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Exploring citation patterns of male and female scholars in Physics

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in Informatik

submitted by
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Statement

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Abstract

We examine the systematic underrecognition of female scientists (Matilda effect) by exploring the citation network of papers published in the American Physical Society (APS) journals. Our analysis shows that articles written by men (first author, last author and dominant gender of authors) receive more citations than similar articles written by women (first author, last author and dominant gender of authors) after controlling for the journal of publication, year of publication and content of the publication. Statistical significance of the overlap between the lists of references was considered as the measure of similarity between articles in our analysis. In addition, we found that men are less likely to cite articles written by women and women are less likely to cite articles written by men. This pattern leads to receiving more citations by articles written by men than similar articles written by women because the majority of authors who published in APS journals are male (85%). We also observed Matilda effect reduces when articles are published in journals with the highest impact factors. In other words, people's evaluation of articles published in these journals is not affected by the gender of authors significantly. Finally, we suggested a method that can be applied by editors in academic journals to reduce the evaluation bias to some extent. Editors can identify missing citations using our proposed method to complete bibliographies. This policy can reduce the evaluation bias because we observed papers written by female scholars (first author, last author, the dominant gender of authors) miss more citations than articles written by male scholars (first author, last author, the dominant gender of authors).

"Dedicated to my beloved parents and sister" For their love, endless support, encouragement and sacrifices

Contents

List of Figures

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List of Symbols

$\widetilde{U_0}$ Approximation of U_0

A Set of articles with more than zero outgoing citations

a_m Number of men's authorships

a_w Number of women's authorships

B Set of articles that received at least two citations

d_i Number of citations from article i to the articles of S_B^k

$K(p^*)$ Number of existing citations between validated pairs at threshold p^*

$M(p^*)$ Number of pairs of articles validated at threshold p^*

N_A Cardinality of set A

N_A^k Cardinality of set S_A^k

N_B Cardinality of set B

N_B^k Cardinality of set S_B^k

$N_{i,j}^k$ Number of references that article i and j have in common in the set S_B^k

p^* Significance threshold of similarity of two articles

$P_{i,j}(p^*)$ Probability of existence a citation between two articles i and j whose similarity is validated at the threshold p^*

$q_{i,j}(k)$ P-value of similarity of articles i and j that cite at least one element in S_B^k

r Relative rate of men's self-citation to women's self-citation

S^k Union of set S_A^k and S_B^k

S_A^k Set of articles that cite at least one element in S_B^k

S_B^k Set of articles with in-degree equal to k

s_m Number of men's self-citations

s_w Number of women's self-citations

$U(0)$ $U(p^*)$ at the smallest value of p^*

$U(p^*)$ Fraction of missing links at a certain confidence level p^*

1. Introduction

1.1. Motivation

"If science is to be meritocratic, similar achievements should receive similar reputations or recognition" [1]. In this research, we investigate if similar publications of female and male authors in American Physical Society (APS) journals are recognized in similar ways. In other words, if male and female scientists' publications are referenced, on average, about the same number of times. We examine the existence of Matilda effect (systematic underrecognition of female scientists) [1] by analysis of citation network of publications of APS journals.

Female scholars experience many negative biases in hiring and promotion and are underrepresented in higher academic ranks. Systematic underrecognition of female scientists may play a role in this context [1]. Therefore, identifying evaluation biases against women and then making policies to correct that can promote gender equality in the scientific workforce. This research suggests a method that can be applied by editors at academic journals to reduce the evaluation bias to some extent. Editors can identify missing citations using our proposed method and simply inform authors about this tendency and encourage authors to be more gender neutral in whom they choose to cite. This policy can reduce the evaluation bias because we observed papers written by female scholars (first author, last author, the dominant gender of authors) miss more citations than articles written by male scholars (first author, last author, the dominant gender of authors).

1.2. Research Question

In this research, first, we investigate gender gap in research performance based on citation count, citations per paper and productivity of scholars who published in APS journals. Then, we show how this gap has been changing over time.

Second, we assess if articles written by men (first author, last author and dominant gender of authors) receive more citations than articles written by women (first author, last author and dominant gender of authors).

Third, we examine the existence of Matilda effect by analyzing the citation network of publications of APS journals. We investigate if articles written by men (first author, last author and dominant gender of authors) receive more citations than similar articles written by women (first author, last author and dominant gender of authors) after controlling for the journal of publication, year of publication and content of the publication. Statistical significance of the overlap between the lists of references is considered as the measure of similarity between articles in our analysis. In other words, we investigate to what extent "People's evaluation of an article's quality and cite-worthiness may be influenced by the authors' gender" [2]. Then, we investigate this question in different APS journals to see to what extent the Matilda effect is influenced by the impact factor of a journal. In other words, we assess if people's evaluation of the articles published in journals with the highest impact factors is less affected by the gender of authors.

Forth, we test the hypothesis that men are less likely to cite articles written by women (first author, last author and dominant gender of authors) and women are less likely to cite articles written by men (first author, last author and dominant gender of authors). Then, we test this hypothesis in different APS journals to see to what extent this pattern is influenced by the impact factor of a journal.

Fifth, we test the hypothesis that If an article is written by a woman, missing a citation is more likely than when it's written by a man and vice versa.

1.3. Contributions and Findings

Many studies investigated gender gap in research performance in STEM (Science, Technology, Engineering, and Mathematics) fields that is the domain of males [2]. However, the gender gap in research performance of physicists who published in APS journals is still unexplored. Our first contribution is to assess gender gap in research performance of scholars in physics, based on citation network of papers published in APS journals. We observed that women have significantly lower productivity and citations per paper that results in lower citation counts. However, the gap in citation counts has been closing over time. Furthermore, we observed that lower research performance of women is affected by lower seniority of women because after controlling the seniority of scholars, the gap in research performance reduced significantly.

Second, we examined the existence of Matilda effect in physics by analysis of the citation network of publications of APS journals. Some studies analyzed the citation network of publications in other fields such as astronomy and international relations and showed that papers written by women receive fewer citations than what would be expected if the papers with the same non-gender specific properties (journal of publication, year of publication, field of publication) were written by the male authors (Matilda effect) [3, 4]. The assumption of these studies is that in each subfield, articles must have the same number of citations when they are published in the same journal. However, women's underrecognition (Matilda effect) might result from research topic choices in each subfield that differ by researchers' gender. Therefore, in this research, we control for the journal of publication, year of publication and content of publication rather than the field of publication. Statistical significance of the overlap between the lists of references is considered as the measure of similarity between articles in our analysis. Our analysis showed that articles written by men (first author, last author and dominant gender of authors) received more citations than similar articles written by women (first author, last author and dominant gender of authors) after controlling for the journal of publication, year of publication and content of the publication. Another contribution of our research is an assessment of Matilda effect based on the gender of the first author, the gender of the last author and the dominant gender of authors. While assessment of the related work is only based on the gender of the first author.

Third, we observed that men are less likely to cite articles written by women (first author, last author and dominant gender of authors) and women are less likely to cite articles written by men (first author, last author and dominant gender of authors). This observation can explain why articles written by men receive more citations than similar articles written by women because the majority of authors who published in APS journals are male (85%).

Fourth, we examined the existence of Matilda effect in each APS journal and observed the same results. However, we observed when articles are published in either RMP or PRL journal (journals with highest impact factors), the gender of their authors (first author, last author, the dominant gender of authors) does not affect the tendency of people to make citations to them significantly.

Fifth, we uncovered missing citations by identifying pairs of papers that their contents are significantly similar. This method can be used by editors of journals to reduce Matilda effect to some extent. They can inform authors when some citations are missing and encourage authors to be more gender neutral in whom they choose to cite. This policy can reduce the Matilda effect because we observed papers written by female scholars (first author, last author, the dominant gender of authors) not only receive fewer citations but also miss more citations than articles written by male scholars (first author, last author, the dominant gender of authors).

1.4. Overview

The structure of this thesis is as follows. In chapter 2, we give an overview of the related work that investigated gender bias in citation patterns. In chapter 3, we describe datasets and data collection methods. In chapter 4, we present the research performance gap of scholars who published in APS journals. In chapter 5, we discuss the gender gap in citations per paper. In chapter 6, we investigate gender gap in citations per paper after controlling for paper content. In chapter 7, we discuss the gender gap in citations per paper in different APS journals. In chapter 8, we discuss the gender gap in the probability of missing citation and in chapter 9, we conclude the thesis and discuss the possible future work.

2. Related Work

Many studies have focused on the performance of women in science and reported contradictory results [2]. In terms of productivity (number of publications), women usually have lower productivity than men [2]. However, some studies didn't find any significant differences in productivity between women and men [2]. Women usually publish fewer articles than men, so they have fewer opportunities to receive citations compared with men and usually have lower citation counts, a measure used for research performance evaluation [2].

The gender gap in citations per paper is likely to be another driver of gender difference in citation counts [2]. Regarding the citations per paper, mixed results have been reported as well. Some suggested women have lower citations per paper than men [2]. In contrast to these studies, some found that women have higher citations per paper than men and some have shown no difference in citations per paper between publications of men and women [2].

Some studies focused on author level analysis and some on paper level analysis. In author level analysis, citations per paper of a scholar is calculated by dividing citation count of the scholar by the number of his publication. Citations per paper is a common measure used for evaluating the average quality of articles written by an author. In the paper level analysis, citations per paper is defined as the mean of the number of citations received by a group of articles. In this study, we analyze the gender gap in citations per paper based on both definitions.

Maliniak et al. [3] studied gender gap in citations per paper (Paper level analysis) in international relations. Their findings revealed that articles written by women are cited less than articles written by men even after controlling for a lot of factors (year of publication, venue of publication, substantive focus, theoretical perspective, methodology, tenure status, and institutional affiliation). In other words, they found that an article written by a woman receives significantly fewer citations than if that same article is written by a man. Therefore, they suggested that "citation counts are not a fair and objective measure of the quality and impact of a scholar" because women have lower citation counts than men, all else equal (topic, or choice of research strategy,. . .).

Maliniak et al. [3] suggested this citation gap can be explained by Matilda effect. They found citations are heavily skewed in favor of men because international relations is heavily dominated by men. In addition, they suggested this citation gap can be affected by fewer self-citations of women. Self-citation increases citation counts and women are less likely to cite themselves. Not only does self-citation increase one's citation counts but also increases one's work visibility that increase citation counts exponentially. In their study, each self-citation results in an additional 3.65

citations from others.

Caplar et al. [4] analyzed the role of first (leading) author gender on the number of citations that a paper receives (paper level analysis). They considered a sample of publications from 1950 to 2015 from five major astronomy journals. They found papers with male first authors receive more citations than papers with female first authors. They used a random forest algorithm to control for the non-gender specific properties of these papers which include seniority of the first author, number of references, total number of authors, year of publication, publication journal, field of study and region of the first author's institution. They showed that papers written by females receive 10.4% fewer citations than what would be expected if the articles with the same nongender specific properties were authored by the male authors.

3. Data Set

The APS (American Physical Society) data set contains bibliographic information on all the articles published by the American Physical Society between 1893 and 2016 [5]. This citation network includes 591168 articles, and 7198567 directed links (citations). The citations refer only to articles of APS journals. The data set is consists of citing article pairs and articles' metadata such as DOI, journal, volume, issue, title, date and authors [5]. The American Physical Society is the second largest organization of physicists and a member of the society of the American Institute of Physics. The Physical Review Journal is a collection of leading peer-reviewed research journals such as Physical Review Letters. The table 1 shows physical review journals, their impact factors and immediacy indexes in 2016.

Journal	Impact Factor 2016	Immediacy Index 2016
Physical Review Letters	8.462	2.923
Physical Review X	12.789	2.589
Physical Review A	2.925	0.837
Physical Review B	3.836	1.024
Physical Review C	3.820	0.909
Physical Review D	4.568	1.938
Physical Review E	2.366	0.556

Table 1: Physical review journals, their impact factors and immediacy indexes in 2016.

3.1. Inferring Gender From Names

To infer the gender of authors we apply the method proposed by Karimi et al. [6] that combines the result of name-based (Genderize [1]) and image-based (Faceplusplus [2]) gender detection services. This method has a high accuracy for most countries compared to other name-based methods. However, this approach performs poorly for Chinese and Korean names (table 2). Therefore, Chinese and Korean names are excluded from our gender-specific analyses. To detect Chinese and Korean names, we use a dataset compiled for this purpose by Jadidi et al. [7]. They compiled unique Chinese names from the China Biographical Database Project (CBDB) [3] and compiled Korean names from Wikipedia. They extracted the page titles of all the backlinks to Korean names [4]. This Asian name detector classifies 88

[1] https://genderize.io/.
[2] https://www.faceplusplus.com/.
[3] http://projects.iq.harvard.edu/cbdb/home/.
[4] https://en.wikipedia.org/wiki/Korean _name/.

out of 100 randomly selected scientists correctly. In addition to Chinese and Korean names, we don't include authors with only first initials since we cannot infer their genders. Those authors for which we cannot detect their genders are not considered for our gender-specific analyses, however, included in all other analyses.

	# instances	SSA	IPUMS	Sexmachine	Genderize	Face++	Mixed1	Mixed2
United States	419	0.82	0.76	0.84	0.83	0.91	0.91	0.90
China	113	0.20	0.11	0.67	0.28	0.65	0.50	0.56
United Kingdom	96	0.94	0.92	0.92	0.94	0.81	0.98	0.94
Germany	82	0.87	0.88	0.96	0.94	0.87	0.96	0.93
Italy	75	0.93	0.92	0.94	0.98	0.79	0.99	1
Canada	60	0.87	0.77	0.86	0.91	0.90	0.96	0.93
France	58	0.93	0.92	0.80	0.96	0.81	0.97	1
Japan	56	0.79	0.70	1	0.90	0.62	0.91	0.94
Brazil	44	0.29	0.29	0.15	0.44	0.81	0.90	0.93
Spain	39	0.96	0.92	0.92	1	0.92	1	1
Australia	31	0.89	0.89	0.90	0.86	0.86	0.94	0.93
India	29	0.67	0.17	0.71	0.78	0.83	0.83	0.93
South Korea	27	0.04	0.00	0.58	0.11	0.74	0.37	0.66
Switzerland	25	0.78	0.70	0.56	0.83	0.88	0.90	0.92
Turkey	21	0.43	0.14	0.79	0.81	0.86	1	1

Table 2: Accuracy of gender detection methods. For most countries mixed approaches perform best. [6].

In the mixed approach proposed by Karimi et al. [6], Genderize is used first. Then for the remaining unidentified names, the image-based method Face++, is used. Genderize utilizes big datasets of information, from user profiles across major social networks and exposes this data through its API. Face++ is an image-based application with high performance. In order to derive the gender for a specific scientist, we collect the first five Google thumbnails using the full name as search query term and then apply image-recognition on the search results. So, we collect a sample of pictures that depict people who are named like the person we searched for. The advantage of this method is that for first names that are ambiguous or unisex, the combination of first and last name is a better indicator of the gender.

3.2. Descriptive Statistics

Our dataset consists of 413455 scientists. After removing initials, Chinese and Korean names, we can only infer gender of 55% of names. We inferred gender of 66% of remained scientists using the mixed method. 85% of authors were identified as men and 15% as women. Figure 1 shows how the community of scholars who published in APS journals is growing and Figure 2 indicates the community is becoming more gender-balanced. In other words, the gender gap is closing over time because men to women ratio decreases from 10.95 in 1975 to 5.38 up until 2017.

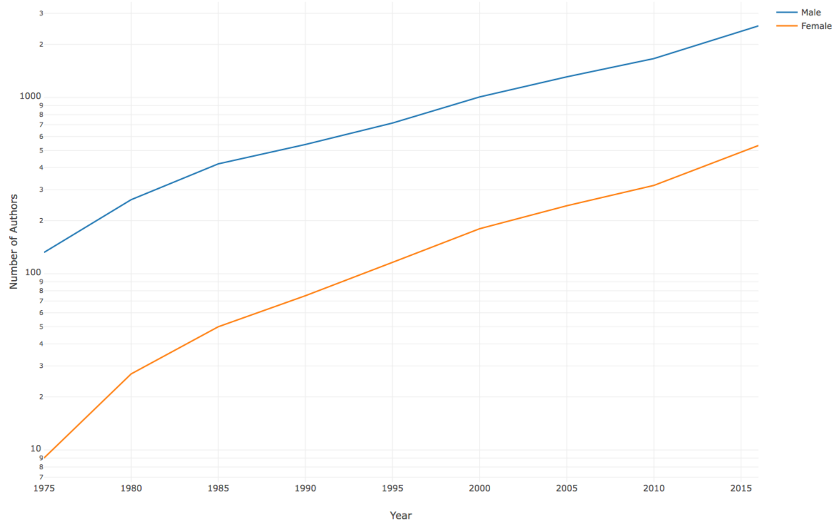

Figure 1: Number of scholars who published in APS journals over time.

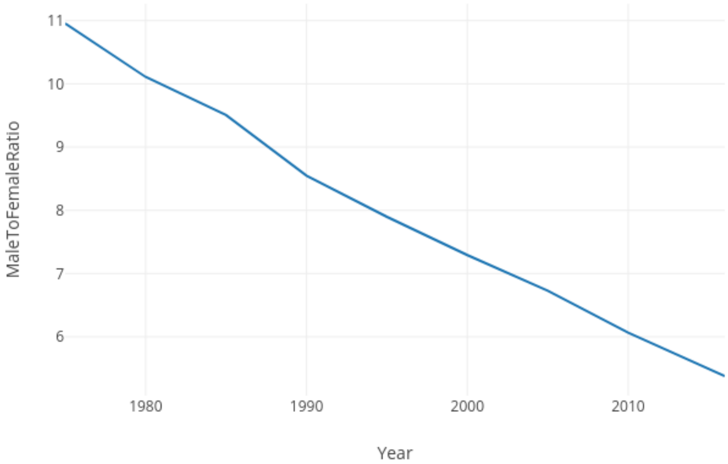

Figure 2: Male to female ratio over time.

4. Gender Gap in Research Performance

Many studies in different fields have observed performance gap between male and female researchers. Men on average publish more papers, and receive more citations than female researchers [14] -[32]. In other words, men usually have higher productivity and higher citations per paper. Productivity shows quantity and citations per paper shows the quality of publications of scholars. The gap in research performance or citation counts is usually the result of the lower productivity of female scholars [18]. Several factors can explain the differences between men and women in quantity and quality of publications [33]:

1. Male scholars have more seniority in scientific communities [33].

2. Women have less funding and are caught in a negative feedback loop: they have less funding, on average than men that reduces the amount of future research, that leads to the reduction in the amount of future funding and productivity [33].

3. Women have a greater share of the burden of domestic responsibilities [23, 47, 44]. Therefore they have less time available for research and are less mobile. Less mobility leads to the smaller breadth of networks that can explain part of the lower scientific impact of women. Since articles written with international partners have higher citation impact [33].

4. Women work in less research-intensive institutions or in more research-intensive institutions have lower-level positions than men [21] . Women do more teaching activities than male colleges. Access to graduate students and post-doctoral researchers as well as to research funding, equipment and available time for doing research were unequally divided among males and females [33].

5. Women specialize less than men. Women work on a wider variety of research topics throughout their careers [51]. Leahey's [51] studies suggested that higher specialization of men results in greater professional expertise. This hypothesis supports the idea that the unfavorable position of women within science is a result of the 'masculine' nature of scientific practices.

The mentioned factors lead to either lower quantity or lower quality of publications of women or both. However, the gap in research performance may be the result of the biased evaluation of research performance. Similar publications of female and male authors are not recognized in similar ways and people's evaluation of an article's quality and cite-worthiness may be influenced by the authors' gender. In other words, articles written by men usually receive more citations than similar articles written by women. This systematical underrecognition of female scientists is called Matilda effect. We will discuss how this effect leads to lower citation counts of female scholars in chapter 6.

In this chapter, we investigate the gender gap in research performance based on citation count measure. We investigate if the difference in research performance is the result of either lower productivity of female scholars or lower quality of papers (citations per paper metric) written by women or both. In all our analysis, we control the effect of self-citation by removing self-citations.

4.1. Gender Gap in Self Citation

In all our analysis, we control the effect of self-citation to perform fairer performance evaluation of scholars because men authors cite their own articles more frequently than do women authors. First, we look at the gender pattern of self-citation in APS citation network and assess whether men authors cite their own articles more frequently than do women authors using the method proposed by King et al. [34]. They found nearly 10 percent of references are self-citations by an article's authors based on the data set of research papers published between 1779 and 2011 in JSTOR journals. They also showed males cited their own papers 56 percent more than did females after controlling for productivity. They controlled productivity because gender difference in self-citation could be caused by the difference in the number of articles that males and females have published rather than gender-specific patterns of behavior.

Let "authorship" be a unique author-paper pair, a_w and a_m be the number of women's and men's authorships, respectively. Let s_w and s_m be the number of women's and men's self-citations, respectively. The relative rate r of men's self-citation to women's self-citation can be calculated by solving the following expression for r [34]:

$$\frac{s_m}{a_m} = r\frac{s_w}{a_w} \tag{1}$$

Solving for r, we find a ratio of 1.44, meaning that, on average, men self-cite 1.44 times more often than women after controlling for productivity. Therefore, we remove the effect of self-citations by removing self-citations from APS citation network. However, this can not remove the effect of self-citations completely because self-citations improve the visibility of articles that results in attracting more citations from other authors [34].

4.2. Gender Gap in Citation Counts

Citation counts (the number of citations) is an important measure of scholarly contributions, at the level of individual scholars, journals, or even institutions [3]. Citation count measures impact of the publications of a scholar and is used in academia to evaluate a scholar's performance [3]. Based on publications of APS journals, female scholars have lower citation counts than male scholars (mean of citation counts of female scholars=26.91, mean of citation counts of male scholars=50.17) (Figure 3).

In order to assess the significance of the gap in citation counts, we use the Mann-Whitney U test to investigate if the distribution of citation counts of female and male scholars are equal. We use this test because the distribution of citation counts is skewed, a small number of researchers have very high citation counts and a large number of researchers have very low citation counts. Mann-Whitney U test (unpaired two-sample Wilcoxon test) is a non-parametric alternative to the unpaired two-sample t-test. It can be used to compare two independent groups of samples when data are not normally distributed. Mann-Whitney U test can be used to determine whether two independent samples were selected from populations having the same distributions. In this test, the alternative hypothesis is that one distribution is statistically greater than the other. However, There are many other ways to formulate the null and alternative hypotheses. A very general formulation is to assume that:

1. All the observations from both samples are independent of each other,
2. The observations are ordinal,
3. The null hypothesis is that the distributions of both populations are equal.
4. The alternative hypothesis is that the distributions are not equal.

Using this test we have found that distribution of citation counts of male scholars is significantly greater than that of female scholars (p-value of Mann Whitney U test $< 2.2e\text{-}16$). Complementary cumulative distribution function (CCDF) of the citation counts of male and female scholars are depicted in figure 4.

Although the results of our analysis indicate that male scholars have better research performance, the gender gap in research performance has been closing over time. In order to investigate how the gap has been changing, we classified scholars according to the date of their first publication. Then we divided the mean of citation counts of men by the mean of citation counts of women in all the classes. Male to female ratio of the mean of citation counts, depicted in figure 5. The gap in the research performance of scholars who published in APS journals has reduced significantly from 2.8 to 1.5 during 40 years that indicates improvement in the research performance of women.

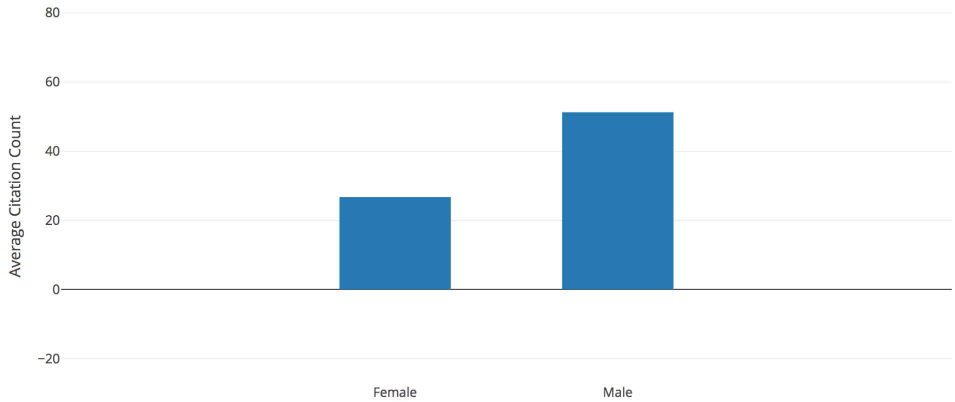

Figure 3: Mean of citation counts of male and female scholars who published in APS journals.

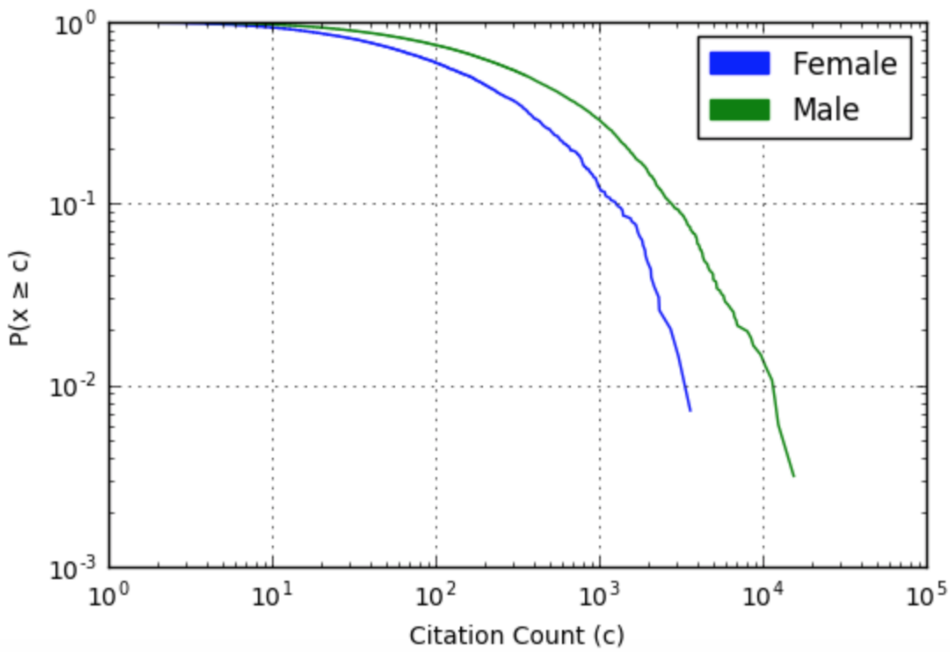

Figure 4: CCDF of citation counts of male and female scholars who published in APS journals.

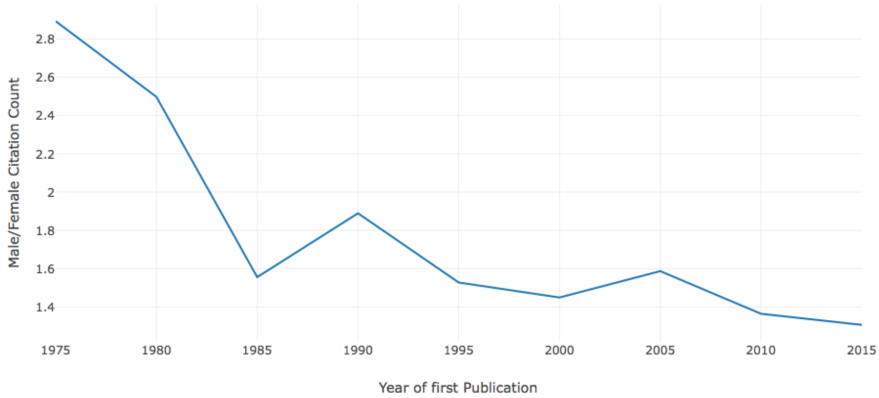

Figure 5: Male to female ratio of mean of citation counts over 40 years.

In addition, we observed the gender gap in citation counts decreases significantly after removing the effect of seniority of authors. In order to remove seniority effect, we calculated citation counts per year by dividing the citation count of an author by his seniority. We defined seniority as the number of years between the first and the last publication of an author. Cameron et al. [8] used this method to compare the publishing patterns of men and women in ecology. They provided a fairer evaluation of research performance by using m-index which is the h-index adjusted for career age, calculated as h-index per years since the first publication. They used this measure to control the effect of the leaky-pipeline problem that explains how women progress in science careers. In this phenomenon, women are not progressing in science careers and are more underrepresented in advanced career stages [19]. Females leave academia sooner because of barriers such as maternity and family responsibilities.

Figure 6 shows the distance between complementary cumulative distribution functions (CCDF) of the citation counts per year of male and female scholars. Compared to the plot in figure 4, the distance between the distributions has reduced significantly. Mann-Whitney U test also shows that the distance between distributions has reduced significantly after controlling seniority of authors (p-value increased from 2.2e-16 to 6.627e-05). Therefore, the lower performance of female scholars can be explained by lower carrier age or seniority of female scholars who published in APS journals.

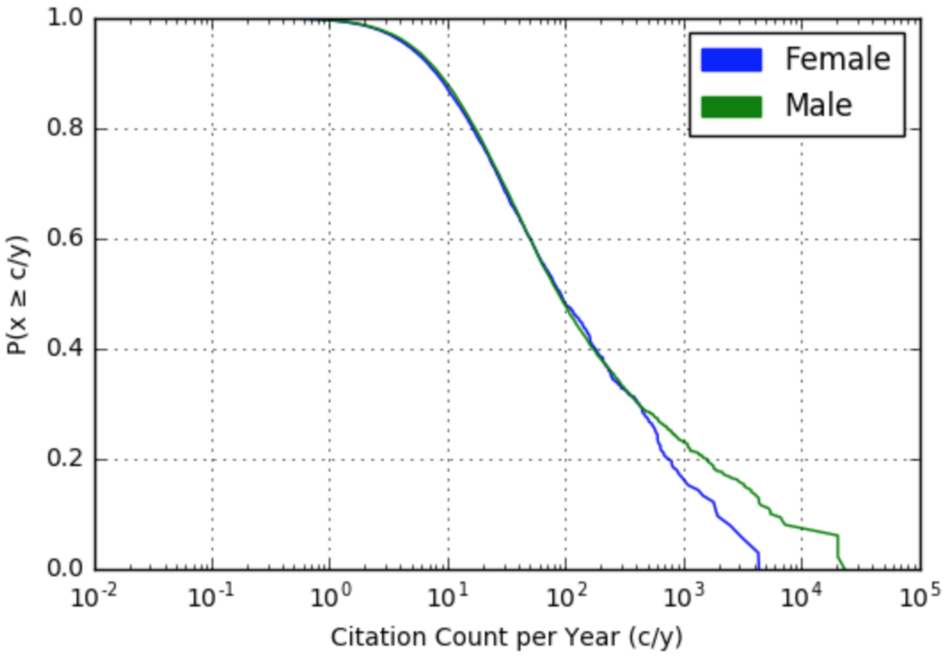

Figure 6: CCDF of citation counts devided by career age of scholars who published in APS journals.

4.2.1. Productivity Gap

Either lower quantity or lower quality of publications or both can lead to lower citation counts or research performance of scholars. Here, we investigate if female scholars have lower productivity than male scholars who published in APS journals. A survey of studies, considering both science as a whole and individual scientific disciplines, shows research productivity (number of publications) gap between men and women. Women generally have lower productivity [20]-[32]. However, there is also research that has reported no significant differences in productivity between males and females [39] -[43]. Unsurprisingly, data from APS citation network show females have lower productivity than males (mean of productivity of males=4.3, mean of productivity of females=2.42) Figure (7). Because the productivity distribution is not normal, we used the Mann Whitney U test to assess the significance of the productivity gap. This test shows that the productivity distribution of males is significantly greater than the productivity distribution of female scholars who published in APS journals (p-value of Mann Whitney U test < 2.2e-16). Figure 8 shows CCDF of productivity of male and female scholars who published in APS journals.

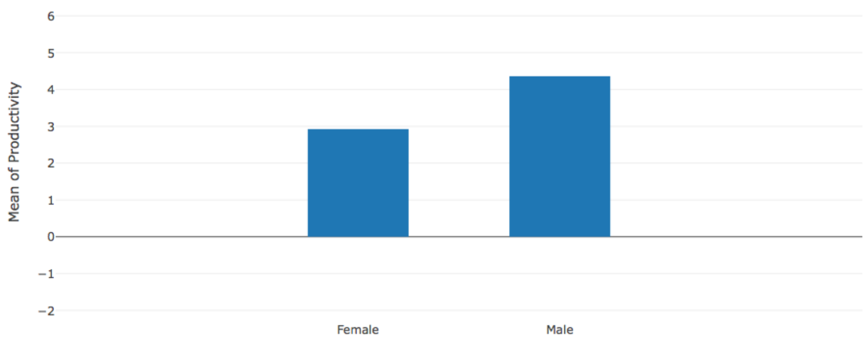

Figure 7: Mean of productivity of male and female scholars who published in APS journals

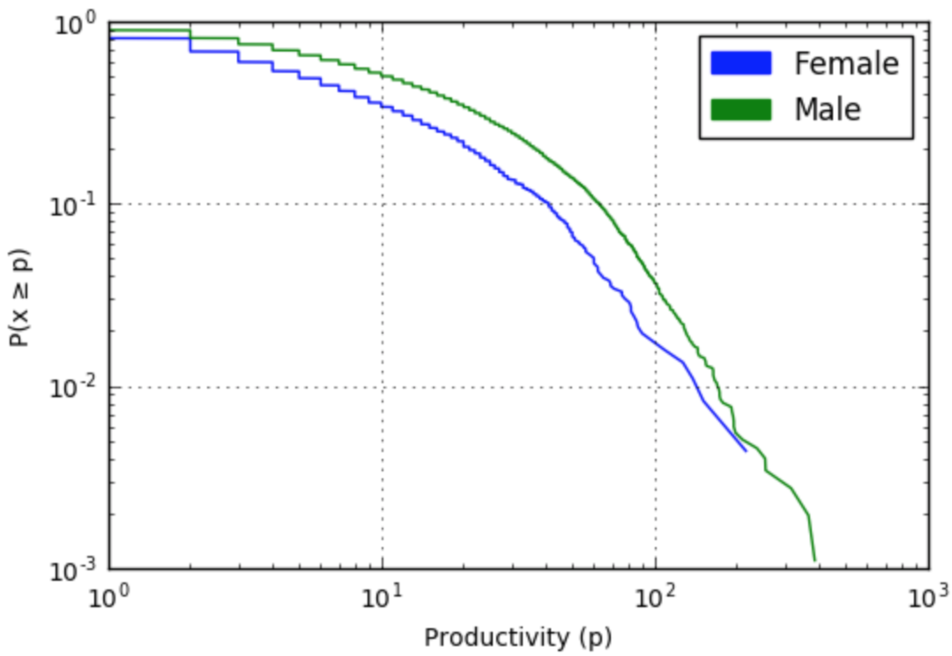

Figure 8: CCDF of productivity of male and female scholars who published in APS journals.

4.2.2. Gender Gap in Citations per Paper

The average impact of papers written by an author can be measured by citations per paper measure. Male and female scholars are not only different in the number of publications or productivity, but also in research quality or impact per paper. Here, we investigate if female scholars have lower citations per paper than male scholars who published in APS journals.

The literature has shown different results based on the citations per paper measure. Some research suggests that women's publications received fewer citations per paper than men's publications. In a study on a sample of sociologists, Hunter and Leahey [44] found that women received fewer citations per paper, even after controlling for children. Pudovkin et al. [45] concluded that male scholars were cited more often than females, in their study on papers of researchers at the Deutsche Rheuma-Forschungszentrum.

In contrast to these studies, some others have shown that women have higher citations per paper than men. Long's [47] studied on the productivity of biochemists and concluded that the average number of citations per paper for women was higher than that of men. In another study, Borrego et al. [48] investigated the gender differences in scientific output and citations and found that articles written by female were cited significantly more often. In addition, the results of some studies have shown no difference in citations per paper between men and women [28, 50, 43].

Here, we investigate the gender gap in citations per paper of scholars who published in APS journals. Citations per paper measure is calculated by dividing the citation counts of a scholar by the number of publications of that scholar. Our analysis (figure 9,figure 10) shows that on average, females have lower citations per paper than males. CCDF plots (figure 10) of citations per paper also indicate that distribution of citations per paper of males is greater than the distribution of female scholars significantly (p-value of Mann Whitney U test $< 2.2e-16$).

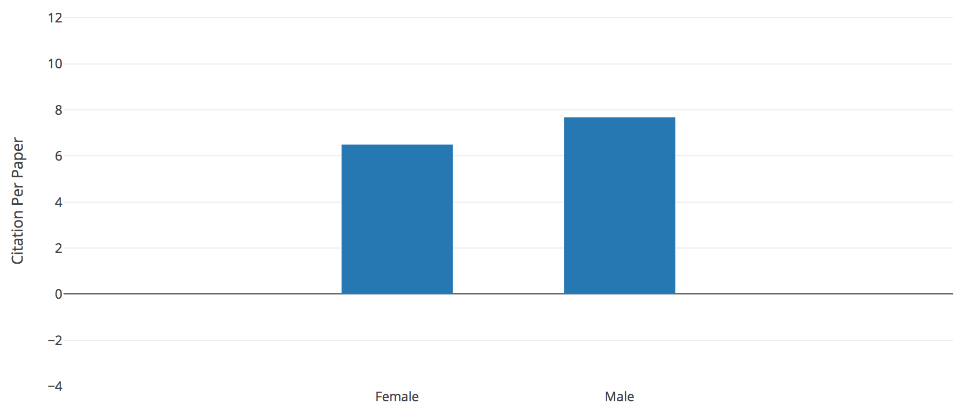

Figure 9: Mean of citations per paper of male and female scholars who published in APS journals (Author level analysis).

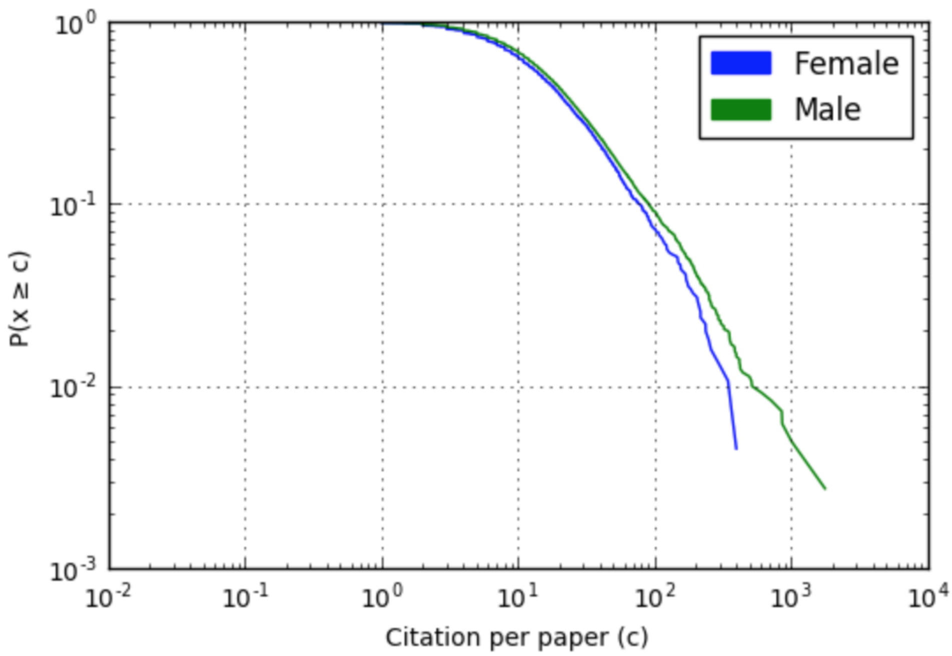

Figure 10: CCDF of citations per paper of male and female scholars who published in APS journals (Author level analysis).

5. Gender Gap in Citations per Paper: Paper Level Analysis

In the last chapter, we discussed the gender gap in citations per paper at the author level. In this chapter, we will discuss the gender gap in citations per paper at the paper level. Some studies observed a significant gender gap in citations per paper at the paper level. Sugimoto et al. [37] showed that women are less likely to be listed as either the first or last author on a paper. They also analyzed the importance of the author positions (sole authorship, first-authorship, and last-authorship) and discovered that when a female was in any of these positions, a paper received fewer citations than when a man was in one of these positions. In another study, in the field of natural science and engineering, authors who published with a larger fraction of female coauthors were cited less than authors who published with more men coauthors, in similar journals [38]. In a study on geography journals, Rigg, McCarragher, and Krmenec [46] showed that citation rates were highest for articles either singly or collaboratively written by males. In contrast to these studies, Feeley and Lee [49] found that female first-authored articles were more often cited than those of males in publications of Journal of Broadcast and Electronic Media.

In this research, we assess gender gap in citations per paper based on the first author gender, the last author gender and dominant gender of authors. The standard order of authors of an article varies significantly between fields of research. In physics, like many other fields, authors are listed in order of their level of contributions in the research. Usually, the principal supervisor is the last in an author list and the lead author (first author) of a research article is usually the person who did the research and wrote the paper. In APS dataset, women are less likely to be either the first or the last author on a paper (figure12) and even less likely to be the last author than the first author. However, men are more likely to be either the first or the last author on a paper than being in other positions in the list of authors (figure12).

In author level analysis, citations per paper is calculated by dividing the citation count of an author by the number of publications of that author. In the paper level analysis, we calculate citations per paper by dividing the number of citations received by a group of papers by the number of papers. In other words, citations per paper is the mean of citations received by a group of papers. In our paper level analysis, we assume that a paper is written by a woman if the first author, the last author or dominant gender of authors is female. In our analysis, we classify articles into 3 classes: articles whose first author gender is known, articles whose last author gender is known and articles whose dominant gender of authors is known. In each class, we have two group of papers, papers written by men and papers written by women. Therefore, in each three classes, we can calculate citations per paper of articles written by men and citations per paper of articles written by women. Figure 11 shows the number of articles in each class. In the next sections, we will test the following hypothesis:

Hypothesis 1: If the first author of a paper is female, the paper receives fewer citations than when the first author is male and vice versa.

Hypothesis 2: If the last author of a paper is female, the paper receives fewer citations than when the last author is male and vice versa.

Hypothesis 3: If the dominant gender of authors of a paper is female, the paper receives fewer citations than when the dominant gender of authors is male and vice versa.

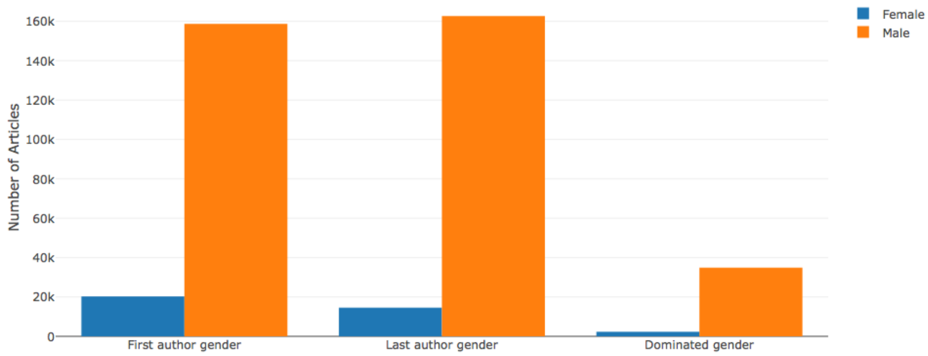

Figure 11: Number of articles whose first author gender, last author gender and the dominant gender of authors is known.

5.1. Gap in Citations per Paper Based on Gender of The First Author

Here, we consider the gender of the first author of articles in our analysis. Plots in both figures 13 and 14 support our hypothesis that if the first author of a paper is female, the paper receives fewer citations than when the first author is male and vice versa. Mean of citations of papers whose first author is male is greater than mean of citations of papers whose first author is female (Figures 13). In order to assess the significance of the gap, we used the Mann Whitney U test because the number of citations received by articles is not normally distributed. As is depicted in figure 14, CCDF of citations of papers whose first author is male is significantly greater than CCDF of citations of papers whose first author is female (p-value of Mann Whitney U test $< 2.2e\text{-}16$).

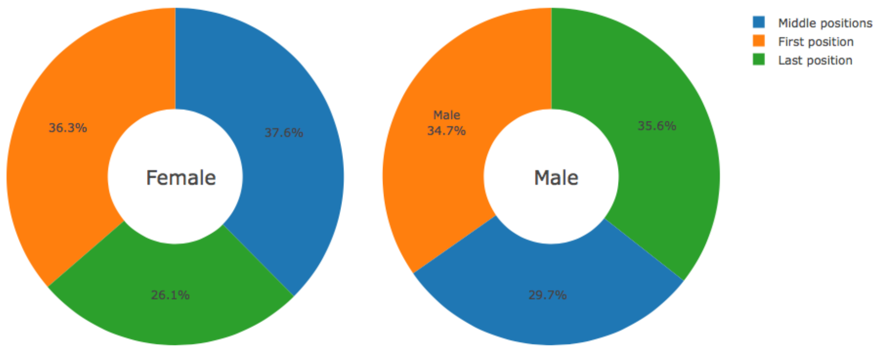

Figure 12: Probability of being the first author, the last author and being in other positions in the list of authors.

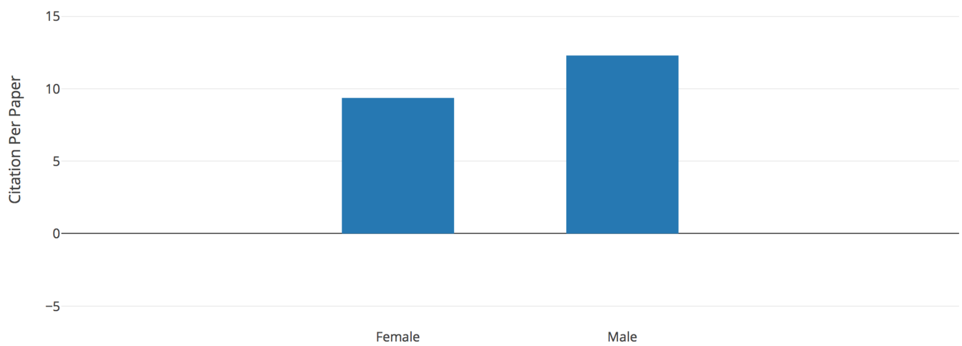

Figure 13: Mean of citations of papers based on gender of the first author.

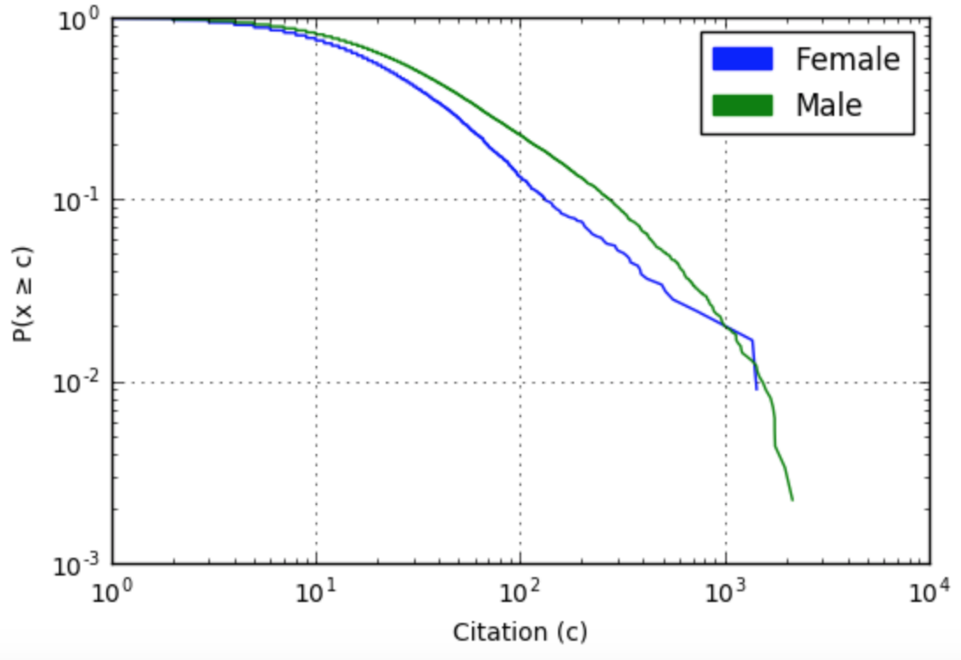

Figure 14: CCDF of citations of papers based on gender of the first author.

5.2. Gap in Citations per Paper Based on Gender of The Last Author

Here, we consider the gender of the last author of articles in our analysis. Plots in both figures 15 and 16 support our hypothesis that if the last author of a paper is female, the paper receives fewer citations than when the last author is male and vice versa. Mean of citations of papers whose last author is male is greater than mean of citations of papers whose last author is female (Figures 15) and as is depicted in figure 16, CCDF of citations of papers whose last author is male is significantly greater than CCDF of citations of papers whose last author is female (p-value of Mann Whitney U test < 2.2e-16).

5.3. Gap in Citations per Paper Based on Dominant Gender of Authors

Here, we consider the dominant gender of authors of articles in our analysis. We assume that if more than 50% of authors of a paper are female, the dominated gender of the authors is female. Otherwise, the dominant gender of the authors is male. We only consider those articles that gender of all authors are known. Plots in both figures 17 and 18 support our hypothesis that if the dominant gender of authors of a paper is female, the paper receives fewer citations than when the dominant gender of authors is male and vice versa. Mean of citations of papers whose dominant gender of authors is male is greater than mean of citations of papers whose dominant gender of authors is female (Figures 17) and as is depicted in figure 18, CCDF of ci-

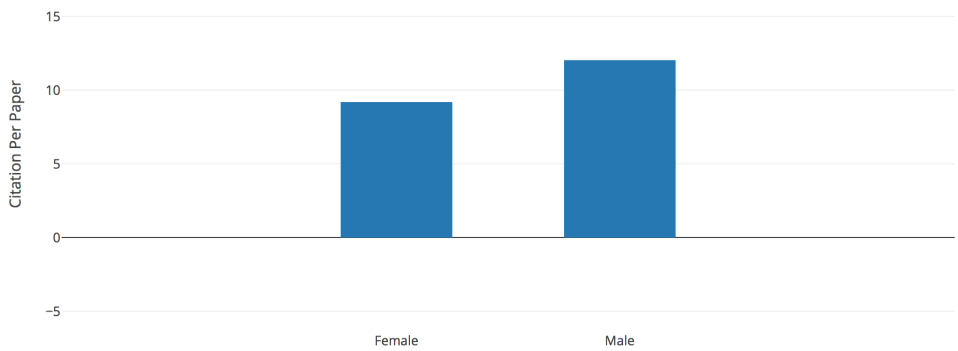

Figure 15: Mean of citations of papers based on gender of the last author.

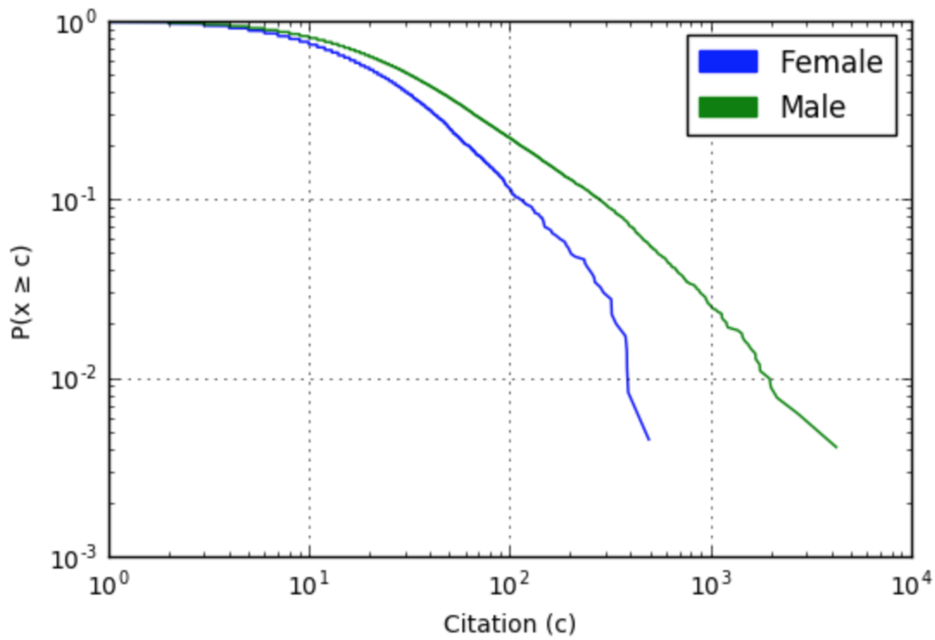

Figure 16: CCDF of citations of papers based on gender of the last author.

tations of papers whose dominant gender of authors is male is significantly greater than CCDF of citations of papers whose dominant gender of authors is female (p-value of Mann Whitney U test < 2.2e-16).

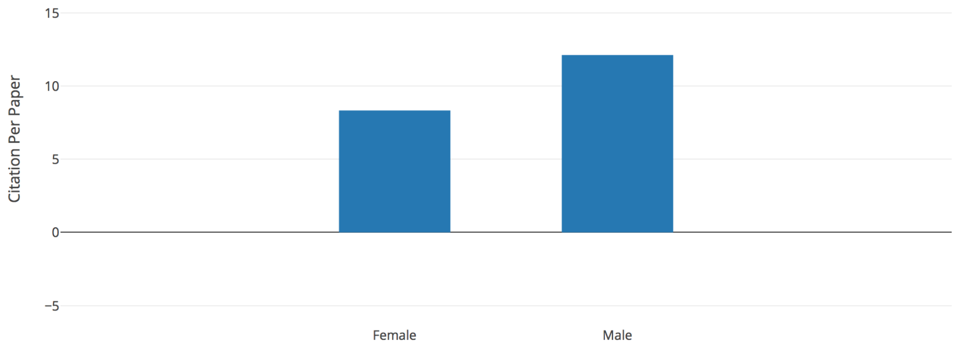

Figure 17: Mean of citations of papers based on the dominant gender of authors.

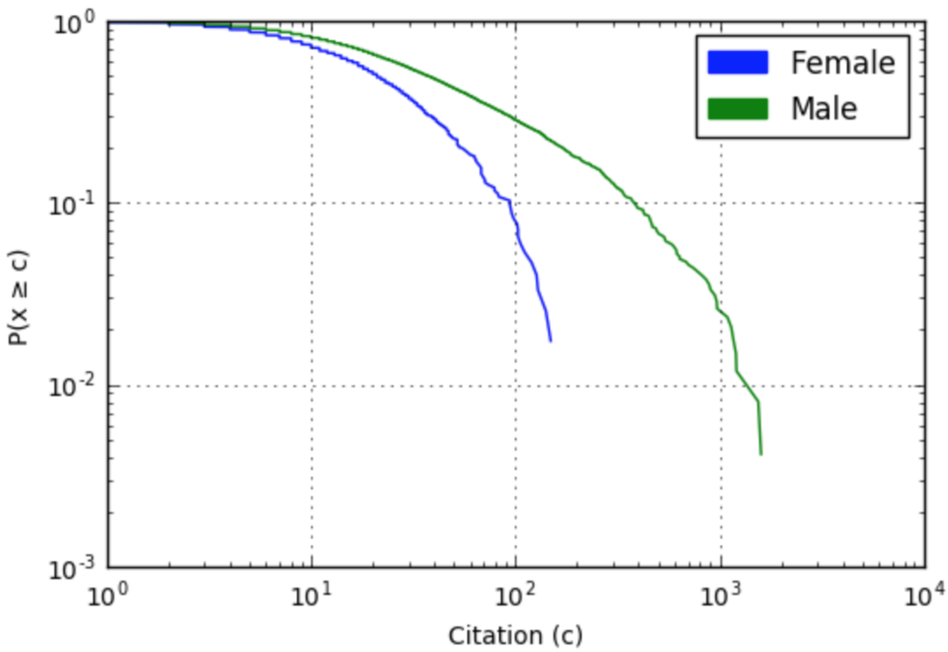

Figure 18: CCDF of citations of papers based on the dominant gender of authors.

6. Gender Gap in Citations per Paper after Controlling for quality

Articles written by male scholars may be read and cited more often only because the author is male. Some studies suggested that there is gender bias in citation pattern of scholars, for example, male scholars cite articles written by males more than similar articles written by female scholars. In a study on International Relation, Maliniak, Powers, and Walter [3] found that women were less cited than men after controlling for a number of factors (year of publication, venue of publication, substantive focus, methodology, tenure status, etc). Caplar et al. [4] analyzed the effect of first author gender on the number of citations that a paper receives based on a sample of publications from five major astronomy journals. Their analysis showed that papers written by females receive fewer citations than what would be expected if the papers with the same non-gender specific features were authored by the males. These results are in line with Matilda effect defined as the systematic underrecognition of female scientists.

The assumption of these studies is that in each subfield, articles must have the same number of citations when they are published in the same journal. However, women's underrecognition in citations might result from research topic choices within a subfield that differ by researchers' gender. Therefore, in this research, we control for paper content instead of paper subfield. We investigate if an article written by a woman receives fewer citations than a similar article written by a man after controlling for content of paper, year of publication and publication journal. In other words, we control for paper quality to investigate if people's evaluation of articles is affected by authors gender.

In order to control for article quality, we look for pairs of articles (one written by a man and one by a woman) whose content is significantly similar at 10^{-2}, were published in the same journal and the difference between the dates of publications is less than one year. We use the method proposed by Ciotti et al. [35] to find pairs of similar articles. This method will be discussed in the following section. We control for article content and journal to be sure that articles in each pair have the same quality and assume that there isn't any editorial or reviewer bias. We control for the year of publication because the number of citations a paper receives depend on the date of its publication. In other words, older papers usually have more citations than newer papers.

In sections 6.2, 6.3 and 6.4 we will discuss if the gender of the first author, last author and dominant gender of authors influence the number of citations an article receives after controlling content of paper, year of publication and publication journal. In addition, we will test the hypothesis that male authors are less likely to cite articles written by female authors than similar articles written by men and vice versa. We consider the gender of the first authors as the gender of scholars who cited articles.

6.1. Quantifying similarity between articles

We need to find similar papers whose similarity validated at a certain statistical threshold. To do this, we use the method proposed by Ciotti et al. [35]. Similarity between two articles can be measured using different methods, for example based on their entire texts, co-occurrence of a few relevant concepts or keywords in the titles or abstracts of the articles and co-occurrence of classification codes such as those included in the Physics and Astronomy Classification Scheme (PACS), that help identify the research areas of each article [35].

Ciotti et al. [35] proposed another measure of similarity based on the comparison between the bibliographic lists of references included in two articles. They proved that, if two articles have the same discipline or research problem, then their bibliographies have a substantial overlap. They proposed a method for assessing the statistical significance of the overlap between the lists of references of two articles, and then applied the statistically validated overlap as a measure of the similarity between the two articles.

Ciotti et al. [35] uncovered missing citations between pairs of highly related articles. By calculating the proportion of missing citations, they compared distinct journals and research sub-fields in terms of their ability to facilitate or impede the dissemination of knowledge. Findings showed that Electromagnetism and Interdisciplinary Physics have the smallest percentage of missing citations. In addition, knowledge transfer is facilitated more effectively by journals of higher visibility, such as Physical Review Letters, than by lower-impact ones. Their study provided a procedure for recommending relevant yet missing references and completing bibliographies of papers.

6.1.1. Overlap between reference lists as a measure of similarity between articles

A natural method to quantify the overlap between two given sets Q_i and Q_j is the Jaccard index, which is defined as "the ratio between the number of common elements in the two sets and the total number of elements in the union of the two sets"[35]:

$$J_{i,j} = \frac{| Q_i \cap Q_j |}{| Q_i \cup Q_j |} \tag{2}$$

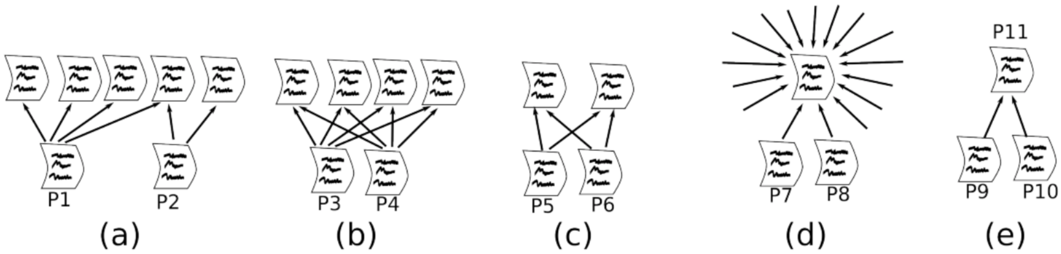

Figure 19: Quantifying similarity between two articles based on their bibliographies [35].

The two sets Q_i and Q_j represent, respectively the articles in the two reference lists of the two articles i and j. Disadvantages of the Jaccard index for measuring the similarity between the bibliographies of two articles is provided in Figure 19 (a)-(b) [35]. It would be expected the two articles in panel (b) to have a value of similarity larger than the two articles in panel(c). Even though P3 and P4 share a larger number of references, the Jaccard index of articles P5 and P6 is equal to 1 and is equal to that of articles P3 and P4.

Another disadvantage is that some citations are more important than others. In other words, it would be expected to assign a higher relevance to the single citation shared by articles P9 and P10 in Figure 19 (e) than to the citation to other highly cited articles shared by articles P7 and P8 in Figure 19 (d). The similarity measure proposed by Ciotti et al. [35], overcome the drawbacks of the Jaccard index discussed above.

6.1.2. Defining statistically significant bibliographic overlaps

In this method, the set A contains all the articles with more than zero outgoing citations, $A = \{i \in V \mid k_i^{out} > 0\}$, while the set B contains all the articles that have received at least two citations, $B = \{i \in V \mid k_i^{in} > 1\}$ [35]. $N_A = \mid A \mid$ and $N_B = \mid B \mid$ are the cardinality of the two sets. This method assign a statistical significance to the similarity between a pair of articles (i, j) in A by comparing the number of common citations in their reference lists against the null hypothesis of random co-occurrence of citations to articles in B [35]. Using this method, pairs of articles in A characterised by overlaps between citations to articles in B that are statistically different from those expected in the null model can be identified [35].

For each value k of indegree of the citation network, they considered the set of articles $S^k = S^k_A \cup S^k_B$, where $S^k_B \subset B$ contains all $N^k_B = \mid S^k_B \mid$ articles with in-degree equal to k, and $S^k_A \subset A$ contains articles that cite at least one element in S^k_B [35].

For each pair of articles $i, j \in S_A^k$, d_i and d_j indicates their respective number of citations to the articles of S_B^k. Under the hypothesis that the articles i and j cite, d_i and d_j distinct articles uniformly at random from S_B^k,the probability that they choose the same X articles is given by the probability function [35]:

$$P(X \mid N_B^k, d_i, d_j) = \frac{\binom{d_i}{X}\binom{N_B^k - d_i}{d_i - X}}{\binom{N_B^k}{d_j}} \tag{3}$$

Then, they associated a p-value to each pair of articles $i, j \in S_A^k$:

$$q_{i,j}(k) = 1 - \sum_{X=0}^{N_{i,j}^k - 1} P(X \mid N_B^k, d_i, d_j) \tag{4}$$

Where $N_{i,j}^k$ is the number of references that article i and j have in common in the set S_B^k. Therefore, $q_{i,j}(k)$ is the probability that the number of articles in the set S_B^k that i and j jointly cite by chance is $N_{i,j}^k$ or more [35].

They repeated the procedure for all values k from k_{min} to k_{max}. Therefore, each pair of articles (i, j) has several p-values, one for each in-degree k of the articles in their reference lists [35]. Finally, they set a significance threshold p^* and validated all the pairs of articles that are associated with a p-value smaller than p^*. Only the validated pairs of articles are considered similar at a given value of p^*.

However, because each pair of articles can have multiple p-values, they applied the False Discovery Rate (FDR) method [36] to do hypothesis-testing multiple times. In this method, the p-values of each pair of articles are not compared directly with the chosen significance threshold p^*, but with a rescaled threshold that takes the number of tests into account. It's assumed that a pair of articles (i, j) is validated if at least one of the $q_{i,j}(k)$ passes the statistical test at p^* [35].

For each value of p^*, they computed the number of pairs of articles $M(p^*)$ validated at that threshold , and the number $K(p^*)$ of existing citations between those validated pairs. Then, they defined the probability $P_{i,j}(p^*)$ that there exists a citation between any two articles whose similarity is validated at the threshold p^* as [35]:

$$P_{i,j}(p^*) = K(p^*)/M(p^*) \tag{5}$$

The obtained values of $P_{i,j}(p^*)$ are reported in Figure 20 as a function of p^*. The plot demonstrate that the probability that an article i cites article j is an increasing function of the similarity between the two articles [35]. In the other words, citations between pairs of articles with highly significant overlap happen with a higher probability than citations between articles whose reference lists are not similar significantly [35]. In Appendix A, we also provided the data of the extracted pairs of

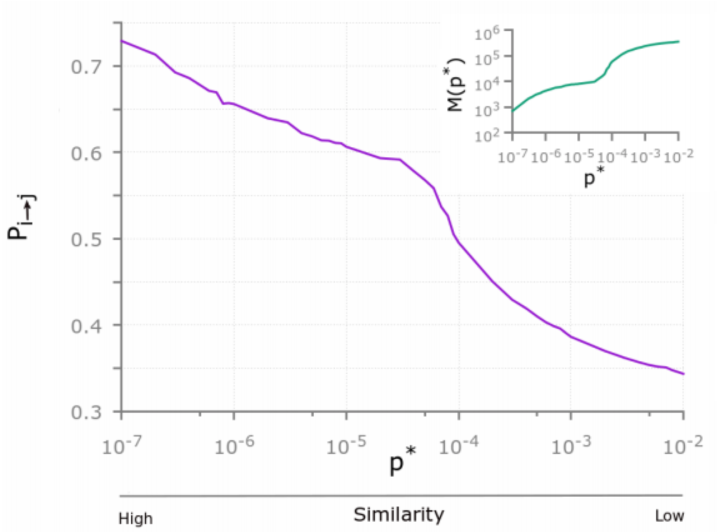

Figure 20: The obtained values of $P_{i,j}(p^*)$ as a function of p^* [35].

articles whose similarity is significant at 10^{-11}. Unsurprisingly, we observed that, first, the titles of papers in each pair are very similar and have many words in common. Second, in each pair, papers are published in the same journal. Third, in each pair, the papers usually have at least an author in common.

Figure 21 shows an example of some validated pairs of articles in the citation network at $p^* = 10^{-7}$. Articles are arranged in increasing order of publication time, from left to right. The existence of a link indicates that the pair of articles has passed the statistical test, while the colour of the link shows that the most recent paper in the pair did (green) or did not (red) cite the other one. Yellow nodes are articles written by researchers in the same group, while article A was written by another group. A lot of missing citations shows that the two groups might haven't been aware of the research of their colleagues in the same field [35].

Ciotti et al. [35] identified similar articles to uncover potentially missing references and quantified the lack of knowledge flows within a journal or a sub-field at a certain confidence level p^* by the fraction of missing links:

$$U(p^*) = 1 - K(p^*)/M(p^*) = 1 - P_{i,j}(p^*) \tag{6}$$

Because this fraction depends on the p^*, they computed the quantity:

$$U_0 = \lim_{p^* \to 0} U(p^*) \tag{7}$$

However, this quantity cannot be computed, since the ratio $K(p^*)/M(p^*)$ would be undetermined [35]. Therefore, they considered the tangent at the curve $U(p^*)$ at

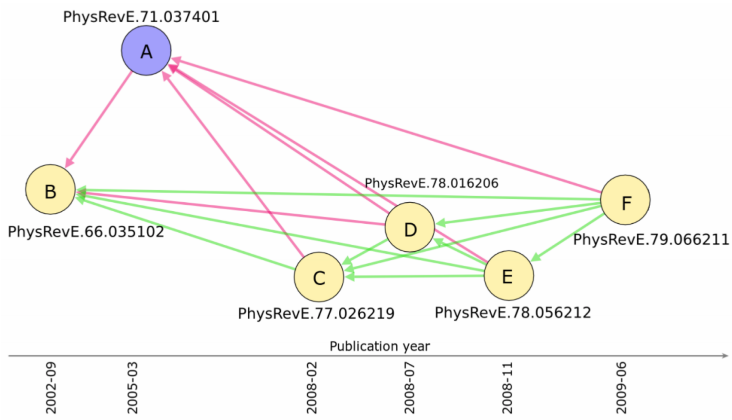

Figure 21: An example of several pairs of similar articles in the APS citation network [35]

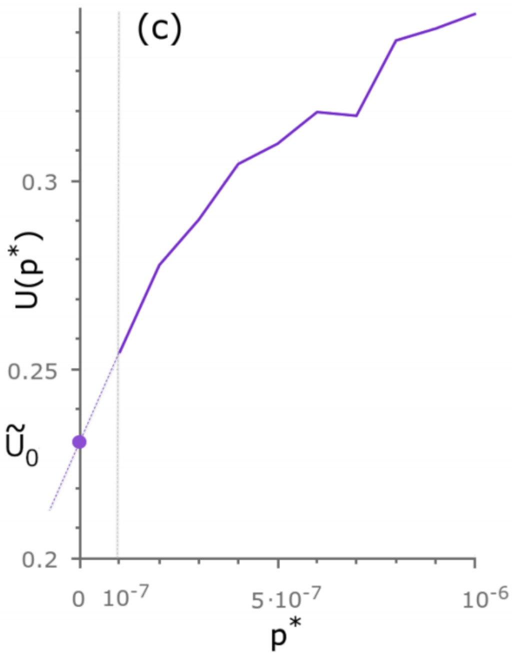

Figure 22: The procedure adopted to compute $\widetilde{U_0}$ [35]

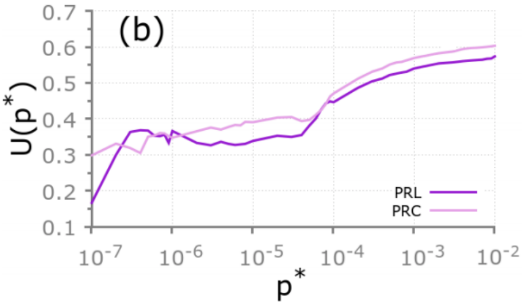

Figure 23: The plots of two APS journals, namely Physical Review Letters and Physical Review C [35]

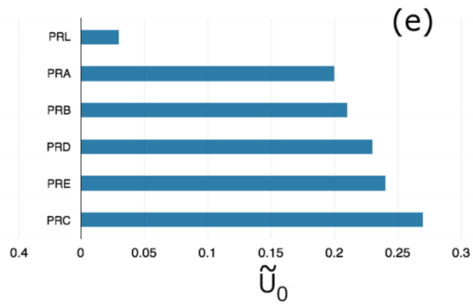

Figure 24: Rankings of APS journals based on the values of $\widetilde{U_0}$ [35]

the smallest value of p^* (10^{-7}) for which the number of pairs is still large enough for having a network of a reasonable size. Then they found the intercept at which this tangent crosses the vertical axis. This value is denoted as $\widetilde{U_0}$, and is used as an approximation of U_0. This method is illustrated in Figure 22.

Figures 23 and 24 show the rankings of APS journals based on the values of $\widetilde{U_0}$ [35]. The lack of knowledge flows between articles published in PRC journal is almost nine times as large as the one in PRL journal that has the widest visibility and largest impact.

6.1.3. False Discovery Rate (FDR) statistical test

Ciotti et al. [35] validated a given pair (i, j) using the FDR method as follows. They selected a statistical threshold p^* and assumed that there are in total N_t tests. Then, they arranged p-values of different tests in increasing order $(q_1 < q_2 < ... < q_{N_t})$. The rescaled threshold was obtained by finding the largest t_{max} such that

$$q_{t_{max}} < p^* t_{max}/N_t \quad (8)$$

Where N_t is the number of distinct pairs of papers that are tested over all the sets

S^k. Then they compared each $q_{ij}(k)$ with the rescaled threshold, and validated the pair (i, j) if $q_{ij}(k) < p^* t_{max}/N_t$.

6.2. Gender Gap in Citations per Paper after Controlling for Content of Article, Year of Publication and Journal

In order to control for article quality, we look for pairs of articles (one written by a man and one by a woman) whose content is significantly similar at 10^{-2}, were published in the same journal and the difference between the dates of publications is less than one year. We use the method proposed by Ciotti et al. [35] to find pairs of similar articles. We apply this method to investigate the gender gap based on the gender of the first authors, the last author and dominant gender of authors.

First, our analysis shows articles written by women receive fewer citations than similar articles written by men according to gender of the first authors after controlling for year of publication, journal and paper content (mean of citations of articles written by women=11.58, mean of citations of articles written by men=13.4) (Figure 25). In order to assess if the gap is statistically significant, we used the Mann Whitney U test because citations of papers are not normally distributed. This test shows that distribution of citations of articles written by men is significantly greater than the distribution of citations of articles written by women (p-value of Mann Whitney U test < 2.2e-16) (Figure 26).

Second, articles written by women receive fewer citations than similar articles written by men according to the gender of the last authors (mean of citations of articles written by women=11.58, mean of citations of articles written by men=13.4) (Figure 25). Mann Whitney U test also shows that distribution of citations of articles written by men is significantly greater than the distribution of citations of articles written by women (p-value of Mann Whitney U test < 2.2e-16) (Figure 27).

Third, articles written by women receive fewer citations than similar articles written by men according to the dominant gender of authors (mean of citations of articles written by women=11.58, mean of citations of articles written by men=13.4) (Figure 25). Mann Whitney U test also shows that distribution of citations of articles written by men is significantly greater than the distribution of citations of articles written by women (p-value of Mann Whitney U test < 2.2e-16) (Figure 28). These three results confirm the presence of the Matilda effect in citation patterns of scholars who published in APS journals.

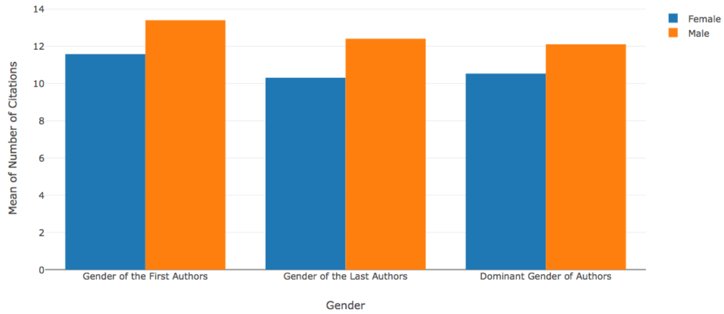

Figure 25: Mean of number of citations of articles after controlling for year of publication, journal of publication and content of article.

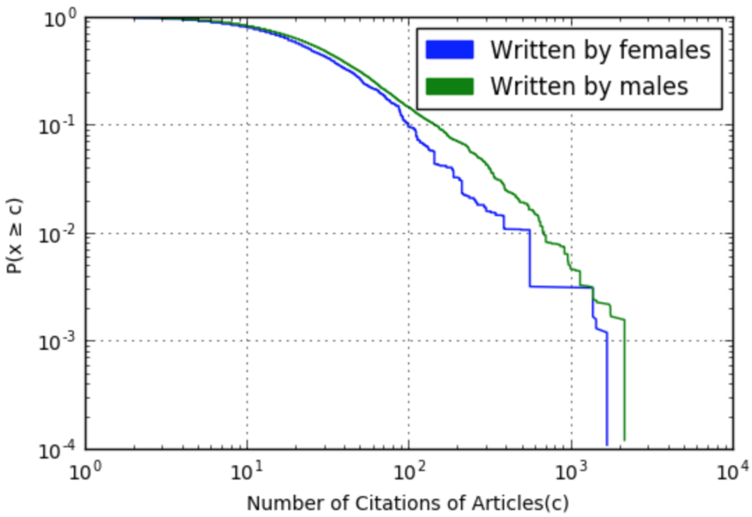

Figure 26: CCDF of citations of articles after controlling for year of publication, journal of publication and content of article based on gender of the first authors.

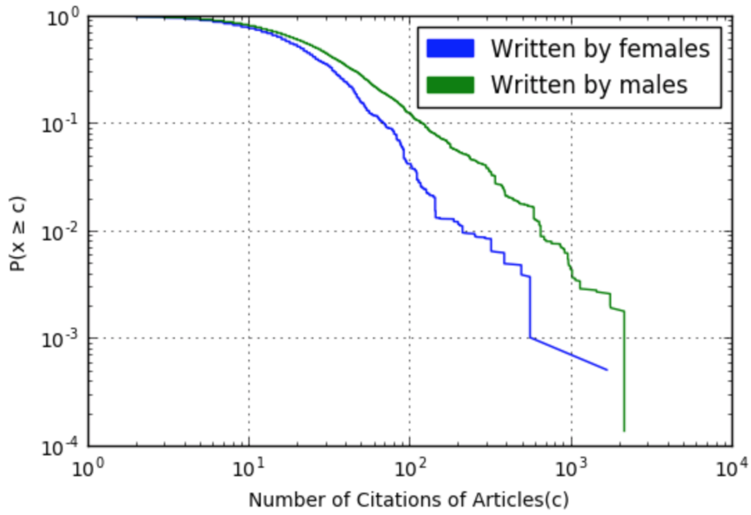

Figure 27: CCDF of citations of articles after controlling for year of publication, journal of publication and content of article based on gender of the last authors.

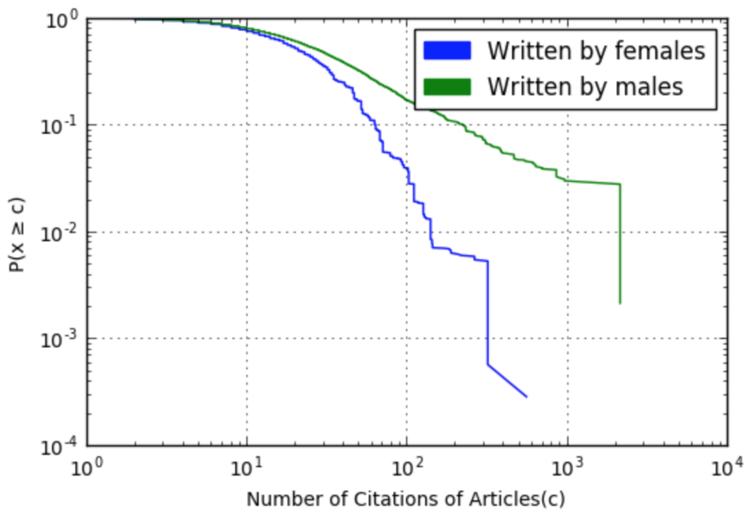

Figure 28: CCDF of citations of articles after controlling for year of publication, journal of publication and content of article based on dominant gender of authors.

7. Gender Homophily in Citations

Here, we test the hypothesis that men are less likely to cite articles written by women than similar articles written by men and women are less likely to cite articles written by men than similar articles written by women. In other words, we assess homophily in the citation network of publications of APS journals and investigate if homophily in citations can explain the presence of the Matilda effect in citations. In order to examine the existence of homophily, we define four ratios: female to male ratio, male to male ratio, male to female ratio and female to female ratio.

Female to male ratio (FMR) is defined as the number of citations from articles written by female authors to the articles written by male authors (FM) divided by the number of citations made by either female or male authors to the articles written by male authors (FM+MM).

$$FMR = \frac{FM}{FM + MM} \tag{9}$$

Male to male ratio (MMR) is defined as the number of citations from articles written by male authors to articles written by male authors (MM) divided by the number of citations made by either female or male authors to the articles written by male authors (FM+MM).

$$MMR = \frac{MM}{FM + MM} \tag{10}$$

Male to female ratio (MFR) is defined as the number of citations from articles written by male authors to articles written by female authors (MF) divided by the number of citations made by either female or male authors to the articles written by female authors (FF+MF).

$$MFR = \frac{MF}{FF + MF} \tag{11}$$

Female to female ratio (FFR) is defined as the number of citations from articles written by female authors to articles written by female authors (FF) divided by the number of citations made by either female or male authors to the articles written by female authors (FF+MF).

$$FFR = \frac{FF}{FF + MF} \tag{12}$$

Therefore, we see gender homophily in citations when:

$$FMR < \text{Female Ratio (FR)} \tag{13}$$

$$FFR > \text{Female Ratio (FR)} \tag{14}$$

$$MMR > \text{Male Ratio (MR)} \tag{15}$$

$$MFR < \text{Male Ratio (MR)} \tag{16}$$

In the last chapter, in order to control for article quality, we extracted pairs of articles (one written by a man and one by a woman) whose content were significantly similar at 10^{-2}, were published in the same journal and the difference between the dates of publications were less than one year. We investigated three samples of paired articles based on the gender of the first authors (sample F), the last authors (sample L) and dominant gender of the authors (sample D). In each sample, female ratio is defined as the percentage of articles whose first authors are female and cited an article in the sample. Male ratio is defined as the percentage of articles whose first authors are male and cited an article in the sample.

In the last chapter, our analysis confirmed the existence" of the Matilda effect based on the gender of the first authors. Here, we assess homophily based on the gender of the first authors. First, we extracted all articles cited an article in the sample F and gender of their first authors are known. Then, we calculated male and female ratios according to the sample F. Our analysis showed that FMR (0.13) < FR (0.18) and FFR (0.22) > FR (0.18). Therefore, we can conclude the female authors are less likely to cite articles written by male authors than similar articles written by female authors. In addition, MFR (0.77) < MR (0.82) and MMR (0.86) > MR (0.82) that indicates male authors are less likely to cite articles written by female authors than similar articles written by men. Therefore, existence of homophily is confirmed based on gender of the first authors.

We applied the same method to assess homophily based on the gender of the last authors. First, we extracted all articles cited an article in the sample L and gender of their first authors are known . Then, we calculated male and female ratios according to the sample L. We observed that FMR (0.12) < FR (0.15) and FFR (0.27) > FR (0.15). Therefore, we can conclude the female authors are less likely to cite articles written by male authors than similar articles written by women. In addition, MFR (0.72) < MR (0.84) and MMR (0.87) > MR (0.84) that indicates male authors are less likely to cite articles written by female authors than similar articles written by men. Therefore, existence of homophily is confirmed based on gender of the last authors.

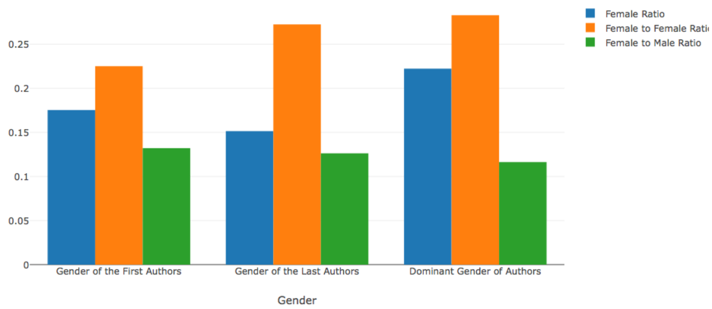

Figure 29: Women (first author) are less likely to cite articles written by men than similar articles written by women.

Finally, we applied the same method to assess homophily based on dominant gender of authors. First, we extracted all articles cited an article in the sample D and gender of their first authors are known. Then, we calculated male and female ratios according to the sample D. We observed that FMR (0.11) < FR (0.22) and FFR (0.28) > FR (0.22). Therefore, we can conclude women are less likely to cite articles written by men than similar articles written by women. In addition, MFR (0.71) < MR (0.77) and MMR (0.88) > MR (0.77) that indicates men are less likely to cite articles written by women than similar articles written by men. Therefore, existence of homophily is confirmed based on dominant gender of authors.

These three results confirmed the presence of homophily in the citation network of publications of APS journals. Because the majority of authors who published in APS journals are male (85%), these observations can explain why articles written by men receive more citations than similar articles written by women (Matilda effect). The results are depicted in figures 29 and 30.

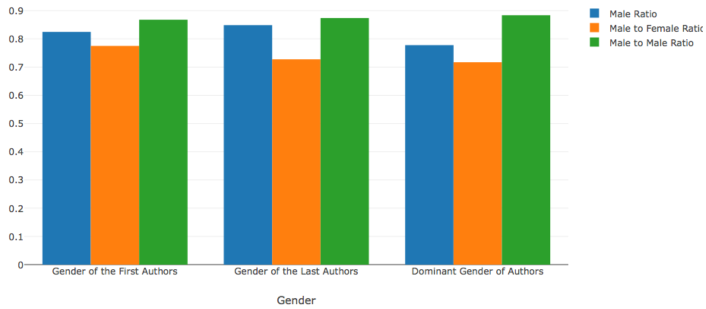

Figure 30: Men (first author) are less likely to cite articles written by women than similar articles written by men.

8. Gender Gap in Citations per Paper in Different APS Journals

In addition to the whole dataset, we observed similar patterns in each APS journal. We found that in all APS journals, articles written by women receive fewer citations than similar articles written by men according to the gender of the first authors, last author and dominant gender of authors. But considering the dominant gender of the authors in PRA and PRL journals articles written by women receive a little bit more citations. The results are depicted in figures 31, 32, 33.

Our analysis showed that in each APS journal, FMR < FR and FFR > FR. Therefore, we can conclude that female authors are less likely to cite articles written by men than similar articles written by women. In addition, in each journal, MFR < MR and MMR > MR that indicate men are less likely to cite articles written by women than similar articles written by men. However, we observed a less significant difference between male and female scholars in their tendency to cite publications of RMP and PRL journals. It can be explained by the highest impact factors of RMP and PRL journals (36.3 and 8.8). The results of our analysis are depicted in figures 34 - 39.

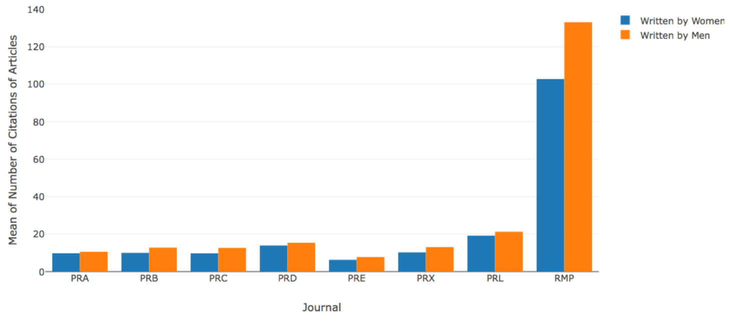

Figure 31: Mean of citations of articles published in different APS journals based on gender of the first authors.

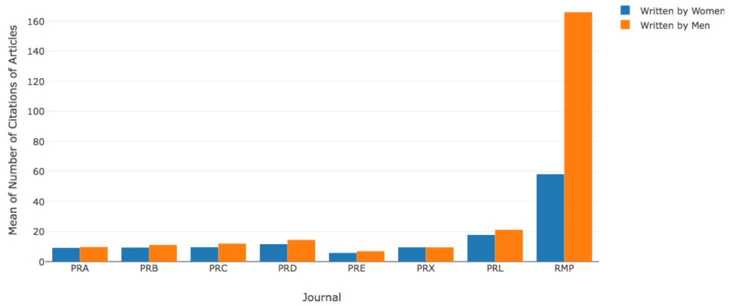

Figure 32: Mean of citations of articles published in different APS journals based on gender of the last authors.

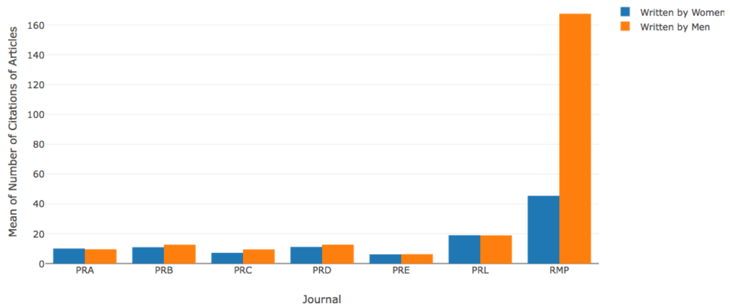

Figure 33: Mean of citations of articles published in different APS journals based on dominant gender of authors.

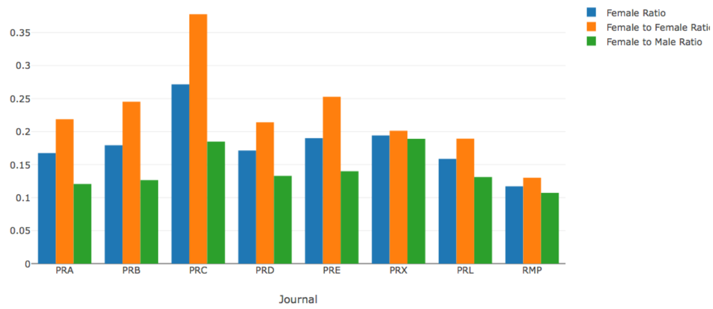

Figure 34: Women (first author) are less likely to cite articles written by men than similar articles written by women based on gender of the first authors.

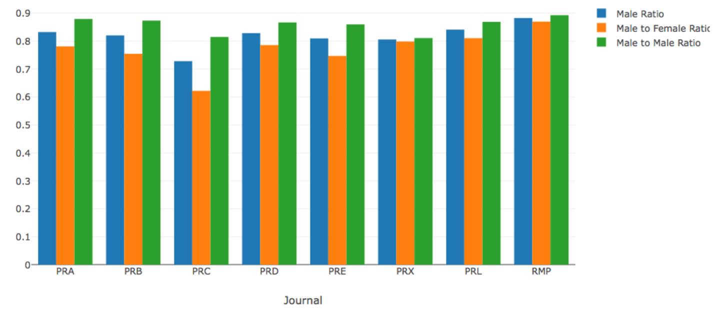

Figure 35: Men (first author) are less likely to cite articles written by women than similar articles written by men based on gender of the first authors.

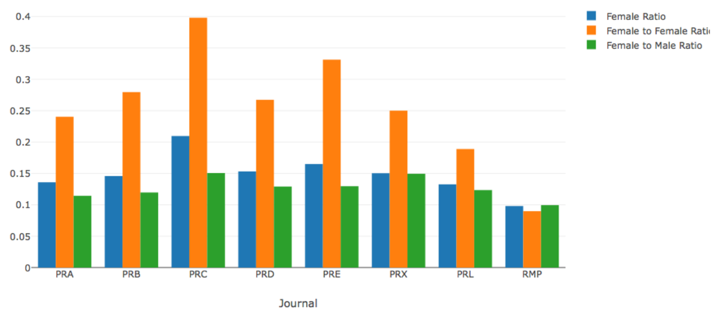

Figure 36: Women (first author) are less likely to cite articles written by men than similar articles written by women based on gender of the last authors.

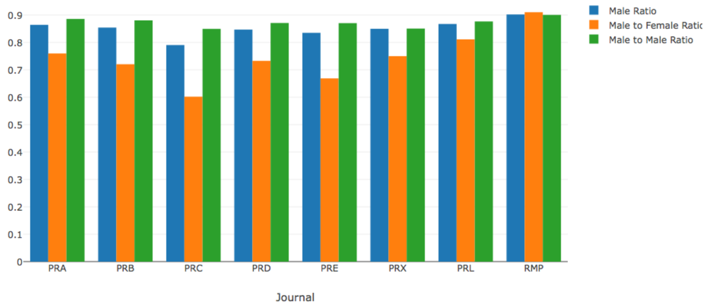

Figure 37: Men (first author) are less likely to cite articles written by women than similar articles written by men based on gender of the last authors.

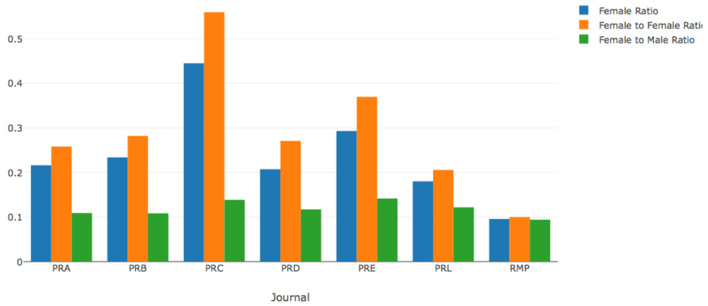

Figure 38: Women (first author) are less likely to cite articles written by men than similar articles written by women based on dominant gender of authors.

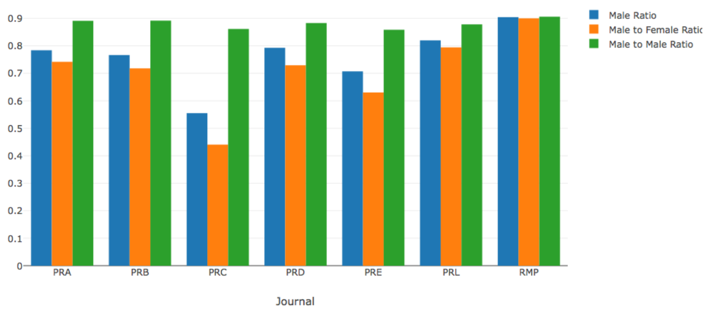

Figure 39: Men (first author) are less likely to cite articles written by women than similar articles written by men based on dominant gender of authors.

9. Gender Gap in Probability of Missing Citation

We observed that papers written by female scholars receive fewer citations than similar papers written by men because of homophily in citations and because most of the scholars who published in APS journals are men. Therefore, the best way to reduce the Matilda effect is encouraging scholars, especially men, to be more gender neutral in choosing articles to read. However, we can reduce the Matilda effect to some extent if editors in scientific journals detect missing citations to articles written by women. If articles written by women miss more citations than those written by men, this policy will reduce the Matilda effect a little bit. We use the method of Ciotti et al. [35] to discover missing citations in the APS citation network. We compute the proportion of missing citations of male and female authors, at a certain confidence level p^*, applying the following equations:

$$U_m(p^*) = 1 - K_m(p^*)/M_m(p^*) \tag{17}$$

$$U_m(0) = \lim_{p^* \to 0} U_m(p^*) \tag{18}$$

$$U_f(p^*) = 1 - K_f(p^*)/M_f(p^*) \tag{19}$$

$$U_f(0) = \lim_{p^* \to 0} U_f(p^*) \tag{20}$$

$M(p^*)$ is the number of all pairs of articles whose similarity is statistically significant at the confidence threshold p^* in the citation network. $M_m(p^*)$ is $M(p^*)$ of those pairs, in each pair, the older article is written by a man. $M_f(p^*)$ is $M(p^*)$ of those pairs, in each pair, the older article is written by a woman.

$K(p^*)$ is the number of existing citations between validated pairs of articles at the confidence threshold p^* in the citation network. $K_m(p^*)$ is $K(p^*)$ of those pairs, in each pair, the older article is written by a man. $K_f(p^*)$ is $K(p^*)$ of those pairs, in each pair, the older article is written by a woman. $U_m(0)$ refers to the proportion of missing citations of male authors, $U_f(0)$ to the proportion of missing citations of female authors. In order to assess the gender gap in the probability of missing citation, we test the following hypothesis in next sections:

Hypothesis 1: If the first author of an article is female, missing a citation is more likely than when the first author is male and vice versa.

Hypothesis 2: If the last author of an article is female, missing a citation is more likely than when the last author is male and vice versa.

Hypothesis 3: If the dominant gender of the authors of an article is female missing a citation is more likely than when the dominant gender of authors is male and

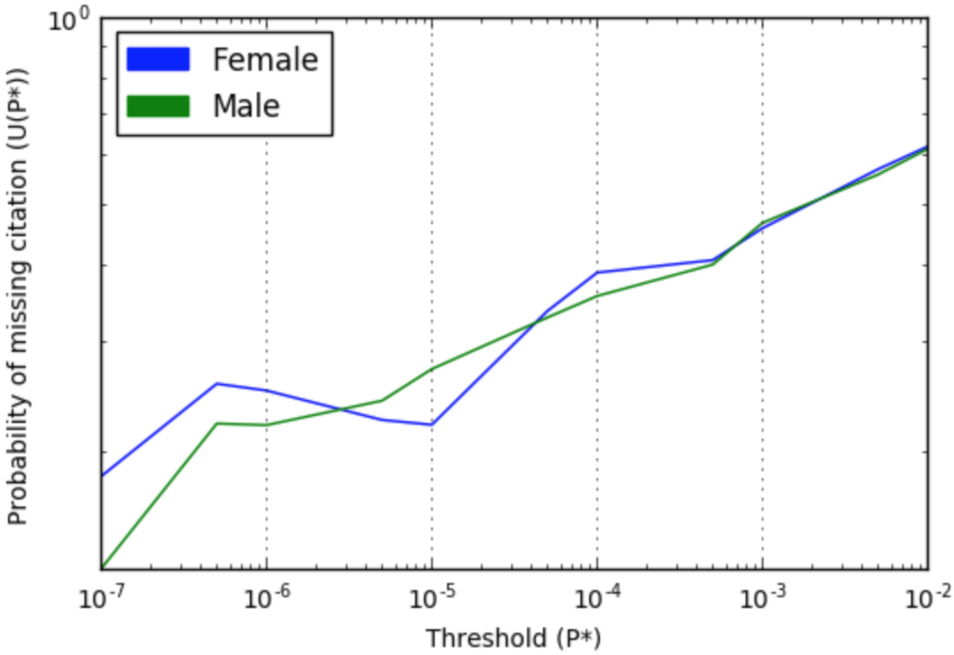

Figure 40: Probability of missing citation based on gender of the first author of an article.

vice versa.

9.1. Probability of Missing Citation Based on Gender of First Author

Here, we consider the gender of the first author of articles. The obtained values of $U_f(p^*)$ and $U_m(p^*)$ as a function of $p^*$are depicted in figure 40. This plot indicates that probability of missing citation when the first author is female ($U_f(0)$) is 0.18 and when the first author is male ($U_m(0)$) is 0.13 (at the confidence level of 10^{-7}). This results support our hypothesis that if the first author of an article is female, missing a citation is more likely than when the first author is male and vice versa.

9.2. Probability of Missing Citation Based on Gender of Last Author

Here, we consider the gender of the last author of articles. The obtained values of $U_f(p^*)$ and $U_m(p^*)$ as a function of $p^*$are depicted in figure 41. This plot indicates that probability of missing citation when the last author is female ($U_f(0)$) is 0.22 and when the last author is male ($U_m(0)$) is 0.19 (at the confidence level of 10^{-7}). This results support our hypothesis that if the last author of an article is female, missing a citation is more likely than when the last author is male and vice versa.

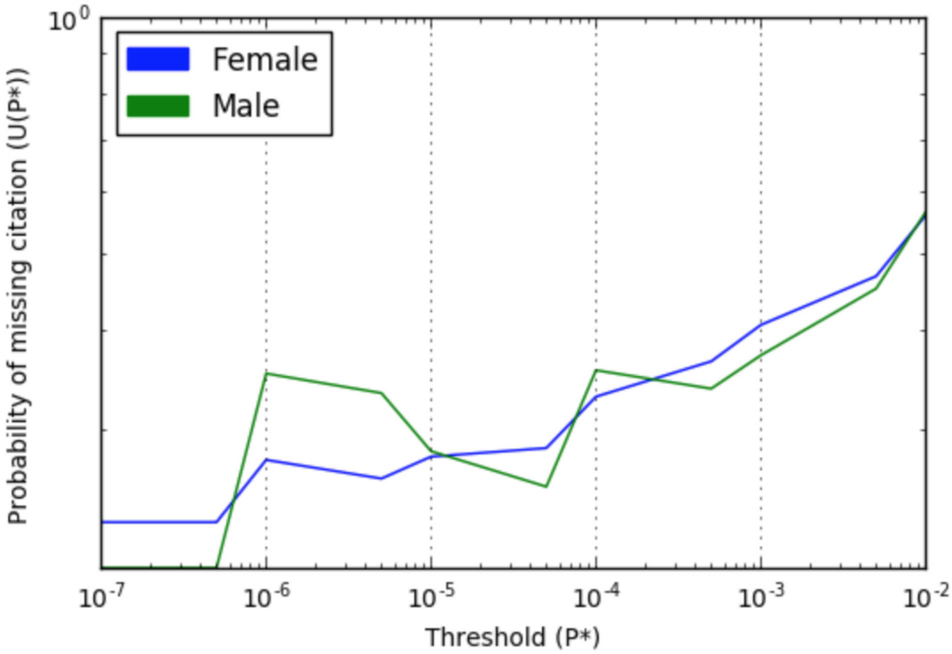

Figure 41: Probability of missing citation based on gender of the last author of an article.

9.3. Probability of Missing Citation Based on Dominant Gender of Authors

Here, we consider dominant gender of authors of articles. The obtained values of $U_f(p^*)$ and $U_m(p^*)$ as a function of $p^*$are depicted in figure 42. This plot indicates that probability of missing citation when the dominant gender of authors is female ($U_f(0)$) is 0.35 and when dominant gender of authors is male ($U_m(0)$) is 0.29 (at the confidence level of 10^{-7}). This results support our hypothesis that if the dominant gender of authors of an article is female, missing a citation is more likely than when the dominant gender of authors is male and vice versa.

Our analysis showed that if an article is written by a female (first author, last author, dominant gender of authors), missing a citation is more likely than when an article is written by a male (first author, last author, dominant gender of authors). Articles written by women are more likely to miss a citation when either the first author is female or the dominant gender of authors is female (figure 43). Therefore, detecting missing citations using this method by editors of journals can reduce the Matilda effect to some extent. However, in the APS citation network, because of the low number of missed citations, including the missed citations didn't reduce the Matilda effect significantly.

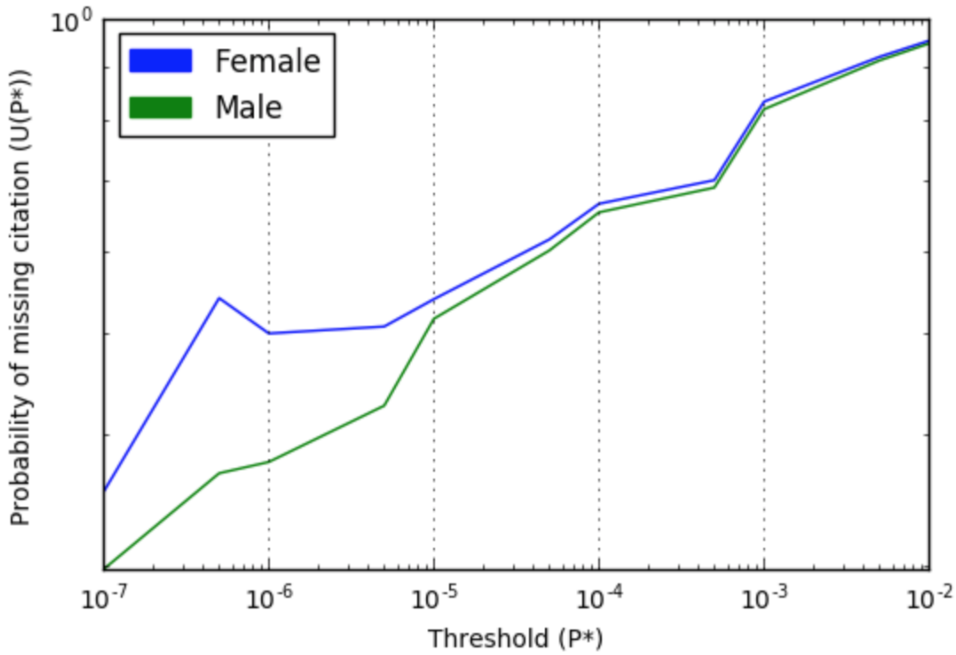

Figure 42: Probability of missing citation based on dominant gender of authors of an article.

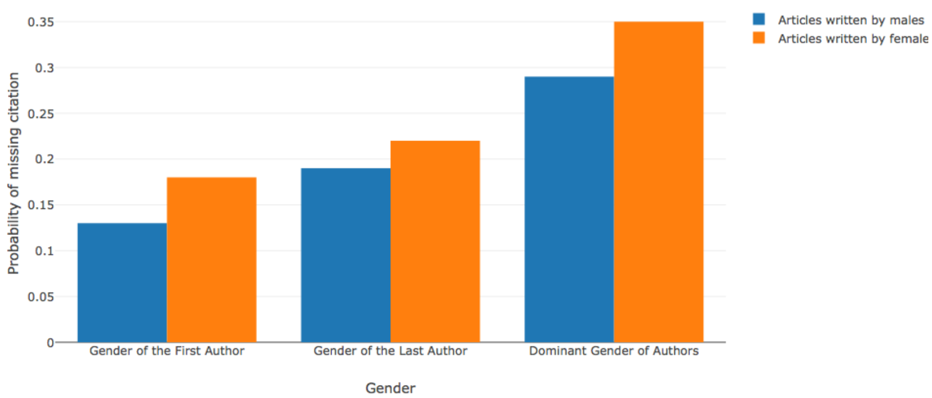

Figure 43: Probability of missing citation

10. Conclusion and Future Work

10.1. Conclusion

We found a significant gap in research performance between male and female scholars who published in APS journals. Women have significantly lower productivity and citations per paper that results in lower citation counts that is a common measure of research impact. However, we found that the gap has been closing over time. In addition, the gender gap in citation counts reduced significantly after controlling for the seniority of authors.

In this research, we showed that articles authored by female scientists received fewer citations than articles authored by male scientists based on the citation network of articles published in APS journals. We found a significant gap in citations per paper based on the gender of the first authors, the last authors and dominant gender of authors. Then we investigated if articles written by women have lower quality or people's evaluation of cite worthiness of articles is affected by authors' gender. In other words, we assessed gender bias in research evaluation (Matilda effect) based on the gender gap in citations per paper.

We controlled for paper quality by controlling for journal of publication, year of publication and content of publication to base the comparison on the same achievements. We extracted pairs of articles (one written by man and one by a woman) published in the same year and same journal with significantly similar content. Statistical significance of the overlap between the lists of references of a pair of articles was considered as a measure of the similarity between the two articles. Our analysis showed that articles written by males (first author, last author and dominant gender of authors) receive more citations than similar articles written by females (first author, last author and dominant gender of authors) and vice versa. These results are in line with Matilda effect defined as a systematic underrecognition of female scientists.

In addition, we found that men are less likely to cite articles written by women than similar articles written by men and women are less likely to cite articles written by men than similar articles written by women. This observed pattern can explain why articles written by men receive more citations than similar articles written by women because the majority of authors who published in APS journals are male (85%).

We examined the existence of Matilda effect in each APS journal, in addition to the whole data set and observed the same results. Our analysis showed that, in each journal, articles written by men (first author, last author and dominant gender of authors) receive more citations than similar articles written by women (first author, last author and dominant gender of authors) and vice versa. We also observed that scholars tend to cite articles written by the same gender. However, we observed when articles are published in either RMP or PRL journal (journals with highest impact factors), the gender of their authors (first author, last author, dominant gender of authors) does not affect the tendency of people to cite them.

Papers were written by female scholars (first author, last author, dominant gender of authors) not only receive fewer citations but also miss more citations than articles written by male scholars (first author, last author, dominant gender of authors). We identified pairs of very similar articles to uncover potentially missing references. Then we quantified the gender gap in the probability of missing citations. Statistical significance of the overlap between the lists of references of a pair of articles was considered as a measure of the similarity between the two articles.

Finally, our suggested method can be applied by editors in academic journals to reduce the evaluation bias (Matilda effect) to some extent. Identifying evaluation biases against women and then making policies to correct it can promote gender equality in the scientific workforce. Using our method, editors can identify missed citations to articles written by female scholars and simply correct this tendency to reduce the evaluation bias.

10.2. Future Work

In this thesis, we assessed the gender gap in research performance of scholars in Physics. Additional research could be performed to explore the gender gap in research performance in other STEM (Science, Technology, Engineering, and Mathematics) fields that are the domain of men. The gender gap in research performance also can be investigated in different countries or different regions of the world. Countries and regions can be rated based on the gender gap in research performance.

In addition, the existence of the Matilda effect can be examined in other STEM fields and in different journals. One can test the hypothesis that the significance of the Matilda effect depends on the percentage of men in a field. In other words, when the percentage of men is higher, the Matilda effect is more significant.

The existence of the Matilda effect can be examined in different countries and regions of the world in future research. Countries can be rated based on this tendency. In other words, one can investigate in which countries or regions women are more underrecognized by analyzing different citation networks.

In addition to the journal of publication, year of publication and content of publication, country or ethnicity of authors can be controlled when investigating the

Matilda effect based on publications of APS journals. Because ethnicity of authors can also affect people's evaluation of cite worthiness and quality of articles. Countries listed in the authors' affiliations in each published paper can be used in this assessment.

Furthermore, gender differences in collaborative behavior of scholars who published in APS journals can be explored based on the collaboration network of the authors. In the collaboration network, each node represents an author and each link indicates that the two authors have written at least one article together. We can examine the existence of homophily in this network that shows to what extent scholars tend to collaborate with scholars of the same gender.

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A. Metadata of a sample of pairs of similar articles

Here, we provide a sample of pairs of very similar articles to verify the method used for extracting very similar articles (at the significance level of 10^{-11}). Unsurprisingly, we observed that, first, the titles of papers in each pair are very similar and have many words in common. Second, in each pair, papers are published in the same journal. Third, in each pair, the papers usually have at least an author in common. These observations show the high accuracy of the applied method for extracting pairs of very similar articles. For each pair in the sample, we provided two tables. The first table shows the metadata of articles in each pair of similar articles. The "Second Paper" is the paper published later than the first paper and therefore we expect a citation from the second paper to the "First Paper". Id of each paper shows the journal of the paper. The second table shows the references the two articles have in common. If the first paper is cited in the second paper "Is Cited" is 1, otherwise, it's 0. "Number of citations" of each common reference shows the impact of the common reference that is an important factor in determining the significance of the similarity.

A.1. Pair 1

	Second Paper
id	10.1103/PhysRevD.92.033012
Authors	Aarti Girdhar , Harleen Dahiya , Monika Randhawa
date	2015-08-26
title	Magnetic moments of JP=32+ decuplet baryons using effective quark masses in a chiral constituent quark model
	First Paper
id	10.1103/PhysRevD.81.073001
Authors	Neetika Sharma , Harleen Dahiya , P. K. Chatley , Manmohan Gupta
date	2010-04-12
title	Spin 12+, spin 32+, and transition magnetic moments of low lying and charmed baryons

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevD.92.033012	10.1103/PhysRevD.81.073001	1	10.1103/PhysRevD.57.452	226
			10.1103/PhysRevD.64.014013	45
			10.1103/PhysRevLett.80.2789	26
			10.1103/PhysRevD.67.074001	22
			10.1103/PhysRevLett.41.1269	663
			10.1103/PhysRevD.79.077503	93
			10.1103/PhysRevD.66.051501	10
			10.1103/PhysRevLett.54.2295	10
			10.1103/PhysRevD.58.092004	30
			10.1103/PhysRevD.21.3175	27
			10.1103/PhysRevD.21.1868	76
			10.1103/PhysRevD.41.920	7
			10.1103/PhysRevD.12.147	14
			10.1103/PhysRevD.18.1585	7
			10.1103/PhysRevD.45.2269	211
			10.1103/PhysRevD.57.5916	14
			10.1103/PhysRevD.35.1665	14
			10.1103/PhysRevD.12.2137	11
			10.1103/PhysRevD.56.5330	14
			10.1103/PhysRevLett.80.3715	78
			10.1103/PhysRevD.34.196	11
			10.1103/PhysRevD.62.093016	10
			10.1103/PhysRevD.57.344	54
			10.1103/PhysRevD.55.2624	42
			10.1103/PhysRevD.57.1801	18
			10.1103/PhysRevD.78.014001	19
			10.1103/PhysRevD.57.4114	14
			10.1103/PhysRevD.64.052002	14
			10.1103/PhysRevD.62.053012	75
			10.1103/PhysRevLett.6.423	7
			10.1103/PhysRevD.15.844	45
			10.1103/PhysRevLett.74.2872	52
			10.1103/PhysRevLett.89.272001	80

A.2. Pair 2

	Second Paper
id	10.1103/PhysRevB.94.125201
Authors	Atchara Punya Jaroenjittichai , Walter R. L. Lambrecht
date	2016-09-09
title	Electronic band structure of Mg IV N2 compounds in the quasiparticle-self-consistent GW approximation
	First Paper
id	10.1103/PhysRevB.84.165204
Authors	Atchara Punya , Walter R. L. Lambrecht , Mark van Schilfgaarde
date	2011-10-07
title	Quasiparticle band structure of Zn IV N2 compounds

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevB.94.125201	10.1103/PhysRevB.84.165204	1	10.1103/PhysRevB.79.245205	7
			10.1103/RevModPhys.77.1173	177
			10.1103/PhysRevB.77.235213	21
			10.1103/PhysRevLett.77.3865	7834
			10.1103/PhysRevB.76.165106	7
			10.1103/PhysRevB.72.155202	7
			10.1103/PhysRevB.76.115205	97
			10.1103/PhysRevB.74.245125	7
			10.1103/PhysRevB.78.115204	82
			10.1103/PhysRevLett.96.226402	5
			10.1103/PhysRevB.81.125117	57

A.3. Pair 3

	Second Paper
id	10.1103/PhysRevD.91.094010
Authors	Harleen Dahiya
date	2015-05-11
title	Quark flavor distribution functions for the octet baryons in the chiral quark constituent model
	First Paper
id	10.1103/PhysRevD.81.114003
Authors	Neetika Sharma , Harleen Dahiya
date	2010-06-01
title	Quark sea asymmetries of the octet baryons

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevD.91.094010	10.1103/PhysRevD.81.114003	0	10.1103/PhysRevD.57.452	45
			10.1103/PhysRevD.53.4775	15
			10.1103/PhysRevD.64.014013	26
			10.1103/PhysRevD.55.6910	22
			10.1103/PhysRevD.67.074001	18
			10.1103/PhysRevLett.81.5519	149
			10.1103/PhysRevLett.41.1269	663
			10.1103/PhysRevD.79.077503	46
			10.1103/PhysRevD.67.034005	93
			10.1103/PhysRevD.44.R2631	11
			10.1103/PhysRevD.66.051501	35
			10.1103/PhysRevD.46.3762	10
			10.1103/PhysRevD.58.092004	26
			10.1103/PhysRevD.21.3175	27
			10.1103/PhysRevD.57.5755	129
			10.1103/PhysRevD.81.073001	98
			10.1103/PhysRevLett.23.930	103
			10.1103/PhysRevD.12.147	12
			10.1103/PhysRevD.71.094015	30
			10.1103/PhysRevD.45.2269	76
			10.1103/PhysRevD.57.5916	7
			10.1103/PhysRevD.12.2137	14
			10.1103/PhysRevD.50.R1	24
			10.1103/PhysRevD.67.114015	14
			10.1103/PhysRevD.56.5330	14
			10.1103/PhysRevLett.80.3715	14
			10.1103/PhysRevLett.23.935	9
			10.1103/PhysRevD.71.094014	78
			10.1103/PhysRevLett.66.2712	28
			10.1103/PhysRevLett.18.1174	54
			10.1103/PhysRevD.59.034013	42
			10.1103/PhysRevD.55.299	117
			10.1103/PhysRevD.57.344	18
			10.1103/PhysRevLett.71.959	45
			10.1103/PhysRevD.55.2624	14
			10.1103/PhysRevD.78.014001	75
			10.1103/PhysRevD.65.034012	14
			10.1103/PhysRevD.57.4114	7
			10.1103/PhysRevD.68.074002	106
			10.1103/PhysRevD.64.052002	45
			10.1103/PhysRevD.40.2832	147
			10.1103/PhysRevD.15.844	52
			10.1103/PhysRevLett.74.2872	80

A.4. Pair 4

	Second Paper
id	10.1103/PhysRevA.47.4768
Authors	Ginette Jalbert , L. F. S. Coelho , N. V. de Castro Faria
date	1993-06-01
title	Production of neutral fragments from the dissociation of fast H3+ ions
	First Paper
id	10.1103/PhysRevA.46.3840
Authors	Ginette Jalbert , L. F. S. Coelho , N. V. de Castro Faria
date	1992-10-01
title	H- formation from collisional destruction of fast H3+ ions in noble gases

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevA.47.4768	10.1103/PhysRevA.46.3840	1	10.1103/PhysRevA.45.2957	10
			10.1103/PhysRevLett.51.1862	6
			10.1103/PhysRevA.45.2978	31
			10.1103/PhysRevA.18.156	11
			10.1103/PhysRevA.39.1767	6
			10.1103/PhysRevLett.53.740	7
			10.1103/PhysRevA.43.5934	8
			10.1103/PhysRevA.36.16	15
			10.1103/PhysRevA.41.1365	10
			10.1103/PhysRevA.8.2870	41
			10.1103/PhysRevA.28.1267	6
			10.1103/PhysRevA.38.658	12
			10.1103/PhysRev.130.1852	6
			10.1103/PhysRevA.29.3122	6
			10.1103/PhysRev.149.62	17

A.5. Pair 5

	Second Paper
id	10.1103/PhysRevD.63.096009
Authors	Eric Braaten , Yu Jia
date	2001-04-10
title	Power-suppressed thermal effects from heavy particles
	First Paper
id	10.1103/PhysRevD.63.045026
Authors	Patrizia Bucci , Massimo Pietroni
date	2001-01-30
title	Boltzmann suppression of interacting heavy particles

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevD.63.096009	10.1103/PhysRevD.63.045026	0	10.1103/PhysRevD.62.023505	7
			10.1103/PhysRevD.61.123508	7
			10.1103/PhysRevD.61.123509	4
			10.1103/PhysRevD.61.023509	7
			10.1103/PhysRevD.59.123511	7

A.6. Pair 6

	Second Paper
id	10.1103/PhysRevB.90.245137
Authors	Sara Lafuerza , Joaquín García , Gloria Subías , Javier Blasco , Javier Herrero-Martín , Sakura Pascarelli
date	2014-12-22
title	Electronic states of RFe2O4(R=Lu,Yb,Tm,Y) mixed-valence compounds determined by soft x-ray absorption spectroscopy and x-ray magnetic circular dichroism
	First Paper
id	10.1103/PhysRevB.89.045129
Authors	Sara Lafuerza , Joaquín García , Gloria Subías , Javier Blasco , Vera Cuartero
date	2014-01-22
title	Strong local lattice instability in hexagonal ferrites RFe2O4 (R = Lu,Y,Yb) revealed by x-ray absorption spectroscopy

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevB.90.245137	10.1103/PhysRevB.89.045129	1	10.1103/PhysRevLett.98.246403	32
			10.1103/PhysRevB.80.220409	7
			10.1103/PhysRevLett.101.227602	8
			10.1103/PhysRevLett.108.187601	40
			10.1103/PhysRevLett.109.016405	11
			10.1103/PhysRevB.82.014304	33
			10.1103/PhysRevLett.99.217202	11
			10.1103/PhysRevLett.101.227601	33
			10.1103/PhysRevLett.103.077602	11
			10.1103/PhysRevB.84.140403	19
			10.1103/PhysRevLett.105.237203	17
			10.1103/PhysRevLett.100.107601	14
			10.1103/PhysRevLett.108.037206	38
			10.1103/PhysRevB.80.024419	7
			10.1103/PhysRevB.63.125120	11
			10.1103/PhysRevB.81.134417	127
			10.1103/PhysRevB.80.020403	13
			10.1103/PhysRevB.76.184105	11
			10.1103/PhysRevB.88.085130	14
			10.1103/PhysRevLett.103.207202	14

A.7. Pair 7

	Second Paper
id	10.1103/PhysRevA.59.2385
Authors	Almut Beige , Gerhard C. Hegerfeldt
date	1999-03-01
title	Cooperative effects in the light and dark periods of two dipole-interacting atoms
	First Paper
id	10.1103/PhysRevA.58.4133
Authors	Almut Beige , Gerhard C. Hegerfeldt
date	1998-11-01
title	Transition from antibunching to bunching for two dipole-interacting atoms

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevA.59.2385	10.1103/PhysRevA.58.4133	1	10.1103/PhysRevA.41.359	14
			10.1103/PhysRevA.21.257	14
			10.1103/RevModPhys.70.101	107
			10.1103/PhysRevA.23.853	6
			10.1103/PhysRevA.45.6721	338
			10.1103/PhysRevA.41.453	7
			10.1103/PhysRevLett.68.580	20
			10.1103/PhysRevLett.76.2049	14
			10.1103/PhysRevA.15.1613	16
			10.1103/PhysRevA.19.1132	54
			10.1103/PhysRevA.47.1336	34
			10.1103/PhysRevA.55.4466	12
			10.1103/PhysRevA.53.2903	55
			10.1103/PhysRevA.42.4343	17
			10.1103/PhysRevA.53.2903.3	11
			10.1103/PhysRevA.35.2164	7
			10.1103/PhysRevLett.40.1334	483
			10.1103/PhysRevA.47.449	27
			10.1103/PhysRevA.52.2965	7
			10.1103/PhysRevA.38.559	7

A.8. Pair 8

	Second Paper
id	10.1103/PhysRevA.82.032505
Authors	Silvina P. Limandri , Rita D. Bonetto , Alejo C. Carreras , Jorge C. Trincavelli
date	2010-09-16
title	$K\alpha$ satellite transitions in elements with 12<Z<30 produced by electron incidence
	First Paper
id	10.1103/PhysRevA.81.012504
Authors	Silvina P. Limandri , Alejo C. Carreras , Rita D. Bonetto , Jorge C. Trincavelli
date	2010-01-19
title	$K\beta$ satellite and forbidden transitions in elements with 12<Z<30 induced by electron impact

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevA.82.032505	10.1103/PhysRevA.81.012504	1	10.1103/PhysRevA.56.4554	9
			10.1103/PhysRevA.14.937	258
			10.1103/PhysRevA.68.022713	5
			10.1103/PhysRevA.36.386	46
			10.1103/PhysRevA.57.1686	6
			10.1103/PhysRevA.39.3956	7
			10.1103/PhysRevA.11.505	4
			10.1103/PhysRevA.38.3467	25
			10.1103/PhysRevA.39.1077	5
			10.1103/PhysRevA.62.062508	11
			10.1103/PhysRevA.16.1543	18
			10.1103/PhysRevA.51.283	4
			10.1103/RevModPhys.39.78	7
			10.1103/PhysRevA.35.1607	5
			10.1103/PhysRevA.66.042713	4
			10.1103/PhysRevA.69.052505	5
			10.1103/PhysRev.50.1	31
			10.1103/PhysRevA.78.022518	3

A.9. Pair 9

	Second Paper
id	10.1103/PhysRevB.90.245137
Authors	Sara Lafuerza , Joaquín García , Gloria Subías , Javier Blasco , Javier Herrero-Martín , Sakura Pascarelli
date	2014-12-22
title	Electronic states of RFe2O4(R=Lu,Yb,Tm,Y) mixed-valence compounds determined by soft x-ray absorption spectroscopy and x-ray magnetic circular dichroism
	First Paper
id	10.1103/PhysRevB.90.085130
Authors	Sara Lafuerza , Gloria Subías , Joaquín García , Javier Blasco , Gareth Nisbet , Kazimierz Conder , Ekaterina Pomjakushina
date	2014-08-21
title	Determination of the sequence and magnitude of charge order in LuFe2O4 by resonant x-ray scattering

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevB.90.245137	10.1103/PhysRevB.90.085130	1	10.1103/PhysRevLett.108.187601	11
			10.1103/PhysRevLett.101.227601	7
			10.1103/PhysRevLett.100.107601	11
			10.1103/PhysRevLett.101.137203	3
			10.1103/PhysRevB.76.184105	19
			10.1103/PhysRevLett.103.207202	13
			10.1103/PhysRevLett.98.246403	14
			10.1103/PhysRevB.80.220409	8
			10.1103/PhysRevB.89.045129	33
			10.1103/PhysRevLett.101.227602	38
			10.1103/PhysRevLett.103.077602	24
			10.1103/PhysRevB.84.140403	11
			10.1103/PhysRevLett.108.037206	40
			10.1103/PhysRevB.86.035121	33
			10.1103/PhysRevLett.109.016405	17
			10.1103/PhysRevLett.99.217202	7
			10.1103/PhysRevB.80.024419	11
			10.1103/PhysRevB.88.085130	14
			10.1103/PhysRevB.82.014304	3
			10.1103/PhysRevLett.105.237203	32
			10.1103/PhysRevB.81.134417	11
			10.1103/PhysRevB.80.020403	14

A.10. Pair 10

	Second Paper
id	10.1103/PhysRevE.88.032122
Authors	Moupriya Das , Deb Shankar Ray
date	2013-09-13
title	Control of logic gates by dichotomous noise in energetic and entropic systems
	First Paper
id	10.1103/PhysRevE.86.041112
Authors	Moupriya Das , Debasish Mondal , Deb Shankar Ray
date	2012-10-09
title	Logic gates for entropic transport

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevE.88.032122	10.1103/PhysRevE.86.041112	1	10.1103/PhysRevE.83.041909	25
			10.1103/PhysRevE.85.031128	98
			10.1103/PhysRevLett.77.783	3
			10.1103/PhysRevE.80.011120	42
			10.1103/PhysRevE.82.051106	24
			10.1103/PhysRevLett.99.148102	31
			10.1103/PhysRevLett.89.198103	11
			10.1103/PhysRevE.84.011149	5
			10.1103/PhysRevE.66.066612	3
			10.1103/PhysRevE.79.011923	14
			10.1103/PhysRevE.75.025201	4
			10.1103/PhysRevE.74.041203	2
			10.1103/PhysRevLett.96.208301	3
			10.1103/PhysRevE.80.020904	4
			10.1103/RevModPhys.70.223	5
			10.1103/PhysRevLett.100.058101	7
			10.1103/PhysRevLett.107.238102	27
			10.1103/PhysRevE.75.061126	19
			10.1103/PhysRevE.64.061106	22
			10.1103/PhysRevLett.69.2318	4
			10.1103/PhysRevE.83.046219	54
			10.1103/PhysRevLett.96.130603	13
			10.1103/PhysRevE.72.061203	6
			10.1103/PhysRevE.85.066129	6
			10.1103/PhysRevE.66.046112	30
			10.1103/PhysRevE.75.051111	27
			10.1103/PhysRevE.82.032103	41
			10.1103/PhysRevE.79.061908	10
			10.1103/PhysRevE.80.045202	3
			10.1103/PhysRevE.59.5354	24
			10.1103/PhysRevLett.104.020601	157
			10.1103/PhysRevE.82.041112	7
			10.1103/PhysRevE.65.036216	57
			10.1103/PhysRevLett.101.130602	5
			10.1103/PhysRevLett.102.104101	837
			10.1103/PhysRevLett.86.3188	30
			10.1103/PhysRevE.79.026114	19
			10.1103/PhysRevLett.100.168105	7
			10.1103/PhysRevE.74.051114	3
			10.1103/PhysRevE.84.011109	14
			10.1103/PhysRevLett.80.5687	7
			10.1103/PhysRevLett.94.048102	23

A.11. Pair 11

	Second Paper
id	10.1103/PhysRevD.93.114030
Authors	Harleen Dahiya , Monika Randhawa
date	2016-06-27
title	Nucleon structure functions and longitudinal spin asymmetries in the chiral quark constituent model
	First Paper
id	10.1103/PhysRevD.91.094010
Authors	Harleen Dahiya
date	2015-05-11
title	Quark flavor distribution functions for the octet baryons in the chiral quark constituent model

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevD.93.114030	10.1103/PhysRevD.91.094010	1	10.1103/PhysRevD.57.452	33
			10.1103/PhysRevD.53.4775	52
			10.1103/PhysRevD.64.014013	45
			10.1103/PhysRevD.55.6910	26
			10.1103/PhysRevLett.80.2789	22
			10.1103/PhysRevLett.99.192001	15
			10.1103/PhysRevD.67.074001	18
			10.1103/PhysRevLett.81.5519	149
			10.1103/PhysRevLett.41.1269	25
			10.1103/PhysRevD.79.077503	39
			10.1103/PhysRevLett.94.152001	100
			10.1103/PhysRevD.67.034005	663
			10.1103/PhysRevD.44.R2631	7
			10.1103/PhysRevD.66.051501	46
			10.1103/PhysRevD.46.3762	11
			10.1103/PhysRevD.58.092004	93
			10.1103/PhysRevD.21.3175	10
			10.1103/PhysRevD.57.5755	13
			10.1103/PhysRevD.19.104	27
			10.1103/PhysRevD.16.216	26
			10.1103/PhysRevLett.88.091802	129
			10.1103/PhysRevD.81.073001	98
			10.1103/PhysRevLett.95.092001	60
			10.1103/PhysRevLett.23.930	12
			10.1103/PhysRevD.58.112001	51
			10.1103/PhysRevD.12.147	103
			10.1103/PhysRevLett.76.587	41
			10.1103/PhysRevD.71.094015	30
			10.1103/PhysRevD.56.4069	76
			10.1103/PhysRevD.18.1585	7
			10.1103/PhysRevD.71.012003	140
			10.1103/PhysRevD.57.5916	14
			10.1103/PhysRevD.45.2269	24
			10.1103/PhysRevD.28.534	8
			10.1103/PhysRevD.35.1665	44
			10.1103/PhysRevD.12.2137	14
			10.1103/PhysRevD.58.038502	14
			10.1103/PhysRevD.64.112006	14
			10.1103/PhysRevD.50.R1	68
			10.1103/PhysRevD.67.114015	11
			10.1103/PhysRevD.56.5330	9
			10.1103/PhysRevLett.80.3715	78
			10.1103/PhysRevD.65.111103	41
			10.1103/PhysRevLett.79.26	28
			10.1103/PhysRevLett.23.935	10
			10.1103/PhysRevLett.108.102001	54
			10.1103/PhysRevD.71.094014	42
			10.1103/PhysRevLett.66.2712	62
			10.1103/PhysRevLett.93.022002	117
			10.1103/PhysRevLett.70.134	88
			10.1103/PhysRevLett.18.1174	5
			10.1103/PhysRevD.55.299	56
			10.1103/PhysRevD.59.034013	18
			10.1103/PhysRevD.57.344	19
			10.1103/PhysRevLett.71.959	45
			10.1103/PhysRevD.55.2624	61
			10.1103/PhysRevLett.98.032301	23
			10.1103/PhysRevD.78.014001	14
			10.1103/PhysRevD.65.034012	14
			10.1103/PhysRevD.57.4114	51
			10.1103/PhysRevD.68.074002	14
			10.1103/PhysRevD.64.052002	75
			10.1103/PhysRevC.69.065501	7
			10.1103/PhysRevD.40.2832	106
			10.1103/PhysRevD.15.844	45
			10.1103/PhysRevD.90.074001	147
			10.1103/PhysRevLett.74.2872	35
			10.1103/PhysRevLett.104.012001	80

A.12. Pair 12

	Second Paper
id	10.1103/PhysRevB.82.195113
Authors	Brando Bellazzini , Mihail Mintchev , Paul Sorba
date	2010-11-10
title	Off-critical Luttinger junctions
	First Paper
id	10.1103/PhysRevB.79.085122
Authors	Brando Bellazzini , Pasquale Calabrese , Mihail Mintchev
date	2009-02-24
title	Junctions of anyonic Luttinger wires

Second Paper	First Paper	Is Cited	Common References	Number of Citations
10.1103/PhysRevB.82.195113	10.1103/PhysRevB.79.085122	1	10.1103/PhysRevB.74.155324	57
			10.1103/PhysRevB.71.155401	16
			10.1103/PhysRevB.66.165327	16
			10.1103/PhysRevLett.94.136405	27
			10.1103/PhysRevLett.86.4628	33
			10.1103/PhysRevB.77.155418	32
			10.1103/PhysRevB.78.205421	48
			10.1103/PhysRevB.65.195101	11
			10.1103/PhysRevB.68.205110	16
			10.1103/PhysRevB.74.045322	51
			10.1103/PhysRevB.46.15233	34
			10.1103/PhysRevLett.89.226404	16
			10.1103/PhysRevB.77.155422	12
			10.1103/PhysRevLett.68.1220	18
			10.1103/PhysRevB.70.195115	609
			10.1103/PhysRevB.71.205327	16
			10.1103/PhysRevB.66.115305	54
			10.1103/PhysRevB.71.075110	23
			10.1103/PhysRevLett.91.206403	471
			10.1103/PhysRevB.59.15694	47
			10.1103/PhysRevLett.95.176402	14