37.2	27.3	4,871	62.8	32.7	7,758	100.0	30.5
Non-solo authors	7,690	43.4	72.7	10,015	56.6	67.3	17,705	100.0	69.5
Total	10,577	41.5	100.0	14,886	58.5	100.0	25,463	100.0	100.0

The boxplots in Figure 8 divide the data into quartiles and show the median, which is higher for each subsequent academic position. The boxes enclose the middle 50% of the data (e.g., across all disciplines, half of full professors are aged between 60 and 70 years, except for DENT, where they are younger). Outliers are located predominantly above the boxes, showing the presence of older scientists within the three academic positions rather than younger ones. There is a clear interdependence between age and academic position as the average level of age increases with the three consecutive academic positions across all 24 disciplines. In addition, the observed average age for each of the three stages of an academic career is similar among all the disciplines. This empirical observation is confirmed by the formal Kruskal–Wallis test (p = 0.001). However, although clearly correlated, the variables of age and academic position emerge as important in previous literature, and therefore, their joint impact on the rate will be studied below.

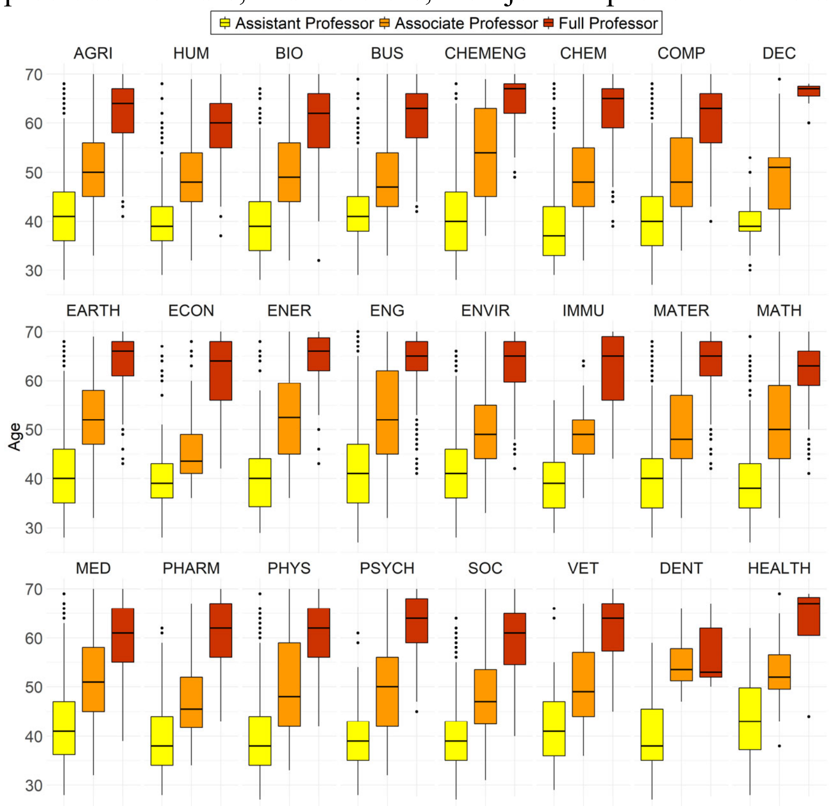


Figure 8. Age distribution of Polish academic scientists in terms of academic position and discipline.

We now examine the individual publishing solo rate by gender and (1) age and (2) age groups in two versions—for solo authors only and for all authors. We divided our sample into the following three age categories: young scientists (aged 39 and younger), middle-aged scientists (aged 40–54), and older scientists (aged 55 and older); of these, middle-aged scientists form the largest age group

(45.79%). The proportion of men and women is almost equal among young scientists—but women comprise less than 30% of older scientists (see Table 10 in the Data Appendices).

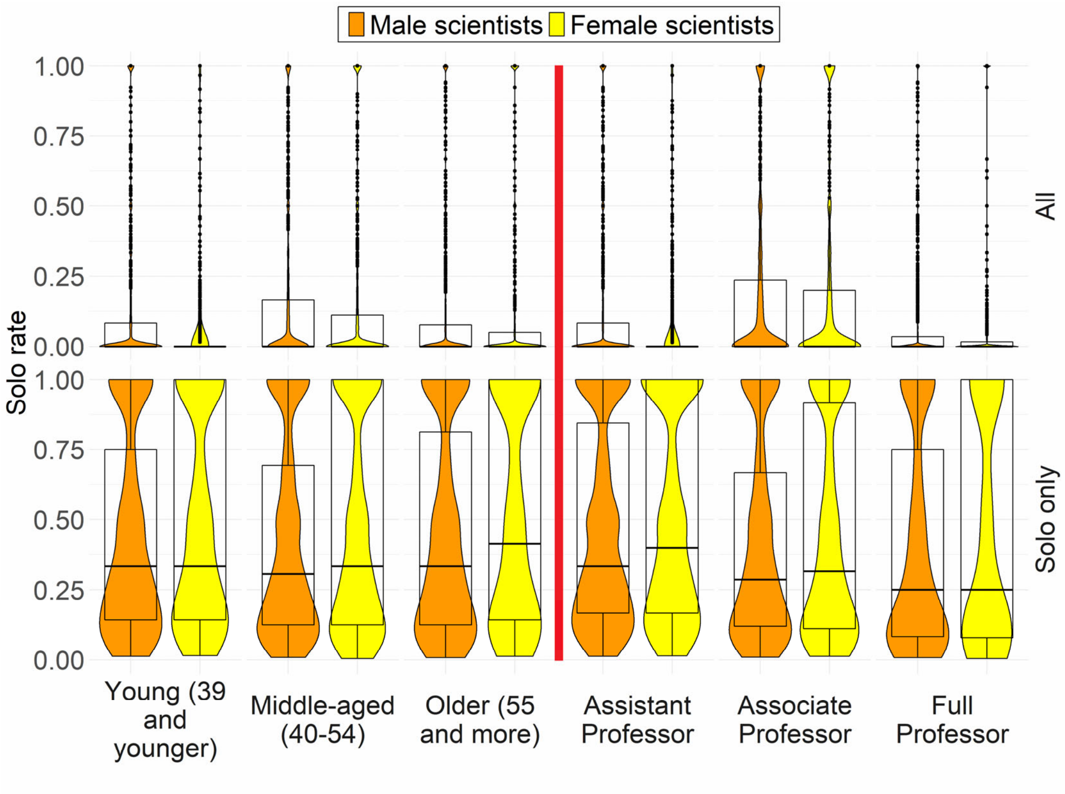
The gender differences in solo publishing patterns by age group are as follows (Table 7): For all authors (top left panel), the rate for young male scientists is higher than for young female scientists—they are more involved in solo publishing. The highest level of solo publishing is noted for middle-aged scientists, for both sexes. Younger scientists and assistant professors have significantly lower individual solo publishing rates than middle-aged scientists and associate professors do, and the differences are higher for women than for men. However, female scientists in all age groups are more intensely involved in solo publishing (top right panel): Female solo authors show considerably higher rates than male solo authors do. For instance, for young scientists, female solo authors have a rate of 0.4845, whereas that for male solo authors is 0.4343; that is, for females who have ever solo-authored, 48.45% of publications in their individual publication portfolios are published solo compared with 43.43% for males. For older scientists, the difference is 51.02% versus 44.73%. The same patterns hold for academic positions: For all authors (left bottom panel), the rate for assistant professors is higher for males than for females, and the rate for assistant professors only is higher for females than males (right bottom panel). Young male scientists and male scientists in the lowest academic position are more involved in solo publishing, but young women and women in the lowest academic position already involved in solo publishing, that is, solo authors, are involved more intensively (all differences are statistically significant).

Table 7. Mean individual publishing solo rates for all authors (left panels) and for solo authors (right panels), by gender and age group (top panels) and academic position (bottom panels).

	Male	**Female**	**Total**	***Z***	***p***	**Male**	**Female**	**Total**	***Z***	***p***
Young	0.1319	0.1037	0.1181	−8.152	<0.001	0.4343	0.4845	0.4545	−2.76	0.006
Middle-aged	0.1579	0.1463	0.1528	−4.962	<0.001	0.4316	0.4628	0.4442	−2.124	0.034
Older	0.1304	0.1363	0.1321	−1.457	0.145	0.4473	0.5103	0.4643	−2.645	0.008
Total	0.1429	0.1301	0.1376	−8.227	<0.001	0.4366	0.4767	0.4515	−3.968	0.000
Assistant Pr.	0.1309	0.1110	0.1214	−7.674	<0.001	0.4715	0.5088	0.4872	−2.596	0.009
Associate Pr.	0.1818	0.1819	0.1818	−1.718	0.086	0.4152	0.4407	0.4245	−0.931	0.352
Full Pr.	0.1115	0.1131	0.1118	−1.378	0.168	0.4003	0.4504	0.4114	−1.169	0.242
Total	0.1429	0.1301	0.1376	−8.227	<0.001	0.4366	0.4767	0.4515	−3.968	0.000

The gender differences by age group (Figure 9, left panels) closely resemble the gender differences by academic position (right panels). Across the three age groups and across the three academic positions, female authors consistently tend to differ from male authors in individual publishing solo rates. The boxplots in Figure 9 divide the data into quartiles and show the median; the boxplots enclose the middle 50% of the data. The median value of the rate for solo authors only is at least equal for females for age groups (bottom left panel) and academic positions (bottom right panel). In terms of within-sex variation, in the case of all authors, male authors are more differentiated than female authors are for each age group and each academic position studied. However, in the case of solo authors only, female authors are more differentiated.

Figure 9. Individual publishing solo rates for all authors (top panels) and solo authors only (bottom panels). Distribution by age group (left panels), academic position (right panels), and gender (boxplots and violin plots combined).



Finally, a more detailed year-by-year approach illustrated by regression lines in Figure 10 generally confirms the two similar trends for both genders. For all authors, the generally upward trend in the rate between 0.05 and 0.15 for male scientists lasts until the age of 40 and for female scientists lasts until the age of 55 (see lower lines in both panels). For both genders, the rate drops for scientists between 60 and 70, in a similar manner. However, the intensity of solo publishing (i.e., the rate for solo authors only) for female scientists is equal or higher for each age (see higher lines in both panels); specifically, it is much higher for young scientists in their 30s. In a specific Polish case, scientists of this age have just received their doctoral degrees. Solo female authors in their 30s have a substantially higher share of solo articles in their publication portfolios, the highest difference for females being in their early 30s. Then, in their 40s, the gender differential in solo publishing intensity is marginal, increasing again for females in their 50s. The most notable gender differential in solo publishing intensity is for scientists in their 30s and 60s when the rate is higher—in the beginning and at the end of academic careers. The dots in Figure 10 represent the median value of the rate for each year of age.

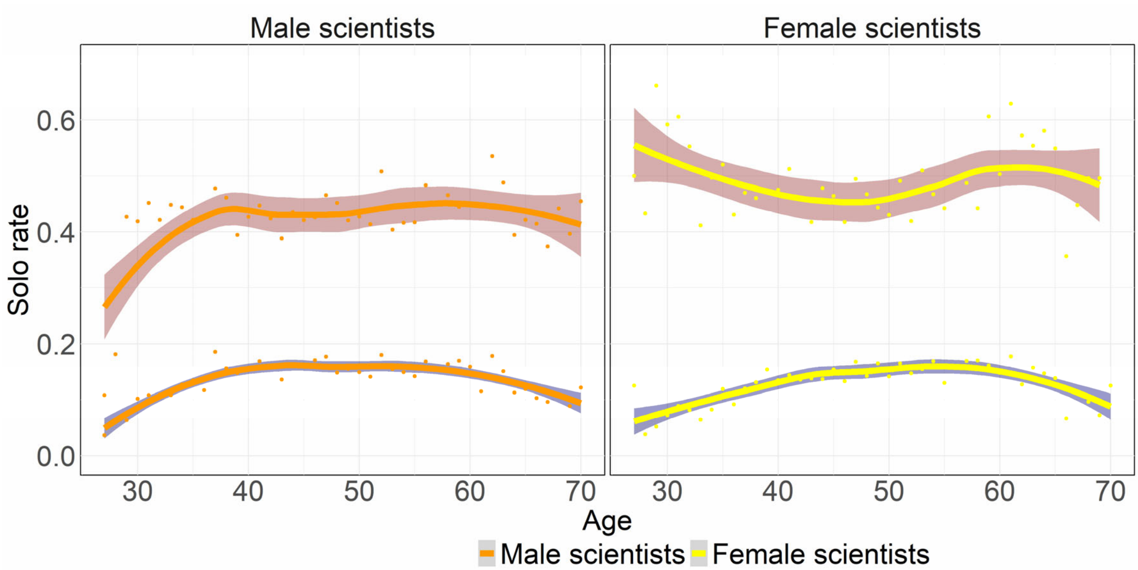


Figure 10. Individual publishing solo rates by gender and age for all authors (lower lines) and solo authors only (upper lines). The regression line was estimated using the method of local polynomial regression fitting. The gray area represents 95% confidence intervals. Each year of age is represented by a single dot (a cut-off point of 70 is used). Dots represent mean values.

4.5. A Modeling Approach: A Fractional Logit Regression Model

H6: Gender and solo publication propensity: We expect that being a female scientist will decrease the propensity to conduct solo research or the individual publishing solo rate (fractional logit regression models) (mixed results: marginal influence of gender).

We use a regression model for a fractional dependent variable—a fractional logit regression model (Papke and Woolridge 1996), designed for variables bounded between 0 and 1 (as with our dependent variable: the solo research ratio). The standard practice of using linear models to examine how a set of explanatory variables influences a given proportion or fractional response variable is not appropriate here (Ramalho et al. 2011, p. 19). In this model, no special data adjustments are needed for the extreme values of 0 and 1. As our dependent variable is fractional (ranging from 0 to 1), we estimate a fractional logit regression model. We estimate odds ratios for conducting solo research, that is, publishing solo articles. We calculate the solo rate as the percentage of solo articles in all the published articles in all the scientists' individual publication portfolios. Using partial effects of fractional logistic regression approach, we estimated the probability of conducting solo research.

In the model, we use both individual-level and organizational-level predictors. Individual-level predictors are gender, age, academic position (expressed through the proxies of doctorate, habilitation, and professorship), dominant ASJC discipline (STEM or non-STEM), average journal prestige rate in a scientist's individual publication portfolio (range, 0–99), average individual productivity in the study period (average number of articles per year, full counting method used), international collaboration rate (in the individual publication portfolio), average team size (mean value of number of collaborators per article in all articles from the study period), and publishing in a male-dominated discipline (male-dominated or female-dominated). The only organizational-level predictor used in the models is highly research-intensive (10 IDUB higher education institutions and the remaining 75 institutions).

We have estimated four models for four distinct populations—for all academic ranks (N = 24,467) and separately for the three ranks (for full professors, N = 3,508; associate professors, N = 7,122; and for assistant professors, N = 13,837). The selected predictors of the individual publishing solo rate in the estimated models explain a very high percentage of the variability of the dependent variable, from 77.5% in the model for associate professors to 82.3% in the model describing relationships in the population of full professors (Table 8). At the same time, it is worth noting that gender does not explain the rate's variability in any of the models (at the significance level $\alpha = 0.05$). The strongest predictor for each population studied was the average team size. An increase in the value of this variable by one author resulted in an average decrease in the rate by 8–11 percentage points (pp) (all other things held constant), depending on the model, which is an order of magnitude higher than other predicators. In addition, in each analyzed population, publishing in STEM fields negatively affects the propensity to publish solo by 3–4 pp on average. The occurrence of collinearity was checked by analyzing the values lying on the main diagonal of the inverted correlation matrix of independent variables. The empirical range of variability of these values ranged from 1 to 2 (see the variance inflation factor, the VIF column in Table 8: VIF provides an index that measures how much the variance of an estimated regression coefficient is increased because of collinearity), which indicates a negligible correlation of independent features.

Although gender is not a significant predictor of the rate, publishing in (quantitatively) male-dominated disciplines has a significant and positive impact on the variable, explained by 1–3 percentage points. An inverse relationship of similar strength can be observed in the influence of the international collaboration rate—an increase of this variable by 1 unit results in an average individual publishing solo rate decrease of 1–4 pp, although it should be noted that, in the case of assistant professors, the influence of this predictor is not significantly different from zero. The influence of similar strength also occurs in the case of working in research-intensive institutions—this results in an average individual publishing solo rate increase of slightly more than 1 pp, but in the case of full professors, the influence of this predictor is not statistically significant.

The average number of articles within a decade in the case of all populations has a significantly positive influence. An increase in the average number of articles by 1 causes an average rate increase of only 0.3–0.5 pp. Large productivity, however, can have a significant impact on the rate, as writing 100 articles in a decade results in an average increase of 30–50 pp. Definitely the weakest impact can be observed for age and average prestige. Both variables have a negative impact on the rate. Increase of average prestige by 1 unit causes average (in each population significant) rate decrease by 0.03 (assistant professors) to 0.09 (associate professors). In the case of age, this decrease is slightly smaller, from 0.02 (all scientists) to 0.15 (associate professors). The exception is assistant professors, for whom age is a positive predictor and causes an average rate increase of 0.07 pp with each completed year of life.

The interval estimation of model parameters indicates overlapping of estimation values for all variables and all models except the team size variable from the model for full professors. In this model, the size of the team has a significantly stronger impact than in the other models (Figure 12). This means that the academic position does not significantly affect the rate. This is indicated by the estimates of Model 1 (for all scientists), where the position of full professor does not affect the rate at all, while for associate professor, although its influence is significantly different from zero, its strength is relatively small. In the case of age, it plays a positive (although weak) role for assistant professors, which can be explained by the willingness to gain independent output enabling promotion. A certain difference can also be mentioned in Model 3 (for associate professors) for the average international collaboration variable, where the position of associate professor is characterized by a significantly weaker influence on the rate than in Models 1 and 2 but almost entirely overlaps with the interval estimate for Model 4.

The analysis of residual components of the models shows that their distribution does not follow the normal distribution (see K-S test results in Table 9). However, distributions of the residuals are characterized by relatively small variability (they are strongly concentrated at zero value, see kurtosis values); there are numerous extreme values among them, but they do not significantly influence the distributions of residuals since the skewness values are close to 0. The number of values exceeding the extremes—that is, not belonging to the range of <-3,3> (which in the analysis of the residuals of regression models mean typical values based on the three-sigmas rule)—is relatively small and oscillates between 1.23% (for assistant professors) and 2.65% (for full professors; see the outliers percentage in Table 9).

Figure 12. Confidence intervals range for models' parameters—comparison of four models, all variables.

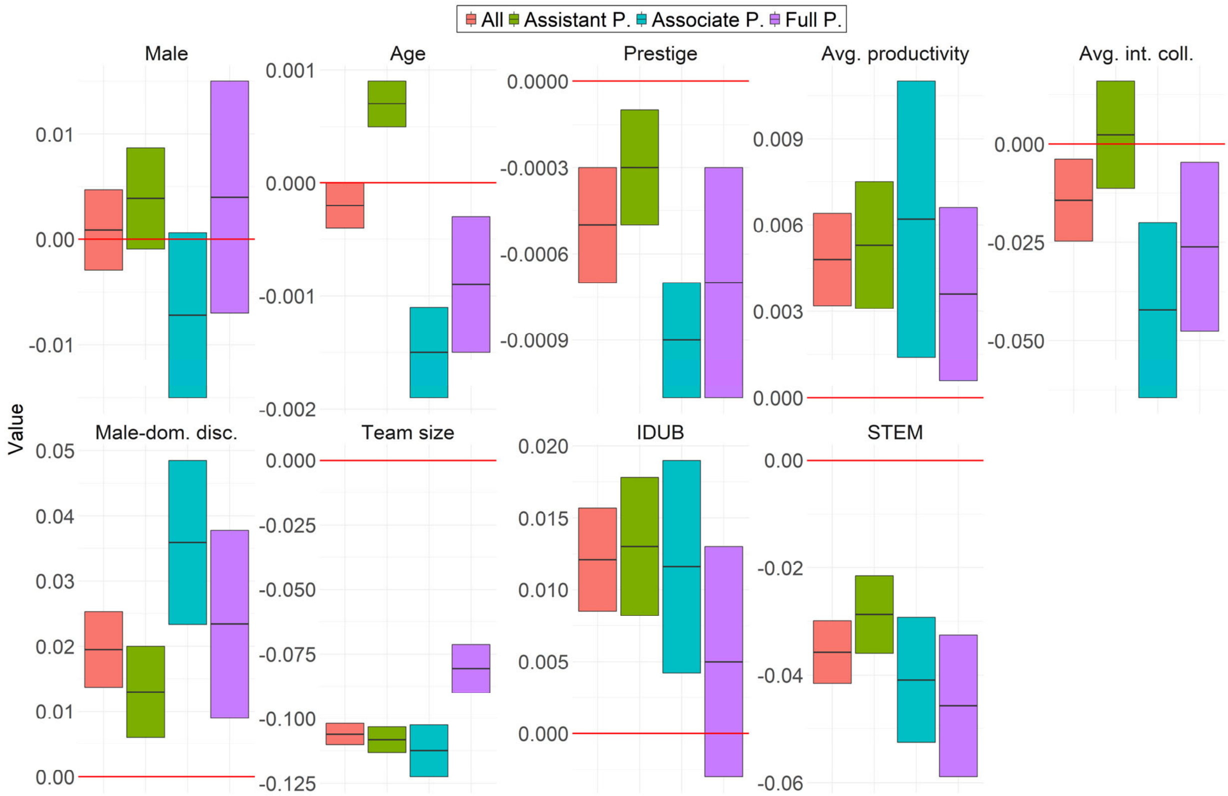


Table 8. Four models.

	Estimate	SE	*t* Value	Pr(>|t|)	VIF
Model 1. Scientists: All Ranks, *N* = 24,467. R^2: 0.786					
Male	0.0009	0.0019	0.441	0.659	1.131
Age	−0.0002	0.0001	−2.037	0.042	2.086
Average prestige	−0.0005	0.0001	−7.849	<0.001	1.245
Productivity in the study period	0.0048	0.0008	5.937	<0.001	1.206
International collaboration rate	−0.0143	0.0052	−2.753	0.006	1.208
Publishing in a male-dominated discipl.	0.0195	0.0029	6.678	<0.001	1.242
Average team size	−0.1061	0.0021	−49.485	<0.001	1.294
Full professor	0.0007	0.0037	0.196	0.844	2.121
Associate professor	0.0256	0.0022	11.725	<0.001	1.403
IDUB	0.0121	0.0018	6.591	<0.001	1.053
STEM	−0.0357	0.0029	−12.310	<0.001	1.120
Model 2. Full Professors, *N* = 3,508. R^2: 0.823					
Male	0.0040	0.0055	0.730	0.466	1.077
Age	−0.0009	0.0003	−3.231	0.001	1.092
Average prestige	−0.0007	0.0002	−4.690	<0.001	1.292
Productivity in the study period	0.0036	0.0015	2.320	0.020	1.207
International collaboration rate	−0.0261	0.0107	−2.451	0.014	1.290
Publishing in a male-dominated discipl.	0.0234	0.0072	3.241	0.001	1.254
Average team size	−0.0807	0.0047	−17.289	<0.001	1.266
IDUB	0.0050	0.0040	1.250	0.211	1.075
STEM	−0.0457	0.0066	−6.918	<0.001	1.190
Model 3. Associate Professors, *N* = 7,122. R^2: 0.775					
Male	−0.0072	0.0039	−1.831	0.067	1.082
Age	−0.0015	0.0002	−6.803	<0.001	1.121
Average prestige	−0.0009	0.0001	−6.294	<0.001	1.282
Productivity in the study period	0.0062	0.0024	2.519	0.012	1.252
International collaboration rate	−0.0422	0.0111	−3.813	<0.001	1.201
Publishing in a male-dominated discipl.	0.0359	0.0063	5.724	<0.001	1.243
Average team size	−0.1125	0.0050	−22.447	<0.001	1.325
IDUB	0.0116	0.0037	3.086	0.002	1.053
STEM	−0.0409	0.0058	−7.112	<0.001	1.127
Model 4. Assistant Professors, *N* = 13,837. R^2: 0.791					
Male	0.0039	0.0024	1.639	0.101	1.119
Age	0.0007	0.0001	4.723	<0.001	1.150
Average prestige	−0.0003	0.0001	−3.998	<0.001	1.221
Productivity in the study period	0.0053	0.0011	5.013	<0.001	1.186
International collaboration rate	0.0023	0.0068	0.338	0.735	1.193
Publishing in a male-dominated discipl.	0.0130	0.0035	3.701	<0.001	1.261
Average team size	−0.1082	0.0025	−43.772	<0.001	1.299
IDUB	0.0130	0.0024	5.529	<0.001	1.050
STEM	−0.0287	0.0036	−8.041	<0.001	1.114

Table 9. Residuals statistics.

	All	**Assistant Professor**	**Associate Professor**	**Full Professor**
Min.	−4.291	−5.346	−4.085	−5.502
1st Quarter	−0.215	−0.178	−0.302	−0.157
Median	−0.013	−0.008	−0.024	−0.010
Mean	0.000	0.000	0.000	0.000
3rd Quarter	0.000	0.000	0.321	0.000
Max.	6.481	5.674	5.009	7.644
Skewness	0.043	0.142	−0.209	0.193
Kurtosis	2.839	2.716	2.247	7.385
K−S test statistic	0.254	0.289	0.180	0.286
p−value	<0.001	<0.001	<0.001	<0.001

5. Summary of Findings, Discussion, and Conclusions

Solo research is a result of voluntarily made individual authorship decisions. Choosing solo research is as consequential for academic careers as choosing same-sex or mixed-sex collaborations (or institutional, national, and international collaborations, not studied here; Kwiek and Roszka 2020a). Individual authorship decisions accumulate over time, accompanying academic careers. While it is known that authorship decisions need to be “intelligent” (Vafeas 2020: 333) and “strategic” (Jeong et al. 2011: 968), men’s decisions may differ from females’ decisions in different institutions, disciplines, and national systems. Women have been reported to be underrepresented as solo publishers (Sarsons et al. 2020; Walker 2019; West et al. 2013), but this research is the first to comprehensively study the gender solo research gap within a whole national system: We examine the gap through “individual publication portfolios” constructed for each internationally visible Polish university professor ($N = 25{,}463$, all assistant, associate, and full professors, and their 158,743 articles published in 2009–2018, including 18,900 solo articles).

Solo research is a special case of academic publishing where scientists, on the one hand, compete individually in the academic marketplace of ideas, taking full responsibility and full risk for publications’ errors (Hudson 1996; Kuld and O’Hagan 2017), and on the other, where there is no ambiguity in credit allocation, and credits unambiguously go to the single author, sending clear signals about their research ability and independence (Barlow et al. 2017; Sarsons 2017; Sarsons et al. 2020). Solo research has been expected to disappear for half a century (Price 1963), but for many reasons, it continues to exist (West et al. 2013). In this paper, we tested the hypothesis that male and female scientists differ in their use of solo publishing, and we termed this difference “the gender solo research gap,” existing alongside many other input-related (e.g., the gender mobility or the gender international collaboration gaps) and output-related gender gaps in science (e.g., the gender tenure or the gender salary gap).

Our focus was on gender differences in solo research from a macro-level perspective of a single national system: In our unique biographical, administrative, publication, and citation database (“Polish Science Observatory”), we have metadata on all scientists with doctoral degrees employed full-time in the research-involved university sector and metadata on all their publications, including solo publications (from Scopus), in all academic disciplines. Our focus was on how male and female scientists of various biological ages, academic positions, institutions, and institutional types make use of, and benefit from, solo publishing. We put forward six hypotheses and tested them against our large-scale data.

We expected that (H1) female solo scientists would have lower individual publishing solo rates in male-dominated than in female-dominated disciplines, and this hypothesis was supported by evidence. Across all disciplines, the rate, ranging from 0 to 1, was slightly higher for men (0.1429) than it was for women (0.1301, $p < 0.001$), and it was higher for men in most male-dominated disciplines. However, female solo scientists showed higher intensity of publishing solo (the rate for solo authors only was 0.4767) than male solo scientists did (0.4366, $p = 0.000$). The differences in the rate within disciplines by gender and between male-dominated and female-dominated disciplines by gender were much smaller than expected. Cross-gender differences were more visible in the intensity of solo publishing by discipline than in individual publishing solo rates. Additionally, 32.7% of males and 27.3% of females had had a solo article published in the decade studied (their individual publishing solo rate was higher than zero).

We also expected that (H2) female scientists located in research-intensive institutions would have higher individual publishing solo rates than those located in institutions less involved in research, and this hypothesis was also supported by our evidence. Previous literature indicated that the more research-focused an institution was, the higher involvement in publishing solo the faculty would have (e.g., Vafeas 2010: 340). We contrasted the 10 research-intensive institutions involved in the Polish Excellence Initiative (IDUB) with 75 other institutions and found that the rate for women in research-intensive institutions was higher than the rate for them elsewhere in the system. In research-intensive institutions, the intensity of solo publishing for women was higher than it was for males by 10 percentage points, which was in accordance with previous literature.

We supposed that (H3) female solo articles would be published in less prestigious journals than male solo articles, and this hypothesis found support in our data. We examined how gender-classified articles authored by male and female scientists were located in the prestige hierarchy of academic journals (Scopus CiteScore percentile ranks, 0–99). Solo articles were published in less prestigious journals compared with other article types, and female solo articles were published in less prestigious journals than male solo articles. The difference between the location of publications written in mixed-sex collaborations and solo publications was substantial: For women, it was almost 15 percentile ranks lower (and for men, 12 percentile ranks lower).

We also thought that (H4) younger scientists would publish solo articles significantly more often than older scientists would and that (H5) scientists lower in academic rank would publish solo articles significantly more often than scientists higher in academic rank would. However, neither hypothesis found support in our data. We examined the rate by gender and age. Younger scientists and assistant professors had significantly lower individual solo publishing rates than middle-aged scientists and associate professors did, and the differences were higher for women than for men. The rate for young male scientists was higher than that for young female scientists. Gender differences by age group closely resembled gender differences by academic position. Across the three age groups and across the three academic positions, female authors consistently tended to differ from males in the rate. The year-by-year approach confirmed similar trends for both genders. However, the intensity of solo publishing for female scientists was at least equal for each age; specifically, it was much higher for young female scientists. Female solo authors in their 30s emerged with a substantially higher share of solo articles in their publication portfolios.

Finally, our expectation was that (H6) being a female scientist would decrease the propensity to conduct solo research (and we used a regression model for a fractional dependent variable—a fractional logit regression model). Using a partial effects of fractional logistic regression approach, we estimated the probability of conducting solo research. We estimated four models for four distinct populations—all academic positions combined and separately for the three positions. The selected predictors of the individual publishing solo rate in the estimated models explained a very high percentage of the variability of the dependent variable, from 77.5% in the model for associate professors to 82.3% in the model describing relationships in the population of full professors. Most importantly, in none of the models did gender explain the rate's variability. The strongest predictor was the average team size, that is, the number of co-authors (an increase by one author resulted in an average decrease in the rate by 8–11 pp, depending on the model). Publishing in STEM fields negatively affected the rate, on average, by 3–4 pp and publishing in male-dominated disciplines positively affected the rate (by 1–3 pp). The influence of international collaboration was negative (an increase of international collaboration rate by 1 unit resulted in an average rate decrease by 1–4 pp). Finally, working in research-intensive universities resulted in an average rate increase of slightly more than 1 pp for all faculty except full professors.

The gender solo research gap that emerges from our research is clearly weaker than expected: Within a more general trend in Polish science away from solo research and toward team research (Kwiek 2020a) and away from national research and toward international research (Kwiek 2020b), gender differences in solo publishing seem to be less relevant than initially assumed based on the research literature. The larger context of the dominating team research in science overshadows the smaller context of gender differences in solo publishing. Our expectations of young and lower ranked female scientists conducting considerably less solo research and being more risk averse toward it than male scientists were not confirmed; there exists a gender solo research gap, but it is not wide. While research by Vafeas (2010) and Kuld and O'Hagan (2018) indicated a much higher role of solo research for young scientists in general, irrespective of their gender, our research does not confirm these findings in the Polish case: The highest share of solo research for both genders is noted for middle-aged scientists (40–54) working as associate professors. Surprisingly, a bigger gender difference was noted in solo research intensity: Those women who are solo authors use this mode of publishing more intensively than male solo authors do (especially while finishing or just after their doctoral dissertations at the age of around 30–35). The low journal prestige level of female solo publications may suggest women's propensity to choose less competitive publication outlets (as suggested in Key and Sumner 2019 and in Sonnert and Holton 1996). Male scientists, publishing in more prestigious journals, seem to be seeking academic reputation more intensely—or more successfully, as our study examined published (i.e., accepted) rather than submitted articles.

Further research could include two new dimensions—a historical and a global one. A new research question could be how the changing shares of solo research by gender evolve over time in Poland and evolve globally. Specifically, we could ask whether the changes in the individual solo publishing rates over time and from a cross-country perspective are similar for both male and female scientists and whether the gender solo research gap is widening or closing in individual disciplines. Our current "Polish Science Observatory" database includes publications from the decade of 2009–2018, and the rate from this period could be compared with rates in the previous decades (e.g., the 2000s and 1990s) to examine the temporal dynamics of changing publishing patterns. The same temporal limitation to a single decade pertains to our parallel "OECD Science Observatory" database of all (gender-defined) scientists and all (gender-classified) articles indexed in Scopus from 1,674 research-involved institutions in 40 OECD economies from the same period; in addition, in this possible cross-national comparative study, biological age would need to be replaced with the academic age, or the time that has passed since the first publication (see Robinson-Garcia et al. 2020; Kuld and O'Hagan 2018). On top of this, certainly, academic careers and the gender gaps that accompany them can be more meaningfully studied if bibliometric data are combined not only with administrative and biographical data, as in this research, but also with large-scale surveys of the academic profession. Finally, there is substantial difference between showing trends in science and providing explanations for them: The effects of some variables cannot be separated, and many important variables cannot be measured (Kuld and O'Hagan 2018: 1223).

Data Appendices

Table 10. Structure of the sample, all Polish internationally visible university professors, by gender, age group, academic position, and discipline (by type: STEM and non-STEM, female-dominated and male-dominated), presented with column and row percentages (young scientists: aged 39 years and younger; middle-aged: aged 40–54 years; and older, aged 55 and more).

		Female			Male			Total		
		N	% col	% row	N	% Col	% Row	*N*	% Col	% Row
Age group	Young	3,128	29.6	49.4	3,199	21.5	50.6	6,327	24.8	100
	Middle-aged	5,584	52.8	44.1	7,074	47.5	55.9	12,658	49.7	100
	Older	1,865	17.6	28.8	4,613	31.0	71.2	6,478	25.4	100
	Total	**10,577**	**100.0**	**41.5**	**14,886**	**100.0**	**58.5**	**25,463**	**100**	**100**
Academic position	Assistant prof.	6,851	64.8	48.0	7,420	49.8	52.0	14,271	56.0	100.0
	Asssoc. prof.	2,822	26.7	38.0	4,596	30.9	62.0	7,418	29.1	100.0
	Full professor	904	8.5	24.0	2,870	19.3	76.0	3,774	14.8	100.0
	Total	**10,577**	**100.0**	**41.5**	**14,886**	**100.0**	**58.5**	**25,463**	**100.0**	**100.0**
Discipline (ASJC) – STEM	AGRI	1,444	13.7	53.4	1,258	8.5	46.6	2,702	10.6	100.0
	BIO	1,068	10.1	60.0	712	4.8	40.0	1,780	7.0	100.0
	CHEM	756	7.1	51.3	719	4.8	48.7	1,475	5.8	100.0
	CHEMENG	185	1.7	38.5	296	2.0	61.5	481	1.9	100.0
	COMP	170	1.6	16.5	860	5.8	83.5	1,030	4.0	100.0
	DEC	24	0.2	44.4	30	0.2	55.6	54	0.2	100.0
	EARTH	385	3.6	33.4	769	5.2	66.6	1,154	4.5	100.0
	ENER	82	0.8	27.8	213	1.4	72.2	295	1.2	100.0
	ENG	501	4.7	14.9	2,857	19.2	85.1	3,358	13.2	100.0
	ENVIR	848	8.0	50.5	832	5.6	49.5	1,680	6.6	100.0
	IMMU	90	0.9	75.6	29	0.2	24.4	119	0.5	100.0
	MATER	495	4.7	33.9	967	6.5	66.1	1,462	5.7	100.0
	MATH	259	2.4	25.2	767	5.2	74.8	1,026	4.0	100.0
	PHARM	169	1.6	66.5	85	0.6	33.5	254	1.0	100.0
	PHYS	182	1.7	16.6	916	6.2	83.4	1,098	4.3	100.0
Discipline (ASJC) – non-STEM	BUS	372	3.5	52.1	342	2.3	47.9	714	2.8	100.0
	DENT	57	0.5	76.0	18	0.1	24.0	75	0.3	100.0
	ECON	186	1.8	49.1	193	1.3	50.9	379	1.5	100.0
	HEALTH	23	0.2	34.3	44	0.3	65.7	67	0.3	100.0
	HUM	527	5.0	49.8	531	3.6	50.2	1,058	4.2	100.0
	MED	1,920	18.2	53.7	1,654	11.1	46.3	3,574	14.0	100.0
	PSYCH	194	1.8	63.8	110	0.7	36.2	304	1.2	100.0
	SOC	494	4.7	49.8	498	3.3	50.2	992	3.9	100.0
	VET	146	1.4	44.0	186	1.2	56.0	332	1.3	100.0
	Total	**10,577**	**100.0**	**41.5**	**14,886**	**100.0**	**58.5**	**25,463**	**100.0**	**100.0**
Gender domination in discipline	Female-dom.	6,918	65.4	54.6	5,759	38.7	45.4	12,677	49.8	100.0
	Male-dom.	3,659	34.6	28.6	9,127	61.3	71.4	12,786	50.2	100.0
	Total	**10,577**	**100.0**	**41.5**	**14,886**	**100.0**	**58.5**	**25,463**	**100.0**	**100.0**
Mean publication	<0,30)	777	7.3	48.7	817	5.5	51.3	1,594	6.3	100.0
	<30,40)	888	8.4	41.3	1,262	8.5	58.7	2,150	8.4	100.0

prestige (percentile)	<40,50)	1,432	13.5	39.7	2,171	14.6	60.3	3,603	14.1	100.0
	<50,60)	2,778	26.3	40.8	4,023	27.0	59.2	6,801	26.7	100.0
	<60,70)	2,573	24.3	40.8	3,728	25.0	59.2	6,301	24.7	100.0
	<70,80)	1,691	16.0	43.4	2,202	14.8	56.6	3,893	15.3	100.0
	<80,90)	373	3.5	39.4	573	3.8	60.6	946	3.7	100.0
	<90,100)	65	0.6	37.1	110	0.7	62.9	175	0.7	100.0
	Total	**10,577**	**100.0**	**41.5**	**14,886**	**100.0**	**58.5**	**25,463**	**100.0**	**100.0**

References

Abramo, G., D'Angelo, C. A., & Caprasecca, A. (2009) The contribution of star scientists to overall sex differences in research productivity. *Scientometrics*, *81*(1), 137–156.

Abramo, G., D'Angelo, C. A., & Di Costa, F. (2019) A gender analysis of top scientists' collaboration behavior: Evidence from Italy. *Scientometrics. 120*, 405–418,

Abramo, G., D'Angelo, C. A., & Rosati, F. (2015) Selection committees for academic recruitment: Does gender matter? *Research Evauation*, *24*(4), 392–404.

Abramo, G., D'Angelo, C. A., & Murgia, G. (2013) Gender differences in research collaboration. *Journal of Informetrics,* 7, 811–822.

Abramo, G., D'Angelo, C. A., & Solazzi, M. (2011) The relationship between scientists' research performance and the degree of internationalization of their research. *Scientometrics*, *86*, 629–643.

Abt, H. A. (2007) The future of single-authored papers. *Scientometrics*, *73*, 353–358, https://doi.org/10.1007/s11192-007-1822-9

Ackers, L. (2008) Internationalization, mobility, and metrics: A new form of indirect discrimination? *Minerva*, 46, 411–435.

Aguinis, H., Gottfredson, R. K., & Joo, H. (2013) Best-practice recommendations for defining, identifying, and handling outliers. *Organizational Research Methods*, *16*(2), 270–301.

Aksnes, D. W., Piro, F. N., & Rørstad, K. (2019) Gender gaps in international research collaboration: A bibliometric approach. *Scientometrics*, *120*, 747–774.

Aksnes, D. W., Rørstad, K., Piro, F. N., & Sivertsen, G. (2011) Are female researchers less cited? A large scale study of Norwegian researchers. *J. Am. Soc. Inf. Sci. Tech.*, *62*(4), 628–636.

Allen, L., Scott, J., Brand, A., Hlava, M., & Altman, M. (2014) Credit where credit is due. *Nature*, *508*(7496), 312–313.

Avolio, B., Chávez, J., & Vílchez-Román, C. (2020) Factors that contribute to the underrepresentation of women in science careers worldwide: A literature review. *Social Psychology of Education*. *23*, 773–794.

Baethge, C. (2008) Publish together or perish: The increasing number of authors per article in academic journals is the consequence of a changing scientific culture. Some researchers define authorship quite loosely. *Dtsch Arztebl Int* 2008. *105*(20), 380–3.

Barbezat, D. A., & Hughes, J. W. (2005) Salary structure effects and the gender pay gap in academia. *Research in Higher Education*, *46*(6), 621–640.

Barlow, J., Stephens, P. A., Bode, M., Cadotte, M. W., Lucas, K., Newton, E., et al. (2017) On the extinction of the single-authored paper: The causes and consequences of increasingly collaborative applied ecological research. *Journal of Applied Ecology*, *55*(1), 1–4.

Bozeman, B., Fay, D., & Slade, C. P. (2012) Research collaboration in universities and academic entrepreneurship: The-state-of-the-art. *The Journal of Technology Transfer*, *38*(1), 1–67.

Bridgstock, M. (1991) The quality of single and multiple authored papers; An unresolved problem. *Scientometrics*, *21*(1), 37–48.

Ceci, S. J., & Williams, W. M. (2011). Understanding current causes of women's underrepresentation in science. *Proceedings of the National Academy of Sciences, 108*(8), 3157–3162.

Ceci, S. J., Ginther, D. K., Kahn, S., & Williams, W. M. (2014) Women in academic science: A changing landscape. *Psychological Science in the Public Interest*, *15*(3), 75–141.

Chuang, K.-Y., & Ho, Y.-S. (2014) Bibliometric profile of top-cited single-author articles in the Science Citation Index Expanded. *Journal of Informetrics, 8*(4), 951–962.

Clauset, A., Arbesman, S., & Larremore, D. B. (2015) Systematic inequality and hierarchy in faculty hiring networks. *Science Advances*, *1*(1), e1400005–e1400005.

Cole, J. R. (1979) *Fair science. Women in the scientific community.* New York: Columbia University Press.
Cruz-Castro, L., & Sanz-Menéndez, L. (2019) Grant allocation disparities from a gender perspective: Literature review. Synthesis Report. GRANteD Project D.1.1. https://doi.org/10.20350/digitalCSIC/10548
Cummings, W. K., & Finkelstein, M. J. (2012) *Scholars in the changing American academy. New contexts, new rules and new roles.* Dordrecht: Springer.
Dargnies, M.-P. (2012) Men too sometimes shy away from competition: The case of team competition. *Manag. Sci.*, *58*(11), 1982–2000.
Diezmann, C., & Grieshaber, S. (2019) *Women professors. Who makes it and how?* Singapore: Springer Nature.
Elsevier (2020) *The researcher journey through a gender lens.* Amsterdam: Elsevier.
Enamorado, T., Fifield, B., Imai, K., (2019) Using a Probabilistic Model to Assist Merging of Large-Scale Administrative Records, *American Political Science Review* (2019) 113(2), 353–371.
Endersby, J. W. (1996) Collaborative research in the social sciences: Multiple authorship and publication credit. *Social Science Quarterly*, *77*, 375–392.
Feeney, M. K., & Bernal, M. (2010) Women in STEM networks: Who seeks advice and support from women scientists? *Scientometrics*, *85*(3), 767–790
Fell, C. B., & König, C. J. (2016) Is there a gender difference in scientific collaboration? A scientometric examination of co-authorships among industrial-organizational psychologists. *Scientometrics*, *108*(1), 113–141.
Fellegi, I. P., & Sunter, A. B. (1969) A theory for record linkage. *J. Am. Stat. Assoc.*, *64*, 1183–1210.
Fisher, B. S., Cobane, C. T., Ven, T. M. V., & Cullen, F. T. (1998) How many authors does it take to publish an article? trends and patterns in political science. *PS: Political Science and Politics*, *31*(4), 847–856.
Flory, J. A., Leibbrandt, A., & List, J. A. (2014) Do competitive workplaces deter female workers? A large-scale natural field experiment on job entry decisions. *Rev. Econ. Stud.*, *82*(1), 122–155.
Fochler, M., Felt, U., & Müller, R. (2016) Unsustainable growth, hyper-competition, and worth in life science research: Narrowing evaluative repertoires in doctoral and postdoctoral scientists' work and lives. *Minerva*, *54*(2), 175–200.
Fox, M. F. (1985) Location, sex-typing, and salary among academics. *Work and Occupations*, *12*(2), 186–205.
Fox, M. F, Realff, M. L., Rueda, D. R., & Morn, J. (2017) International research collaboration among women engineers: Frequency and perceived barriers, by regions. *Journal of Technology Transfer*, *42*(6), 1292–1306.
Frehill, L. M., & Zippel, K. (2010) Gender and international collaborations of academic scientists and engineers: Findings from the survey of doctorate recipients, 2006. *Journal of the Washington Academy of Sciences*, *97*(1), 49–69.
Ghiasi, G., Larivière, V., & Sugimoto, C. R. (2015) On the compliance of women engineers with a gendered scientific system. *PLOS ONE*, *10*(12), 1–19.
Ghiasi, G, Mongeon, P., Sugimoto, C., & Larivière, V. (2018) Gender homophily in citations. In *Conference Proceedings: the 3rd International Conference on Science and Technology Indicators (STI 2018)* (pp. 1519–1525).
Ghiasi, G., Sainte-Marie, M., & Larivière, V. (2019) Making it personal: Examining personalization patterns of single-authored papers. In *17th International Conference on Scientometrics & Informetrics. September 2-5, 2019* (pp. 2088–2093).
Glänzel, W. (2002) Coauthorship patterns and trends in the sciences 1980–1998: A bibliometric study with implications for database indexing and search strategies. *Library Trends*, *50*(3), 461–473.
Goastellec, G., & Vaira, M. (2017) Women's place in academia: Case studies of Italy and Switzerland. In: H. Eggins (Ed.), *The changing role of women in higher education* (pp. 173–191). Cham: Springer.
Greguletz, E., Diehl, M.-R., & Kreutzer, K. (2018) Why women build less effective networks than men: The role of structural exclusion and personal hesitation. *Human Relations*, 001872671880430.
Gupta, N. D., Poulsen, A., & Villeval, M. C. (2013) Gender matching and competitiveness: Experimental evidence. *Economic Inquiry*, *51*(1), 816–835.
Halevi, G. (2019) Bibliometric studies on gender disparities in science. In W. Glänzel, H. F. Moed, U. Schmoch, & M. Thelwall (Eds.), *Springer handbook of science and technology indicators* (pp. 563–580). Cham: Springer.

Harron, K., Dibben, C., Boyd, J., Hjern, A., Azimaee, M., Barreto, M. L., & Goldstein, H. (2017) Challenges in administrative data linkage for research. *Big Data Soc.*, *July–December*, 1–12.

Hartley, J. (2005) Refereeing and the single author. *Journal of Information Science*, *31*(3), 251–256. https://doi.org/10.1177/0165551505052474

Heffernan, T. (2020) Academic networks and career trajectory: There's no career in academia without networks. *Higher Education Research & Development*, published online: 06 Aug 2020. https://doi.org/10.1080/07294360.2020.1799948. 1–14.

Heffner, A. G. (1979) Authorship recognition of subordinates in collaborative research. *Social Studies of Science*, *9*(3), 377–384.

Henriksen, D. (2016) The rise in co-authorship in the social sciences (1980–2013) *Scientometrics*, *107*, 455–476.

Herzog, T. N., Scheuren, F. J., & Winkler, W. E. (2007) *Data quality and record linkage techniques*. Dordrecht: Springer.

Holman, L., & Morandin, C. (2019) Researchers collaborate with same-gendered colleagues more often than expected across the life sciences. *PLOS ONE*, *14*(4), e0216128.

Brown, N., Horiuchi, Y., Htun, M., & Samuels, D. (2020). Gender Gaps in Perceptions of Political Science Journals. *PS: Political Science & Politics, 53*(1), 114-121.

Huang, D.-W. (2015) Temporal evolution of multi-author papers in basic sciences from 1960 to 2010. *Scientometrics*, *105*, 2137–2147.

Huang, J., Gates, A. J., Sinatra, R., & Barabási, A.-L. (2020) Historical comparison of gender inequality in scientific careers across countries and disciplines. *Proc. Natl. Acad. Sci. U.S.A.*, *117*(9), 4609–4616.

Hudson, J. (1996) Trends in multi-authored papers in economics. *The Journal of Economic Perspectives: A Journal of the American Economic Association*, *10*(3), 153–158.

Hutson, S. R. (2006) Self-citation in archaeology: Age, gender, prestige, and the self. *Journal of Archaeological Method and Theory*, *13*(1), 1–18.

Jabbehdari, S., & Walsh, J. P. (2017) Authorship norms and project structures in science. *Science, Technology, & Human Values*, *42*(5), 872–900.

Jadidi, M., Karimi, F., Lietz, H., & Wagner, C. (2018) Gender disparities in science? Dropout, productivity, collaborations, and success of male and female computer scientists. *Adv. Complex Syst.*, *21*(3–4), 1750011.

Jaeger, A., & Dinin, A. J. (2018) *The postdoc landscape. The invisible scholar*. London: Academic Press.

Jaro, M. A. (1989) Advances in record linkage methodology as applied to the 1985 census of Tampa Florida. *J. Am. Stat. Assoc.*, *84*(406), 414–420.

Jeong, S., Choi, J. Y., & Kim, J. (2011) The determinants of research collaboration modes: Exploring the effects of research and researcher characteristics on co-authorship. *Scientometrics*, *89*(3), 967–983.

Jöns, H. (2011) Transnational academic mobility and gender. *Globalisation, Societies and Education*, 9(2), 183–209.

Kanter, R. M. (1977) Some effects of proportions on group life: Skewed sex ratios and responses to token women. *American Journal of Sociology*, *82*(5), 965–990.

Kegen, N. V. (2013) Science networks in cutting-edge research institutions: Gender homophily and embeddedness in formal and informal networks. *Procedia Soc. Behav. Sci.*, *79*, 62–81.

Key, E., & Sumner, J. L. (2019) You research like a girl: Gendered research agendas and their implications. *PS: Political Science & Politics*, *52*(4), 663–668.

King, M. M., Bergstrom, C. T., Correll, S. J., Jacquet, J., & West, J. D. (2017) Men set their own cites high: Gender and self-citation across fields and over time. *Socius*, *3*, 1–22.

Kuld, L., & O'Hagan, J. (2018) Rise of multi-authored papers in economics: Demise of the 'lone star' and why? *Scientometrics*, *114*, 1207–1225.

Kwiek, M. (2015) Inequality in academic knowledge production. The role of research top performers across Europe. In E. Reale & E. Primeri (Eds.), *Universities in transition. Shifting institutional and organizational boundaries* (pp. 203–230). Rotterdam: Sense.

Kwiek, M. (2016) The European research elite: A cross-national study of highly productive academics across 11 European systems. *High Educ. (Dordr)*, *71*(3), 379–397.

Kwiek, M. (2018a) Academic top earners. Research productivity, prestige generation and salary patterns in European universities. *Sci. Public Policy*, *45*(1), 1–13.

Kwiek, M. (2018b) High research productivity in vertically undifferentiated higher education systems: Who are the top performers? *Scientometrics*, *115*(1), 415–462.

Kwiek, M. (2019) *Changing European academics. A comparative study of social stratification, work patterns and research productivity.* London and New York: Routledge.

Kwiek, M. (2020a) What large-scale publication and citation data tell us about international research collaboration in Europe: Changing national patterns in global contexts. *Studies in Higher Education., 45*, on-line first April 10, 2020, 1–21.

Kwiek, M. (2020b) Internationalists and locals: International research collaboration in a resource-poor system. *Scientometrics*, *124*, 57–105.

Kwiek, M. (2020c) The prestige economy of higher education journals: A quantitative approach. *Higher Education*, online first June 13, 2020. https://doi.org/10.1007/s10734-020-00553-y.

Kwiek, M., & Roszka, W. (2020a) Gender disparities in international research collaboration: A large-scale bibliometric study of 25,000 university professors. *Journal of Economic Surveys*, on-line first November 18, 2020. https://doi.org/10.1111/joes.12395.

Kwiek, M., & Roszka, W. (2020b) Gender-based homophily in research: A large-scale study of man-woman collaboration, https://arxiv.org/abs/2006.03935.

Larivière, V., & Gingras, Y. (2010) The impact factor's Matthew effect. A natural experiment in bibliometrics. *J. Am. Soc. Inf. Sci. Tech.*, *61*(2), 424–427.

Larivière, V., Gingras, Y., & Archambault, É. (2006) Canadian collaboration networks: A comparative analysis of the natural sciences, social sciences and the humanities. *Scientometrics*, *68*(3), 519–533, https://doi.org/10.1007/s11192-006-0127-8

Larivière, V., Sugimoto, C. R., Chaoquin, N., Gingras, Y., & Cronin, B. (2013) Global gender disparities in science. *Nature*, *504*, 211–213.

Larivière, V., Sugimoto, C.R., Tsou, A., & Gingras, Y. (2015) Team size matters: Collaboration and scientific impact since 1900. *Journal of the Association for Information Science and Technology*, *66*(7), 1323–1332.

Larivière, V., Vignola-Gagné, E., Villeneuve, C., Gelinas, P., & Gingras, Y. (2011) Sex differences in research funding, productivity and impact: An analysis of Quebec university professors. *Scientometrics*, *87*(3), 483–498.

Latour, B., & Woolgar, S. (1986) *Laboratory life. The construction of scientific facts*. Princeton: Princeton University Press.

Leišytė L., & Hosch-Dayican, B. (2017) Gender and academic Work at a Dutch university. In H. Eggins (Ed.), *The changing role of women in higher education* (pp. 95–117). Cham: Springer.

Lerchenmueller, M., Hoisl, K., & Schmallenbach, L. (2019) Homophily, biased attention, and the gender gap in science. Paper presented at DRUID19, Copenhagen Business School, Copenhagen, Denmark, June 19–21, 2019.

Lindsay, L. (2011) *Gender roles. A sociological perspective.* Fifth Edition. Boston: Prentice Hall.

MacNeil, C. (2019) "One is the loneliest number"; Are we witnessing the death throes of the single-author research paper in the field of biological invasions? *Management of Biological Invasions*, *10*(1), 1–5.

Maddi, A., Larivière, V., & Gingras, Y. (2019) Man-woman collaboration behaviors and scientific visibility: Does gender affect the academic impact in economics and management? *Proceedings of the 17th International Conference on Scientometrics & Informetrics, September 2–5, 2019* (pp. 1687–1697).

Madison, G., & Fahlman, P. (2020) Sex differences in the number of scientific publications and citations when attaining the rank of professor in Sweden. *Studies in Higher Education*, 1–22, https://doi.org/10.1080/03075079.2020.1723533.

Maliniak, D., Powers, R., & Walter, B. F. (2013) The gender citation gap in international relations. *Int. Organ.*, *67*(4), 889–922.

Marsh, H. W., Bornmann, L., Mutz, R., Daniel, H.-D., & O'Mara, A. (2009) Gender effects in the peer reviews of grant proposals: A comprehensive meta-analysis comparing traditional and multilevel approaches. *Review of Educational Research*, *79*(3), 1290–1326.

McDowell, M. J., Singell, L. D. Jr., & Stater, M. (2006) Two to tango? Gender differences in the decisions to publish and coauthor. *Econ. Inq.*, *44*(1), 153–168.

McDowell, J. M., & Smith, J. K. (1992) The effect of gender-sorting on propensity to coauthor: Implications for academic promotion. *Econ. Inq.*, *30*(1), 68–82.

Merton, R. K. (1968) The Matthew effect in science. *Science*, *159*(3810), 56–63.

Mihaljević-Brandt, H., Santamaría, L., & Tullney, M. (2016) The effect of gender in the publication patterns in mathematics. *PLOS ONE*, *11*(10), e0165367.
Miller, J., & Chamberlin, M. (2000) Women are teachers, men are professors: A study of student perceptions, *Teach. Sociol.*, *28*(4), 283–298.
Mishra, S., Fegley, B. D., Diesner, J., & Torvik, V. I. (2018) Self-citation is the hallmark of productive authors, of any gender. *PLOS ONE*, *13*(9), e0195773.
Müller, R. (2012) Collaborating in life science research groups: The question of authorship. *Higher Education Policy*, *25*(3), 289–311, https://doi.org/10.1057/hep.2012.11
Müller, R., & Kenney, M. (2014) Agential conversations: Interviewing postdoctoral life scientists and the politics of mundane research practices. *Science as Culture*, *23*(4), 537–559. https://doi.org/10.1080/09505431.2014.916670
Nabout, J. C., Parreira, M. R., Teresa, F. B., Carneiro, F. M., da Cunha H. F., de Souca Ondei, L., et al. (2015) Publish (in a group) or perish (alone): The trend from single- to multi-authorship in biological papers. *Scientometrics*, *102*, 357–364.
Niederle, M., & Vesterlund, L. (2007) Do women shy away from competition? Do men compete too much? *Q. J. Econ.*, *122*(3), 1067–1101, https://doi.org/10.1162/qjec.122.3.1067
Nielsen, M. W. (2016) Gender inequality and research performance: Moving beyond individual-meritocratic explanations of academic advancement. *Stud. High. Educ.*, *41*(11), 2044–2060.
Olechnicka, A., Ploszaj, A., & Celinska-Janowicz, D. (2019). *The geography of scientific collaboration*. London and New York: Routledge.
Ossenblok, T. L. B., Verleysen, F. T., & Engels, T. C. E. (2014) Coauthorship of journal articles and book chapters in the social sciences and humanities (2000–2010). *Journal of the Association for Information Science and Technology*, *65*(5), 882–897, https://doi.org/10.1002/asi.23015
Potthoff, M., & Zimmermann, F. (2017) Is there a gender-based fragmentation of communication science? An investigation of the reasons for the apparent gender homophily in citations. *Scientometrics*, *112*(2), 1047–1063.
Price, de Solla D. J. (1963) *Little science, big science*. New York: Columbia University Press.
Ramalho, E.A., Ramalho, J.J.S., Murteira, J.M.R. (2011). Alternative Estimating and Testing Empirical Strategies for Fractional Regression Models. *Journal of Economic Surveys. 25*(1). 19–68.
Rivera, L. A. (2017) When two bodies are (not) a problem: Gender and relationship status discrimination in academic hiring. *American Sociological Review*. *82*, 1111–1138.
Robinson-Garcia, N., Costas. R., Sugimoto, C.R., Larivière, V., Nane, G.F. (2020). Task specialization across research careers. *eLife*, 2020, 9: e60586 doi: 10.7554/eLife.60586
Rutledge, R., & Karim, K. (2009) Determinants of coauthorship for the most productive authors of accounting literature. *Journal of Education for Business*, *84*(3), 130–134, https://doi.org/10.3200/joeb.84.3.130–134
Ryu, B. K. (2020) The demise of single-authored publications in computer science: A citation network analysis. arXiv:2001.00350.
Santos, J. M., Horta, H., & Amâncio, L. (2020) Research agendas of female and male academics: A new perspective on gender disparities in academia. *Gender and Education*, on-line first, 1–19.
Sarsons, H. (2017) Recognition for group work: Gender differences in academia. *American Economic Review*, *107*(5), 141–145. https://doi.org/10.1257/aer.p20171126
Sarsons, H., Gërxhani, K., Reuben, E., & Schram, A. (2020) Gender differences in recognition for group work. Forthcoming in *J. Political Econ.*
Scopus (2021) The Scopus dataset, available from www.scopus.com (institutional subscription required).
Shapin, S. (1991) "The mind is its own place": science and solitude in seventeenth-century England. *Science in Context*, *4*(1), 191–218.
Shapiro, J. R., & Williams, A. M. (2011) The role of stereotype threats in undermining girls' and women's performance and interest in STEM fields. *Sex Roles*, *66*(3–4), 175–183.
Sonnert, G., & Holton, G. (1996) Career patterns of women and men in the sciences. *Am. Sci.*, *84*(1), 63–71. JSTOR.
Statistics Poland (2020) *Higher education institutions and their finances in 2019*. Warsaw: Statistics Poland.
Stephan, P. (2012) *How economics shapes science.* Cambridge: Harvard University Press.

Sugimoto, C. R., Ni, C., & Larivière, V. (2015) On the relationship between gender disparities in scholarly communication and country-level development indicators. *Science and Public Policy*, *scv007*, https://doi.org/10.1093/scipol/scv007

Thelwall, M. (2020) Gender differences in citation impact for 27 fields and six English-speaking countries 1996–2014. *Quantitative Science Studies*, *1*(2), 599–617.

Thelwall, M., Bailey, C., Tobin, C., & Bradshaw, N.-A. (2019) Gender differences in research areas, methods and topics: Can people and thing orientations explain the results? *Journal of Informetrics*, *13*(1), 149–169.

Toutkoushian, R. K., & Bellas, M. L. (1999) Faculty time allocations and research productivity: Gender, race and family effects. *Rev. High. Educ*., 22(4), 367–390.

Uhly, K. M., Visser, L. M., & Zippel, K. S. (2017) Gendered patterns in international research collaborations in academia. *Studies in Higher Education*, *42*(4), 760–782.

Vabø, A., Padilla-Gonzales, L.E., Waagene, E., & Naess, T. (2014) Gender and faculty internationalization. In F. Huang, M. Finkelstein, & M. Rostan (Eds.), *The internationalization of the academy. Changes, realities and prospects* (pp. 183–206). Dordrecht: Springer.

Vafeas, N. (2010) Determinants of single authorship. *EuroMed Journal of Business*, *5*(3), 332–344.

Van den Besselaar, P., & Sandström, U. (2015) Early career grants, performance, and careers: A study on predictive validity of grant decisions. *J. Informetr.*, *9*(4), 826–838.

Van den Besselaar, P., & Sandström, U. (2016) Gender differences in research performance and its impact on careers: A longitudinal case study. *Scientometrics*, *106*(1), 143–162.

Van den Besselaar, P., & Sandström, U. (2017) Vicious circles of gender bias, lower positions, and lower performance: Gender differences in scholarly productivity and impact. *PLOS ONE*, https://doi.org/10.1371/journal.pone.0183301.

Van den Brink, M., & Benschop, Y. (2013) Gender in academic networking: The role of gatekeepers in professorial recruitment. *Journal of Management Studies*, *51*(3), 460–492.

Walker, K. A. (2019) Females are first authors, sole authors, and reviewers of entomology publications significantly less often than males. *Annals of the Entomological Society of America*, https://doi.org/10.1093/aesa/saz066

Ward, M. E., & Sloane, P. J. (2000) Non-pecuniary advantages versus pecuniary disadvantages: Job satisfaction among male and female academics in Scottish universities. *Scottish Journal of Political Economy*, *47*(3), 273–303.

Weisshaar, K. (2017) Publish and perish? An assessment of gender gaps in promotion to tenure in academia. *Social Forces*, *96*(2), 529–560, https://doi.org/10.1093/sf/sox052

West, J. D., Jacquet, J., King, M. M., Correll, S. J., & Bergstrom, C. T. (2013) The role of gender in scholarly authorship. *PLOS ONE*, *8*(7), e66212.

Winkler, W. (1990) String comparator metrics and enhanced decision rules in the Fellegi-Sunter model of record linkage. In *Proceedings of the Section on Survey Research Methods*, *American Statistical Association* (pp. 354–359).

Wu, C., Fuller, S., Shi, Z., & Wilkes, R. (2020) The gender gap in commenting: Women are less likely than men to comment on (men's) published research. *PLOS ONE*, *15*(4), e0230043.

Wuchty, S., Jones, B. F., & Uzzi, B. (2007) The increasing dominance of teams in production of knowledge. *Science*, *316*(5827), 1036–1039, https://doi.org/10.1126/science.1136099

Xie, Y., & Shauman, K. A. (2003) *Women in science. Career processes and outcomes.* Cambridge, MA: Harvard University Press.

Yudkevich, M., Altbach, P. G., & Rumbley, L. (2015) *Young faculty in the twenty-first century: International perspectives*. Albany: State University of New York.

Zippel, K. (2017) *Women in global science.* Stanford: Stanford University Press.