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Women in science and higher education: A bibliometric approach

Tahereh Dehdarirad

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Universitat de Barcelona

Faculty of Library and Information Science

Department of Library and Information Science

Doctorate program in Information and Documentation in the Knowledge Society

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Tahereh Dehdarirad

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Supervisors: Dr. Maite Barrios

Dr. Anna Villarroya

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Abstract

The main objective of this thesis work is to assess and map international research concerning gender in science and higher education. To do this, two different studies were designed: first, to examine the development and growth of scientific literature on women in science and higher education, and, second, to map and analyse the structure and evolution of the scientific literature on gender differences in higher education and science, focusing on factors related to differences. For the first study, development and growth of scientific literature on women in science and higher education, a total of 1415 articles and reviews published between 1991 and 2012, were extracted from the Thomson Reuters Web of Science database. For the second study, mapping the evolution of scientific literature on gender differences, the data set comprised a corpus containing 651 articles and reviews published between 1991 and 2012, extracted from the Thomson Reuters Web of Science database.

The methodology and procedures employed included standard bibliometric indicators and laws (e.g., Price's, Lotka's, and Bradford's laws), Relative Intensity Index (RII) and the Gender Inequality Index (GII). Data sets in the second study were evaluated for different time periods; co-word analysis and hierarchical cluster analysis were undertaken.

The results of these studies suggest an upward trend in both the number of papers, and also the number of authors per paper. However, this increase in the number of authors was not accompanied by an increase in international collaboration. Interest in gender differences in science extends to many authors (n = 3064), countries (n = 67), and research areas (n = 86). The data showed a high dispersion of the literature with a small set of core journals focused on the topic. The research area with the highest frequency of papers was Education and Educational Research.

The results also indicated a significant increase in the number of themes over the years. Furthermore, the fact that gender differences in science and higher education have been considered by specific research disciplines, suggests important research-field-specific variations.

Resumen

El principal objetivo de esta tesis consiste en evaluar y mapear la investigación internacional sobre género en ciencia y educación superior. Para ello, se han diseñado dos estudios: por un lado, el análisis del desarrollo y crecimiento de la literatura científica sobre la participación de las mujeres en la ciencia y la educación superior, y, por otro lado, el análisis de la estructura y evolución de la literatura científica sobre diferencias de género en educación superior y ciencia, haciendo especial hincapié en los factores que se hallan detrás de estas diferencias.

Para el primer estudio, centrado en el desarrollo y crecimiento de la literatura científica sobre la participación de las mujeres en la ciencia y la educación superior, se extrajeron un total de 1.415 artículos y revisiones publicadas entre los años 1991 y 2012 en la base de datos Web of Science de Thomson Reuters. Para el segundo estudio, enfocado en la evolución de la literatura científica sobre diferencias de género, el conjunto de datos comprende un corpus de 651 artículos y revisiones publicadas entre los años 1991 y 2012 en la base de datos Web of Science de Thomson Reuters.

La metodología y procedimientos empleados incluyen indicadores y leyes bibliométricas estándar (por ej. Price, Lotka y Bradford), el Índice Relativo de Intensidad (RII) y el Índice de Desigualdad de Género (GII). El conjunto de datos del segundo estudio se evalúa en diferentes períodos de tiempo, a partir de un análisis de co-ocurrencia de palabras y de agrupamiento jerárquico.

Los resultados de estos análisis muestran una tendencia al alza tanto en el número de artículos como en el número de autores por artículo. Sin embargo, este aumento en el número de autores no se ve acompañado de un aumento en la colaboración internacional. Los resultados ponen también de relieve cómo el interés en el estudio de las diferencias de género en la ciencia y en la educación superior se extiende a muchos autores (n = 3.064), países (n = 67) y áreas de investigación (n = 86). Los datos muestran también una gran dispersión de la literatura con un pequeño conjunto de revistas especializadas en el tema, siendo el área de “Educación e Investigación para la Educación” el área con más trabajos.

Los resultados también indican un aumento significativo del número de temas analizados a lo largo de los años. Asimismo, el hecho que las diferencias de género en ciencia y educación superior hayan sido objeto de estudio de diferentes disciplinas sugiere importantes variaciones en campos de estudio específicos.

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List of abbreviations

AAUP: American Associations of University Professors

AUT: Association of University Teachers

EC: European Commission

EU: European Union

GII: Gender Inequality Index

IC-RII: International Collaboration Relative Intensity Index

LERU: League of European Research Universities

NAS: National Academy of Science

NAWE: National Association for Women in Education

NSF: National Science Foundation

OECD: Organization for Economic Co-operation and Development

RII: Relative Intensity Index

SET: Science, Engineering and Technology

STEM: Science, Technology, Engineering, and Mathematics

UNDP: United Nations Development Program

UNESCO: United Nations Educational, Scientific and Cultural Organization

WSHE: Women in Science and Higher Education

Preface

Preface

This thesis examines and maps the international research in the area of women in science and higher education. Women's participation in science and higher education as an indicator of social and economic progress has attracted considerable attention from individual researchers and both national and international organizations. As a result, a variety of initiatives and reports have been undertaken in different parts of the world in order to analyse the participation of women in science and higher education and to promote gender equality.

Gender equality is not solely an issue for women anymore, because it is a global problem that hinders development, productivity and the economic growth of societies (World Bank, 2012; Bandiera and Natraj, 2013). It also results in severe individual and societal losses for a nation in general (Kamrany and Robinson, 2012) and underutilization of female talent and research capacity in universities and higher education in particular (LERU, 2015). Consequently, the insufficient use of women as human capital decreases potential advantage for research and innovation-related business and for overall economic development, as well as having devastating social consequences (European Commission, 2015). As it is stated in the UNESCO *Priority Gender Equality Action Plan* (2014), gender equality is not only a basic human right, but its achievement has enormous socio-economic ramifications. Evidence shows that promoting gender equality at all levels contributes to achieving excellence and efficiency (European Commission, 2012). At the research and higher education level, this particularly results in excellent quality research and competitiveness (LERU, 2015).

The centrality of gender equality has been highlighted in both developed and developing countries. However, this issue is addressed differently by both sets of countries as they face different manifestations of gender inequality. While the focus of some reports carried out by the UNESCO, which mainly track gender equality in developing countries, is generally on equal opportunity for both women and men to access to primary education and literacy programmes, reports from more developed countries published by the European Commission and the League of European Research Universities (LERU) address issues like glass ceiling, women at top level positions and decision making activities, and presence of women in Science, Technology, Engineering, and Mathematics (STEM) fields amongst others.

In order to describe the inequalities and barriers women face to progress and advance their career in science and higher education, numerous metaphors have been used in the literature. For instance, *leaky pipeline* is a metaphor frequently used to describe the fact that women leave organizations at many different stages of career trajectory (Blickenstaff, 2005; Bilimoria, Joy and Liang, 2008). The *sticky floor* has been used to describe a situation in which women being held back in lowly paid jobs at the bottom levels of organizations (Kee, 2006) or *chilly climate*, which depicts the fuzzy academic processes for women, reflects inconveniences in the academic environment (Husu, 2001).

The *glass ceiling* is another metaphor which has been used to explain the absence of women at higher organizational levels due to absolute barriers (Powell, 2012). Some alternative metaphors to the glass ceiling which has been introduced in the literature are the *labyrinth* (Eagly and Carli, 2007), and the *firewall* (Bendl and Schmidt, 2010). The *Labyrinth* captures the varied challenges confronting women as they travel, often on indirect paths, sometimes through alien territory, on their way to leadership (Eagly and Carli, 2007).

The *Firewall* metaphor is used for describing discrimination against women and other minority groups within an organization. It focuses on the view that discrimination is a process practiced by developers. More precisely, it hints at creators and administrators of discrimination who decide who is allowed to enter their system. The *Matilda effect* is another metaphor introduced by Rossiter (1993) which refers to systematic under-recognition of female scholars in the academic world. This effect deals with the systematic underrepresentation of women and the reduced recognition of women's academic contributions (Kretschmer and Kretschmer, 2013).

Given the recognition of the importance of gender equality, women's empowerment and participation during the past few decades, numerous studies have also looked at various aspects of participation and performance of women in science and higher education. These include scientific production, research impact and other academic activities apart from scientific productivity and factors that have an effect on the scientific and academic contribution of women.

Overall, the literature on women in science and higher education, as indicated by Ceci et al. (2014), is contradictory. The great evidence is the apparently contradictory research results that sometimes confirm an equal contribution from both genders, occasionally show a superiority for females' and sometimes for males' performances. It is, therefore, crucial to constantly monitor females' roles and performances in science and higher education, as an essential step towards understanding the underlying factors and thereby eradicating the inequalities (Fox, 2005). As also indicated by Leahey (2006), studying women's contribution to science and higher education is important to discover not only the gender gap in scientific and academic activities, but also its resulting gender imbalance.

Despite the growing recognition of the importance of the issue of women in science and higher education, and the increasing number of academic publications, initiatives, and reports in this area, no systematic analysis has yet been carried out on the large body of research in this area. Thus, the aim of this thesis is to assess and map international research concerning women in science and higher education, using a bibliometric approach. This will provide a clear picture of the field and its evolution over time.

Bibliometric studies are useful as they provide an assessment of research or scientific production in a specific area over a period of time using indicators and the calculation of certain classical laws (Van Raan, 2005). Given that, this thesis uses standard bibliometric indicators (such as the number of papers and authors, and productivity by country, among others) and laws (Price's, Lotka's, and Bradford's laws) to study the development and growth of research in this field. Additionally, in order to describe the evolution and current state of the literature on gender differences in science, co-word analysis is used. This bibliometric technique, proposed by Callon et al. (1983), will help us to visualize the division of the field (in this case, the explanatory factors for gender differences in science) into several subfields and show the relationships between them, thereby providing insights into the evolution of the main topics discussed in the field over the years. The technique will also help us to identify the major research topics in the area of women of science and higher education, as well as to suggest issues to be addressed or strengthened in further work. This is particularly important as these techniques have not been applied before in other studies to address the literature in this area as well as the above-mentioned issues.

Finally, by providing an overview of the factors accounting for gender differences, this work would help to guide future research and practices in the field. This will be also of interest to policy makers, funders, and academic administrators in terms of identification of necessary actions to accelerate the closure of the gender gap.

This study attempts to address the aim of thesis and the above-mentioned issues, with a particular focus on the following sets of questions:

- What is the importance and the growth rate of the scientific literature on women in science and higher education over the time?

- What is the relevance and interest of the area of women in science and higher education across different research areas?
- What authorship trends and collaboration efforts do exist in the area of women in science and higher education?
- What is the relative contribution of the countries to the scientific literature on women in science and higher education?
- What is the importance and relevance of the area of women in science and higher education among countries at international level?
- What is the relationship between the scientific contribution of countries to the area of women in science and higher education and their level of development in gender equality?
- What is the distribution, relevance and interest of the area of women in science and higher education across journals of different disciplines?
- What is the importance, interest and growth rate of the number of publications on factors accounting for gender differences in science and higher education over time?
- What is the growth rate of the number of sub-fields (themes) which address the factors accounting for gender differences in science and higher education, over time?
- What is the interest and evolution of themes on the factors accounting for gender differences in science and higher education over time?

In order to address all the above-mentioned questions, this thesis is comprised six chapters. It starts with chapter Preface, which provides a brief introduction to the thesis. It then follows by Chapter 1, the Review of the Literature, which presents a broad evaluation of previous studies. After a brief introduction, three groups of literature in the area of women in science and higher education are discussed extensively. Chapter 2, Objectives, presents the main and specific objectives of the thesis. In Chapters 3 (Study 1) and 4 (Study 2), methods for data collection and data analysis of each study, results and discussion are presented. Sources and databases used to collect data are also introduced. In Chapter 5, Conclusion, the main findings of each research question in the conducted studies are presented. It then follows by contributions of the conducted research. Finally, it presents some limitations of the thesis followed by some recommendations for future research.

Chapter 1. Literature review

Chapter 1. Literature review

1.1. Introduction

The scientific literature contains ample evidence regarding different aspects of women's participation and performance in science and higher education. To situate the current research, a review of the most recent and relevant literature was conducted. The literature review is divided into three broad sections: publication productivity, impact and collaboration patterns, other issues related to gender in academia and science, and factors accounting for gender differences.

The *publication productivity, impact and collaboration patterns* section provides insights into those studies that deal with scientific publication, research impact, collaboration patterns and authorship order, from a gender perspective.

The *issues related to gender in academia and science* section focuses on literature addressing elements other than publication productivity that have an influence on the development of a scientific career. This includes elements such as manuscript reviewing, access to funding resources and academic employment, hiring, being a member of an editorial board amongst others.

Finally, given that the performance of researchers in the two above-mentioned groups of scientific activities can be affected by several factors, section three provides insights into the factors accounting for these gender differences. These include family related, institutional, socio-cultural and behavioural factors amongst others.

1.2. Publication productivity, impact and collaboration patterns

This review is concerned with different aspects of publication productivity, impact and collaboration as mentioned above in relation to gender.

1.2.1. Number of publications

In terms of the number of publications characterized by Cole and Zuckerman (1984) as a productivity puzzle, the literature generally tends to agree that women have lower publication rates and that men perform better (Cole and Zuckerman, 1984; Xie and Shauman, 1998; Prpić, 2002; Sax Hagedorn, Arredondo, and Dicrisi III, 2002 ; Bordons, et al., 2003; Fox, 2005; Gallivan, and Benbunan-Fich, 2006; Mauleón and Bordons, 2006; Symonds et al., 2006; Puuska, 2009; Abramo, D'Angelo, and Caprasecca, 2009; D'Amico, Vermigli, and Canetto, 2011; Larivière, et al., 2013).

However, there is also research that reports no significant differences in productivity between the two sexes (Lewison, 2001; Bordons, Morillo, Fernández and Gómez, 2003; Tower, Plummer and Ridgewell, 2007; Mauleón, Bordons, and Oppenheim, 2008; Sotudeh and Khoshian, 2014).

Some studies have also presented mixed results, depending on the variables examined. In their study on 162 professors of organization science, Rothausen-Vange, Marler and Wright (2005) suggested that women publish more than men in more research oriented departments, but less than men in less research oriented departments. Women were also found to begin their careers at a later age than men (Karamessini, 2004; Prozesky, 2008). In this sense, women produce fewer publications than men during the first decade of their career, but by the later stages of their career they have a similar number of publications as male researchers (Long, 1992; Symonds et al., 2006). Similarly, in a study conducted on academic psychologists in United States, Joy (2006) found that males tend to publish more than females during their initial push for tenure, but not thereafter, whereas females tend to increase their publication rates as they mature professionally. Another variable which is reported to lead in diverse results is discipline. Van Arensbergen et al. (2012), studied research performance differences between male and female researchers from social sciences particularly psychology and economics in the Netherlands. The results showed that in psychology in average men outperform women, whereas in economics the differences are not statistically significant. A large-scale study on seven science, technology, engineering, and mathematics (STEM) disciplines conducted by Duch et al. (2012) showed that for disciplines where research expenditures are high, such as molecular biology, females consistently publish at a rate significantly lower than males, whereas for industrial engineering no significant difference between genders was observed.

Regarding academic rank as another variable leading to mixed results, Borrego’s et al. (2010) study on 731 Ph.D. holders at Spanish universities between 1990 and 2002, showed that while scientific output before obtaining a Ph.D. was similar for both gender groups, the median number of papers published after obtaining a Ph.D. was lower in the female group. Studying gender differences among radiation oncologists at U.S. academic institutions, Holliday et al. (2014) found that men had higher number of publications compared to women. However, after controlling for rank, these differences were largely non-significant. They concluded that women who achieve senior status have productivity metrics comparable to their male counterparts.

Finally, with regard to the type of program offered at institutions, Jordan, Clark and Vann (2011) studied gender differences in the publication productivity of accounting family members at both doctoral and non-doctoral granting programs. The results showed no gender differences in the publication output of faculty members at non-doctoral granting programs. At doctoral granting programs, however, men publish at greater rates compared to women.

To sum up, the results regarding the number of publications for female and male scholars are mixed, depending on the variables studied. These include age, tenure, discipline, academic rank, type of program offered in one institute, amongst others.

1.2.2. Research impact and visibility of researchers' output

The research impact of female and male researchers has been evaluated in different studies, using different indicators such as the number of citations, the journal impact factor or the H-index.

Regarding the number of received citations, the literature has shown mixed results. Some research suggests that women's publications are cited at lower rates than men's publications. In their study on a sample of tenure-track and tenured linguists and sociologists, Hunter and Leahy (2010) found that women were disadvantaged in terms of the number of received citations, even after controlling for children. Pudovkin et al. (2012) also in their study on 313 papers of research staff at the Deutsche Rheuma-Forschungszentrum, concluded that male scientists were more prolific and cited more often than females. In their study on some selected prestigious geography Journals, Rigg, McCarragher, and Krmenec (2012) showed that citation rates were highest for articles either singly or collaboratively authored by males. In a more recent study on citations and publication patterns in the literature on international relation (IR), Maliniak, Powers, and Walter (2013) also found that women are systematically less cited than men after controlling for a large number of factors including year of publication, venue of publication, substantive focus, theoretical perspective, methodology, tenure status, and institutional affiliation. They included this is likely because of the following reasons: women tend to cite themselves less than men, and men who make up a disproportionate share of IR scholars tend to cite men more than women. In contrast to these studies, some have found that women receive more citations per paper than men. Long's pioneering study on the productivity of biochemists (1992) in the United States (US) concluded that the average number of citations per publication for women was higher than that of men.

In a study of 721 PhDs from Spanish universities (1990–2002), Borrego et al. (2010) explored the gender differences in scientific output and citations. They also found that articles authored by female PhDs were cited significantly more often (even when self-citations were excluded).In another study on research staff at the Deutsche Rheuma-Forschungszentrum, Kretschmer, Pudovkin, and Stegmann (2012) classified the staff in two sub-groups of ‘‘high-end (star)’’ (25% of the population) scientists and the complementary (75% of the population). The results revealed that apart from the small group of star (high-end) scientists, female researchers had a slightly higher performance with respect to their male counterparts in the large complementary subgroup.

In addition to the two above-mentioned groups of studies, there are also some other studies which have indicated no difference incitation rates between publications authored by males and females. Symond et al. (2006) in their study on the publication records of a cohort of 168 life scientists in the field of ecology and evolutionary biology from British and Australian universities, found no difference in the median number of citations per paper for males and females. Studying gender differences in citation rates for dendrochronologists, Copenheaver et al. (2010) found no effect of gender on a paper’s probability to be cited. They suggested that the high productivity of female dendrochronologists and a pattern of co-authoring with male colleagues bring the work of females to the attention of their male colleagues and thus eliminate the gender bias in citation of women’s work common to other disciplines. Sotudeh and Khoshian (2014) in a more recent study investigated women's scientific impact compared to men in 18 nano science and technology journals. Similarly, the results of their study showed no significant differences between the mean impacts of women and men researchers.

Studies on journal impact factor have also produced mixed findings. While some of them have highlighted the similarity of the journals in which women and men publish (Lewison, 2001; Bordons et al., 2003; Mauleón and Bordons, 2006; Gonzalez-Brambila and Veloso, 2007; Mauleón et al., 2008; Barrios, Villarroya and Borrego, 2013), others have shown that men choose to publish in journals with a higher impact factor (Hunter and Leahey, 2010). Alternatively, Borrego et al. (2010) argued that it is women that tend to publish in higher impact journals. Similarly, Ghiasi, Larivière and Sugimoto (2015) in their study on women engineers, also indicated that women publish their papers in journals with higher impact factors than their male peers. They concluded that women are equally or more influential and prominent than their male peers as they publish their papers in journals with higher citations rates. However, their articles are cited less. They interpreted this finding within the framework of the "Matilda effect" by which women's publications receive less recognition than what is expected (in this case, expected from the journal in which their discoveries were published).

Regarding the H-index, some studies suggest that women have a lower overall H-index compared with men (Holliday et al., 2014; Lopez et al., 2014). However, the difference was smaller when comparing men and women within the same academic rank (Pashkova et al., 2013; Holliday et al., 2014; Lopez et al., 2014). In their study on faculty members from 25 academic anaesthesiology departments in the United States, Pashkova et al. (2013) found that male anaesthesiologists had a statistically higher h-index. However, upon further examination by academic rank, h-indices were not statistically different between genders at the level of assistant and associate. Holliday et al. (2014) also in their study on 1031 faculty members from Radiation Oncology in the United States found that overall men had a higher median h-index than women. However, when controlled by academic rank, there was likewise no significant difference between men and women in the same position.

To sum up, the evidence is inconclusive with regard to research impact of female and male researchers depending on the year of publication, venue of publication, rank, country and discipline.

1.2.3. Collaboration patterns

The literature on gender differences in scientific collaboration has mainly studied the following three issues: studies related to the impact of gender on the number of collaborators, cross-gender collaboration and co-authorship, and finally, international collaboration.

Regarding the first issue, the impact of gender on collaboration and the number of collaborators, the literature generally agrees that men collaborate more than women (Bozeman and Corley, 2004; Lee and Bozeman, 2005; Özel, Kretschmer and Kretschmer, 2013). Additionally, women tend to have fewer collaborators than men (Bozeman and

Corley, 2004; Lee and Bozeman, 2005). In their current study on national level publications in social sciences in Turkey, Özel, et al. (2013) found that male authors are in general keener to collaborate than females.

In contrast to what has been indicated in the above-mentioned literature, there are some studies which have shown no gender differences in collaboration (Hunter and Leahy, 2008) or that women are more likely to collaborate (Bozeman and Gaughan, 2011; Abramo, D’Angelo and Murgia, 2013). Studying a sample of articles in two leading sociology journals between 1935 and 2005, Hunter and Leahey (2008) found no significant gender differences in rates of collaboration. They attributed this finding to women’s inroads into sociology. In a different way, using data from NSF-funded Survey of Academic Researchers conducted in the United States in 2004–2005, Bozeman and Gaughan (2011) found that men and women differ relatively little with respect to research collaborations. They also found, somewhat surprisingly that women have more collaborators, especially when controlling for structural (tenure status, professional age, discipline, teaching load and number of active grants) and climate factors. Similarly, in a more recent study on the scientific publications of Italian professors from 11 University disciplinary areas, Abramo et al. (2013) demonstrated that in general female researchers have a greater propensity to collaborate than their male colleagues. They associated this issue to women’s higher percentage of co-authored publications.

In terms of cross-gender collaboration the results are also inconsistent. Some studies have suggested that women are involved in inter-gender collaborations more than men.

Additionally, they have more female collaborators than male authors (McDowell and Smith, 1992; Bozeman and Corley, 2004; Boschini and Sjogren, 2007). As one of the first studies on this issue, McDowell and Smith' (1992) study examined the publications of a sample of 178 PhDs from the top 20 United States institutions (1969-1986) and found that women were over five times more likely than men to have female co-authors. Examining data from 451 scientists and engineers at academic research centres in the United States, Bozeman and Corley (2004) found that female scientists have a somewhat higher percentage (36 %) of female collaborators, than males have (24%). However, they found that there are great differences, according to rank, with non-tenure track females having 84% of their collaborations with females. By contrast, tenured females collaborate with only 34% females. Boschini and Sjogren (2007) also in their analysis of articles published in three economics journals found that women are more than twice as likely as men to have a female co-author. They also found that the female-male gap in the propensity to co-author with a woman increases with the increase in the presence of women. They suggested this gender segregation may be linked to the prevalence of teamwork.

By contrast, some other studies have indicated that women have a higher propensity to part take in cross-sex and mixed gender collaboration (Fisher, et al, 1998; Zawacki-Richter and von Prümmer, 2010; Farrell and Smyth, 2014).

Fisher, et al. (1998) in a study on three leading journals in political sciences found that over half of the articles published by women in the leading journals resulted from cross-sex collaboration. In contrast, men appear more likely to author articles on their own or to co-author articles with other men. The results of Zawacki-Richter and von Prümmer's (2010) study on papers published in five prominent distance education journals also indicated that more women than men collaborated with members of the opposite sex. Farrell and Smyth (2014) in their study on articles published in the Group of Eight (Go8) law reviews in Australia have shown that males collaborate with other males much more than females collaborate with other females. They postulated that a reason for these gender differences in co-authorship might be the existence of old boy networks in male dominated professions, which females find difficult to access.

Regarding international collaboration, in general the literature shows that female researchers have a lower propensity to collaborate at an international level (Finkelstein, Walker and Chen, 2009; Frehill, Vlaicu, and Zippel, 2010; Larivière et al., 2011; Abramo et al., 2013; Larivière et al., 2013).

Globally, what can be inferred from the literature is that the following variables might have an impact on the number of collaborators of both female and male scholars: the percentage of scholars in a discipline in terms of their gender, tenure status, professional age, discipline, teaching load, number of grants, and climate factors, amongst others. Regarding cross-gender collaboration and co-authorship, we can mention rank, teamwork, the presence (number) of women in a field, discipline, and the existence of old boy networks among others. Finally, the lower propensity of female scholars to collaborate internationally could be due to the lack of research funds, which limits the breadth of collaboration networks for the individual academic (Bozeman and Corley, 2004). It might also be due to the prejudices against women that still exist in certain countries and which lead local researchers, who are primarily men, to avoid undertaking collaborations with women colleagues (Frehill, et al., 2010; Abramo et al., 2013). Family ties might also limit collaboration duration as well as geographic extension (Frehill, et al., 2010).

1.2.4. Authorship positions and author by-line order

Author by-line order and authorship position usually gives an indication of the contribution, responsibility and accountability made by each author to a piece of published work (Tscharntke, et. al., 2007; Clement, 2014). According to the literature, the most important authorship positions are first, last and corresponding (Costas and Bordons, 2011; Rigg, McCarragher and Krmenec, 2012). In this sense, first-position authors are generally held to have made the greatest contribution to the research (Clement, 2014), while the last author typically represent the most senior, predominantly supervisory role in the research (Costas and Bordons, 2011). The corresponding author is typically the person who receives the reviewers' comments, the proofs etc. and whose contact details are listed in the article (Albert and Wagner, 2003). Corresponding authorship is frequently used as a way to share credit between senior individuals (Costas and Bordons, 2011). However, it should be considered that in different countries, research groups or disciplines, the policy on crediting contributions and author by line order may differ (Weltzin, et al., 2006, Tscharntke, et. al., 2007).

In terms of gender, literature in this area suggests that women are generally underrepresented as first author (Li et al., 2007; Ochuko-Emore, Beezhold, and Morakinyo, 2010; Shields, Hall and Mamun, 2011; Barrios et al., 2013; Larivière et al., 2013, West et al., 2013) and corresponding author (Barrios et al., 2013). Furthermore, they lagged behind their male colleagues as last (senior) authors (Shah et al., 2013; Liang, et al., 2015).

West et al. (2013) associated these disparities in prestigious authorship positions to informal negotiation between a team of authors about author position order. They pointed out that men negotiate more successfully for more prestigious positions. As a second reason for this, they also referred to the bias which exist against women in the review process, such that when they are in the more prestigious author positions, papers of equal quality are less likely to be accepted than when men occupy prestigious positions.

1.3. Issues related to gender in science and academia

This section provides an overview of three important issues related to gender in science and academia: manuscript reviewing, access to funding resources and academic employment.

1.3.1. Manuscript (peer) reviewing

Literature in this area covers various aspects of the peer review process including gender differences in manuscript reviewing and publishing, the relationship between the author's gender and the reviewer's gender, and the presence of women on editorial boards.

Regarding the first aspect, gender differences in manuscript reviewing and getting work published, as indicated by Lee et al. (2013), the prevailing assumption has been that in comparison to women, men are treated more favourably in the peer review process. In a study on journal acceptance rates for manuscripts submitted by women to Behavioral Ecology, Budden et al. (2008) observed that acceptance rate for female first-authored manuscripts increased by 7.9% in the 4 year after the onset of blind review, compared with the 4 year prior. This suggests that when reviewers were aware of authors' sex, they were less likely to accept women's manuscripts. Kaufman and Chevan (2011), also in their study on gender gap in peer-reviewed publications by physical therapy faculty members, found that there was a significant difference in peer-reviewed publication rates between male and female respondents. Their results also revealed that female gender was a negative predictor of peer-reviewed publication. However, some studies on gender difference in peer review and publication have reported some contradictory results (Whittaker, 2008; Primack, et al., 2009; Handley et al., 2015). Analysing 1,140 manuscripts submitted to the Journal of Biogeography, Whittaker (2008) found no difference in the acceptance/rejection ratio for male and female authors. Primack, et al. (2009) in a study on a sample of 1856 papers submitted to the journal Biological Conservation between 2004 and 2007 also found no evidence of differences in acceptance rates among genders.

Similarly, in a recent study on the peer review process of the American Fisheries Society journals, Handley et al. (2015) observed a small but statistically significant difference between male and female authors in getting their work published throughout the peer-review process. However, when background variables, other demographics, and stages in the review process were controlled, the difference became non-significant.

Regarding the second aspect, the author's gender and the reviewer's gender, conflicting results have been reported. Some studies have shown that the acceptance rate for manuscripts with female authors was higher when they were reviewed by female reviewers (Ferber and Teiman, 1980; Lloyd, 1990). Whereas other studies have found a similar rate of manuscript acceptance for both female and male authors (Harper and Willis, 1989; Lane and Linden, 2009; Buckley, et al., 2014), when the reviewer was male, or an even higher acceptance rate for female authors (Borja, 2015). Using the reviews of the manuscripts submitted to the North eastern Journal of Agricultural and Resource Economics during 1984-88 for possible publication, Harper and Willis (1989) found a very similar acceptance rate by reviewers for both female and male lead authors. In their study on the manuscripts submitted to the Journal of Neurophysiology during January 1,2007 to June 30, 2007, Lane and Linden (2009) also found the accept rate for papers with female and male authors in first and last authorship positions was not different. Similarly, Buckley et al. (2014) performed a gender analysis of the publication process in the New Zealand Journal of Ecology (NZJE) for manuscripts reviewed between 2003 and 2012. The results of their study showed that publication success was not biased by gender, nor was it related to the gender of the editor.

Studying 190 manuscripts to several Elsevier journals (i.e. Continental Shelf Research, Journal of Sea Research and Marine Pollution Bulletin), Borja (2015) found that female authors obtain significantly higher rates of acceptance than male authors.

Regarding the presence of women on editorial boards, research agrees in the lack of female representation on editorial boards in different academic fields, including management (Metz and Harzing, 2009, 2012; Metz, Harzing and Zyphur 2015), social sciences (Addis and Villa, 2003), STEM fields such as information systems (Cabanac, 2012), medicine (Galley and Colvin, 2013 ; Ioannidou and Rosania, 2015), environmental biology and natural resource management (Cho, et al., 2014) and in all fields of science in Spain (Mauleón et al., 2013). This disparity is often even greater at more senior editorial levels (Addis and Villa, 2003; Mauleón et al., 2013; Fox, et al., 2016).

Overall, the findings with regard to three discussed aspects (differences in manuscript reviewing and publishing, the relationship between the author's gender and the reviewer's gender, and the presence of women on editorial boards) are inconclusive. Possible reasons for the first aspect might be discipline, lack of women on editorial boards, presence of men in authorship teams, etc. Regarding the second aspect, discipline could be a reason. Literature has suggested that bias against women is stronger in male-dominated fields than in female-dominated or neutral fields (Lloyd, 1990). Policies of journals regarding providing the names of authors to reviewers might also be another possible reason.

The reasons for low presence of women on editorial boards could be due to unconscious psychological factors, which results in men being promoted over women (Handelsman, et al., 2005). Due to the absence of institutional support, women tend to be more focused on teaching or clinical activities as opposed to research, resulting in women receiving less scholarly recognition (Buckley, et al., 2000). As a result, fewer women are promoted to senior academic positions and fewer receive the honours and awards which come from scholarly productivity (Ioannidou and Rosania, 2015). Additionally, institutional leadership frequently is influenced by traditional gender roles and expectations, resulting in barriers for the advancement of women (Nonnemaker, 2000).

1.3.2. Access to funding resources

Access to funding is important for success in academic careers, both for women and men, providing essential support for research and publications (Husu and de Cheveigné, 2010). However, the issue of gender and research funding has only attracted substantial attention fairly recently and is still addressed less often in the literature than gendered structures and career dynamics (European Commission, 2009). The literature in this area is globally concerned with the following issues: funding rates (amount of fund awarded), success rates (how successful women and men are in terms of receiving funding) and application behaviour.

With regard to first and second issues, a number of studies have reported gender disparities in favour of men in both the amount of funding awarded (Feldt, 1986; Stack, 2004; Head, et al., 2013) and the success rate in acquiring grant funding (Bailyn, 2008; Van der Lee and Ellemers, 2015). In their study on infectious disease research funding in the United Kingdom, Head et al. (2013) found that women have a lower number of studies funded and receive less funding in absolute and in relative terms. In the European Union, a study of 28 European Union countries found that in 21 countries, women who applied for grants were less successful than men (European Commission, 2009). However, when controlling for factors that correlate with grant success and grant rate including discipline, institution, investigator's experience level, and past research (Hosek et al., 2005), academic rank (Waisbren et al., 2008), and percentage of female applicants (Pohlhause et al., 2011) studies have reported no gender differences. In their study on male and female faculty members at eight Harvard Medical Schools in the United States, Waisbren et al. (2008) found that the grant success rates for men and women were not significantly different, after controlling for academic rank. In their study on outcomes of grant applications submitted to federal agencies by women and men in the United States, Hosek et al. (2005) found that women and men were similarly successful in obtaining the United States National Science Foundation and the United States Department of Agriculture funding, when controlling for discipline, institution, experience, and past research output. Similarly, Pohlhause et al. (2011) found in their study on NIH extramural grants in 2010 that success and funding rates for men and women were not significantly different in most award programs. However, in programs where participation was lower for women than men, funding rates were generally higher for men than for women. They suggested this disparity was primarily related to a lower percentage of women applicants compared to men, rather than decreased success rates or funding rates.

As indicated in Ranga, Gupta and Etzkowitz (2012)'s literature review on funding and gender, studies of funding application behaviour generally addresses the following issues: propensity to apply for grant funding, number of grants applied for, and amount of funding requested. The majority of studies in this area agree that women have a lower propensity to apply for grants, (Hosek, et al., 2005; European Commission, 2009; Pohlhaus, et al., 2011; Boyle, 2015) and that women apply for a smaller numbers of grants and request smaller amounts of money (Blake and La Valle, 2000; Waisbren et al., 2008; Bedi, Van Dam and Munafo, 2011). Pohlhaus' et al. (2011) study have introduced a variety of factors, including family circumstances, self-confidence, and other barriers resulting from gender stereotypes responsible for female's lower application rates and lower amount of funding requested compared to males.

To sum up, the results of studies regarding funding rates and success rates of female and male scholars are varied, depending on discipline, institution, investigator's experience level, past research, academic rank, and percentage of female applicants. Regarding application behaviour, factors such as family circumstances, self-confidence, and gender stereotypes are suggested to be the cause of different behaviour of female and male scholar in the funding application process.

1.3.3. Academic employment

This section first provides an overview of faculty employment and career development in relation to gender in academia and higher education. It then addresses the issue of women in leadership and top level positions. Finally, it deals with the issues of salary and academic work in higher education in relation to gender.

1.3.3.1. Faculty employment and career development

One important aspect related to faculty employment and career development is employment status (e.g. full time, part time). According to different reports, female researchers are generally more likely to work part time (European Commission, 2013). In the European Union, a study of 33 EU countries, conducted by Burri and Aune (2013), showed that in all countries analysed, the share of females in part time employment was higher than that of men. Similarly, in the United States, data from the National Survey of Postsecondary Faculty that was conducted in 1970-2013 by the National Centre for Educational Statistics, found that after four decades of efforts to fully involve women in the academic workforce, only 42% of all fulltime faculty members were women.

Another significant aspect of faculty employment and career development is tenure. According to are port done by the United States National Association for Women in Education (NAWE), although employment for women PhDs has been progressively rising, women are predominantly clustered in the general untenured ranks of assistant professors and lecturers (NAWE, 1997). The results of a survey conducted by the American Chemical Society on the top 50 universities (2001) showed that women currently account for 7% of full professors, and 20% of assistant professors. Similarly, results of a report by American Associations of University Professors (AAUP), conducted by Misra et al. (2011), also indicated that men still hold more than three quarters of full professorships in the United States and women's share of full professorships has increased only marginally in recent decades. They also further indicated that women are less likely to be promoted to full professor than men, and their promotions take longer.

D'Amico et al. (2011), in their study on career status of female and male psychology faculty members in Italian universities, also indicated that women represented two thirds of assistant professors but only one third of full professors. According to the Australian Department of Education and training report in 2014, Australian women held 52.5% of lecturer faculty positions, 53.1% of below lecturer faculty positions, 43% of senior lecturer faculty positions and only 29.9% of above senior lecturer faculty positions. In other words, the higher the rank, the fewer the women. Similarly, according to the latest "She Figures" report published by the European Commission (2015), women continue to be vastly underrepresented in Grade A positions within the Higher Education Sector. Grade A corresponds to full professors or the highest grade/post at which research is normally conducted. In 2013, women made up only 21% of the top-level researchers (grade A), showing very limited progress compared to 2010 (20%).

To sum up, the review of the literature in this section demonstrates that over years, women have not achieved the same status as men in terms of faculty employment and career development. Overall, women are less likely than men to be employed as full-time tenure-track faculty members and to hold tenured or full professor positions.

1.3.3.2. Decision-making and top level positions

In terms of decision making and top level positions, data from the “She Figures 2012” report published by the European Commission (2013) show that only a small proportion of women are at the head of institutions in the Higher Education Sector or in decision making committees. In 2010, on average throughout the EU-27, 15.5 % of institutions in the Higher Education Sector were headed by women and 10 % of universities had a female rector. According to the most recent She Figures report (2015), in 2014, the proportion of women among heads of higher education institutions in the EU-28 rose to 20 % from 15.5 % in the EU-27 in 2010. According to the same report, there is wide variation between individual countries in this area, ranging from 10.2 % in France to 53.8 % in Serbia. This represents an improvement from 2010, where the figures ranged from 5.5 % in Turkey to 31.8 % in Norway. Indeed, whilst 31.8 % was the highest proportion observed in 2010, there are now five countries – namely Denmark, Norway, Iceland, Sweden and Serbia – which have surpassed this figure, indicating that there has been a shift towards rectifying the under-representation of women as heads of institutions.

Similar, findings with regard to the low representation of women in senior position (e.g. leader, president, provost, rector) have also been documented in different countries and in divergent cultural and geopolitical contexts (Morley et al. 2006; Singh, 2002, 2008; Bilen-Green, Froelich, and Jacobson, 2008).

The most recent publication of the Association of Commonwealth universities reports that in 70% of Commonwealth countries, all universities were led by men in 2007. Furthermore, the participation of women in leadership in Commonwealth universities has remained stable for a decade and only one in ten Vice Chancellors or Presidents of Commonwealth universities has been female (Singh, 2008).

In their study on proportion of women in senior academic leadership positions in doctoral granting institutions in the United States, Bilen-Green, Froelich, and Jacobson (2008) found that27research institutions (13.5%) out of the 200 studied were led by women presidents, and that forty seven institutions (23.5%) had women provosts.

Overall, the literature shows a gender gap in terms of senior and top level positions in academia in favour of men, despite some improvements and growth in the proportion of women in this area over years.

1.3.3.3. Salary

Numerous scholars have addressed the issue of gender salary gap in the academic profession (Ward, 2001; Ginther, 2003, 2004; Takahashi and Takahashi, 2011; Takahashi, Takahashi and Maloney, 2015). Using a data set of 900 academics from five traditional Scottish Universities, Ward (2001) examined gender salary gap in the academic labour market. The results revealed that male academics experience a 7.7% salary advantage over female academics. However, controlling for rank, this differential reduced to just over 3%, which was no longer significant. Using a 1973-1997 survey of Doctorate Recipients in the Massachusetts Institute of Technology (MIT), Ginther (2003) evaluated gender differences in salaries in the sciences (STEM, biology, physics). The data showed a persistent salary gap between male and female science academics over time. However, in another study done by Ginther (2004), using data from the Survey of Earned Doctorates (SED) and the Survey of Doctorate Recipients (SDR), the gender salary gap in political science was small and almost entirely explained by differences in observable characteristics (such as academic rank and differences in productivity) of faculty members.

In a study conducted on Economics Departments in Japan regarding the gender salary differences, Takahashi and Takahashi (2011) found a 7% gender salary gap and no promotion differences. In addition, the results showed no evidence that the gender salary gap is reducing over time. Using original survey data on Japanese academics in science and engineering, Takahashi et al. (2015) examined gender salary gap. They found a 6% gender salary gap after controlling for ranks. This gap was persistent even after controlling the quality and quantity of publications. In the United Kingdom, according to the Higher Education Statistics Agency report (2015), female academics lose out in the pay stakes with 19% mean gender pay gap over the United Kingdom as a whole. This mean gender pay gap rises to 21.6% in Scotland, 19.7% in Wales and 20.6% in Northern Ireland. It is 18.6% in England.

Globally, what can be inferred from the above-mentioned literature is that some variables such as academic rank, publication productivity, discipline and country might lead in different results with regard to gender salary gap.

1.3.3.4. Academic work

The final aspect with regard to academic employment is gender differences in academic work. Traditionally, the work of faculty members consists of teaching, research and scholarship, and various forms of service (Curtis, 2011). Faculty service includes attending committee meetings, answering e-mail queries from students and colleagues, consulting, and scheduling lecture series and conferences (Ward, 2003).

Numerous studies have indicated that women faculty members spend a greater proportion of their time on teaching than men, specifically in relation to undergraduate teaching and student advising. They also spend more time on service, whether as part of departmental or institutional committees or outside organizations (Russell, 1991; Park, 1996; Toutkoushian and Bellas, 1999; Bradburn and Sikora, 2002; Association of University Teachers, 2004, Porter, 2008; DesRoches et al., 2010; Curtis, 2011; Misra et al., 2011; Olinto and Leta, 2011).

In a survey of 11,013 full and part time faculty members in 450 colleges and universities in the United States, Russell (1991) found that on average, men spent a higher percentage of time on research activities, while women spent a higher percentage of time in teaching and service activities.

A study by the Association of University Teachers (AUT) (2004) in the United Kingdom has also argued that ‘institutionalized sexism’ is denying female academics recognition for the research activity, which is vital to their career prospects. Men in some universities are up to five times more likely to be classified as ‘research-active’ and participate in the research assessment exercise compared with their female colleagues.

In a survey of 3,080 life sciences faculty members at the 50 universities in the United States, DesRoches et al. (2010) also demonstrated that men and women have somewhat different jobs, especially once they become full professors. Compared with male full professors, female full professors worked more hours overall and spent significantly more time in administrative and professional activities, and less time conducting research.

In a survey of 350 faculty members at the University of Massachusetts, Amherst (United States), conducted in 2008–2009, Misra et al. (2011) found that the work trends differed by gender, suggesting that women felt particularly pressured by the demands of service, mentoring, and teaching. Olinto and Leta (2011)’s study on gender differences in teaching and research activities in Brazilian universities showed that women receive a larger share of teaching assignments which might jeopardize their involvement with research.

Overall, the above mentioned studies demonstrate a persistent gender gap over years with regard to academic work as women academics have spent greater proportion of their time on teaching and service rather than research activities. Moreover, this gap also seems to be persistent in different countries.

1.4. Factors accounting for gender differences in science and higher education

As the review of literature on the previous two groups of studies on women in science and higher education suggests (publication productivity and other issues related to gender in science and academia) different studies have reported diverse results. Hence, numerous studies have sought to explain the systematic disparities between men and women by incorporating different factors into their analysis. Thus, this section provides an overview of the literature on the explanatory factors that account for these inconsistent findings and the gender gap.

1.4.1. Family-related factors

The focus of this section is on two main issues of family-related factors: the presence of children and marital status. In terms of children and faculty's role as parents, several authors have underlined the fact that having children has an adverse impact on the productivity of women (Hargens, McCann, and Reskin, 1978; Long, Allison, McGinnis, 1993; Bentley, 2003; Prozesky, 2008; Mason, Goulden and Frasch, 2009; Hunter and Leahey, 2010). As indicated in Hargens et al., (1978) study on research chemists in the United States, rearing children takes a considerable amount of time and effort, potentially reducing the amount of time and energy devoted to scholarship, which could diminish professional performance in terms of productivity or visibility. Bentley (2003) also noted that women faculty members are placed at a particular disadvantage by family responsibilities during child-rearing years, which negatively affects career advancement and hence earnings of women faculty members. Using data from the Survey of Doctorate Recipients, Mason et al. (2009) found that women who have children within 5 years of PhD receipt are less likely to have tenure than either men or women who delay or forsake child birth. Hunter and Leahey (2010) also analysed the effects of children on the entire careers of female and male academics in two disciplines of linguistics and sociology in research universities in the United States. Their finding suggests that children account for part of the productivity gender gap in sociology and linguistics. They indicated this not surprising finding – that children have a more negative effect for women's rate of publication growth – is due to typical division of labour in the home. Moreover, the demanding family–work balancing activities that academics, particularly women, feel necessary to perform, may be more challenging as a career progresses. This consequently contributes to women's stagnating productivity growth rates.

However, considering the ages of children, some studies have found that having children may or may not reduce research productivity (Kyvik, 1990; Kyvik and Teigen, 1996; Stack, 2004; Fox, 2005; Abramo et al., 2009; Krapf, Ursprung, and Zimmermann, 2014). This is because children of different ages demand different amounts of time and energy from their parents (Hunter and Leahy, 2010). In a sample of all academic fields, Kyvik (1990) found that women with children are more productive than women without children, but the age of the children matters. In comparison with men, women with young children are less productive than their male counterparts, but women whose children are aged 10 years or older are just as productive as men in the same family situation and academic position (Kyvik, 1990; Kyvik and Teigen, 1996). A reasonable explanation to this might be that women take more responsibility than their male colleagues for preschool and early school-age children. Similarly, in a sample of PhD recipients in science (including social science) and engineering, Stack (2004) found that female scientists with pre-school children were less productive than other scientists, even women with multiple children in other age ranges. He suggested that as young children require more parental attention than older children, we would expect that the influence of young children might have the strongest negative impact on productivity.

In contrast to previous studies, Fox (2005) found that women engineers and scientists with pre-school children are more productive than their childless counterparts or women with school-age children. Pursuing the factors that may be associated with this finding, she suggested that women scientists with pre-school children are socially selective in terms of marriage, family patterns, research interests and allocation of time. Additionally, they allocate more time in research-related activities and less in non-research-related activities. Almost one decade after, Krapf et al. (2014) conducted a research on the effect of pregnancy and parenthood on the research productivity of nearly 10,000 highly skilled academic economists who registered in RePEc (Research Papers in Economics) database. Their findings revealed that mothers of at least two children are, on average, more productive than mothers of only one child, and mothers in general are more productive than childless women. There are dips in productivity when the children are very young, but if we consider the whole career of the person, then on average, the person (with at least two children) is doing better. They associated this finding to planned motherhood. In other words, woman who aspires to an academic career and wishes to have children will certainly plan ahead and try to optimize the timing of her professional and family-related actions.

Regarding marital status, mixed results have also been reported. Some previous studies reported the positive effect of marriage on the scientific and academic performance of both female and male academics (Luukkonen-Gronow and Stolte-Heiskanen, 1983; Long, 1990), whereas some current studies reported the positive effect of marriage only on female academics (Aiston and Jung, 2015; Juraqulova, Byington and Kmec, 2015).

In their survey of a sample of Finnish scientists, Luukkonen-Gronow and Stolte-Heiskanen (1983) found that being married is positively correlated to being productive, for both women and men. In a study on a sample of female and male academics who received a PhD in biochemistry, Long (1990) found that marriage correlated positively to research productivity of both female and male scientists.

Using Changing Academic Profession (CAP) survey data for five countries, Aiston and Jung (2015) in a recent study found that married academic women are more productive than single academic women on average. Using data from a survey of 9,000 full-time faculty members from 13 leading U.S. research universities, Juraqulova et al. (2015) examined how the perception of marriage impacts academics' career success of faculty members in STEM and non-STEM fields. They found that women in both fields reported higher perceptions of perceived gains in professional productivity and involvement due to marriage compared to their male counterparts.

Nevertheless, some other studies have found a positive relation between marriage and scientific impact of male academics only (Prpić, 2002; Hancock and Baum, 2010). Studying a sample of 840 young scientists in Croatia, Prpić (2002) showed that men receive the greater share of the benefit due to the presence of a spouse. Similarly, in their survey of roughly 5,000 assistant professors from 80 countries, Hancock and Baum (2010) found that overall marriage provides a greater productivity boost to men than women.

Another group of studies have reported a negative or no relationship between marriage and productivity and academic performance of female academics (Sax, et al., 2002; Ginther, 2006; Wolfinger, Mason and Goulden, 2008). Using data from the Survey of Doctorate Recipients (SDR), Ginther (2006) studied tenure track science and social science faculty members. The result of the study showed that unmarried women were significantly more likely to have tenure track jobs than unmarried men. Using longitudinal data from the 1981-1995 Surveys of Doctorate Recipients, Wolfinger, et al. (2008) also found that marriage presents a barrier to securing ladder-rank employment for women. Compared to a married man, a married woman has 12% lower odds of getting an academic job. Results of the study of Sax et al. (2002) on 8,544 full-time teaching faculty members in the United States indicated that marital status appeared not to be related to women's level of research productivity.

Summing up the literature on family-related factors (i.e. presence of children and marital status), it can be concluded that these variables have different effect on research productivity of both female and male scholars depending on the age of children, allocation of time, context (country, discipline, and time frame under study) and planned motherhood. There are also some other factors such as policies and programs of countries regarding maternity leave, child-care, having access to kindergarten or care mothers, work-life balance as well as level of income that might have an effect on the relation between parental and marital status and the level of productivity.

1.4.2. Institutional factors

Institutional factors are those practices, policies and conditions that have a role in the success or failure of both female and male academics' career advancement within a university setting (National Academy of Science, 2007; Robinson, 2012). These factors that have been examined in different studies include institutional culture [climate] (Settles et al., 2006; Shollen, et al., 2009; Riffle et al., 2013), access to networks, senior mentors and role models (Bagilhole, 1993; Bagilhole and Goode, 2001; Gardiner et al., 2007), and access to institutional resources (Keith et al., 2002; Ceci and Williams, 2011), among others.

In regards to university culture, there is some evidence which suggests the existence of a normative masculinist culture within academia that can disadvantage women (Wolffensberger, 1993; Willemsen, 2002; Chliwniak, 1997; Riley et al., 2006; Bagilhole et al., 2008). Willemsen (2002) found that while management in organizations is represented as gender neutral, it often involves practices that are consistent with characteristics traditionally valued in men. Riley et al. (2006) also indicated that the reason for low participation of female academics in *The Psychologist* journal arises out of a combination of the sexism cultures of academia and psychology. Similarly, in their literature review on the cultures of Science, Engineering and Technology (SET) in the United Kingdom, Bagilhole et al. (2008) indicated that SET cultures make it difficult for women with children to succeed. They mentioned the reasons to this are: first, the lack of suitable policies to support working mothers, second, and the fact that success in SET is measured against traditionally masculine norms. In other words, the successful SET professionals are not perceived as feminine or to possess supposedly feminine qualities.

The importance of mentors and role models in academic advancement for both male and female professionals has been indicated in several studies (Levinson, et al., 1991; Fried and MacCleave, 2010; National Research Council, 2010; Drury, Siy, and Cheryan, 2011). Some scholars use the term role model interchangeably with mentor (Crow and Matthews, 1998; Dixon-Reeves, 2003). However, other authors argue that role modelling is very different from academic mentors—role model is someone you wish to emulate (and may or may not have a personal relationship with), while mentor is an individual with whom you have a more personal relationship that is useful for career advancement (Johnson, Rose, and Schlosser, 2007; Sugimoto, 2009). Thus, academic mentoring relationship is a reciprocal and mutual relationship between mentor and mentee (protégé) in which mentors provides career assistance, social support, emotional support, and serve as role model to protégé to facilitate his/her advancement (Johnson, 2007).

The results of a major study done by Levinson et al. (1991) showed that women with mentors and role models have more publications in peer-review journals, spend more time on research, and have greater career satisfaction than women without mentors. This study was conducted by analysing the result of a survey of 558 full-time female faculty members, aged 50 years and younger, in departments of medicine in the United States. Some years later, the National Research Council's committee in charge of the Gender Differences report (2010) also indicated that female academics (at both assistant and associate ranks) who had a mentor did better in terms of receiving funding than females without one. Regarding male academics the results showed that, while male associate professors with mentor had slightly higher success rate in terms of grant funding, male assistant professors without mentor were more successful. They reached this conclusion by analysing the results of two national surveys, taken in 2004 and 2005, of tenure-track and tenured faculty members in six fields (biology, chemistry, mathematics, civil engineering, electrical engineering, and physics) at 89 U.S. research universities.

Nonetheless, as female academics are less likely to have access to networks and senior mentors, they have little chance of progressing in the same way as men (Bagilhole and Goode, 2001). This leaves women professionally and socially isolated, and makes it difficult to them to stay informed about professional matters and relevant information within the organization (Bagilhole, 1993; Gardiner, et al., 2007).

Access to institutional resources and facilities is another institutional factor that has an effect on the academic performance of both female and male academics according to several studies (Strebler, Thompson and Heron, 1997; Keith et al., 2002; National Academy of Sciences, 2010; Ceci and Williams, 2011). According to the report of the National Academy of Sciences (2010) in the United States, the reason for a higher productivity of women science and engineering faculty over the last 30 years is having access to institutional resources. Ceci and Williams (2011) also indicated that women are as successful at publishing as men, when comparisons are made between men and women with similar resources and characteristics (e.g. type of institution, access to funding and resources, tenure, teaching load).

1.4.3. Socio-cultural factors

Socio-cultural factors have been identified as significant constraints to women pursuing academic careers (Steinke, 1997; Shin and Bang, 2013). Stereotypes and socio-cultural beliefs about women's roles and abilities are also among the important socio-cultural factors that have been addressed by several studies (Smith, Sansone and White, 2007; Bagilhole, 2008; Schmidt and Møller, 2011; Cheyran, Master and Meltzoff, 2015). GenSET[1] briefing material on gender stereotypes and attitudes in assessment of women's work (2011) points to stereotypes as an important factor constraining the equitable contribution and participation of men and women in science and research, especially in terms of decision making power.

[1]. GenSET is an innovative project aiming to improve the excellence of European science through inclusion of the gender dimension in research and science knowledge making.

According to Smith et al. (2007), existence of negative gender stereotypes can lead to changes in women's perceptions about their ability and competence in science and can further lead to poorer performance, even when women are highly capable of succeeding in these areas. In a study done by Schmidt and Møller (2011), stereotypic beliefs were found to be a barrier for women to ascend to senior management. Several studies have also associated the underrepresentation of women in the traditional male fields of science, technology, engineering, and Mathematics (STEM) to gender stereotyping (Stake, 2003; Suter; 2006; Bagilhole, 2008; American Association of University Women, 2010; Cheyran, et al., 2015). Suter (2006) argued that stereotypes deter women from careers in STEM fields because many believe these fields to be more related to male than female characteristics. The American Association of University Women report (AAUW) (2010) also noted that women undergraduates are much less likely to major in STEM compared to their male counterparts due to negative stereotypes about females in STEM studies and cultural aspects of the society. In their study on the students who majored in the fields of computer science and engineering in the United States, Cheyran et al. (2015) also proposed that stereotypes about the culture of these fields, drives girls away from these fields and constrains their learning opportunities and career aspirations.

1.4.4. Behavioural factors

Regarding behavioural and attitudinal factors, some research indicates that women's attitudes and lack of confidence to succeed often leads to making decisions that affect their career prospects (Sonnert and Holton, 1995; Blanch, Hall and Roter, 2008; Sax, 2008).

In their study on high-achieving men and women scientists, Sonnert and Holton (1995) found that more men considered their scientific ability to be above average and more women considered their ability to be average. Similar results were also found in terms of self-evaluation of technical skills. The result of a literature survey by Blanch et al. (2008) showed that while there is no consistent gender difference in academic performance, female medical students tend to underestimate their abilities while males tend to overestimate theirs. Sax (2008) also reported that women express lower levels of academic confidence than their male peers even when their demonstrated academic abilities are equal to that of for men. The study was done based data from a sample of approximately 17,000 male and female students from 200 institutions in the United States.

According to Shin and Bang (2013), women are less likely to promote themselves; when they are successful, they are more likely to credit the team or circumstance, and when they fail, they are more likely to blame themselves.

Chapter 2. Objectives

Chapter 2. Objectives

2.1. Main objectives

To reach the aim of the thesis, to assess and map international research concerning women in science and higher education, the following two main objectives are addressed in two different studies, called Study 1 and Study 2:

- First, to examine the development and growth of scientific literature on women in science and higher education (Study 1).
- Second, to identify the major research topics in this area, with a special focus on explanatory factors accounting for gender differences in science and higher education (Study 2).

2.2. Specific objectives

To reach these main research objectives, this thesis more specifically seeks to investigate the following objectives:

Regarding the first main objective, this thesis more specifically examines:

- The scientific growth of the literature on women in science and higher education over time. This will provide a global understanding of how the scientific contribution to and interest in the studied field has changed over years.

- The contribution of different research areas to the area of women in science and higher education. This will help us to investigate the relevance and importance of the studied area among different research areas as well as its degree of multidisciplinarity. Furthermore, it will allow us to identify top research areas contributed to the studied field.

- Author productivity. This will enable us to detect the highly productive authors in the studied field. Furthermore, it will help to study the evolution of the number of authors per paper over time, which is an indicator of the collaboration efforts in the studied field.

- Relative publication productivity by country. It will provide insights into the country's position in terms of publication productivity in the studied field relative to global research production.

- International publication productivity by country. It will illustrate the importance and relevance of the studied field among countries and thereby their scientific contribution at international level.

- The relationship between the publication productivity of countries and their level of gender equality. It will give us a global understanding of the interest and scientific contribution of different countries in the studied field in association with their level of development in gender equality.

- The dispersion of scientific output across journals. It will help us to investigate the distribution, relevance and interest of the studied field across journals of different disciplines.

Regarding the second main objective, which is thematic evolution of factors accounting for gender differences, this thesis more specifically examines:

- The evolution of the number of documents addressing those factors across three consecutive sub-periods. The number of documents as the indicator of performance analysis will allow us to measure the importance and interest of the studied field as well as its growth over time.

- The evolution of the number of themes and main concepts addressing those factors across three consecutive sub-periods. This performance analysis will allow us to track the growth of the sub-fields (themes) over time thereby providing a global understanding of the diversification and specialization of the studied field.

- The evolution of main themes and concepts addressed with regard to those factors across three consecutive sub-periods. This will help us to show the relationships between sub-fields (themes) across sub-periods. Additionally, this will allow to detect the most prominent themes as well as the themes less addressed at different time periods. The later will provide insight into possible gaps in the literature.

Chapter 3. Research on women in science and higher education: a bibliometric analysis (Study 1)

Chapter 3. Research on women in science and higher education: a bibliometric analysis

Using standard bibliometric indicators (such as the number of papers and authors, and productivity by country, among others), laws (Price's, Lotka's, and Bradford's laws) and an index for measuring gender disparity [the Gender Inequality Index (GII)], this chapter investigates the development and growth of research in the field of women in science and higher education by reviewing the related scientific literature. In other words, this chapter presents methods used for data collection and data analysis, sources used, as well as results, conclusions and discussion of Study 1.

3.1. Data collection and processing

A total of 1415 articles and reviews published between 1991 and 2012 were extracted from the Thomson Reuters Web of Science database. Several strategies were used to retrieve the related scientific literature (Fig. 1). First, three different searches were carried out, taking into account the three main topics in the field: publication productivity, impact and collaboration patterns, issues related to gender in academia and science, and factors accounting for gender differences.

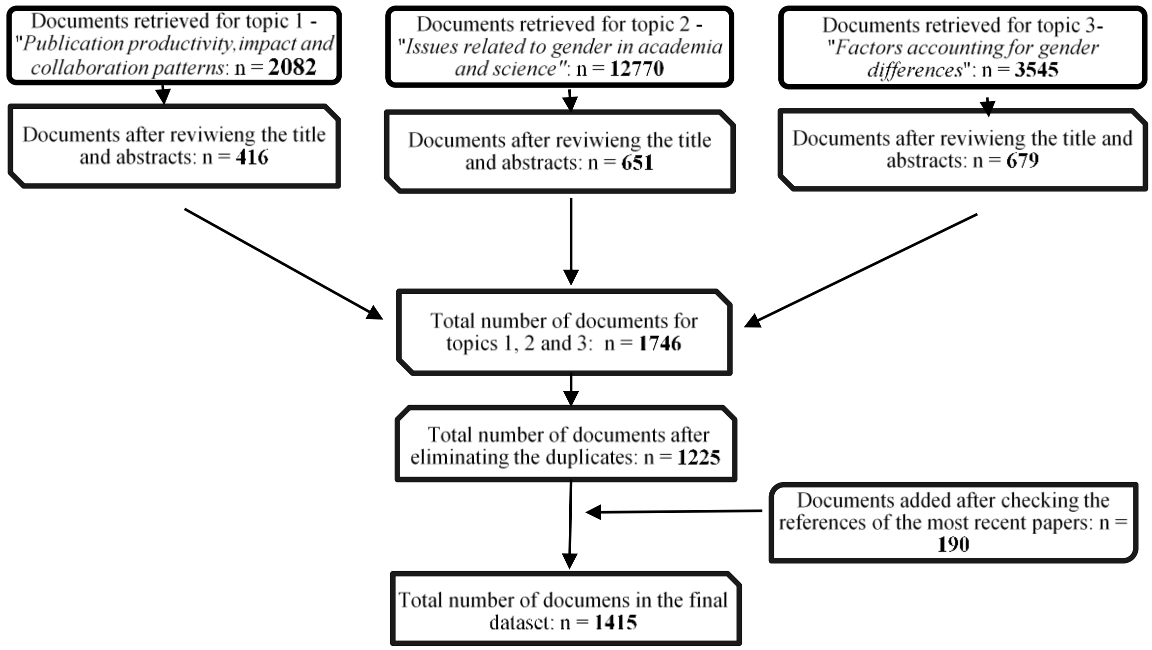

Fig. 1 Flowchart illustrating the process of data collection for Study 1

To do so, for each topic we went through the related literature in order to identify the related key terms. A preliminary combination of key terms was used to extract the papers related to the subject. Next, after reviewing the keywords of these preliminary papers, we added more specific terms to the query in order to check whether these new terms increased the number of records retrieved; if they did, they were included in the query, and if not, they were eliminated. A summary of these key terms is presented in Table 1. It should be considered that wildcards and truncation were used in the search strategy.

Table 1 A summary of common key terms extracted from the literature on women in science and higher education referring to each term in the conducted search strategy

Term	*Referring key terms*
Higher education and science	Academia, university, scientific community, science career, science organization, science institution, research institution, research
Gender	Gender studies, gender, women , men , female , male , sex
Publication productivity, impact and collaboration patterns	Bibliometrics, scientometrics, informetrics, webometrics, scientific (publication) productivity, collaboration, citation, publication (performance), impact factor, H-index, authorship, author(ship) order (position)
Factors accounting for gender differences	Behavioural (individual) characteristic, family, marital status, parenting, parenthood, motherhood, marriage, maternity, children, child rearing, (masculinist) culture (climate), societal norms, stereotypes, sexism, glass-ceiling, leaky pipeline, sticky floor, nepotism, mentor, role model
Issues related to gender in academia and science	(Academic) Employment, career development, tenure, teaching load, manuscript reviewing, peer review, fellowship, grant, scholarship, fund, editorial board, top level(senior, leading) position, rector, president, decision making, salary, payment

In order to retrieve the related records on first topic i.e. *Publication Productivity, impact and collaboration patterns* a combination of the following three groups of terms were used in the topic field of the Web of Science:

(Publication Productivity, impact and collaboration patterns)*, (*Higher Education and Science)* and *Gender

For the second topic i.e. *Issues related to gender in academia and science,* the combination of the three following groups of terms was used:

(Issues related to gender in academia and science), (Higher Education and Science)* and *Gender

Finally for the third topic i.e. *factors accounting for gender differences*, the combination of the three following groups of terms was used:

(Factors accounting for gender differences),* (*Higher Education and Science)* and *Gender

As a result of this step, 2,082 records were initially retrieved for the first topic, 12,770 for the second topic and 3,545 for the third topic. Titles and abstracts from these three pools of papers were then checked one by one to find related records. As a result of this step, a total of 1,746 papers were retrieved: 416 (23.83%) records for the publication productivity, impact and collaboration patterns topic, 651 (37.29%) records for the issues related to gender in academia and science topic, and 679 (38.88%) records for the factors accounting for gender differences topic. After elimination of duplicates a total of 1,225 records were considered. Additionally, and in order to ensure that all the references dealing with the subject were included in the database, the references of the most recent papers were checked. If any new paper was found it was added to the database. We continued doing this until no new references were identified. This process led to the inclusion of 190 new papers. As a result the final corpus comprised 1,415 articles and reviews, all of which were coded according to the three topics mentioned above. It should be noted that any given paper may simultaneously address more than one issue, and it will therefore belong to more than one group.

3.2. Data analysis and statistical procedures

The main bibliometric laws were applied to study scientific growth over time, the dispersion of scientific output across journals, and author productivity.

Scientific growth over time was assessed using Price's law (Price, 1963), which proposes that the growth of scientific production follows an exponential function. In order to test whether our data followed Price's law, different regression models were fitted, including linear, exponential and logistic curves, the latter being applied to assess the hypothesis of literature growth saturation.

Bradford's law (Bradford, 1934, 1948) was applied in order to study the dispersion of the literature. Specifically, Bradford's law describes how the articles in a specific area are scattered across journals, postulating a model of concentric productivity zones with a decreasing information density. Following the proposal of Egghe (1986, 1990), the Bradford multiplier was obtained by $K = (1.781 \cdot y_m)^{1/P}$ where y_m is the number of articles published by the most productive journal and P is the number of zones including the core. The estimated k value for each zone was calculated by the ratio between the number of journals in a given zone and the number of journals in any immediate zone. The number of Bradford zones was determined by the solution that minimized the difference between the Bradford multiplier k

and each estimated value of k, and between the estimated values of k. In addition, the predicted frequencies were fitted according to Leimkuhler's formulation (Leimkuhler, 1967), obtaining the constants as $\mathrm{A} = \mathrm{y}_0/\log_{\mathrm{e}}\mathrm{k}$ and $\mathrm{B} = (\mathrm{k}-1)/\mathrm{r}_0$ where y_0 is the constant number of articles in each group ($\mathrm{y}_{0=\mathrm{a}/\mathrm{P}}$, where a is the total number of articles and both P and k are as defined above) and r_0 is the expected number of journals in the core ($\mathrm{r}_0 = \frac{\mathrm{T(K-1)}}{\mathrm{k^p-1}}$ where T is the total number of journals, and k and Pare as defined above). The estimated cumulative number of articles produced by the journals of rank 1, 2…r was obtained by: $R(r) = A \cdot \log_e(1 + B \cdot r)$.

After standardization of authors' names (we began with a total of 3,538 authors and after standardization we ended with a total of 3,064 single authors), Lotka's law was also applied using the method proposed by Pao (1985), including both the first author and co-authors in the analysis. According to Lotka's law the number of authors (y_x) with x number of articles is inversely proportional to x. This relationship is expressed by the formula:

$$x^n \cdot y_x = C,$$

where y_x is the number of authors producing x number of articles in a given research field, and C and n are constants that can be calculated from the observed data set.

We used the least-squares method in order to calculate the n exponent, using the following formula:

$$N = \frac{N \sum XY - \sum X \ \sum Y}{N \sum \mathrm{X}^2 - (\sum \mathrm{X})^2}$$

where N is the number of pairs considered, X is the logarithm of x and Y is the logarithm of y_x. The constant C is calculated using the formula:

$$C = \frac{1}{\sum (1/x^n)}$$

In addition, and in order to verify that the observed data fitted the estimated distribution, the non-parametric Kolmogorov–Smirnov goodness-of-fit test was applied.

In order to calculate relative measures of productivity and international collaboration productivity by country, the Relative Intensity Index (RII) (Larivière et al., 2013 a, b) and the International Collaboration Relative Intensity Index (IC-RII) were calculated for each country. Both measures indicate the relative proportion of publications of a given country in a domain relative to the proportion of the world in the same domain. Thus, the RII indicates the relative proportion of publications of a given country in the women in science and higher education (WSHE) area relative to the proportion of the world in the same domain. The RII was calculated for each country using the following formula:

$$RII = \frac{\dfrac{nWSHE_{country}}{n_{country}}}{\dfrac{nWSHE_{World}}{n_{World}}}$$

Where $nWSHE_{country}$ is the number of publications of a given country in the WSHE area, $n_{Country}$ is the total number of publications of the country in all disciplines, $nWSHE_{World}$ is the total publications of the world dealing with WSHE, and n_{World} is the total of publications in all disciplines in the world.

The IC-RII indicates the relative proportion of publications of a country in the WSHE area in international collaboration relative to the proportion of the world's publications published through international collaboration in the same area. The IC-RII is expressed by the formula:

$$RII = \frac{\frac{nIC\_WSHE_{country}}{nIC\_{country}}}{\frac{nIC\_WSHE_{World}}{nIC\_{World}}}$$

Where all terms have the same meaning as above except this time publications include only those carried out through international collaboration.

In both cases a value above 1 means that an observed country publishes more in the domain than would be expected, while an index value below 1 indicates the opposite. It is worth saying that by ''World'' in our study we mean just those countries which contributed to the publication productivity in WSHE, while by the number of papers we mean the number of scientific papers by authors from a given country, as indicated in the address field. To do so, we used the full counting method. In other words, each paper is counted once for each country listed in the address field. For example if a paper is authored by two researchers from Germany and one from Spain, this paper is counted once for each country.

Finally, with the aim of exploring the existence of a possible relationship between the interest of different countries in that topic and the existence of a broad spectrum of gender inequalities in these countries, the most recent GII[2], at the time our study was conducted, was considered. GII is an index for measuring gender disparity that was introduced in the 2010 Human Development Report (20th anniversary edition) of the United Nations Development Program (UNDP). According to the UNDP (2013), this index is a composite measure which yields insights, within the same country, about gender gaps in major areas of human development. It uses three dimensions to do so: reproductive health, measured by maternal mortality ratio and adolescent birth rates; empowerment, measured by proportion of parliamentary seats occupied by females and proportion of adult females and males aged 25 years and older with at least some secondary education; and labour market participation measured by employment rates of female and male populations aged 15 years and older. The GII values range between 0 to 1, where a value close to 0 means equality between genders and a value close to 1 means inequality.

[2]. By the most recent GII, in this thesis, we refer to the GII which was available at the time the study conducted, which was the end of year 2013.

3.3. Results

3.3.1. Number of papers

Data showed an upward trend in the percentage of publications, 52.29% of which appeared in the last 7 years (2006–2012). The linear, exponential, and logistic regression models were fitted in order to test whether the data followed Price's law. Although all three regression models were statistically significant and captured a high proportion of the explained variance, the exponential model (R^2 = .834) explained a higher proportion of the variance than did either the linear (R^2 = .707) or logistic (R^2 = .578) approaches, showing a good fit to Price's law (Fig. 2).

An upward trend was also observed in the three main topics of the field. Table 2 shows the frequency, percentage, and regression fit for the three topics. As can be seen from the table, the research line with the highest frequency of papers was "Issues related to gender in academia and science". Furthermore, all the topics showed a good fit to the exponential model.

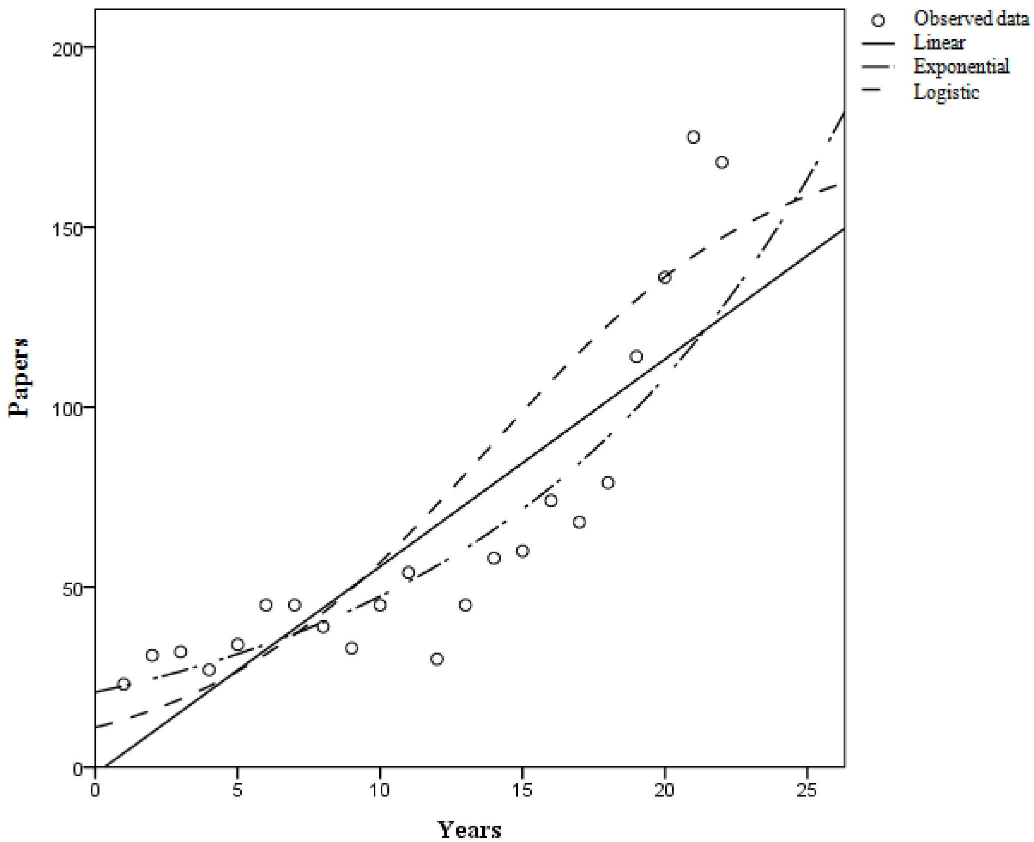

Fig. 2 Growth of literature over time (1991–2012): linear, exponential and logistic regression model fit to Price's law

Table 2 Growth of literature over time (1991–2012) by topic: publication frequency and regression fit

Topic	*fi (%)*[a]	R^2 *linear*	R^2 *exponential*	R^2 *logistic*
1. Publication productivity, impact and collaboration patterns	275 (19.43)	0.597	0.677	0.578
2. Issues related to gender in academia and science	943 (66.64)	0.708	0.779	0.596
3. Factors accounting for gender differences	438 (30.95)	0.657	0.726	0.581

Note: fi frequency
[a] Note that a given paper may simultaneously address different topics. Consequently, the sum of papers is more than the total number of papers, and the sum of percentages exceeds 100%

3.3.2. Research areas

According to the classification of journal areas used in Thomson Reuters WOS, the top ten research areas in terms of frequency of papers were Education and Educational Research (n = 71, 18.3%), Psychology (n = 237, 11.7%), Information Science and Library Science (n = 212, 10.5 %), Business and Economics (n = 167, 8.2%), Women's Studies (n = 165, 8.1%), Computer Science (n = 95, 4.7%), Sociology (n = 93, 4.6%), General and Internal Medicine (n = 63, 3.1%), Health Care Sciences and Services (n = 58, 2.9%), and, finally, Science and Technology—Other Topics (n = 53, 2.6%). Figure 3 shows the contribution of these top ten research areas in the three topics. Information Science and Library Science was the research area with the highest number of publications (n = 90, 30.41%) in topic 1 followed by Computer Science (n = 48, 20.61%).

Education and Educational Research and Psychology were the research areas with the highest number of publications in topics 2 and 3. Education and Educational Research corresponds respectively to 27.03% (n = 276) of publications in topic 2 and 28.45% (n = 132) in topic 3, while Psychology corresponds respectively to 14.99% (n = 153) of publications in topic 2 and 20.26% (n = 94) in topic 3.

3.3.3. Number of authors

The total number of authors who contributed to the output set was 3064, with the mean number of authors per article being 2.41 (SD = 1.60, M = 2). The data showed that 477 (33.71%) of the papers had a single author, 398 (28.12%) had two, 266 (18.79%) had three, and 274 (19.36%) had more than three authors. It can be seen in Fig. 4 that the number of papers with a single author showed a decreasing trend, whereas the number of papers with three authors and with more than three authors increased slightly over time. Over the same period there was a fluctuation in the number of papers with two authors.

With regard to the productivity of authors the data showed that 2750 (89.75%) of them contributed with just one item to the field. Lotka's law was applied using the method proposed by Pao (1985), and all the authors of publications (first authors and collaborators) were considered for the analysis. To determine whether the data fitted Lotka's law, the n value was calculated using the least squares method (n = 3.40), yielding a C value of 0.88. The critical value obtained by the non-parametric Kolmogorov–Smirnov goodness of-fit test was 0.029. As the maximum difference between the observed and the estimated accumulated frequencies was 0.014, which is below the critical value, we can conclude that the data fitted Lotka's law.

3.3.4. Countries

Sixty-seven countries participated in publishing the set of studies, although it should be noted that the provenance of authors was not available for 204 papers (14.4%). Only 8% (n = 113) of papers involved international collaboration and of these, 22.12% (n = 25) were published recently (in 2012). The top ten countries in terms of absolute contributions, RII, and IC-RII are shown in descending order in Table 3.

While the United States and United Kingdom are the most productive countries in terms of absolute contributions, Nicaragua and Botswana, based on the RII, are the countries that showed the highest proportion of publications in WSHE relative to the proportion of the world in the same area. Taking into account just those papers published in international collaboration, based on the IC-RII, Sudan, Nepal and Ghana are the countries with the highest international collaboration productivity.

Interestingly, a significant positive correlation coefficient was obtained between the most recent GII and the RII (r = .277, p = .029) and the IC-RII (r = .497, p = .001), showing that countries that present higher gender inequalities present higher relative productivity related to the topic as well as higher levels of international collaboration productivity. As the GII was not available for five countries, only 62 countries were considered in the analysis of the above-mentioned correlations.

Table 3 Top ten countries based on absolute contributions, relative intensity index (RII), and international collaboration relative intensity index (IC-RII)

Country	*fi* (%)	Country	RII	Country	IC-RII
USA	638 (45.08)	Nicaragua	20.94	Sudan	35.33
UK	126 (8.90)	Botswana	6.24	Nepal	24.69
Canada	70 (4.94)	Sudan	5.47	Ghana	21.39
Australia	63 (4.45)	Cyprus	4.86	Philippines	18.02
Spain	57 (4.02)	Nepal	4.5	Luxembourg	17.65
Germany	41 (2.89)	Lebanon	3.83	Cyprus	15.18
Netherlands	29 (2.04)	Luxembourg	3.54	Lebanon	14.41
Sweden	29 (2.04)	Ghana	3.21	Malaysia	14.39
China	20 (1.41)	Philippines	3.03	Bangladesh	9.09
Brazil/Italy/Turkey	17 (1.20)	SriLanka	2.93	Turkey	6.78

Note: fi frequency

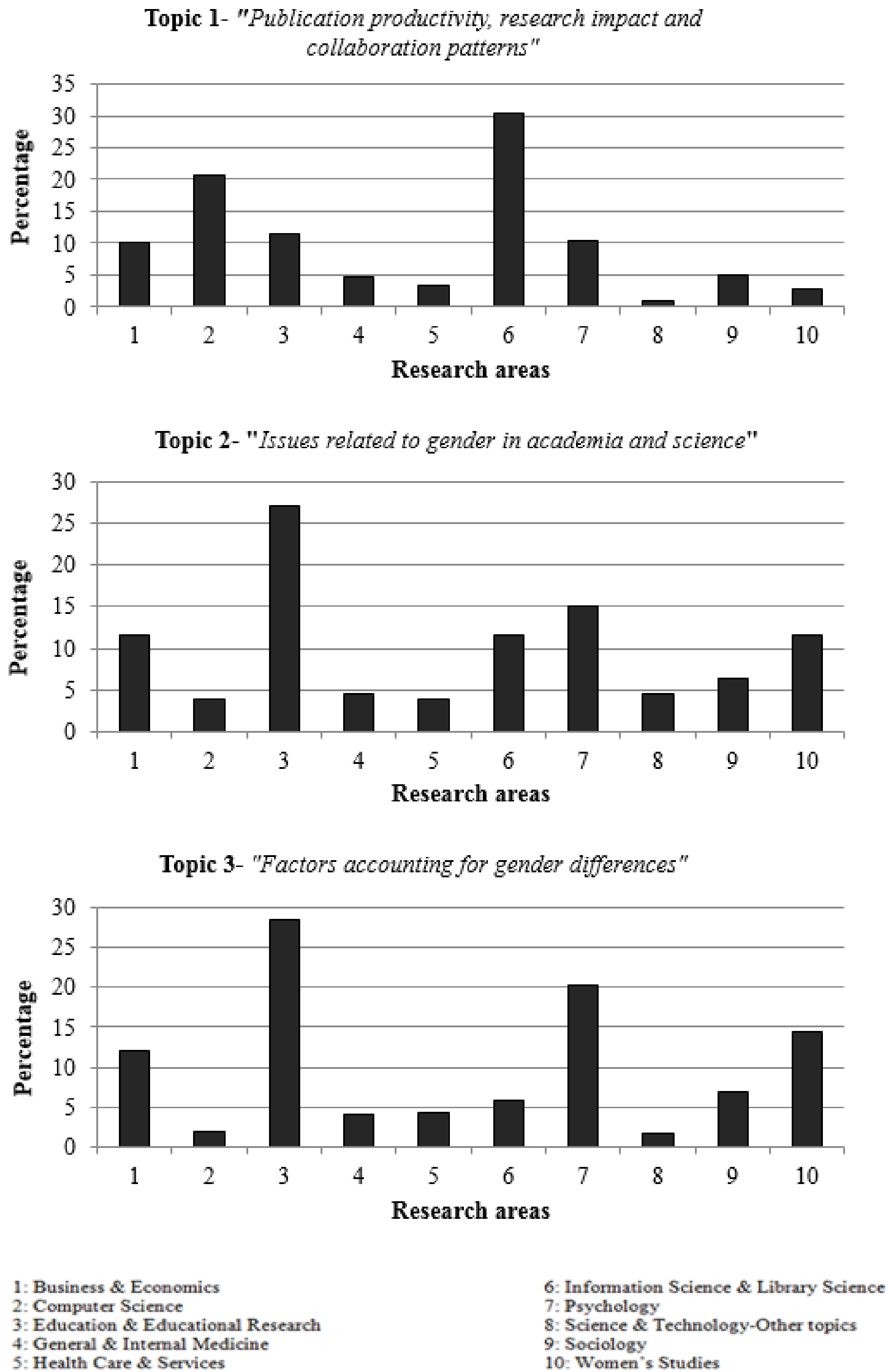

Fig. 3 Percentage of papers for the top ten research areas in the three topics.

Regarding the topics, *Issues related to gender in academia and science* (topic 2) was the most frequent among the top ten countries in terms of absolute frequency. Among the papers involving international collaboration, 56.64% (n = 64) of them dealt with the topic of *issues related to gender in academia and science*, 30.08% (n = 34) addressed *factors accounting for gender differences*, and 28.31% (n = 32) examined *publication productivity, impact and collaboration patterns*. As any given paper may simultaneously address more than one topic, the sum of papers is more than the total number of papers, and the sum of percentages exceeds 100%.

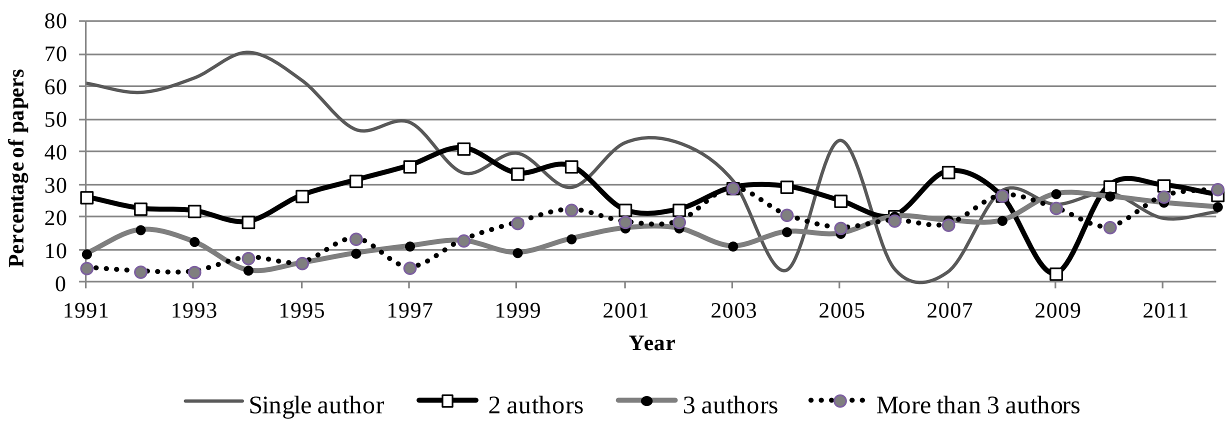

Fig. 4 Changes over time (1991–2012) in the number of authors per paper

3.3.5. Journals

The papers included in the present study were published in a total of 595 journals, of which 366 (61.5%) published only one paper. The distribution of papers published in the set of journals was described using Bradford's law, which revealed that the papers were distributed in four zones. The core was composed of 13 journals.

Table 4 shows the expected number of journals given the Bradford multiplier (3.17), the actual number of journals in each zone, the number of articles included in each zone, the cumulative number of articles, the estimated values of *k*, and, finally, the predicted cumulative number of articles *R(r)*.

Table 4 Data fit to Bradford's law

Zone	Expected number of journals	Number of journals	Number of articles	Cumulative articles	Estimated *k*	*R(r)*
1	13	13	366	366	–	355.86
2	41.1	41	250	616	3.15	634.02
3	129.98	130	343	959	3.17	959.77
4	411	411	456	1415	3.16	1303.04

Note: Constants according to Leimkuhler's formulation were $A = 306.26$ and $B = 0.168$

Table 5 shows core journals, publication frequency and the corresponding research areas of each journal based on the Thomson Reuters WOS. As can be seen from the table, six of the core journals belong to the area of Education and Educational Research, and Scientometrics is the journal with the highest number of papers related to topic 1, while the rest of the journals published more papers related to topic 2.

Table 5 Core journals, the corresponding research area, total publication frequency and publication frequency in each topic (1991–2012)

Core journal	Research Area	Total *fi* (%)	Topic 1* *fi* (%)	Topic 2* *fi* (%)	Topic 3* *fi* (%)
Scientometrics	Computer Science; Information Science & Library Science	57 (15.57)	45(78.95)	20(35.09)	2(3.51)
Sex roles	Psychology; Women's Studies	42 (11.48)	2 (4.76)	27 (64.29)	22 (52.38)
Academic medicine	Education & Educational Research; Health Care Sciences & Services	39 (10.66)	7 (17.95)	27 (69.23)	16 (41.03)
Higher Education	Education & Educational Research	36 (9.84)	3 (8.33)	26 (72.22)	15 (41.67)
Research in higher education	Education & Educational Research	31 (8.47)	5 (16.13)	22 (70.97)	15 (48.39)
Gender and education	Education & Educational Research	30 (8.20)	0 (0.00)	25 (83.33)	10 (33.33)
Scientist	Information Science & Library Science; Science & Technology – Other Topics	29 (7.92)	1 (3.45)	27 (93.10)	4 (13.79)
Women's studies international forum	Women's Studies	19 (5.19)	1 (5.26)	15 (78.95)	6 (31.58)
Gender work and organization	Business & Economics; Women's Studies	18 (4.92)	0 (0.00)	12 (66.67)	9 (50.00)
Journal of higher education	Education & Educational Research	17 (4.64)	1 (5.88)	13 (76.47)	7 (41.18)
Journal of vocational behavior	Psychology	17 (4.64)	0 (0.00)	13 (76.47)	5 (29.41)
Journal of womens' health	Public, Environmental & Occupational Health; General & Internal Medicine; Obstetrics & Gynecology; Women's	16 (4.37)	0 (0.00)	12 (75.00)	6 (37.50)
Academic psychiatry	Education & Educational Research; Psychiatry	15 (4.10)	1(6.67)	14 (93.33)	2 (13.33)

Note: fi frequency
a Some papers may simultaneously address more than one topic

3.4. Conclusions and discussion

This study has analysed the main bibliometric indicators in relation to the literature on women's participation in science and higher education. With regard to the number of publications, results showed a significant increase and interest in the field over the last 21 years, particularly since 2002, when a steady increase begins. This increment was supported by the fit of the data to Price's law, which indicates that productivity in the studied field shows an exponential growth. Of the three topics considered, namely *publication productivity, impact and collaboration patterns*, *issues related to gender in academia and science*, and *factors accounting for gender differences*, the highest number of papers corresponded to the second topic (i.e., issues related to gender in academia and science), accounting for 66.64% of the total publications.

This topic was also the most frequently addressed in papers involving international collaboration (56.64%). This result may be due to the fact that this topic addresses a wide variety of issues such as a scientific career, having access to funding, mentoring and networking, and being a member of an editorial board or a peer reviewer, among others. Furthermore, these studies often consider the other two topics as well in an attempt to examine existing differences in academia and science by searching for explanatory factors, and they often using bibliometric indicators such as publication productivity.

Regarding the research areas showing the most interest in the studied field, it can be inferred that scholars from different disciplines, such as Education and Educational Research, Psychology, Information Science and Library Science, Computer Science, Business and Economics, and Women's Studies, among others, have all contributed to the field, thereby indicating a high degree of multidisciplinarity. However, the interest of these areas in the three different topics is quite unbalanced. Not surprisingly, Information Science and Library Science and Computer Science were the areas with the highest contributions in the third topic, publication productivity, while Education and Educational Research and Psychology were the areas with the highest weight in the topics *issues related to gender in academia and science*, and *factors accounting for gender differences.*

In addition, the result of Bradford's law identified a small set of core journals focused on the studied field, which were also from eleven different research areas. Ordered according to frequency these core journals correspond to the following areas: Computer Science; Information Science and Library Science; Psychology; Women's Studies; Education and Educational Research; Health Care Sciences and Services; Business and Economics; Public, Environmental, and Occupational Health; General and Internal Medicine; Obstetrics and Gynaecology; and Psychiatry. This means that this field is widely scattered across journals of different disciplines and is regarded as relevant in many research areas. However, it should be noted that the most productive research area is Education and Educational Research, accounting for 6 out of 13 (46.15%) core journals identified by Bradford's law.

With respect to the number of authors, a large number of papers (477; 33.71%) are single author papers, suggesting that the scientific community in the field is composed of small groups and individual authors. Furthermore, author productivity was found to fit Lotka's law, indicating that there are a few, highly productive authors and a great majority who only contribute occasionally to research on women in science and higher education. However, analysis of how the number of authors has evolved over time showed an increasing trend in terms of the number of papers being signed by three authors or more, a trend that was paralleled by a clear reduction in the percentage of single-author papers. On the one hand, this may reflect the constitution of research groups, which is a feature associated with the consolidation of a field (Barrios, et al., 2008). On the other hand, and as has already been mentioned in other studies, this trend may be due to academic factors such as the increasing pressure to publish, the specialization of research expertise, collaborative efforts, or the interdisciplinarity of this field (Wren et al., 2007; Lozano, 2013).

Authors contributing to the articles came from 67 different countries. It should be noted, however, that the increase in the number of authors and the high number of countries that contributed to the field have not been accompanied by greater international collaboration; only 8% of papers involved this kind of joint work, and the largest proportion of these were published recently. This indicates a field of study that has yet to become truly international and in which collaboration between countries and institutions needs to be reinforced.

The most productive countries, in absolute terms, are the United States and the United Kingdom, generating around half the total scientific production in this field (54%). However, when RII, a relative measure to calculate country productivity, were used, Nicaragua and Botswana were the countries that showed the highest productivity in WSHE, relative to the proportion of the world in the same area. Similarly, when IC-RII were used to measure the relative proportion of publications of a country in international collaboration, Sudan, Nepal and Ghana were the countries that showed the highest international collaboration productivity.

With regard to the GII, the results showed a direct relationship between the most recent GII and the RII and IC-RII. This means that countries with higher GII values (higher inequality) are, in relative terms, the most productive in the field and are the most likely to collaborate internationally. Thus, although countries such as the United States and the United Kingdom are the most productive countries in terms of absolute contributions, countries with higher levels of inequality showed higher relative values of productivity in the field. This last finding is consistent with Glänzel's (2001) study, which analysed country profiles and compared domestic and internationally co-authored papers. According to his findings, some countries compensate relatively weak domestic activities through international collaboration or even intensify their own strong activities in the preferred science fields by international collaboration. However, as Glänzel (2001) points out, international scientific collaboration has proved to be a complex and heterogeneous phenomenon which cannot be sufficiently characterized by bibliometric indicators alone.

In summary, the present study provides an overview of how scientific output in the field of WSHE has evolved over time. The results show that since 1991 until the present day there has been a clear upward trend in the number of publications, with increasing interest extending to many authors, countries, and scientific journals, as well as to several research areas. These results are consistent with Zosuls et al.'s (2011) conclusion that the growth in the diversity of topics covered by researchers over the past few decades has mainly been due to the multidimensionality of gender, and that the idea that the assumptions made about one domain of gender development can predict all others has come under serious scrutiny. Moreover, the need for precise and clear terminology, more sophisticated methods and analytic techniques, and a greater diversity of topics of study have been increasingly encouraged.

Chapter 4. Research trends in gender differences in higher education and science: a co-word analysis (Study 2)

Chapter 4. Research trends in gender differences in higher education and science: a co-word analysis

This chapter examines the second main objective of the thesis, the thematic evolution of factors accounting for gender differences in science and higher education, and its specific objectives (the evolution of the number of documents and number of themes as well as the evolution of main themes and concepts accounting for gender differences in science and higher education), as indicated in chapter 2. Thus, this chapter presents methods used for data collection and data analysis, sources used, as well as results, conclusions and discussion of Study 2.

4.1. Data collection and processing

The data set comprised a corpus containing 651 articles and reviews published between 1991 and 2012, extracted from the Thomson Reuters WOS database in February 2013. Different steps were taken in order to extract the data set, as shown in Fig 5. After conducting a search by using a preliminary combination of key terms[3], a total of 50,970 records were initially retrieved. In a next step, records were refined by subject area, such that those papers classified

[3]. A summary of these key terms can be found in Chapter 3, table 1. Similar to Study 1, in order to retrieve records on factors accounting for gender differences in science and education, a combination of keywords referring to gender, higher education and science and factors were used. However, the number of records obtained for this study was slightly lower than the ones retrieved for Study 1. The reason for this is that the search for Study 1 was conducted at the end of February 2013, whereas for this study (Study 2), the search was performed at the beginning of the February 2013. Thus, as a result of the actualization of the WOS database, more records were retrieved for Study 1 than Study 2.

in research areas not directly related to the topic were discarded (e.g., history, zoology, toxicology, allergy, and transportation). Titles and abstracts from the remaining pool of papers (n = 12,743) were then manually checked to find related records. A corpus of 651 articles and reviews dealing with factors related to gender differences in science and higher education, published between 1991 and 2012, were finally used.

In order to study the evolution of the topic and to see how the results changed over time, the records were divided into three consecutive sub-periods: 1991-2001, 2002- 2007, and 2008-2012. The time spans were selected based on the number of target documents published per period; so following Cobo et al. (2011) and Muñoz-Leiva et al. (2012), we fixed a longest first sub-period in order to get a representative number of published papers and keywords. Thus, the first period (1991–2001) spans 11 years (and includes a total of 164documents: 25%), the second period (2002–2007) spans 6 years (and 147 documents: 23%) and the last period (2008–2012) spans 5 years (and 340 documents: 52%).

In addition, an important event in women’s access to higher education and science occurs within each period. Thus, the ‘‘World Conference on Education for All’’ took place in 1990 and during the years 2002 and 2008, UNESCO launched its ‘‘Gender Equality Action Plans’’ for the periods 2002–2007 and 2008–2013, respectively.

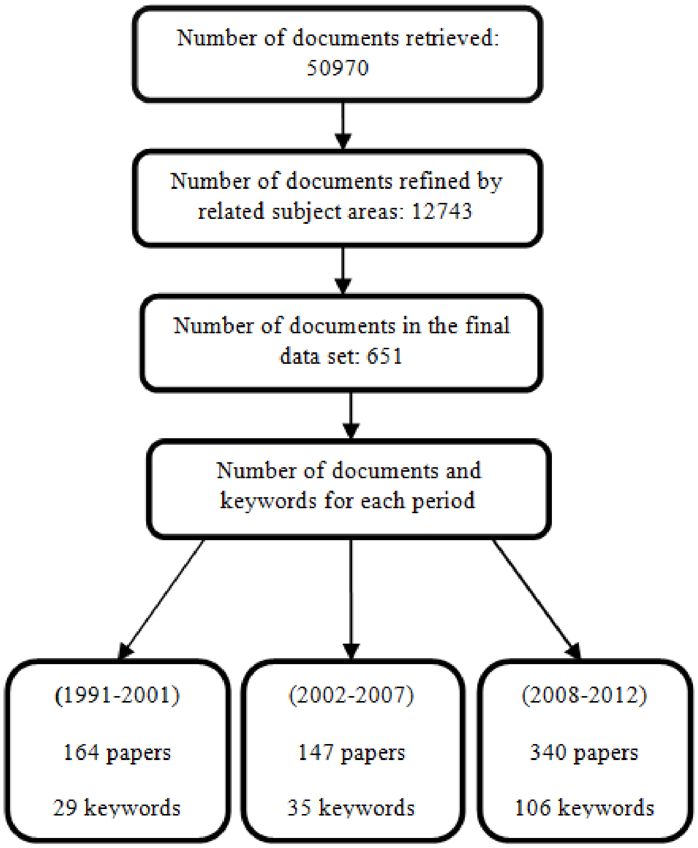

Fig 5. Flowchart illustrating the process of data collection for Study 2

4.2. Data analysis and statistical procedures

In order to address the objectives of this study, co-word analysis and hierarchical cluster analysis were undertaken.

Co-word analysis is a content analysis technique based on the assumption that the subject of a paper can be summarized in a number of few key terms that reflect its core contents. The frequency of word occurrence in the subject can reflect the importance of themes, and the co-occurrence of keywords across papers can be interpreted as indicating similarity between publications. According to Börner et al. (2003), the more keywords two publications have in common, the more similar the two publications are. Therefore, the main purpose of a co-word analysis is to map the dynamics of a subject and identify the core research topics based on the pattern of co-occurrence of pairs of keywords, which represent the different themes in a selected body of literature (He, 1999). The co-word analysis conducted in this thesis involved five sequential steps: extraction of the data, standardization of keywords, construction of the co-occurrence matrix, clustering, and visual presentation of keyword groups (See Fig. 6). First, author-provided keywords were extracted from papers, with keywords plus being used in those instances where no author-provided keywords were available. Once the data had been extracted, keywords and phrases were standardized manually in order to refine the dataset (e.g., keywords occurring in different forms, plural and singular forms, uppercase and lowercase words).

Keywords denoting the same concepts were changed into the most frequent key term occurring in the data set. For instance, the terms research productivity, scientific productivity, publication productivity, academic publishing, scholarly productivity, medical publication, publication rates, publications, and research output were considered as synonymous keywords and were all identified as research productivity, which was the most frequent term.

By contrast, those keywords which were very closely related but different in meaning were kept separate, for example: gender issues, children, family, marriage, motherhood or salary, salary gap and promotion. Any keywords that were unrelated to the topic were also eliminated in this step (for instance, names of countries and statistical tests). After standardization, a total number of 170 unique keywords or phrases were selected.

The word-document occurrence matrix was automatically built using SPSS v20. Only those keywords and phrases with a frequency greater than or equal to 5 in each temporal sub-period were considered in the analysis. Totally, this accounts for (170, 29.51%) of the total number of unique keywords (576) in all sub-periods. The total number of unique keywords for each sub-period is shown in Fig. 2. The resulting matrix for each sub-period was then exported to Ucinet (Borgatti et al., 2002) in order to calculate the word co-occurrence matrix.

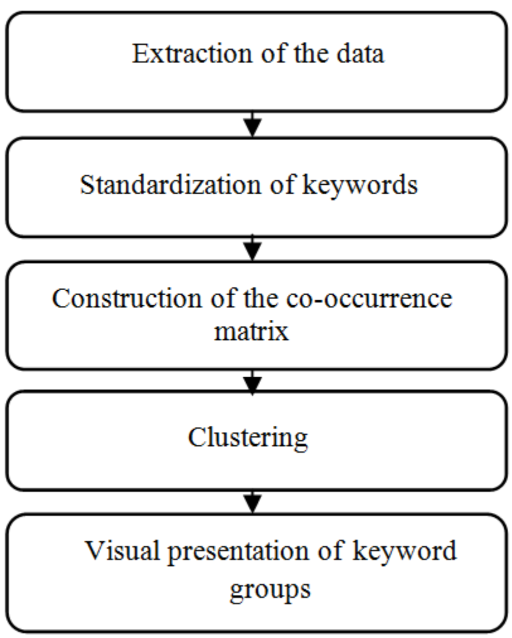

Fig 6. Flowchart illustrating the co-word analysis steps

The similarities between items were also calculated using the jaccard similarity index. Hierarchical clustering analysis was then conducted using Ward's method, and squared Euclidean distance was applied as the distance measure using SPSS v20. Ward's method involves an agglomerative clustering algorithm. It starts with n clusters of size 1 and continues until all the observations are included in one cluster. In contrast to other agglomerative clustering algorithms such as single link clustering used in Callon's original proposal of co-word analysis, Ward's method tends to produce same-size and spherical clusters (Everitt et al., 2011). The result of the clustering was then visualized in a dendrogram, which displays the steps in the clustering process and illustrates how individual words are combined in order to form gradually larger clusters. The clusters were then transformed into networks in Ucinet.

Finally, in the last step, and in order to identify and visualize the importance and position of clusters considered as themes, as well as their relational patterns, strategic diagrams were built for each sub-period. A strategic diagram is a two-dimensional space built by plotting themes according to their centrality and density, where the abscissa axis represents the centrality, the ordinate axis represents the density, and the origin is denoted by the median or mean value of the two, centrality and density (Callon et al., 1991; Cobo et al., 2011). The density, or the internal cohesion index, indicates the strength of the linkage that each word has with other words within the same cluster (or theme). It is an indicator of the internal strength of a cluster and represents the conceptual development of a theme. The centrality, or the external cohesion index, indicates the strength of the linkage that each keyword has with other keywords in other clusters. It is a measure of the strength of a subject area's interaction with other subject areas and represents the central position of a theme within the overall network. The value of the density and the centrality of a given cluster can be measured in several ways (He, 1999). In this thesis density was computed as the average value (mean) of the internal links (Turner et al., 1988) and centrality was computed as the sum of squares of all external link values (Bauin et al., 1991). The origin of the strategic diagram was calculated by the mean value of centrality and the mean value of density.

The strategic diagram divides the space into four quadrants, such that there are four types of themes according to their location (Callon et al., 1991; He, 1999). Themes located in the upper-right quadrant are considered to be well-developed and important themes for the structure of a research field. They are known as the motor themes of the specialty, given that they present strong centrality and high density. The placement of themes in this quadrant implies that they are externally related to concepts applicable to other themes that are conceptually closely related.

Themes in the upper-left quadrant have well-developed internal ties (high density) but unimportant external ties (weak centrality), and so are of only marginal importance for the field. These themes are very specialized and peripheral in nature. Themes placed in the lower-left quadrant are both weakly developed (low density) and marginal (weak centrality), and are considered as emerging or disappearing themes. Finally, themes in the lower-right quadrant are important for a research field (strong centrality) but present low internal development (low density). Therefore, this quadrant comprises transverse and general or basic themes.

After calculating density and centrality for each cluster, the themes were then displayed, using Excel, in a strategic diagram according to their internal and external cohesion indices. The themes were represented by spheres of different sizes, which were proportional to the number of papers that they each represented.

4.3. Results

A total of 170 keywords were obtained from the 651 documents. In what follows, we show the dendrograms, strategic diagrams for each sub-period, and tables containing the names of clusters, the number and percentage of documents by cluster, the centrality and density values, and a brief explanation of each theme.

4.3.1. Period 1: 1991–2001

The dendrogram shows that the 29 keywords of the documents are divided into four clusters (Fig.7). Table 6 gives the names and descriptive values of each cluster, while Fig.8 shows the corresponding strategic diagram. The origin of the strategic diagram is based on the centrality value (5.750) and density value (0.117). ‘‘Gender discrimination in labour markets and universities’’ (C1) is located in the upper right quadrant. This means that this cluster contains close internal connections and is also widely connected to other clusters. Given its position and the number of papers that deal with this theme, it can be considered as the motor theme of this period. Because of its high/medium density and centrality (upper-left quadrant), ‘‘Mobility of women academics’’ (C3) was regarded as a specialized theme with high conceptual development but weak external inter connection with other themes. A further two themes, namely ‘‘Institutional issues’’ (C2) and ‘‘Sex differences in promotion’’ (C4) (lower-left quadrant), were regarded as either emerging or disappearing themes because of their showing both low density and low centrality.

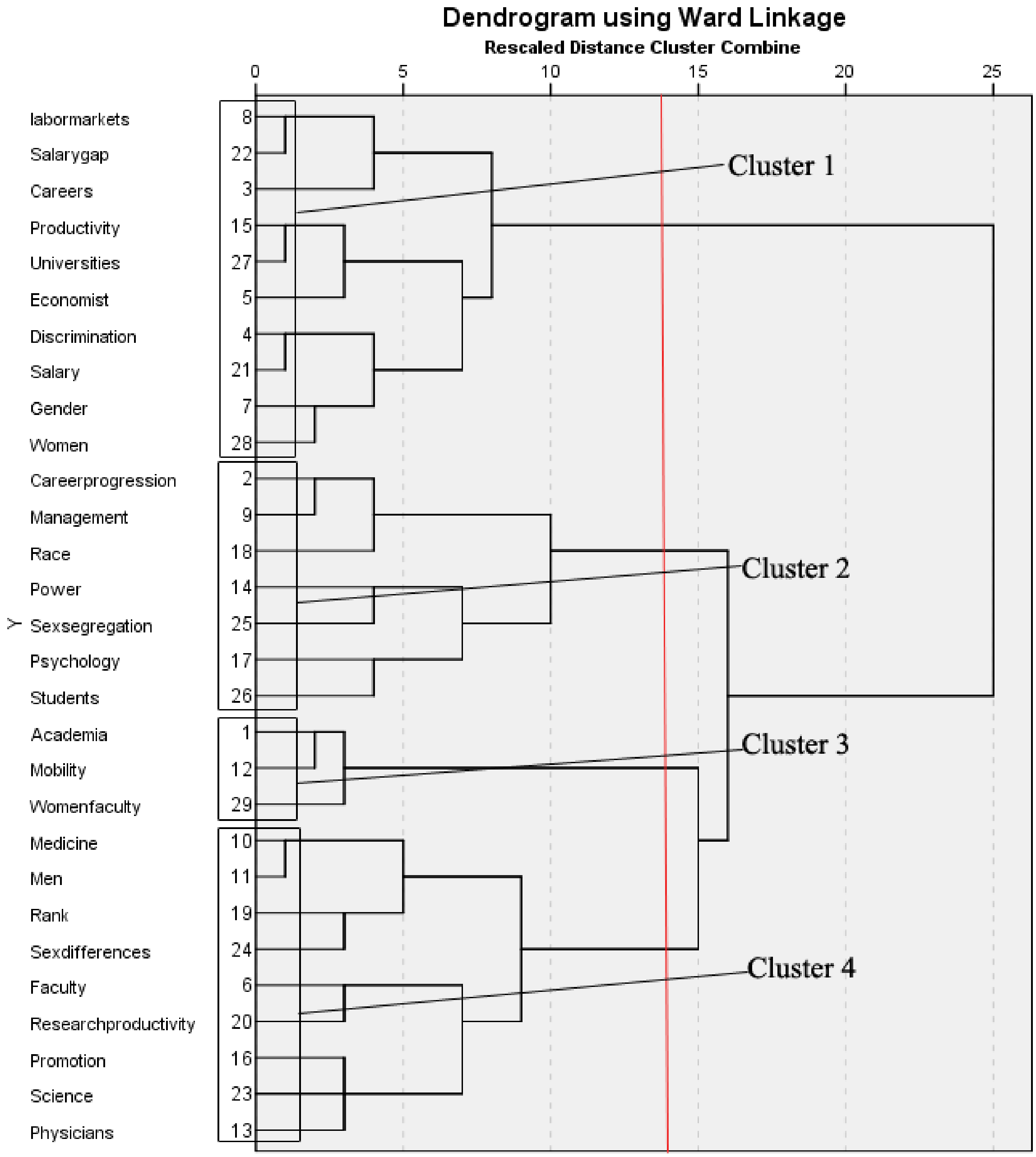

Fig. 7 Dendrogram for the first sub-period (1991–2001)

Table 6 Descriptive values of clusters for the first sub-period (1991–2001)

Cluster number	Name of cluster	No of keywords	No of documents (%)	Centrality	Density
1	Gender discrimination in labour markets and universities	10	86 (52.4%)	16.640	0.141
	Challenges and gaps that still hinder women's full participation in the labour market generally and in the academic labour market specifically.				
2	Institutional issues	7	31 (18.9%)	0.665	0.046
	Issues related to organization such as working hours, organizational structure, retention and exclusion, etc.				
3	Mobility of women academics	3	12 (7.3%)	0.420	0.185
	Mobility of women academics or students to another institution within or outside their own country to study or teach for a limited time.				
4	Sex differences in promotion	9	62 (37.8%)	5.509	0.095
	Sex differences and gaps in acquiring a higher rank, promotion to top positions, academic progression and finally how publication rates are correlated with promotion.				

* Note that the total number of documents is higher than the number of documents per period. As each document can have more than one keyword, it can therefore appear in more than one cluster. Percentage was calculated based on the total number of documents per period.

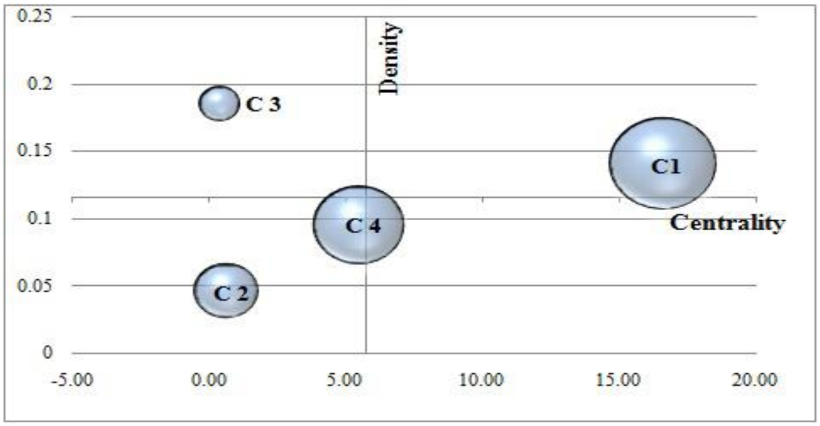

Fig. 8 Strategic diagram for the first sub-period (1991-2001)

4.3.2. Period 2: 2002–2007

In this period, the 35 keywords of the documents were divided into ten major themes, as shown in Table 7. The dendrogram of the cluster analysis and the strategic diagram are shown respectively in Figs. 9 and 10. The origin of the strategic diagram is based on the centrality value (0.953) and the density value (0.130). In this period, two new motor themes appeared: ‘‘Career satisfaction in medicine’’ (C1) and ‘‘Academic career in sociology’’ (C9). Besides being a motor theme, ‘‘Career satisfaction in medicine’’ (C1) was the cluster with the highest number of documents.

Table 7 Descriptive values of clusters for the second sub-period (2002–2007)

Cluster number	Name of cluster	No of keywords	No of documents (%)	Centrality	Density
1	Career satisfaction in medicine	6	37 (25.2%)	4.053	0.162
	Women and men physicians' job perceptions and factors influencing their satisfaction with a career in medical practice.				
2	Sex differences in promotion	4	32 (21.7%)	0.768	0.144
	Sex differences and gaps in acquiring a higher rank, promotion to top positions, academic progression and finally how publication rates are correlated with promotion.				
3	Gender stereotypes and discrimination	3	18 (12.2%)	0.319	0.162
	Stereotypes and social norms that foster gender discrimination and hinder women academics in fulfilling their potential by limiting choices and opportunities.				
4	Gender roles in management	3	13 (8.8%)	0.084	0.079
	How gender roles and expectations affect women being on boards and in senior management positions.				
5	Mentorship	3	20 (13.6%)	0.176	0.114
	Women's mentoring experiences in academic careers and students' experiences of having mentors of their own race and gender.				
6	Mobility of women academics	3	17 (11.5%)	0.149	0.110
	Mobility of women academics or students to another institution within or outside their own country to study or teach for a limited time.				
7	Racial discrimination at universities	4	23 (15.6%)	0.360	0.095
	Experiences of racial and ethnic minority academics and the issue of being under-represented in academia.				
8	Work-life balance in academia	8	34 (23.1%)	0.536	0.120
	How different aspects of an academic career make it difficult for women to manage their responsibilities outside their academic work.				
9	Academic career in sociology	2	9 (6.1%)	2.987	0.222
	Difficulties faced by women in academic careers in the field of sociology.				
10	Gender issues in geography	3	31 (21.1%)	0.097	0.090
	Female representation and gender inequalities in geography higher education institutions.				

* Note that the total number of documents is higher than the number of documents per period. As each document can have more than one keyword, it can therefore appear in more than one cluster. Percentage was calculated based on the total number of documents per period.

The clusters ‘‘Mobility of women academics’’ (C6), ‘‘Sex differences in promotion’’ (C2) and to some extent ‘‘Gender stereotypes and discrimination,’’ (C3) all present in the previous period, also appeared in this period. ‘‘Mobility of women academics’’ (C6) showed a decrease in density but a higher percentage of documents compared with the previous period. It was now relocated to the lower-left quadrant, suggesting that it is either an emerging or a disappearing theme. In contrast, ‘‘Sex differences in promotion’’ (C2) and ‘‘Gender discrimination in labour markets and universities’’ (C1), which became ‘‘Gender stereotypes and discrimination’’ (C3) in this second period, showed an increase in density and a lower percentage of documents compared with the previous period, and they were relocated to the upper-left quadrant as specialized themes with a higher conceptual development but weak external interconnections with other themes.

Compared with the previous period, the number of emerging (or disappearing) themes increased from two to six. In addition to ‘‘Mobility of women academics’’ (C6), five new themes appeared: ‘‘Gender roles in management’’ (C4), ‘‘Mentorship’’ (C5), ‘‘Racial discrimination at universities’’ (C7), ‘‘Work-life balance in academia’’ (C8), and ‘‘Gender issues in geography’’ (C10).

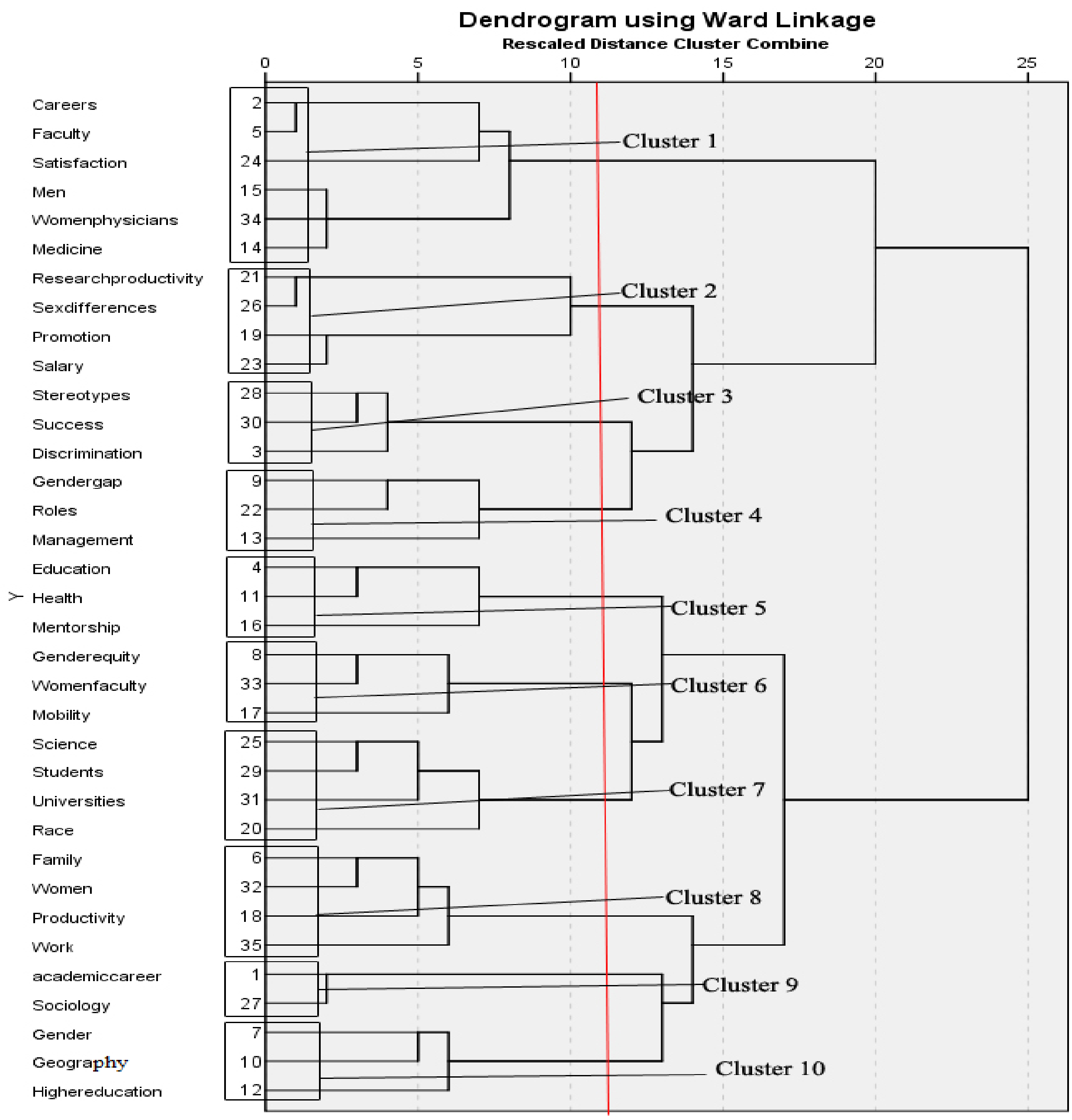

Fig. 9 Dendrogram for the second sub-period (2002–2007)

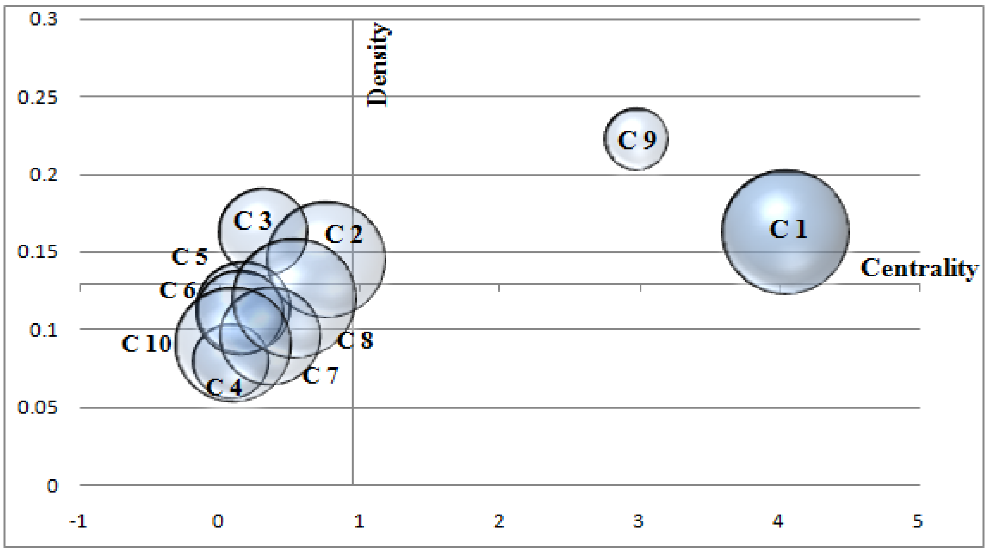

Fig. 10 Strategic diagram for the second sub-period (2002–2007)

4.3.3. Period 3: 2008–2012

Based on the hierarchical clustering of 106 keywords, 16 clusters of keywords (themes) were identified in the last period, as shown in Table 8. The dendrogram of the cluster analysis and the strategic diagram are shown respectively in Figs. 11 and 12. The origin of the strategic diagram is based on the centrality value (1.500) and density value (0.099).

In this period, just one motor theme was found: ‘‘Advancement in academic medicine’’ (C9). This theme includes articles related mainly to success and progression in medicine. This cluster is similar to the cluster labelled ‘‘Career satisfaction in medicine’’ (C1), identified in the second period as a motor theme. ‘‘Gender discrimination in labour markets and universities’’ (C1), which was present as a motor theme in the first period and as a specialized theme in the second, reappeared in this third period, where it showed a decrease in the percentage of documents compared with the previous periods and an increase in centrality with respect to the second period. Therefore, it moved from the upper right quadrant in the first period to the upper-left quadrant in the following two periods as specialized themes with a peripheral character. Additionally, six new themes appeared in this quadrant as specialized themes: ‘‘Gender differences in productivity’’ (C2), ‘‘Employment stratification’’ (C3), ‘‘Personal factors’’ (C5), ‘‘Stereotypes in mathematics’’ (C7), ‘‘Institutional issues’’ (C10), and ‘‘Women’s studies’’ (C15). ‘‘Institutional issues’’ (C10), which appeared as an emerging theme in the first period but was absent in the second period, re-emerged in the third period as a specialized theme, although it had a lower percentage of documents.

Table 8 Descriptive values of clusters for the third sub-period (2008–2012)

Cluster number	Name of cluster	No of keywords	No of documents (%)	Centrality	Density
1	Gender discrimination in labour markets and universities	3	23 (6.7%)	0.881	0.270
	Challenges and gaps that still hinder women’s full participation in the labour market generally and in the academic labour market specifically.				
2	Gender differences in productivity	4	47 (13.8%)	0.733	0.140
	Research performance differences, productivity, and publication disparities between male and female researchers.				
3	Employment stratification	4	22 (6.5%)	0.759	0.143
	Differences in employment of women and men and the degree to which jobs and the occupational status that women and men hold differ.				
4	Glass ceiling barriers	15	112 (32.9%)	3.658	0.032
	Institutionalized barriers against women accessing male-dominated positions and upper echelons, which are nearly impossible to break through.				
5	Personal factors	4	23 (6.7%)	0.411	0.103

	Factors caused by women themselves not by their organization. These are related to issues such as lack of confidence, empathy or motivation; stress; and individual personality and abilities.				
6	Mobility, career choice, and sex composition	7	28 (8.2%)	1.289	0.069
	Sex differences in preferences for certain kinds of careers and career mobility, and how they have an impact on the gender composition of occupations.				
7	Stereotypes in mathematics	5	35 (10.2%)	1.415	0.129
	Beliefs and stereotypes that have an effect on inspiring women and girls to enter the field of math and on their math performance in academia.				
8	Work-life balance in engineering	10	96 (28.2%)	1.875	0.045
	How different aspects of an academic career in the engineering field make it difficult for women to manage their responsibilities outside their academic work.				
9	Advancement in academic medicine	8	46 (13.5%)	4.551	0.102
	Challenges female faculty physicians and non-physicians face in receiving recognition, including salary, promotion, rank, seniority, etc. in academic medicine.				
10	Institutional issues	4	17 (5%)	0.391	0.102
	Issues related to organization such as working hours, organizational structure, retention and exclusion, etc.				
11	Climate and staff composition in academia	6	34 (10%)	1.617	0.097
	How organizational culture and structure contribute to gender disparities in the composition of academic staff.				
12	Senior positions in medicine	8	66 (40.2%)	0.906	0.047
	Obstacles women in academic medicine face in relation to obtaining top positions and leadership.				
13	Inequality and diversity in higher education	10	230 (67.6%)	2.751	0.056
	Gender and other types of inequalities (such as race, people with disabilities, etc.) in higher education, as well as the diversity issues related to the participation of these groups in the				
14	Bibliometric indicators: Research productivity, impact,	5	62 (18.2%)	0.793	0.098
	How the participation of women and men in research is different in terms of bibliometric indicators.				
15	Women studies	3	15 (4.4%)	0.143	0.102
	Issues and controversies addressed in women's studies, also known as feminist studies.				
16	Work-life balance in psychology	10	59 (17.3%)	1.877	0.045
	How different aspects of an academic career in the field of psychology make it difficult for women to manage their responsibilities outside their academic work.				

* Note that the total number of documents is higher than the number of documents per period. As each document can have more than one keyword, it can therefore appear in more than one cluster. Percentage was calculated based on the total number of documents per period.

The theme of ‘‘Mobility, career choice, and sex composition’’ (C6), similar to ‘‘Mobility of women academics’’, had been present in the two previous periods and appeared again in the third period. It corresponded to a similar percentage of documents in the three periods, although it went from being a specialized theme in the first period to an emerging or disappearing theme in the second and third periods. ‘‘Senior positions in medicine’’ (C12) and ‘‘Bibliometric indicators’’ (C14) were new themes which also appeared in this quadrant as emerging or disappearing themes. Finally, five themes, namely ‘‘Glass ceiling barriers’’ (C4), ‘‘Work-life balance in engineering’’ (C8), ‘‘Climate and staff composition in academia’’ (C11), ‘‘Inequality and diversity in higher education’’ (C13), and ‘‘Work-life balance in psychology’’ (C16), appeared in the lower-right quadrant. It is interesting to see how the theme ‘‘Work-life balance in academia’’ (C8), which was present in the second period, reappears twice in the third period and in the same quadrant in the form of ‘‘Work-life balance in psychology’’ (C16) and ‘‘Work-life balance in engineering’’ (C8), indicating that the topic of work-life balance has attracted the attention of researchers from different research fields. Finally, ‘‘Inequality and diversity in higher education’’ (C13), similar to the cluster labelled ‘‘Racial discrimination at universities’’ in the second period, showed a significant increase both in centrality and the percentage of documents compared with the previous period. Consequently, it was relocated to the lower-right quadrant. As can be seen in Fig.12, this theme had the largest number of documents among all themes in all periods.

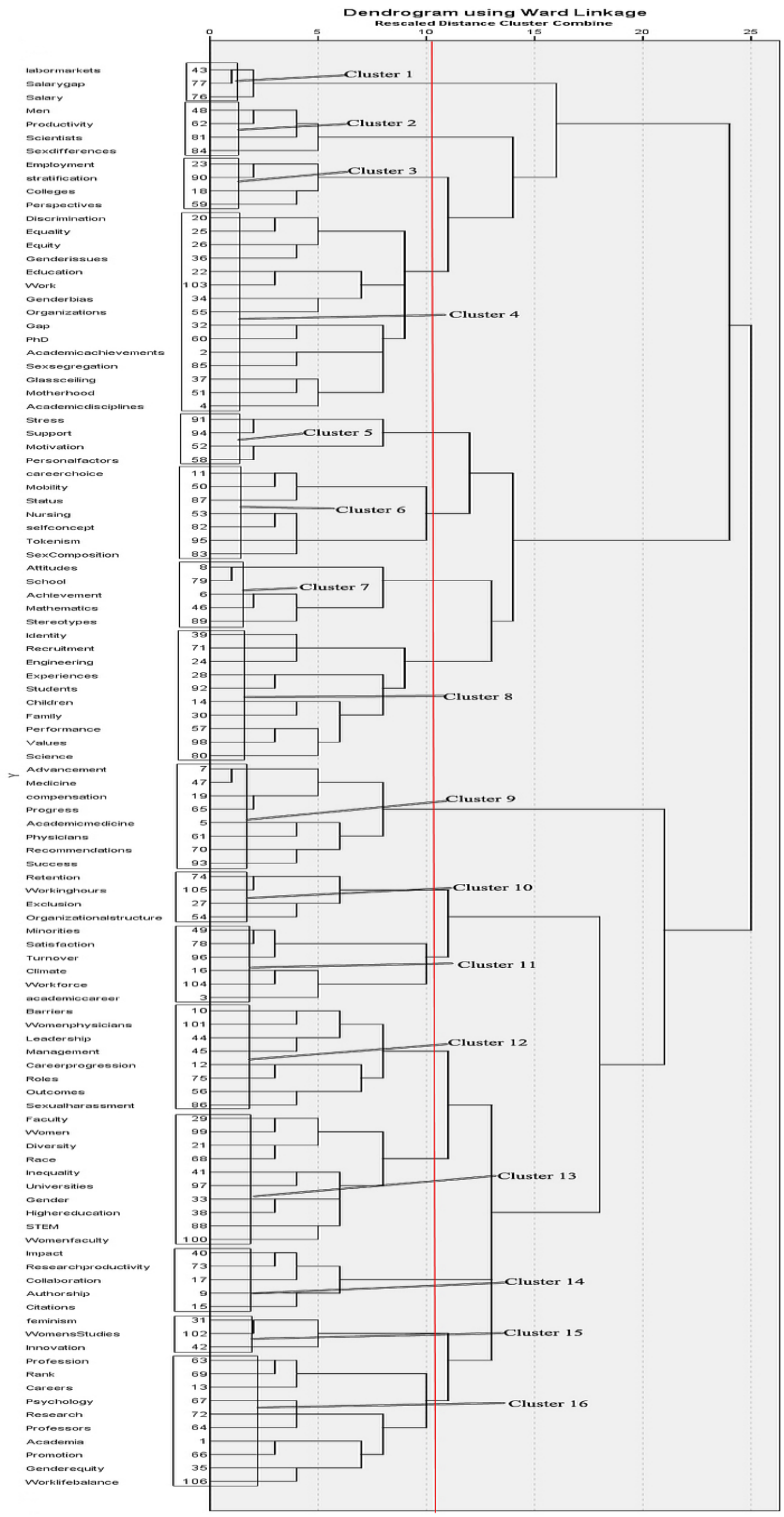

Fig 11 Dendrogram for the third sub-period (2008–2012)

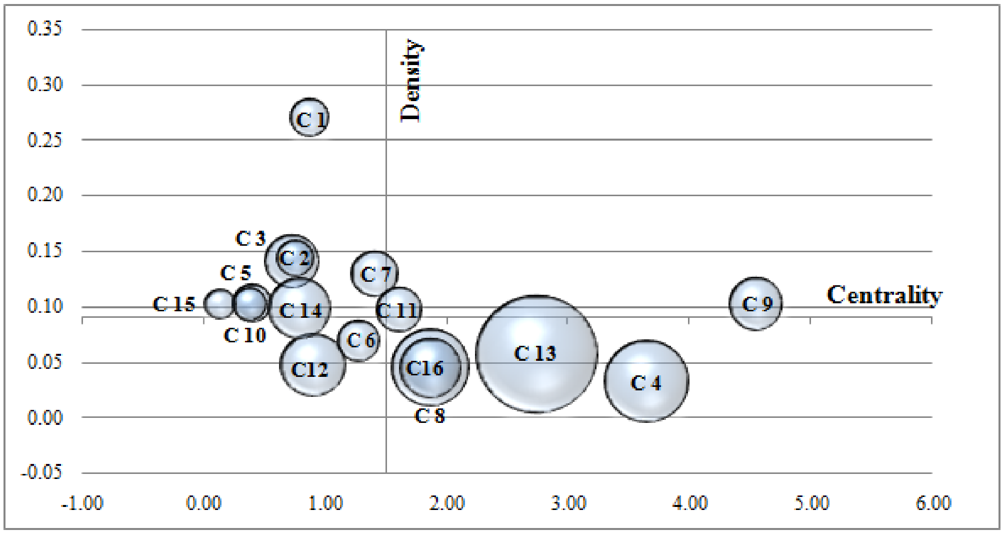

Fig. 12 Strategic diagram for the third sub-period (2008–2012)

4.4. Conclusions and discussion

Using co-word analysis, the present study describes the evolution and current state of the literature on gender differences in higher education and science, and more specifically of those papers that deal with factors that cause these differences. It also examines the evolution of this topic by dividing the literature into three sub-periods (i.e., 1991–2001, 2002–2007, and 2008–2012). Regarding the evolution of the number of documents, the results reveal that more than fifty percent of the total body of literature was published in the last five years (2008–2012), suggesting that this is a current topic which has aroused the interest of researchers. Specifically, ‘‘Inequality and diversity in higher education’’ is the theme with the largest number of documents over this period. This broad topic addresses gender and other types of inequalities in higher education, as well as diversity issues. While some papers in this cluster mainly evidence gender and race inequalities related to academic degree, salary, socio-economic status, disciplines, rank, tenure, or mentoring etc., others focus on the potential value of diversity in terms of enhancing work processes and organizational mechanisms through the incorporation of women and members of other underrepresented groups such as racial/ethnic minority groups (Homan et al., 2008; Gonzalez and DeNisi, 2009; Rosser, 2012).

The results also showed that the number of themes has increased significantly over the years, ranging from four in the first period to ten in the second and sixteen in the third period. This suggests a greater interest in the study of factors related to gender differences in higher education and science, as well as a diversification and specialization of the research field over time. ‘‘Work-life balance in academia’’ provides a good illustration of the latter issue: this theme appeared for the first time in the second period, mainly in relation to the issue of work-life balance in universities, while in the third period it became specialized and was covered by specific fields of study such as engineering and psychology (i.e. ‘‘Work-life balance in engineering’’ (C8) and ‘‘Work-life balance in psychology’’(C16). The relevance of this topic has recently been underlined in the latest release of Education at a Glance by the OECD (2013). According to this report, the issue remains a key element for achieving gender equality, since women still bear the main burden of care and domestic work.

In terms of trends in the evolution of themes, the strategic diagrams reveal that many themes are still immature in the studied field. Only four motor themes appeared in the upper right quadrant of the diagrams, the location for those that could be regarded as mature and well-developed themes. The specific themes in each period were ‘‘Gender discrimination in labour markets and universities’’ in the first period, ‘‘Career satisfaction in medicine’’ and ‘‘Academic career in sociology’’ in the second period, and ‘‘Advancement in academic medicine’’ in the third period. Moreover, only two themes, ‘‘Mobility of women academics’’ and ‘‘Gender discrimination in labour markets and universities’’, were present in all three periods. Some themes emerged and remained in subsequent periods: ‘‘Work-life balance in academia’’ and ‘‘Advancement in academic medicine’’ appeared in both the second and third periods, while ‘‘Sex differences in promotion’’ appeared in both the first and second periods. Other themes such as ‘‘Institutional issues’’ emerged (first period), disappeared (second period), and then reemerged (third period).

The results also indicate that gender differences in higher education and science have been considered by specific research disciplines such as medicine, psychology, geography, sociology, engineering, and mathematics, suggesting important research-field-specific variations. Indeed, after the second period a number of specific research disciplines can be seen to show an interest in gender issues. Notably, medicine is a discipline that appears in both of the two most recent periods (2002–2007 and 2008–2012) as a motor theme related to satisfaction and success in an academic medical career. Furthermore, an additional cluster in the field of medicine appears in the third period as an emerging theme related to senior positions in medicine. Particular research fields related to STEM disciplines, such as mathematics and engineering, also appear in the third period. It is worth noting that while in engineering and mathematics the main problem is located at the entry point (i.e., a problem of convincing girls to undertake these studies and embark on a research career), the challenge in the humanities and social and health sciences is not so much one of attraction but of retention, such that in these research fields the particular pipeline is relatively more leaky (LERU, 2012). It is worth mentioning that although the study aims to identify the main explanatory factors that could account for gender differences in higher education and science, several of the themes identified refer to the differences themselves rather than explanatory factors. For instance, ‘‘Sex differences in promotion’’ and ‘‘Gender discrimination in labour markets’’ correspond to differences described in the literature; but actually, they are not factors related to gender differences. In our view, this result could have two main reasons: the topic of the papers and the selection of keywords. On the one hand, most of the papers in the sample focus on the analysis of gender differences (e.g., salary, promotion, publication rates, etc.) and they sought to explain these differences via some possible factors.

On the other hand, authors need to summarize their research in a limited number of keywords, and this point is in fact the biggest problem that is attributed to co-word analysis (He, 1999). In co-word analysis, the keywords used for the description of the content of a publication are used as the unit of analysis to map the research field structure. Law and Whittaker (1992), indeed, point out that some keywords are too general and that indexers sometimes put the wrong emphasis on key wording; this has been called the ‘‘indexer effect’’. However, as Courtial et al. (1984) note there is a general structure in each specific field which underlies the co-occurrence of the keywords, and this structure does not seem to be sensitive to variations or redundancies of terms used by indexers. In order to partially solve this issue and to improve the validity of the data, the recommendation is to normalize the key words or to use a combination of words from abstracts, title words or full-text (He, 1999; Wang et al., 2012).

In our view, the evidence presented in this work allows the most prominent themes at different time periods to be identified together with possible gaps in the literature. For instance, ''Teaching load differences'' and ''Funding support'' are examples of institutional factors that do not appear in our results, indicating that these issues generate little interest among researchers, despite the fact that some studies report clear gender differences based on these issues (LERU, 2012).

Chapter 5. Conclusions

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This section draws conclusions about the main findings of each research question in the conducted studies. It then outlines the contributions of the conducted research. Finally, it presents some limitations of the thesis, followed by some recommendations for future research.

5.1. Main findings regarding research questions

As no prior work has provided a systematic analysis of the large body of literature in the area of women in science and higher education, the current work filled this gap in previous research through the use of bibliometric indicators, laws and techniques such as co-word analysis (cluster analysis and strategic diagrams). The value of bibliometric indicators and laws is that they provide an assessment of research performance or scientific production in a specific area over a period of time (Van Raan, 2005; 2014), thereby providing insights to a field from various aspects (e.g. author, journal, country levels etc.). The value of the strategic diagrams is that they identify the motor themes for the topic and also provide information about the less visible and emerging themes. Furthermore, studying the evolution of results across the three periods (1991-2001, 2002-2007, and 2008-2012) provides information about specific transient trends, for example, themes that have emerged, disappeared, and emerged again. These data illustrate the utility of co-word analysis for understanding the dynamic structure of a subject, and they could serve to predict future development or to identify gaps that could be taken into account when setting priorities for research policy.

The first study focused on the development and growth of scientific literature on women in science and higher education, examined the evolution of scientific literature on women in science and higher education by investigating questions number one to seven of the thesis, as follows.

The results of this study have been published in the following paper:

Dehdarirad, T., Villarroya, A., & Barrios, M. (2015). Research on women in science and higher education: a bibliometric analysis. *Scientometrics*, 1-18. doi: 10.1007/s11192-015-1574-x

1. What is the importance and the growth rate of the scientific literature on women in science and higher education over the time?

The results of analysis suggested an upward trend in the percentage of papers published over the last 22 years (1991-2012). Of the total papers studied, 52.29% were published in the last seven years (2006–2012). This result was also supported by the fulfilment of Price's law, which indicated an exponential growth rate of the publication productivity in this field. What can be globally suggested from the above mentioned results is the growing attention that the studied field has attracted, especially over the last seven years.

2. What is the relevance and interest of the area of women in science and higher education across different research areas?

The results showed that scholars from different disciplines, such as Education and Educational Research, Psychology, Information Science and Library Science, Computer Science, Business and Economics, and Women's Studies, among others, have all contributed to the field, thereby indicating a high degree of multidisciplinarity. It might also indicate the gradual increasing awareness of different disciplines regarding the integration of gender analysis into research content and process, as well as female empowerment as a key goal for economic development. As indicated in LERU´s report (2015), adopting a "gendered innovation" perspective can benefit excellence in research, policy and practice in many fields, from health and medicine, to engineering, the social sciences, and more.

However, the relevance of these areas in the three studied topics is quite unbalanced. While, "Information Science and Library Science" and "Computer Science" were the areas with the highest contributions to the first topic, "*publication productivity, impact and collaboration patterns*", "Education and Educational Research" and "Psychology" were the areas with the highest weight in the topics "*issues related to gender in academia and science*", and "*factors accounting for gender differences*".

3. What authorship trends and collaboration efforts do exist in the area of women in science and higher education?

For this research question, the finding indicated that a large number of papers (477; 33.71%) are single authored, suggesting a scientific community in the field which is composed of small groups and individual authors. Furthermore, the results of Lotka's law revealed that there are a few highly productive authors and a great majority who only contribute occasionally to research on women in science and higher education. With regard to collaboration efforts, the results indicated an increasing trend in terms of the number of authors per paper in parallel with a decreasing trend in the percentage of single-author papers.

These results suggest on the one hand, the establishment of research groups, which is a feature associated with the consolidation of a field (Barrios, et al., 2008). On the other hand, this trend may be due to academic factors such as the increasing pressure to publish, the specialization of research expertise, collaborative efforts, or the interdisciplinarity character of this field (Wren et al., 2007; Lozano, 2013).

4. What is the relative contribution of the countries to the scientific literature on women in science and higher education?

With regard to this question, the findings showed that a large number of countries (n = 67) have contributed to the studied area, showing a great interest among countries in the studied field. This might also suggest that the topic of women in science and higher education is still a global issue, despite substantial initiatives and policies undertaken at national and international level (World Bank, 2012; Bandiera and Natraj, 2013, Larivière, et al., 2013b). The most productive countries, in absolute terms, were the United States and the United Kingdom, accounting for around half the total scientific production in this field (54%). However, interestingly when relative contribution (relative to the proportion of the world) of the countries to the studied field was studied, Nicaragua and Botswana showed to be the countries with the highest productivity in the studied area, relative to the proportion of the world in the same area.

5. What is the importance of the area of women in science and higher education among countries at international level?

The results for this question indicated that only 8% of papers involved an international collaboration, and that the largest proportion of these were published recently. This might be due to social context, policies and cultural values of countries about gender and scientific work, which might impact the way in which scholars approach and engage in research and international collaborations (Sugimoto, Ni, and Larivière, 2015).

The obtained result suggests that the field of women in science and higher education needs to become truly international and collaboration between countries and institutions are needed to be reinforced in the near future. This could be addressed through international policies, calls, projects and conferences that promote international collaboration, particularly between developed and less developed nations in terms of gender equality, while considering the particular context of each country. This is because factors related to gender disparities in countries with high levels of gender equality are different from the ones in countries with low levels of gender equality. Therefore, solutions to achieve equality must be tailored to the particular context of each country. It is also necessary to have initiatives that can be applied globally, not just in one country or region.

6. What is the relationship between the scientific contribution of countries to the area of women in science and higher education and their level of development in gender equality?

As regards the sixth question, the results suggested that countries with higher levels of inequality (higher GII values) such as Nicaragua and Botswana, measured by the Gender Inequality Index, tend to show higher relative values of scientific productivity in the field and are the most likely to collaborate internationally. The latter result is in line with a study conducted by Sugimoto, et al. (2015) on the relation between gender disparities in scholarly communication and country-level development indicators. They also found that countries with lower levels of gender inequality sought international collaboration at a higher rate.

Therefore, while countries such as the United States and the United Kingdom are the most productive countries in terms of absolute contributions, countries with higher levels of inequality showed higher relative values of productivity in the field. This finding is in accordance with Glänzel’s (2001) study, which pointed out that some countries compensate relatively weak domestic activities through international collaboration or even intensify their own strong activities in the preferred science fields by international collaboration.

7. What is the distribution, relevance and interest of the area of women in science and higher education across journals of different disciplines?

With regard to the seventh question, the data showed a high dispersion of the literature and a small set of core journals (n=13) from different research areas focused on the topic. This accounts for 366 (25.86%) of the total of studied papers. These research areas, ordered by the frequency of their core journals, were: Computer Science*;* Information Science and Library Science*;* Psychology*;* Women's Studies*;* Education and Educational Research*;* Health Care Sciences and Services*;* Business and Economics*;* Public, Environmental, and Occupational Health*;* General and Internal Medicine*;* Obstetrics and Gynecology*;* and Psychiatry, respectively.

This indicates a field of study which is widely distributed across journals of different disciplines and is regarded as relevant in many research areas. However, it should be borne in mind that of the 13 identified core journals by Bradford's law, six of them belongs to the area of the area of Education and Educational Research. That means that the most productive research area in the field of women in science and higher education is Education and Educational Research.

The second study, aimed at identifying the major research topics in this area, with a special focus on explanatory factors accounting for gender differences in science and higher education, addressed the factors elucidating gender differences by examining questions number eight to ten of the thesis as follow. The results of this study has been published as:

Dehdarirad, T., Villarroya, A., & Barrios, M. (2014). Research trends in gender differences in higher education and science: a co-word analysis. *Scientometrics*, 1-18. doi: 10.1007/s11192-014-1327-2

8. What is the importance, interest and growth rate of the number of publications on factors accounting for gender differences in science and higher education over time?

For this research question, the finding revealed that more than fifty percent of the total body of literature was published in the last studied five years (2008–2012), of the three periods studied (1991-2001, 2002-2007, and 2008-2012). This suggests that, the studied issue is a topic which has recently aroused the interest of researchers. ‘‘*Inequality and diversity in higher education*’’ was the theme with the highest number of documents over the three studied sub-periods. This broad topic addresses gender and other types of inequalities in higher education, as well as diversity issues. While some papers in this cluster mainly evidence gender and race inequalities related to academic degree, salary, socio-economic status, disciplines, rank, tenure, or mentoring etc., others focus on the potential value of diversity in terms of enhancing work processes and organizational mechanisms through the incorporation of women and members of other underrepresented groups such as racial/ethnic minority groups (Homan et al. 2008; Gonzalez and DeNisi 2009; Rosser 2012).

9. What is the growth rate of the number of sub-fields (themes) which address the factors accounting for gender differences in science and higher education, over time?

Regarding the ninth question, the results showed that the number of themes has increased significantly over the years. This suggests a greater interest in the study of factors related to gender differences in higher education and science, as well as a diversification and specialization of the research field over time (1991-2001, 2002-2007, and 2008-2012).
"*Work-life balance in academia*'' provides a good example of the latter issue: this theme appeared for the first time in the second period (2002.2007), mainly in relation to the issue of work-life balance in universities, while in the third period (2008-2012) it became specialized and was covered by specific fields of study such as engineering and psychology. The relevance of this topic has also been underlined in some reports such as She Figures (2012, 2015). According to these reports, the work-life issue remain a key element in achieving gender equality, since women still bear the main burden of care and domestic work.

10. What is the interest and evolution of themes on the factors accounting for gender differences in science and higher education over time?

Finally, in terms of the last question of this thesis, the findings revealed that many themes are still immature and needed to be further studied. They were: "*work-life balance in Psychology*"*"*, "*work-life balance"*, "*inequality and diversity in higher education"*, and "*glass-ceiling barriers"*. The importance of the latter topic, the glass ceiling phenomenon, whereby the representation of women decreases as the seniority of the role increases, has been debated in many recent reports including She Figures´ 2015 report. According to this report, striking gender inequalities persist when it comes to career advancement and participation in academic decision-making**.** In 2013, women made up only 21 % of the top-level researchers (grade A), showing very limited progress compared to 2010 (20 %). Despite significant progress in their level of education relative to men over the last few decades, women are increasingly under-represented as they move up the stages of an academic career.

The results also showed that there are only very few themes that are well-developed: "*Gender discrimination in labor markets and universities*", "*Career satisfaction in medicine*", "*Academic career in sociology",* " and "*Advancement in academic medicine*". It is interesting to see that two of these themes addressed issues related to academic medicine. This might be due to the recognition of the importance of women's academic capital to medical academe (Carr, et al., 2015) and the existence of gender equity programmes in the field of academic medicine. As mentioned by Caffrey et al. (2016), the under-representation of women in academic medicine wastes public investment and may constitute a threat to international competitiveness of a country's translational research.

Furthermore, there are specific research disciplines that have shown interest in gender issues, particularly after the second time period (2002–2007), including medicine, psychology, STEM (science, technology, engineering and mathematics), geography and sociology.

Overall, the increasing body of evidence obtained from both studies showed that gender inequality remains a global problem, despite substantial initiatives and policies undertaken at national and international level (Larivière et al. 2013 a, b). Although progress continues to be made, change is on average slow, patchy, and subject to significant variation according to country, research field, and other factors (LERU, 2012). Numerous scholars from different parts of the world continue to address this problem and provide valuable material for evidence-based policies.

5.2. Research contributions

To the best of our knowledge, this is the first study based on bibliometric indicators, laws and techniques such as co-word analysis focused on the literature on gender differences in science and higher education. The results obtained through the bibliometric indicators and laws, co-word analysis (cluster analysis and strategic diagrams) complement and confirm previous findings (LERU, 2012; European Commission, 2013), adding new information and bringing a new perspective to the subject.

As such, some key contributions of this thesis are: first, it provides a state-of-the-art for the field of women in science and higher education by conducting a systematic analysis of the scientific literature in this area using bibliometric indicators, laws and techniques. It measures the importance of the studied field over years (1991-2012). This work found a significant increase and interest in the field over the last 21 years. In addition, it was observed that more than half of the total body of literature was published in the last five years (2008–2012), suggesting that this is a current area which has recently generated interest among researchers. Second, it provides a global understanding of the degree of the multidisciplinarity and specialization of the studied area. It was found that scholars from different disciplines have contributed to the area, indicating a high degree of multidisciplinarity. In addition, the number of themes being addressed by scholars has increased over years. This suggests a greater interest in the study of themes related to gender differences in science higher education, as well as a diversification and specialization of the research field over time. Third, it measures the importance of the studied area among countries by investigating their contributions relative to global research productivity as well as at international level. It was found that although a high number of countries have contributed to the studied area, a very small proportion of papers were conducted internationally. This indicates a field of study in which more collaboration efforts between countries needs to be encouraged. Fourth, this work helps to illustrate the contribution of countries to the studied area, in association with their level of development in gender equality. It was found that countries with a higher level of gender inequality are, in relative terms, the most productive in the studied area. In addition, they are the most likely to be involved in international collaborations.

Fifth, this thesis provides an approach to analyse and study the thematic evolution of a research field using co-word analysis. It also provides an opportunity to anticipate interesting developments in the field studied by identifying the major research topics in the area of women in science and higher education. It was found that there are only four themes that are mature and well developed. These are: *Gender discrimination in labour markets and universities*, *career satisfaction in medicine*, *academic career in sociology*, and *advancement in academic medicine.* Sixth, it uncovers the potential issues for future research by detecting the gaps in the literature and the issues needed to be addressed or strengthened in further work. "*Teaching load differences*", "*work-life balance*", "*glass-ceiling barriers*", and "*inequality and diversity in higher*" education are some examples.

Finally, given the above-mentioned contributions, researchers, governments, and funding agencies could draw upon this type of analysis in order to get insights into the current situation of the field and to take necessary actions to promote research in the gaps identified in the literature.

5.3. Some limitations of the conducted research

- The first limitation of this research is related to the database used for the analysis. Most of the journals included in the Web of Science database are in English and it only includes a very limited number of journals in languages other than English (Andersen, 2000; Archambault and Gagné, 2004; Yang and Meho, 2006; Harzing, 2010; Miri and Bahmani, 2012). In our study, this limited coverage also showed itself as a bias in favour of English language journals from English speaking countries. As it has been indicated by Archambault et al. (2006) it is difficult to rely solely on Thomson Scientific database and therefore any benchmarking based on this database will underestimate the production of non-English speaking countries. Additionally, the Web of Science database does not index all journals, and its coverage in some fields is less complete than in others (Wáng et al., 2014).

- The second limitation of this research is that it only relies on quantitative aspects of the area of women in science and higher education using bibliometrics. Although bibliometric studies are useful in terms of analysing the patterns of scholarly communication and evaluation of research output, publications are not the only elements (but certainly are very important ones) in measuring different aspects of scientific fields.

- The third limitation of this study is regarding the WOS reliability and its inconsistency in the number of retrieved records. We repeated the same search query at different times during a month for both studies (Study 1, Study 2). However, we retrieved different results due to continuous actualization of the database.

- The fourth limitation of this study is related to key wording and the indexer effect. By the former, we refer to the fact that authors have to summarize their research in a limited number of keywords. By the later, we mean the wrong emphasis that the indexers may sometimes put on some keywords.

5.4. Recommendations for future research

- This work provided a thematic evolution of factors accounting for gender differences using co-word analysis techniques and bibliometric indicators. For this analysis, author-provided keywords and keywords plus were used. This analysis could be improved in future studies by using a combination of keywords from title and abstracts in addition to author provided keywords and keyword plus. Such an analysis has been beyond the scope of this thesis.

- Although the Web of Science is one of the most important bibliographical data bases, it does not index all journals, and its coverage in some fields and of languages other than English is less complete than others. Thus, future research could also focus on other bibliographic database such as Scopus, Google scholar, etc., enabling a wider analysis.

- Future research can complement the results obtained by this thesis using other techniques such as topic modelling.

- The evolution of the themes on the factors accounting for gender differences in science and higher education over time has been addressed in this thesis. It would be interesting to further investigate the evolution of these themes by studying them in another sub-period (e.g. 2013-2016) and comparing the achieved results with the ones obtained from the three current studied sub-periods (i.e. 1991-2001, 2002-2007, 2008-2012).

- The thesis helped to identify the gaps (e.g. teaching load differences, work-life balance, glass-ceiling barriers, and inequality and diversity in higher) in the literature in the area of women in science and higher education. These issues can be further addressed and examined in future studies.

- For stakeholders, researchers, governments, and funding agencies, this thesis may serve as the basis for further analysis of the area of women in science and higher education, developing and improving research policy in this area and calling for necessary actions to accelerate the closure of the gaps identified in this research.

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Annexes

Annex 1

Table 9 Cluster number, cluster name and the key words corresponding to each cluster in the first sub-period

Cluster No	keywords	Name of cluster
C1	Labor markets, salary gap, careers, productivity, universities, economist, discrimination, salary, gender, women	Gender discrimination in labor markets and universities
C2	Career progression, management, race, power, sex segregation, psychology, students	Institutional issues
C3	Academia, mobility, women faculty	Mobility of women academics
C4	Medicine, men, rank, sex differences, faculty, research productivity, promotion, sciences, physicians	Sex differences in promotion

Table 10 Cluster number, cluster name and the key words corresponding to each cluster in the second sub-period

Cluster No.	Keywords	Name of cluster
C1	Careers, faculty, satisfaction, men, women physicians, medicine	Career satisfaction in medicine
C2	Research productivity, sex differences, promotion, salary	Sex differences in promotion
C3	stereotypes, success, discrimination	Gender stereotypes and discrimination
C4	Gender gap, roles, management	Gender roles in management
C5	Education, health, mentorship	Mentorship
C6	Gender equality, women faculty, mobility	Mobility of women academics
C7	Science, students, universities, race	Racial discrimination at universities
C8	Family, women, productivity, work	Work-life balance in academia
C9	Academic career, sociology	Academic career in sociology
C10	Gender, geography, higher education	Gender issues in geography

Table 11 Cluster number, cluster name and the key words corresponding to each cluster in the third sub-period

Cluster No.	Keywords	Name of cluster
C1	Labor markets, salary gap, salary	Gender discrimination in labor markets and universities
C2	Men, productivity, scientists, sex differences	Gender differences in productivity
C3	Employment, stratification, colleges, perspectives	Employment stratification
C4	Discrimination, equality, equity, gender issues, education, work, gender bias, organizations, gap, PhD, academic achievements, sex segregation, glass ceiling, motherhood, academic disciplines	Glass ceiling barriers
C5	Stress, support, motivation, personal factors	Personal factors
C6	Career choice, mobility, status, nursing, self-concept, tokenism, sex composition	Mobility, career choice, and sex composition
C7	Attitudes, school, achievement, mathematicians, stereotypes	Stereotypes in mathematics
C8	Identity, recruitment, engineering, experiences, students, children, family, performance, values, science	Work-life balance in academia
C9	Advancement, medicine, compensation, progress, academic medicine, physicians, recommendations, success	Advancement in academic medicine
C10	Retention, working hours, exclusion, organizational structure	Institutional issues

C11	Minorities, satisfaction, turn over, climate, workforce, academic career	Climate and staff composition in academia
C12	Barriers, women physicians, leadership, management, career progression, roles, outcomes, sexual harassment	Senior positions in medicine
C13	Faculty, women, diversity, race, inequality, universities, gender, higher education, STEM, women faculty	Inequality and diversity in higher education
C14	Impact, research productivity, collaboration, authorship, citations	Bibliometric indicators
C15	Feminism, women studies, innovation	Women studies
C16	Profession, rank, career, psychology, research, professors, academia, promotion, gender equality, work life balance	Work-life balance in psychology

Annex 2

Table 12 A summary of themes in each studied sub-period

1st period	2nd period	3rd period
Motor themes		
▪ Gender discrimination in labor markets and universities (C1)	▪ Career satisfaction in medicine (C1) ▪ Academic career in sociology (C9)	▪ Advancement in academic medicine (C9)
Specialized themes		
▪ Mobility of women academics (C3)	▪ Gender stereotypes and discrimination (C3) ▪ Sex differences in promotion (C2)	▪ Gender discrimination in labor markets and universities (C1) ▪ Gender differences in productivity (C2) ▪ Employment stratification (C3) Personal factors (C5) ▪ Stereotypes in mathematics (C7) ▪ Institutional issues (C10) ▪ Women's studies (C15)
Emerging (disappearing) themes		
▪ Institutional issues (C2) ▪ Sex differences in promotion (C4)	▪ Mobility of women academics (C6) ▪ Gender roles in management (C4) ▪ Mentorship (C5) ▪ Racial discrimination at universities (C7) ▪ Work-life balance in academia (C8) ▪ Gender issues in geography (C10)	▪ Mobility, career choice, and sex composition (C6) ▪ Senior positions in medicine (C12) ▪ Bibliometric indicators (C14)
Transverse (basic) themes		
		▪ Glass ceiling barriers (C4) ▪ Work-life balance in engineering (C8) ▪ Climate and staff composition in academia (C11) ▪ Inequality and diversity in higher education (C13) ▪ Work-life balance in psychology (C16)

Table 13 A summary of the themes appeared in more than one period

1st and 2nd period	1st and 3rd period	2nd and 3rd period	All periods
▪ Sex differences in promotion: present as (C4) in first period and as (C2) in the second period	▪ Institutional issues: present as (C2) in the first period and as (C10) in the third period	▪ Work-life balance in academia: present as (C8) in the second period and similar to Work-life balance in psychology (C16) and Work-life balance in engineering (C8) in third period ▪ Inequality and diversity in higher education: present as (*C13*) in the third period and similar to Racial discrimination at universities (C7) in the second period ▪ Advancement in academic medicine: present as (C9) in the third period and similar to Career satisfaction in medicine *(*C1*)* in the second period	▪ Mobility, career choice, and sex composition: present as (C6) in the third period and similar to mobility of women academics in first period (C3) and second period (C6) ▪ Gender discrimination in labour markets and universities: present as (C1) in both first and third periods and similar to Gender stereotypes and discrimination" (C3) in the second period

Annex 3

List of the scientific publications of the thesis

Journals

Dehdarirad, T., Villarroya, A., & Barrios, M. (2015). Research on women in science and higher education: a bibliometric analysis. *Scientometrics*, 1-18. doi: 10.1007/s11192-015-1574-x

Dehdarirad, T., Villarroya, A., & Barrios, M. (2014). Research trends in gender differences in higher education and science: a co-word analysis. *Scientometrics*, 1-18. doi: 10.1007/s11192-014-1327-2

The full text of these two publications can be found at the end of this annex.

Presentations in international and national conferences

Dehdarirad, T. Villarroya, A. and Barrios, M. (2015). Women In Science and Higher Education. 3rd International Seminar on Library and Information Science Education and Research (LIS-ER), Barcelona, 4-5 June.

Dehdarirad, T. Villarroya, A. and Barrios, M. (2014)." Women in Science and Higher Education: a bibliometric study". 10th International Conference on Webometrics, Informetrics, and Scientometrics (WIS) and the 15th COLLNET Meeting, Ilmenau, Germany, 3-5 September 2014.

Dehdarirad, T. Villarroya, A. and Barrios, M. (2013). "A Co-word-based Analysis of Factors related to Gender Differences in Science". ISSI 2013 – 14th International Conference of the International Society for Scientometrics and Informetrics. Vienna, Austria, 15th-19th July 2013.

Dehdarirad, T. Villarroya, A. and Barrios, M. (2013). "Factors related to Gender Differences in Science" . STI 2013 – 18th International Conference on Science and Technology Indicators "Translational twists and turns: Science as a socio-economic endeavor", Berlin, Germany, 4th-6th September, 2013.

Presentations of the thesis

PhD forum, 15th International Conference on Scientometrics and Informetrics, 29 June - 4 July 2015, Istanbul, Turkey.

Personal Thesis Presentation, ETH, 7 October 2014, Zurich, Switzerland.

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Research on women in science and higher education: a bibliometric analysis

Tahereh Dehdarirad[1] · Anna Villarroya[2] · Maite Barrios[3]

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Abstract The main objective of this paper is to study the development and growth of scientific literature on women in science and higher education. A total of 1415 articles and reviews published between 1991 and 2012 were extracted from the Thomson Reuters Web of Science database. Standard bibliometric indicators and laws (e.g. Price's, Lotka's, and Bradford's laws) were applied to these data. In addition, the Gender Inequality Index (GII) was obtained for each country in order to rank them. The results suggest an upward trend not only in the number of papers but also in the number of authors per paper. However, this increase in the number of authors was not accompanied by greater international collaboration. The interest in gender differences in science extends too many authors ($n = 3064$), countries ($n = 67$), and research areas ($n = 86$). Data showed a high dispersion of the literature and a small set of core journals focused on the topic. Regarding the research areas, the area with the highest frequency of papers was Education and Educational Research. Finally, our results showed that countries with higher levels of inequality (higher GII values) tend to present higher relative values of scientific productivity in the field.

Keywords Gender differences · Higher education · Science · Bibliometrics

Mathematics Subject Classification 01-00 · 62-07

JEL Classification C10 · O30

✉ Maite Barrios
mbarrios@ub.edu

[1] Department of Library and Information Science, University of Barcelona, Barcelona, Spain

[2] Department of Public Economy, Political Economy and Spanish Economy, University of Barcelona, Barcelona, Spain

[3] Department of Methodology of the Behavioural Sciences, University of Barcelona, Passeig de la Vall d'Hebron 171, 08035 Barcelona, Spain

Introduction

According to the latest indicators referred to the European Union, although women's entry into and progression within science is progressing towards a more equal representation, they are still under-represented in leading positions (European Commission 2013). As a consequence, numerous reports and initiatives have emerged in Europe but also in different parts of the world with the aim of analyzing the presence of women in science and higher education (WSHE), and to advocate for a more gender-balanced structure of science (LERU 2012; Deloitte Consulting 2013; European Commission 2013; the Organization for Economic Co-operation and Development [OECD] 2013).

The scientific literature contains ample evidence regarding different aspects of women's participation and performance in science and higher education. A significant body of studies has examined gender disparities in publication productivity, addressing issues such as the number of publications, citations, impact of researchers' output, and patterns of collaboration. In terms of the number of publications many studies have demonstrated that female academics publish less, on average, than do their male colleagues (Braisher et al. 2005; Kelly and Jennions 2006; Symonds et al. 2006; Sidhu et al. 2009; Jagsi et al. 2011; Schrager et al. 2011). However, there is also research reporting no significant differences in productivity between the two sexes (Xie and Shauman 1998; Lewison 2001; Bordons et al. 2003; Tower et al. 2007; Mauleón et al. 2008), especially when it comes to younger generations of researchers (Arensbergen et al. 2012). Some of these studies have also evaluated the impact of publications, through the number of citations or the journal impact factor. The literature in this area has shown mixed results, including no differences in the citation patterns of male and female academics (Cole and Zuckerman 1984; Lewison 2001; Ledin et al. 2007; Mauleón et al. 2008; Copenheaver et al. 2010), a higher number of citations for female-authored papers (Long 1992; Symonds et al. 2006; Borrego et al. 2010), and fewer citations of papers authored by women (Hunter and Leahey 2010; Larivière et al. 2011, 2013a, b). Recently, the global, cross-disciplinary bibliometric study undertaken by Larivière et al. (2013a, b) showed that papers with female authors in key positions (sole authorship, first- and last-authorship) are cited less than those with males in key positions.

Studies on the journal impact factor have also produced mixed findings: while some of them have highlighted the similarity of the journals in which women and men publish (Lewison 2001; Bordons et al. 2003; Mauleón and Bordons 2006; Gonzalez-Brambila and Veloso 2007; Mauleón et al. 2008), others have shown that men choose to publish in journals with a higher impact factor (Hunter and Leahey 2010), or alternatively that women are the ones who tend to publish in higher impact journals (Borrego et al. 2010). Another approach to the study of scientific activity concerns the collaborative practices of researchers. Here, there is ample evidence showing that women collaborate to a lesser extent than do men with foreign authors (Lemoine 1992; Lewison 2001; Webster 2001; Larivière et al. 2011, 2013a, b). However, the results on authorship patterns have proved inconclusive: whilst some research has obtained similar rates of co-authorship among women and men (Maske et al. 2003; McDowell et al. 2006), other studies have found significantly lower rates of co-authorship for women (Boschini and Sjögren 2007; West et al. 2013; Larivière et al. 2013a, b). Another sizeable body of research on WSHE has addressed elements that have an influence on the development of a scientific career, such as grant and manuscript reviewing, access to funding and hiring and career progression. With regard to manuscript reviewing, Budden et al. (2008) reported that the acceptance rate for female first-authored manuscripts increased after the onset of blind review, suggesting that when reviewers were aware of the authors' sex they were less likely to accept manuscripts from women. However, further work on this issue has found no differences in the acceptance/rejection ratio for papers submitted by male and female corresponding authors (Aarssen et al. 2008; Whittaker 2008). The situation is different in relation to the participation of women in peer review processes, where many more authors have found gender differences in female recruitment as editors and reviewers (Gilbert et al. 1994; Dickersin et al. 1998; Davo et al. 2003). Concerning grant peer reviewing, one of the most frequently cited studies on gender bias, that carried out by Wennerås and Wold (1997), demonstrated that female applicants for postdoctoral fellowships at the Swedish Medical Research Council had to be 2.5 times more productive than the average male applicant in order to obtain the same peer-review rating for scientific competence. Since then, an ever-growing body of academic research has found no conclusive evidence of sex discrimination in the awarding of specific project grants (Wellcome Trust 1997; Ward and Donnelly 1998; Bornmann et al. 2007; Marsh et al. 2008). In this regard, the meta-analyses conducted by Bornmann et al. (2007) and Marsh et al. (2009), and more recently the study by Mutz et al. (2012), have all concluded that there is negligible evidence of gender bias in grant awarding programs. There is also a body of academic literature attesting to the idea that male scientists face fewer difficulties when seeking to access financial support and better facilities (Stack 2004; Larivière et al. 2011; LERU 2012), since they occupy a greater proportion of high positions from which it is possible to apply for and receive larger grants (Blake and La Valle 2000; Waisbren et al. 2008; Ranga et al. 2012). Other aspects that have been clearly highlighted in the literature are the overrepresentation of women in lower faculty ranks (D'Amico et al. 2011), due to the difficulties of progressing up the academic ladder (LERU 2012), a persistent gender pay gap (Ward 2001; Ginther 2003; Henderson et al. 2014), and gender bias in researcher recruitment (Andersen 2001), especially in certain male-dominated areas (Isaac et al. 2009). Recent research suggests that many mechanisms prevalent in recruitment and appointment practices of professors result in disadvantages for women and privileges for men (Van den Brink 2011). These mechanisms include "gate keeping", academic networks that are male-dominated and the way scientific excellence is defined (LERU 2012). Based on an empirical study of professorial appointments in the Netherlands, Van den Brink and Benschop (2012) show how gender bias is practised in the evaluation of professorial candidates, resulting in substantial inequalities in the construction of excellence.

As the above-mentioned evidence suggests, different studies have reported diverse results. Hence, many of these studies have sought to explain the systematic disparities between men and women by incorporating different factors into their analysis. Factors surrounding family formation and childrearing have been one of the major causes of female underrepresentation in academia evidenced by the literature (Sax et al. 2002; Stack 2004; Fox 2005; Ginther and Kahn 2006; Prozesky 2008; Hunter and Leahey 2010). Another large body of literature has focused on structural factors such as the greater presence of women in less research-oriented institutions (Allison and Long 1990; Xie and Shauman 1998), the higher teaching and service load among females (Taylor et al. 2006; Snell et al. 2009; DesRoches et al. 2010), their lower degree of specialization (Leahey 2006) and of academic status and rank (Leta and Lewison 2003; Tower et al. 2007; Puuska 2010; Pashkova et al. 2013), their difficulties in accessing funding (Xie and Shauman 1998), the low percentage of women on selection committees (European Commission 2009; Zinovyeva and Bagues 2011), or the academic assessment systems that have traditionally ignored factors that especially affect women (LERU 2012). From a psychological perspective, gender differences have been explained by women's lower levels of career orientation, ambition, and aggressiveness (Sonnert 1996). Similarly, career preferences, ability, and biological differences have been key factors proposed to explain female underrepresentation in science, technology, engineering, and mathematics (STEM) disciplines. Finally, there is also a body of academic research attesting to overt or unconscious gender bias as the main factor against retention and progression of female scientists in academia (Dewandre 2002; Moss-Racusin et al. 2012; Shen 2013).

Despite the relevance of the issue and the number of academic publications, initiatives, and reports on *WSHE*, no systematic analysis has yet to be carried out of the large body of research in this area. Using standard bibliometric indicators (such as the number of papers and authors, and productivity by country, among others), laws (Price's, Lotka's, and Bradford's laws) and an index for measuring gender disparity [the Gender Inequality Index (GII)], this article aims to assess the development and growth of research in this field by reviewing the related scientific literature.

Methods

Data collection

The data were extracted from the Thomson Reuters Web of Science (WOS) in February 2013, with the search in the topic field covering the period from 1991 to 2012. Several strategies were used to retrieve the related scientific literature (Fig. 1). First, three different searches were carried out, taking into account the three main topics in the field: *publication*

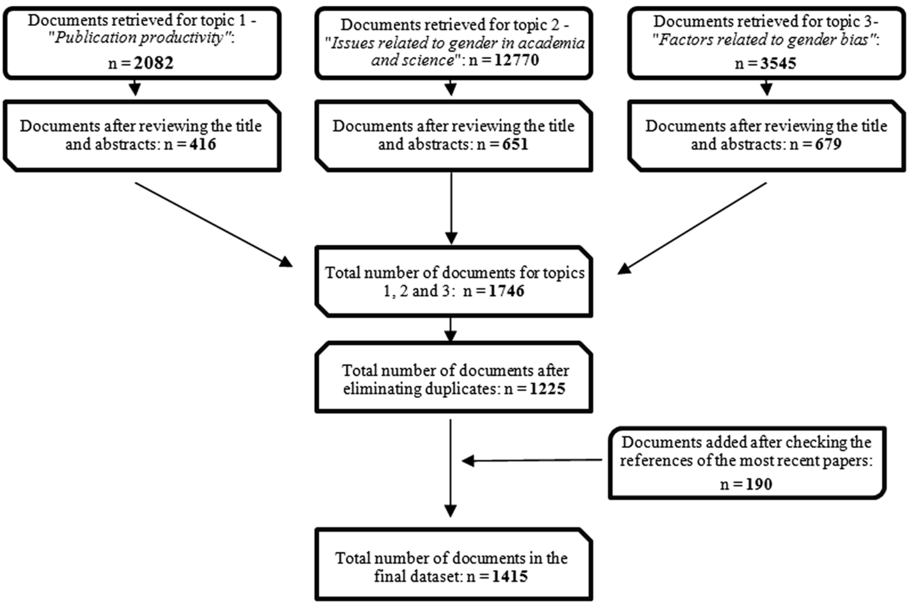

Fig. 1 Flowchart illustrating the process of data collection

productivity, *issues related to gender in academia and science*, and *factors related to gender bias*.

To do so, for each topic we went through the related literature in order to identify the related key terms. A preliminary combination of key terms was used to extract the papers related to the subject. Next, after reviewing the keywords of these preliminary papers, we added more specific terms to the query in order to check whether these new terms increased the number of records retrieved; if they did, they were included in the query, and if not, they were eliminated.

By *publication productivity* we refer to those papers dealing with scientific productivity, citation, and collaboration patterns. Papers addressing elements other than publication productivity that have an influence on the development of a scientific career, such as interviewing and hiring, salaries, promotion and advancement, having access to funding, mentoring and networking, and being a member of an editorial board or a peer reviewer were categorized in the second group, labeled *issues related to gender in academia and science*. Finally, given that the performance of researchers in the two above-mentioned groups of scientific activities can be affected by several factors, another pool of papers were considered as a third group called *factors related to gender bias*. Among these factors we took into account family-related issues (e.g. marital status, childrearing activities, home stress, family formation, work-home balance, etc.), structural or institutional variables (e.g. type of institution, research support, academic system, etc.), professional issues (e.g. job stress, motivation, rank, research orientation, etc.), biological factors (e.g. age, race, etc.), psychological traits (e.g. self-esteem, ambition, aggressiveness, etc.), social and cultural factors (e.g. stereotypes, norms and values, etc.) and political variables (policies and legislation regarding WSHE).

As a result of this step, 2082 records were initially retrieved for the first topic, 12,770 for the second and 3545 for the third. In order to identify the papers related to these three main topics the titles and abstracts of each paper were checked. Papers which focused on the field of higher education and science, dealt with one or more of above three topics mentioned, and in which gender was one of the variables of interest, were included in the sample.

Finally, a total of 1746 papers were retrieved: 416 (23.83 %) records for the *publication productivity* topic, 651 (37.29 %) records for the *issues related to gender in academia and science* topic, and 679 (38.88 %) records for the *factors related to gender bias* topic. After elimination of duplicates a total of 1225 records were considered. Additionally, and in order to ensure that all the references dealing with the subject were included in the database, the references of the most recent papers were checked. If any new paper was found it was added to the database, and we continued doing this until no new references were identified. This process led to the inclusion of 190 new papers. As a result the final corpus comprised 1415 articles and reviews, all of which were coded according to the three headings mentioned above. It should be noted that any given paper may simultaneously address more than one issue, and it will therefore belong to more than one group.

Data analysis

The main bibliometric laws were applied to study scientific growth over time, the dispersion of scientific output across journals, and author productivity.

Scientific growth over time was assessed using Price's law (Price 1963), which proposes that the growth of scientific production follows an exponential function. In order to test whether our data followed Price's law, different regression models were fitted, including linear, exponential and logistic curves, the latter being applied to assess the hypothesis of literature growth saturation.

Bradford's law (Bradford 1934, 1948) was applied in order to study the dispersion of the literature. Specifically, Bradford's law describes how the articles in a specific area are scattered across journals, postulating a model of concentric productivity zones with a decreasing information density. Following the proposal of Egghe (1986, 1990), the Bradford multiplier was obtained by $k = (1.781 \times y_{\mathrm{m}})^{1/P}$ where y_{m} is the number of articles published by the most productive journal and P is the number of zones including the core. The estimated k value for each zone was calculated by the ratio between the number of journals in a given zone and the number of journals in any immediate zone. The number of Bradford zones was determined by the solution that minimized the difference between the Bradford multiplier k and each estimated value of k, and between the estimated values of k.

In addition, the predicted frequencies were fitted according to Leimkuhler's formulation (Leimkuhler 1967), obtaining the constants as $A = y_0 / \log_e k$ and $B = (k-1)/r_0$ where y_0 is the constant number of articles in each group ($y_{0=a/P}$, where a is the total number of articles and both P and k are as defined above) and r_0 is the expected number of journals in the core ($r_0 = \frac{T(K-1)}{k^p - 1}$, where T is the total number of journals, and k and P are as defined above). The estimated cumulative number of articles produced by the journals of rank $1, 2, \ldots, r$ was obtained by: $R(r) = A \times \log_e(1 + B \times r)$.

After standardization of authors' names (we began with a total of 3538 authors and after standardization we ended with a total of 3064 single authors), Lotka's law was also applied using the method proposed by Pao (1985), including both the first author and co-authors in the analysis. According to Lotka's law the number of authors (y_x) with x number of articles is inversely proportional to x. This relationship is expressed by the formula:

$$x^n \times y_x = C,$$

where y_x is the number of authors producing x number of articles in a given research field, and C and n are constants that can be calculated from the observed data set.

In our study, we used the least-squares method in order to calculate the n exponent, using the following formula:

$$N = \frac{N \sum XY - \sum X \sum Y}{N \sum X^2 - \left(\sum X\right)^2}$$

where N is the number of pairs considered, X is the logarithm of x and Y is the logarithm of y_x. The constant C is calculated using the formula:

$$C = \frac{1}{\sum (1/x^n)}$$

In addition, and in order to verify that the observed data fitted the estimated distribution, the non-parametric Kolmogorov–Smirnov goodness-of-fit test was applied.

In order to calculate relative measures of productivity and international collaboration productivity by country, the Relative Intensity Index (RII) (Larivière et al. 2013a, b) and the International Collaboration Relative Intensity Index (IC-RII) were calculated for each country. Both measures indicate the relative proportion of publications of a given country in a domain relative to the proportion of the world in the same domain. Thus, the RII indicates the relative proportion of publications of a given country in the WSHE area relative to the proportion of the world in the same domain. The RII was calculated for each country using the following formula:

$$\mathrm{RII} = \frac{\frac{n_{\mathrm{WSHE\,country}}}{n_{\mathrm{country}}}}{\frac{n_{\mathrm{WSHE\,world}}}{n_{\mathrm{world}}}}$$

where $n_{\mathrm{WSHE\,country}}$ is the number of publications of a given country in the WSHE area, n_{country} is the total number of publications of the country in all disciplines, $n_{\mathrm{WSHE\ world}}$ is the total publications of the world dealing with WSHE, and n_{world} is the total of publications in all disciplines in the world.

The IC-RII indicates the relative proportion of publications of a country in the WSHE area in international collaboration relative to the proportion of the world's publications published through international collaboration in the same area. The IC-RII is expressed by the formula:

$$\mathrm{IC\text{-}RII} = \frac{\frac{n_{\mathrm{IC\_WSHE\,country}}}{n_{\mathrm{IC\_country}}}}{\frac{n_{\mathrm{IC\_WSHE\,world}}}{n_{\mathrm{IC\_world}}}}$$

where all terms have the same meaning as above except this time publications include only those carried out through international collaboration.

In both cases a value above 1 means that an observed country publishes more in the domain than would be expected, while an index value below 1 indicates the opposite.

It is worth saying that by "World" in our study we mean just those countries which contributed to the publication productivity in WSHE, while by the number of papers we mean the number of scientific papers by authors from a given country, as indicated in the address field. To do so, we used the full counting method. In other words, each paper is counted once for each country listed in the address field. For example if a paper is authored by two researchers from Germany and one from Spain, this paper is counted once for each country.

Finally, with the aim of exploring the existence of a possible relationship between the interest of different countries in that topic and the existence of a broad spectrum of gender inequalities in these countries, the most recent GII was considered. GII is a new index for measuring gender disparity that was introduced in the 2010 Human Development Report (20th anniversary edition) of the United Nations Development Program (UNDP). According to the UNDP (2013), this index is a composite measure which yields insights, within the same country, about gender gaps in major areas of human development. It uses three dimensions to do so: reproductive health, measured by maternal mortality ratio and adolescent birth rates; empowerment, measured by proportion of parliamentary seats occupied by females and proportion of adult females and males aged 25 years and older with at least some secondary education; and labour market participation measured by employment rates of female and male populations aged 15 years and older. The GII values range between 0 to 1, where a value close to 0 means equality between genders and a value close to 1 means inequality.

Results

Number of papers

Data showed an upward trend in the percentage of publications, 52.29 % of which appeared in the last 7 years (2006–2012). The linear, exponential, and logistic regression models were fitted in order to test whether the data followed Price's law. Although all three regression models were statistically significant and captured a high proportion of the explained variance, the exponential model ($R^2 = .834$) explained a higher proportion of the variance than did either the linear ($R^2 = .707$) or logistic ($R^2 = .578$) approaches, showing a good fit to Price's law (Fig. 2).

An upward trend was also observed in the three main topics of the field. Table 1 shows the frequency, percentage, and regression fit for the three topics. As can be seen from the table, the research line with the highest frequency of papers was *issues related to gender in academia and science*. Furthermore, all the topics showed a good fit to the exponential model.

Research areas

According to the classification of journal areas used in Thomson Reuters WOS, the top ten research areas in terms of frequency of papers were *Education and Educational Research* ($n = 71$, 18.3 %), *Psychology* ($n = 237$, 11.7 %), *Information Science and Library Science* ($n = 212$, 10.5 %), *Business and Economics* ($n = 167$, 8.2 %), *Women's Studies* ($n = 165$, 8.1 %), *Computer Science* ($n = 95$, 4.7 %), *Sociology* ($n = 93$, 4.6 %), *General and Internal Medicine* ($n = 63$, 3.1 %), *Health Care Sciences and Services* ($n = 58$, 2.9 %), and, finally, *Science and Technology—Other Topics* ($n = 53$, 2.6 %).

Figure 3 shows the contribution of these top ten research areas in the three topics. *Information Science and Library Science* was the research area with the highest number of publications ($n = 90$, 30.41 %) in topic 1 followed by *Computer Science* ($n = 48$, 20.61 %). *Education and Educational Research* and *Psychology* were the research areas with the highest number of publications in topics 2 and 3. *Education and Educational Research* corresponds respectively to 27.03 % ($n = 276$) of publications in topic 2 and 28.45 % ($n = 132$) in topic 3, while *Psychology* corresponds respectively to 14.99 % ($n = 153$) of publications in topic 2 and 20.26 % ($n = 94$) in topic 3.

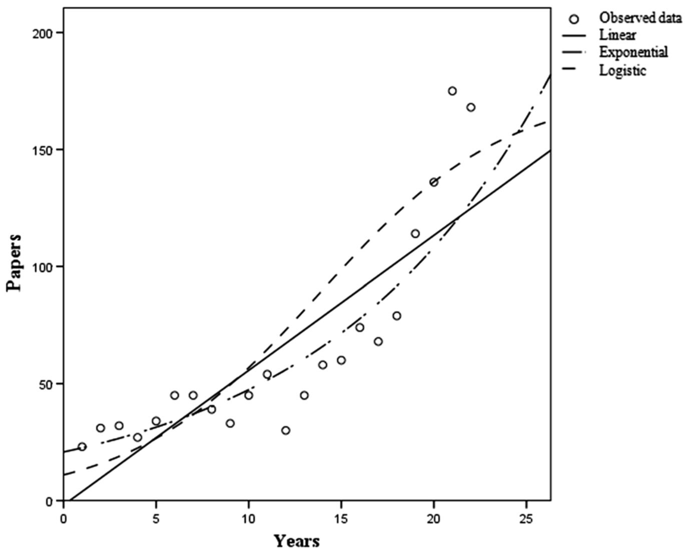

Fig. 2 Growth of literature over time (1991–2012): linear, exponential and logistic regression model fit to Price's law

Table 1 Growth of literature over time (1991–2012) by topic: publication frequency and regression fit

Topic	f_i (%)[a]	R^2 linear	R^2 exponential	R^2 logistic
1. Publication productivity	275 (19.43)	.597	.677	.578
2. Issues related to gender in academia and science	943 (66.64)	.708	.779	.596
3. Factors related to gender bias	438 (30.95)	.657	.726	.581

fi frequency

[a] Note that a given paper may simultaneously address different topics. Consequently, the sum of papers is more than the total number of papers, and the sum of percentages exceeds 100 %

Number of authors

The total number of authors who contributed to the output set was 3064, with the mean number of authors per article being 2.41 (SD = 1.60, M = 2). The data showed that 477 (33.71 %) of the papers had a single author, 398 (28.12 %) had two, 266 (18.79 %) had three, and 274 (19.36 %) had more than three authors. It can be seen in Fig. 4 that the number of papers with a single author showed a decreasing trend, whereas the number of papers with three authors and with more than three authors increased slightly over time. Over the same period there was a fluctuation in the number of papers with two authors.

With regard to the productivity of authors the data showed that 2750 (89.75 %) of them contributed with just one item to the field. Lotka's law was applied using the method proposed by Pao (1985), and all the authors of publications (first authors and collaborators) were considered for the analysis. To determine whether the data fitted Lotka's law, the n value was calculated using the least squares method ($n = 3.40$), yielding a C value of 0.88. The critical value obtained by the non-parametric Kolmogorov–Smirnov goodness-of-fit test was 0.029. As the maximum difference between the observed and the estimated accumulated frequencies was 0.014, which is below the critical value, we can conclude that the data fitted Lotka's law.

Countries

Sixty-seven countries participated in publishing the set of studies, although it should be noted that the provenance of authors was not available for 204 papers (14.4 %). Only 8 % ($n = 113$) of papers involved international collaboration and of these, 22.12 % ($n = 25$) were published recently (in 2012). The top ten countries in terms of absolute contributions, RII, and IC-RII are shown in descending order in Table 2. While the United States and United Kingdom are the most productive countries in terms of absolute contributions, Nicaragua and Botswana, based on the RII, are the countries that showed the highest proportion of publications in WSHE relative to the proportion of the world in the same area. Taking into account just those papers published in international collaboration, based on the IC-RII, Sudan, Nepal and Ghana are the countries with the highest international collaboration productivity.

Interestingly, a significant positive correlation coefficient was obtained between the most recent GII and the RII ($r = .277$, $p = .029$) and the IC-RII ($r = .497$, $p = .001$), showing that countries that present higher gender inequalities present higher relative productivity related to the topic as well as higher levels of international collaboration productivity. As the GII was not available for five countries, only 62 countries were considered in the analysis of the above-mentioned correlations.

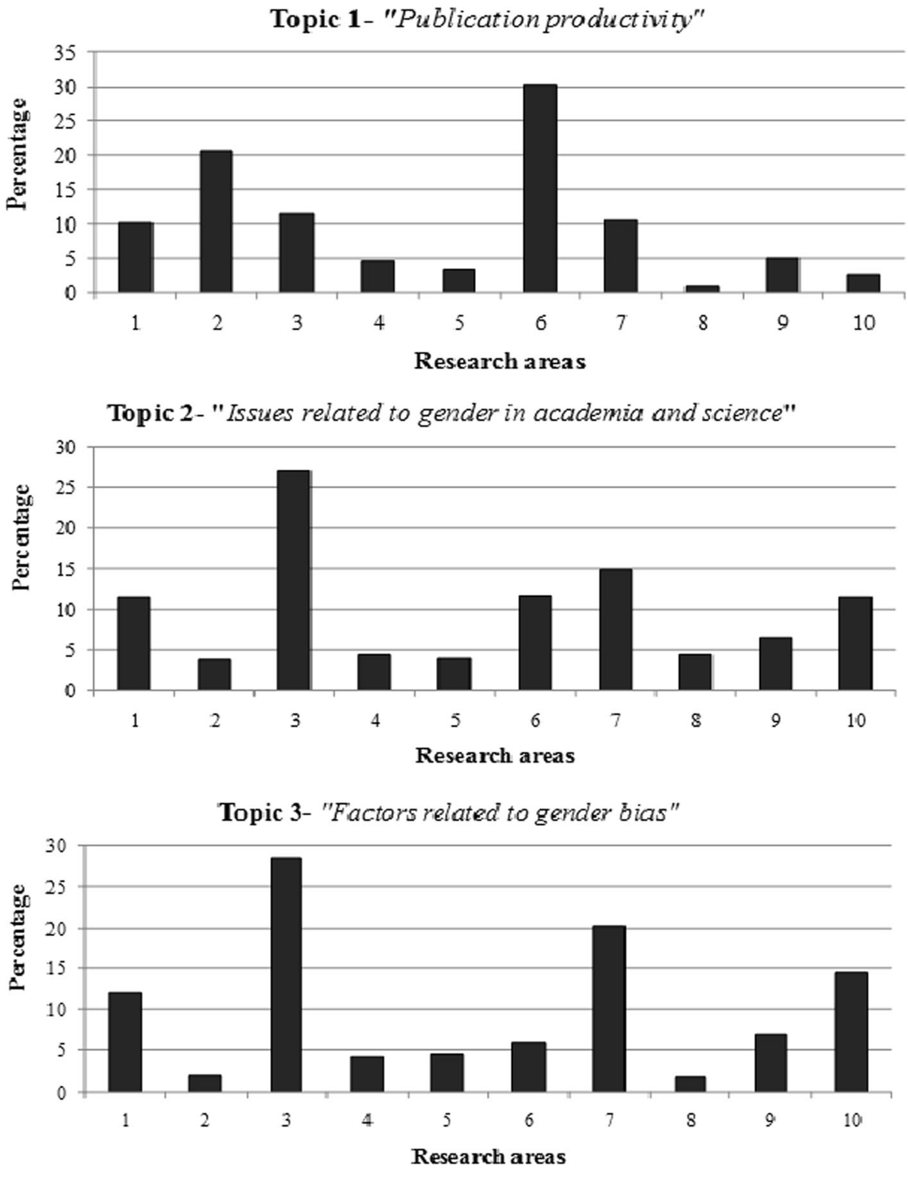

Fig. 3 Percentage of papers for the top ten research areas in the three topics. *1* Business and Economics, *2* Computer Science, *3* Education and Educational Research, *4* General and Internal Medicine, *5* Health Care and Services, *6* Information Science and Library Science, *7* Psychology, *8* Science and Technology—Other Topics, *9* Sociology, *10* Women's Studies

Regarding the topics, *Issues related to gender in academia and science* (topic 2) was the most frequent among the top ten countries in terms of absolute frequency. Among the papers involving international collaboration, 56.64 % ($n = 64$) of them dealt with the topic of *issues related to gender in academia and science*, 30.08 % ($n = 34$) addressed *factors related to gender bias*, and 28.31 % ($n = 32$) examined *publication productivity*. As any

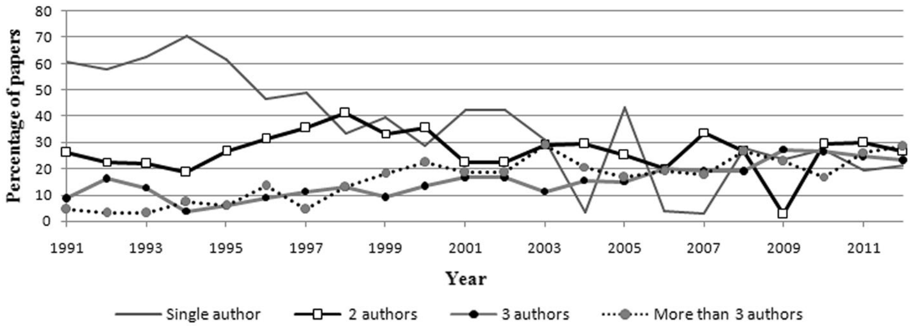

Fig. 4 Changes over time (1991–2012) in the number of authors per paper

Table 2 Top ten countries based on absolute contributions, relative intensity index (RII), and international collaboration relative intensity index (IC-RII)

Country	f_i (%)	Country	RII	Country	IC-RII
USA	638 (45.08)	Nicaragua	20.94	Sudan	35.33
UK	126 (8.90)	Botswana	6.24	Nepal	24.69
Canada	70 (4.94)	Sudan	5.47	Ghana	21.39
Australia	63 (4.45)	Cyprus	4.86	Philippines	18.02
Spain	57 (4.02)	Nepal	4.50	Luxembourg	17.65
Germany	41 (2.89)	Lebanon	3.83	Cyprus	15.18
Netherlands	29 (2.04)	Luxembourg	3.54	Lebanon	14.41
Sweden	29 (2.04)	Ghana	3.21	Malaysia	14.39
China	20 (1.41)	Philippines	3.03	Bangladesh	9.09
Brazil/Italy/Turkey	17 (1.20)	SriLanka	2.93	Turkey	6.78

f_i frequency

given paper may simultaneously address more than one topic, the sum of papers is more than the total number of papers, and the sum of percentages exceeds 100 %.

Journals

The papers included in the present study were published in a total of 595 journals, of which 366 (61.5 %) published only one paper. The distribution of papers published in the set of journals was described using Bradford's law, which revealed that the papers were distributed in four zones. The core was composed of 13 journals. Table 3 shows the expected number of journals given the Bradford multiplier (3.17), the actual number of journals in each zone, the number of articles included in each zone, the cumulative number of articles, the estimated values of k, and, finally, the predicted cumulative number of articles $R(r)$.

Table 4 shows core journals, publication frequency and the corresponding research areas of each journal based on the Thomson Reuters WOS. As can be seen from the table, six of the core journals belong to the area of Education and Educational Research, and Scientometrics is the journal with the highest number of papers related to topic 1, while the rest of the journals published more papers related to topic 2.

Table 3 Data fit to Bradford's law

Zone	Expected number of journals	Number of journals	Number of articles	Cumulative articles	Estimated k	$R(r)$
1	13	13	366	366	–	355.86
2	41.10	41	250	616	3.15	634.02
3	129.98	130	343	959	3.17	959.77
4	411	411	456	1415	3.16	1303.04

Constants according to Leimkuhler's formulation were $A = 306.26$ and $B = 0.168$

Discussion

This study has analyzed the main bibliometric indicators in relation to the literature on women's participation in science and higher education. With regard to the number of publications, results showed a significant increase and interest in the field over the last 21 years, particularly since 2002, when a steady increase begins. This increment was supported by the fit of the data to Price's law, which indicates that productivity in the studied field shows an exponential growth. Of the three topics considered, namely *publication productivity*, *issues related to gender in academia and science*, and *factors related to gender bias*, the highest number of papers corresponded to the second topic (i.e., *issues related to gender in academia and science*), accounting for 66.64 % of the total publications. This topic was also the most frequently addressed in papers involving international collaboration (56.64 %). This result may be due to the fact that this topic addresses a wide variety of issues such as a scientific career, having access to funding, mentoring and networking, and being a member of an editorial board or a peer reviewer, among others. Furthermore, these studies often consider the other two topics as well in an attempt to examine existing differences in academia and science by searching for explanatory factors, and they often using bibliometric indicators such as publication productivity.

Regarding the research areas showing the most interest in the studied field, it can be inferred that scholars from different disciplines, such as *Education and Educational Research*, *Psychology*, *Information Science and Library Science*, *Computer Science*, *Business and Economics*, and *Women's Studies*, among others, have all contributed to the field, thereby indicating a high degree of multidisciplinarity. However, the interest of these areas in the three different topics is quite unbalanced. Not surprisingly, *Information Science and Library Science* and *Computer Science* were the areas with the highest contributions in the third topic, *publication productivity*, while *Education and Educational Research* and *Psychology were the areas with the highest weight in the topics* "issues related to gender in academia and science", and "factors related to gender bias".

In addition, the result of Bradford's law identified a small set of core journals focused on the studied field, which were also from eleven different research areas. Ordered according to frequency these core journals correspond to the following areas: *Computer Science*; *Information Science and Library Science*; *Psychology*; *Women's Studies*; *Education and Educational Research*; *Health Care Sciences and Services*; *Business and Economics*; *Public, Environmental, and Occupational Health*; *General and Internal Medicine*; *Obstetrics and Gynecology*; and *Psychiatry*. This means that this field is widely scattered across journals of different disciplines and is regarded as relevant in many research areas. However, it should be noted that the most productive research area is

Table 4 Core journals, the corresponding research area, total publication frequency and publication frequency in each topic (1991–2012)

Core journal	Research area	Total f_i (%)	Topic 1[a] f_i (%)	Topic 2[a] f_i (%)	Topic 3[a] f_i (%)
Scientometrics	Computer Science; Information Science and Library Science	57 (15.57)	45 (78.95)	20 (35.09)	2 (3.51)
Sex roles	Psychology; Women's Studies	42 (11.48)	2 (4.76)	27 (64.29)	22 (52.38)
Academic medicine	Education and Educational Research; Health Care Sciences and Services	39 (10.66)	7 (17.95)	27 (69.23)	16 (41.03)
Higher education	Education and Educational Research	36 (9.84)	3 (8.33)	26 (72.22)	15 (41.67)
Research in higher education	Education and Educational Research	31 (8.47)	5 (16.13)	22 (70.97)	15 (48.39)
Gender and education	Education and Educational Research	30 (8.20)	0 (0.00)	25 (83.33)	10 (33.33)
Scientist	Information Science and Library Science; Science And Technology—Other Topics	29 (7.92)	1 (3.45)	27 (93.10)	4 (13.79)
Women's studies international forum	Women's Studies	19 (5.19)	1 (5.26)	15 (78.95)	6 (31.58)
Gender work and organization	Business and Economics; Women's Studies	18 (4.92)	0 (0.00)	12 (66.67)	9 (50.00)
Journal of higher education	Education and Educational Research	17 (4.64)	1 (5.88)	13 (76.47)	7 (41.18)
Journal of vocational behavior	Psychology	17 (4.64)	0 (0.00)	13 (76.47)	5 (29.41)
Journal of womens' health	Public, Environmental and Occupational Health; General and Internal Medicine; Obstetrics and Gynaecology; Women's Studies	16 (4.37)	0 (0.00)	12 (75.00)	6 (37.50)
Academic psychiatry	Education and Educational Research; Psychiatry	15 (4.10)	1 (6.67)	14 (93.33)	2 (13.33)

f_i frequency

[a] Some papers may simultaneously address more than one topic

Education and Educational Research, accounting for 6 of the 13 (46.15 %) core journals identified by Bradford's law.

With respect to the number of authors, a large number of papers (477; 33.71 %) are single author papers, suggesting that the scientific community in the field is composed of small groups and individual authors. Furthermore, author productivity was found to fit Lotka's law, indicating that there are a few, highly productive authors and a great majority who only contribute occasionally to research on *WSHE*. However, analysis of how the number of authors has evolved over time showed an increasing trend in terms of the number of papers being signed by three authors and by more than three authors, a trend that was paralleled by a clear reduction in the percentage of single-author papers. On the one hand, this may reflect the constitution of research groups, which is a feature associated with the consolidation of a field. On the other hand, and as has already been mentioned in other studies, this trend may be due to academic factors such as the increasing pressure to publish, the specialization of research expertise, collaborative efforts, or the interdisciplinarity of this field (Wren et al. 2007; Lozano 2013).

Authors contributing to the articles came from 67 different countries. It should be noted, however, that the increase in the number of authors and the high number of countries that contributed to the field have not been accompanied by greater international collaboration; only 8 % of papers involved this kind of joint work, and the largest proportion of these were published recently. This indicates a field of study that has yet to become truly international and in which collaboration between countries and institutions needs to be reinforced.

The most productive countries, in absolute terms, are the United States and the United Kingdom, generating around half the total scientific production in this field (54 %). However, when RII, a relative measure to calculate country productivity, were used, Nicaragua and Botswana were the counties that showed the highest productivity in WSHE, relative to the proportion of the world in the same area. Similarly, when IC-RII were used to measure the relative proportion of publications of a country in international collaboration, Sudan, Nepal and Ghana were the countries that showed the highest international collaboration productivity.

With regard to the GII, the results showed a direct relationship between the most recent GII and the RII and IC-RII. This means that countries with higher GII values (higher inequality) are, in relative terms, the most productive in the field and are the most likely to collaborate internationally. Thus, although countries such as the United States and the United Kingdom are the most productive countries in terms of absolute contributions, countries with higher levels of inequality showed higher relative values of productivity in the field. This last finding is consistent with Glänzel's (2001) study, which analyzed country profiles and compared domestic and internationally co-authored papers. According to his findings, some countries compensate relatively weak domestic activities through international collaboration or even intensify their own strong activities in the preferred science fields by international collaboration. However, as Glänzel (2001) points out, international scientific collaboration has proved to be a complex and heterogeneous phenomenon which cannot be sufficiently characterized by bibliometric indicators alone.

In summary, the present study provides an overview of how scientific output in the field of *WSHE* has evolved over time. The results show that since 1991 until the present day there has been a clear upward trend in the number of publications, with increasing interest extending to many authors, countries, and scientific journals, as well as to several research areas. These results are consistent with Zosuls et al.'s (2011) conclusion that the growth in the diversity of topics covered by researchers over the past few decades has mainly been due to the multidimensionality of gender, and that the idea that the assumptions made about one domain of gender development can predict all others has come under serious scrutiny. Moreover, leaders in the field have encouraged increasingly precise and clear terminology, more sophisticated methods and analytic techniques, and a greater diversity of topics of study.

Overall, this increasing body of evidence shows that gender inequality remains a global problem, despite substantial initiatives and policies undertaken at national and international level (Larivière et al. 2013a, b). Although progress continues to be made, change is on average slow, patchy, and subject to significant variation according to country, research field, and other factors (LERU 2012). Numerous scholars from different parts of the world continue to address this problem and provide valuable material for evidence-based policies.

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Research trends in gender differences in higher education and science: a co-word analysis

Tahereh Dehdarirad · Anna Villarroya · Maite Barrios

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Abstract The aim of this study is to map and analyze the structure and evolution of the scientific literature on gender differences in higher education and science, focusing on factors related to differences between 1991 and 2012. Co-word analysis was applied to identify the main concepts addressed in this research field. Hierarchical cluster analysis was used to cluster the keywords and a strategic diagram was created to analyze trends. The data set comprised a corpus containing 652 articles and reviews published between 1991 and 2012, extracted from the Thomson Reuters Web of Science database. In order to see how the results changed over time, documents were grouped into three different periods: 1991–2001, 2002–2007, and 2008–2012. The results showed that the number of themes has increased significantly over the years and that gender differences in higher education and science have been considered by specific research disciplines, suggesting important research-field-specific variations. Overall, the study helps to identify the major research topics in this domain, as well as highlighting issues to be addressed or strengthened in further work.

Keywords Gender differences · Higher education · Science · Co-word analysis · Strategic diagram

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T. Dehdarirad
Department of Library and Information Science, University of Barcelona, Barcelona, Spain

A. Villarroya
Department of Public Economy, Political Economy and Spanish Economy, University of Barcelona, Barcelona, Spain

M. Barrios (✉)
Department of Methodology of Behavioral Sciences, University of Barcelona,
Passeig de la Vall d'Hebron 171, 08035 Barcelona, Spain
e-mail: mbarrios@ub.edu

Introduction

Women's participation in higher education and science as an indicator of social and economic progress has attracted considerable attention from numerous researchers and national and international organizations. A variety of initiatives and reports have been undertaken to analyze the participation of women in science and higher education and to promote gender equality. Among these initiatives we can mention: the Association for Women in Science (AWIS), founded in 1971; the Helsinki Group on Women and Science, set up in 1999; the Korea Federation of Women's Science Associations, set up in 2003; the WIRDEM (Women in Research Decision Making) expert group established in 2006; and the EU-funded genSET project, which ran from September 2009 to February 2012. Among the most recent reports are: the *She Figures* by the European Commission; the *Global Gender Gap Report*, introduced by the World Economic Forum in 2006; the annual *World Development Report: Gender Equality and Development*, published by the World Bank; the UNESCO *World Atlas of Gender Equality in Education* (2012); and the National Science Foundation's reports on Women, Minorities, and Persons with Disabilities in Science and Engineering.

The latest data published by the OECD (2013) indicate that, despite some progress, gender inequalities in higher education and science persist. In OECD countries, younger women have higher attainment rates than younger men in upper-secondary and tertiary education. In 2011, an average of 84 % of younger women attained at least upper-secondary education while 81 % of younger men did. While the proportion of women is relatively high at the level of tertiary education, that proportion diminishes in the later stages of academic careers, especially in top-level positions; and women receive lower wages than those of similarly qualified men. As is also indicated in the UNESCO World Atlas of Gender Equality in Education (2012), enhanced access to higher education by women has not always translated into enhanced career opportunities, including the opportunity to use their doctorates in the field of their research. In addition to working conditions, including differences in salary, women encounter bias at many levels in their academic careers: they receive less funding through research grants; they are significantly underrepresented on the boards of research institutions, funding organizations, scientific councils and academies; and they are rarely found among the heads of higher education institutions (LERU 2012).

The persistent gender gap has prompted many studies seeking to identify different explanatory factors in various areas of science, across different time periods, and in diverse national settings. Much of this research has identified factors related to family formation and childrearing as being the most influential causes of women's under-representation in academia (Wennerås and Wold 1997; Sax et al. 2002; Stack 2004; Fox 2005; Ginther and Kahn 2009; Hunter and Leahey 2010). Along with fertility choices (that weigh more heavily on the career goals of women) and issues of work-home balance (female scientists are more likely than males to bear domestic duties), there are also significant gender differences in hours worked and lifestyle preferences (Ledin et al. 2007; Ferriman et al. 2009; Fox et al. 2011; Shen 2013).

Traditionally, gender disparities in career attainment have been explained largely by differences in research productivity (Cole and Zuckerman 1984; Prpic 2002; Fox 2005; Leahey 2006). At the institutional level, there is also a considerable body of literature suggesting that differences are caused by: structural factors such as the type of institution, insofar as women are more likely than men to work at teaching-intensive colleges (Allison and Long 1990; Xie and Shauman 1998); the teaching load, which is traditionally higher for women than for men (Taylor et al. 2006); the degree of specialization (Leahey 2006); financial resources, since women tend to occupy positions offering fewer resources (Xie and Shauman 1998); academic status, insofar as women tend to occupy lower academic positions (Leta and Lewison 2003) and research assistance (Ceci and Williams 2011). Some studies have also shown that the lower the percentage of women in selection committees is, the less likely women are to be appointed (European Commission 2009; Zinovyeva and Bagues 2011). Additionally, research has evidenced that academic assessment systems have traditionally ignored factors that especially affect women. Examples would be the way in which scientific excellence is defined (Van den Brink and Benschop 2011), the fact that selection criteria tend to value quantity of research output over quality, when men tend to produce more publications (Symonds et al. 2006), or attaching less importance to female characteristics (Lawrence 2006).

As a complement to the above, the psychological literature has explained gender disparities in terms of women's lower levels of career orientation, ambition, and aggressiveness (Sonnert 1996).

In addition to all the above-mentioned factors that place women at a disadvantage in all fields, career preferences, ability, and biological differences have been the main variables proposed in the literature to explain their underrepresentation in STEM (science, technology, engineering, and mathematics) disciplines. Empirical research in these fields has pointed to career preferences and choices, both freely made and constrained, as important causes of women's underrepresentation in academia (Ceci and Williams 2011), and it is suggested that some of these choices originate before or during adolescence (Ginther and Kahn 2009; Ferriman et al. 2009; Mason and Goulden 2009). Hence, adolescent girls frequently prefer careers linked to the humanities and social sciences as opposed to STEM-based fields.

Beyond all these explanatory factors, impediments to women scientists may also be a consequence of the overt or unconscious gender bias that still persists at most universities (Dewandre 2002; Moss-Racusin et al. 2012; Shen 2013). However, some research has suggested that after controlling for structural, family, and discipline variables, there is no evidence of discriminatory treatment, because women and men in the same circumstances (e.g., same type of institution, discipline, and amount of experience) fare equivalently (Ceci and Williams 2011).

One of the problems in relation to these findings is that the large body of research in this area does not provide the kind of systematic and comprehensive overview of factors related to gender differences that would help to guide future research and practices in the field. In response to this situation, the present study uses co-word analysis in order to describe the evolution and current state of the literature on gender differences in science, focusing on factors that influence gender inequality in higher education and science. This bibliometric technique, proposed by Callon et al. (1983), will help us to visualize the division of the field (in this case, the explanatory factors for gender differences in science) into several subfields and show the relationships between them, thereby providing insights into the evolution of the main topics discussed in the field over the years. The technique will also help us to identify the major research topics in the domain, as well as to suggest issues to be addressed or strengthened in further work. The results obtained through this process will be of interest to policy makers, funders, and academic administrators who are seeking to provide adequate facilities and to gauge research activities in a proper direction (Sudhier and Abhila 2011).

Method

Data collection

The data were extracted from the Thomson Reuters Web of Science in February 2013, using a search that combined the principal terms related to the subject. Figure 1 shows the steps followed to collect the data. First, in order to retrieve the available scientific literature on the subject we went through the related literature with the purpose of identifying the related key terms. A preliminary combination of key terms was used to extract the papers related to the subject. Next, after reviewing the keywords of these preliminary papers, we added more specific terms to the query in order to check whether these new terms increased the number of records retrieved; if they did, they were included in the query, and if not, they were eliminated. A total of 50,970 records were initially retrieved. In a next step, records were refined by subject area, such that those papers classified in research areas not directly related to the topic were discarded (e.g., history, zoology, toxicology, allergy, and transportation). Titles and abstracts from the remaining pool of papers ($n = 12{,}743$) were then manually checked to find related records. A corpus of 651 articles and reviews dealing with factors related to gender differences in science, published between 1991 and 2012, were finally considered. In order to study the evolution of the topic and to see how the results changed over time, the records were divided into three consecutive sub-periods: 1991–2001, 2002–2007, and 2008–2012. The time spans were selected based on the number of target documents published per period; so following Cobo et al. (2011) and Muñoz-Leiva et al. (2012), we fixed a longest first sub-period in order to get a representative number of published papers and keywords. Thus, the first period (1991–2001) spans 11 years (and includes a total of 164 documents: 25 %), the second period (2002–2007) spans 6 years (and 147 documents: 23 %) and the last period (2008–2012) spans 5 years (and 340 documents: 52 %). In addition, an important event in women's access to higher education and science occurs within each period. Thus, the "World Conference on Education for All" took place in 1990 and during the years 2002 and 2008, UNESCO launched its "Gender Equality Action Plans" for the periods 2002–2007 and 2008–2013, respectively.

Data process

Co-word analysis is a content analysis technique based on the assumption that the subject of a paper can be summarized in a number of few key terms that reflect its core contents. The frequency of word occurrence in the subject can reflect the importance of themes, and the co-occurrence of keywords across papers can be interpreted as indicating similarity between publications. According to Börner et al. (2003), the more keywords two publications have in common, the more similar the two publications are. Therefore, the main purpose of a co-word analysis is to map the dynamics of a subject and identify the core research topics based on the pattern of co-occurrence of pairs of keywords, which represent the different themes in a selected body of literature (He 1999).

The co-word analysis conducted in the present study involved five sequential steps: extraction of the data, standardization of keywords, construction of the co-occurrence matrix, clustering, and visual presentation of keyword groups. First, author-provided keywords were extracted from papers, with keywords plus being used in those instances where no author-provided keywords were available. Once the data had been extracted, keywords and phrases were standardized manually in order to refine the dataset (e.g., keywords occurring in different forms, plural and singular forms, uppercase and lowercase

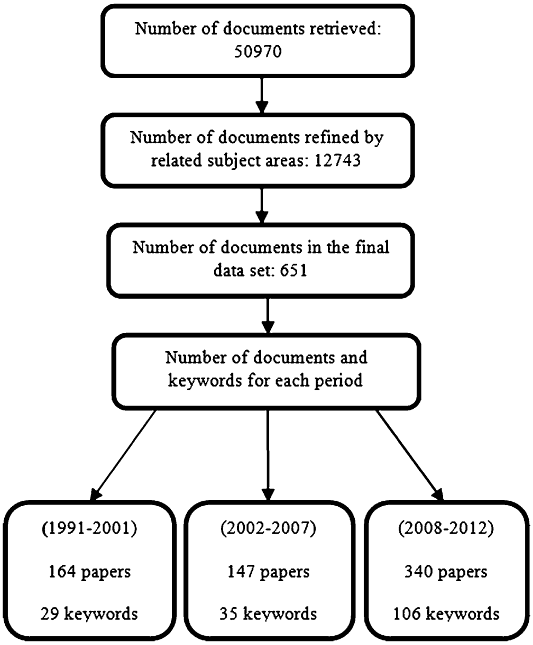


Fig. 1 Flow chart illustrating the process of data collection

words). Keywords denoting the same concepts were changed into the most frequent key term occurring in the data set. For instance, the terms *research productivity, scientific productivity, publication productivity, academic publishing, scholarly productivity, medical publication, publication rates, publications*, and *research output* were considered as synonymous keywords and were all identified as *research productivity,* which was the most frequent term. By contrast, those keywords which were very closely related but different in meaning were kept separate, for example: *gender issues, children, family, marriage, motherhood* or *salary, salary gap* and *promotion*. Any keywords that were unrelated to the topic were also eliminated in this step (for instance, names of countries and statistical tests). After standardization, a total number of 170 unique keywords or phrases were selected.

The word-document occurrence matrix was automatically built using SPSS v20. Only those keywords and phrases with a frequency greater than or equal to 5 in each temporal sub-period were considered in the analysis. The total number of keywords for each sub-period is shown in Fig. 1. The resulting matrix for each sub-period was then exported to Ucinet (Borgatti et al. 2002) in order to calculate the word co-occurrence matrix. The similarities between items were also calculated using the jaccard similarity index. Hierarchical clustering analysis was then conducted using Ward's method, and squared Euclidean distance was applied as the distance measure using SPSS v20. Ward's method involves an agglomerative clustering algorithm. It starts with n clusters of size 1 and continues until all the observations are included in one cluster. In contrast to other agglomerative clustering algorithms such as single link clustering used in Callon's original proposal of co-word analysis, Ward's method tends to produce same-size and spherical clusters (Everitt et al. 2011). The result of the clustering was then visualized in a two-dimensional diagram, known as a dendrogram, which displays the steps in the clustering process and illustrates how individual words are combined in order to form gradually larger clusters. The clusters were then transformed into networks in Ucinet. Finally, in the last step, and in order to identify and visualize the importance and position of clusters considered as themes, as well as their relational patterns, strategic diagrams were built for each sub-period. A strategic diagram is a two-dimensional space built by plotting themes according to their centrality and density, where the abscissa axis represents the centrality, the ordinate axis represents the density, and the origin is denoted by the median or mean value of the two, centrality and density (Callon et al. 1991; Cobo et al. 2011). The density, or the internal cohesion index, indicates the strength of the linkage that each word has with other words within the same cluster (or theme). It is an indicator of the internal strength of a cluster and represents the conceptual development of a theme. The centrality, or the external cohesion index, indicates the strength of the linkage that each keyword has with other keywords in other clusters. It is a measure of the strength of a subject area's interaction with other subject areas and represents the central position of a theme within the overall network. The value of the density and the centrality of a given cluster can be measured in several ways (He 1999). In our study density was computed as the average value (mean) of the internal links (Turner et al. 1988) and centrality was computed as the sum of squares of all external link values (Bauin et al. 1991). The origin of the strategic diagram is calculated by the mean value of centrality and the mean value of density. The strategic diagram divides the space into four quadrants, such that there are four types of themes according to their location (Callon et al. 1991; He 1999). Themes located in the upper-right quadrant are considered to be well-developed and important themes for the structure of a research field. They are known as the motor themes of the specialty, given that they present strong centrality and high density. The placement of themes in this quadrant implies that they are externally related to concepts applicable to other themes that are conceptually closely related. Themes in the upper-left quadrant have well-developed internal ties (high density) but unimportant external ties (weak centrality), and so are of only marginal importance for the field. These themes are very specialized and peripheral in nature. Themes placed in the lower-left quadrant are both weakly developed (low density) and marginal (weak centrality), and are considered as emerging or disappearing themes. Finally, themes in the lower-right quadrant are important for a research field (strong centrality) but present low internal development (low density). Therefore, this quadrant comprises transverse and general or basic themes.

After calculating density and centrality for each cluster, the themes were then displayed, using Excel, in a strategic diagram according to their internal and external cohesion indices. The themes were represented by spheres of different sizes, which were proportional to the number of papers that they each represented.

Results

A total of 170 keywords were obtained from the 651 documents. In what follows, we show the dendrograms, strategic diagrams for each sub-period, and tables containing the names of clusters, the number and percentage of documents by cluster, the centrality and density values, and a brief explanation of each theme.

Period 1: 1991–2001

The dendrogram shows that the 29 keywords of the documents are divided into four clusters (Fig. 2). Table 1 gives the names and descriptive values of each cluster, while

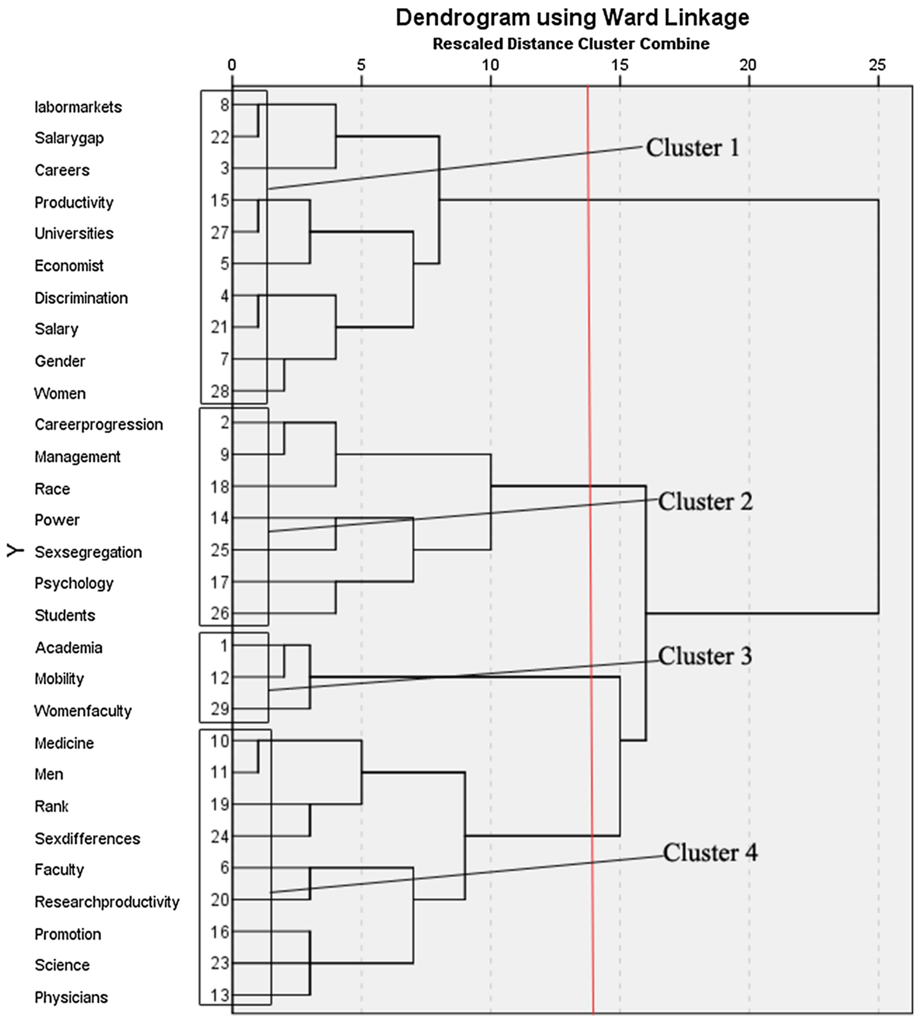


Fig. 2 Dendrogram for the first sub-period (1991–2001)

Fig. 3 shows the corresponding strategic diagram. The origin of the strategic diagram is based on the centrality value (5.750) and density value (0.117).

"*Gender discrimination in labor markets and universities*" (C1) is located in the upper-right quadrant. This means that this cluster contains close internal connections and is also widely connected to other clusters. Given its position and the number of papers that deal with this theme, it can be considered as the motor theme of this period. Because of its high/medium density and centrality (upper-left quadrant), "*Mobility of women academics*" (C3) was regarded as a specialized theme with high conceptual development but weak external interconnection with other themes.

A further two themes, namely "*Institutional issues*" (C2) and "*Sex differences in promotion*" (C4) (lower-left quadrant), were regarded as either emerging or disappearing themes because of their showing both low density and low centrality.

Table 1 Descriptive values of clusters for the first sub-period (1991–2001)

Cluster number	Name of cluster	No of keywords	No of documents (%)	Centrality	Density
1	Gender discrimination in labor markets and universities	10	86 (52.4)	16.640	0.141
	Challenges and gaps that still hinder women's full participation in the labor market generally and in the academic labor market specifically				
2	Institutional issues	7	31 (18.9)	0.665	0.046
	Issues caused by organization such as working hours, organizational structure, retention and exclusion, etc				
3	Mobility of women academics	3	12 (7.3)	0.420	0.185
	Movement of women academics or students to another institution within or outside their own country to study or teach for a limited time				
4	Sex differences in promotion	9	62 (37.8)	5.509	0.095
	Sex differences and gaps in acquiring a higher rank, promotion to top positions, academic progression and finally how publication rates are correlated with promotion				

* Note that the total number of documents is higher than the number of documents per period. Because clusters were calculated from the keywords of papers, each document can appear in more than one cluster. Percentage was calculated based on the total number of documents per period

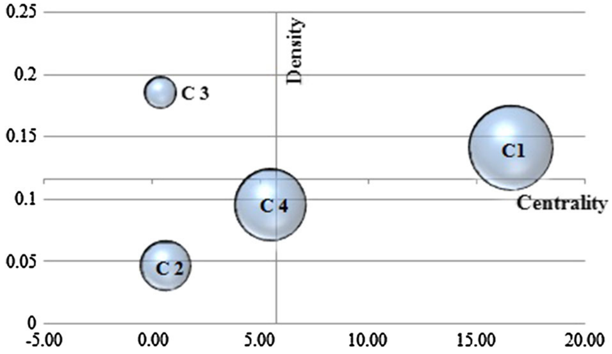


Fig. 3 Strategic diagram for the first sub-period (1991–2001)

Period 2: 2002–2007

In this period, the 35 keywords of the documents were divided into ten major themes, as shown in Table 2. The dendrogram of the cluster analysis and the strategic diagram are shown respectively in Figs. 4 and 5. The origin of the strategic diagram is based on the centrality value (0.953) and the density value (0.130).

In this period, two new motor themes appeared: "*Career satisfaction in medicine*" (C1) and "*Academic career in sociology*" (C9). Besides being a motor theme, "*Career satisfaction in medicine*" (C1) was the cluster with the highest number of documents.

The clusters "*Mobility of women academics*" (C6), "*Sex differences in promotion*" (C2) and to some extent "*Gender stereotypes and discrimination*," (C3) all present in the previous period, also appeared in this period. "*Mobility of women academics*" (C6) showed a decrease in density but a higher percentage of documents compared with the

Table 2 Descriptive values of clusters for the second sub-period (2002–2007)

Cluster number	Name of cluster	No of keywords	No of documents (%)	Centrality	Density
1	Career satisfaction in medicine	6	37 (25.2)	4.053	0.162
	Women and men physicians' job perceptions and factors influencing their satisfaction with a career in medical practice				
2	Sex differences in promotion	4	32 (21.7)	0.768	0.144
	Sex differences and gaps in acquiring a higher rank, promotion to top positions, academic progression and finally how publication rates are correlated with promotion				
3	Gender stereotypes and discrimination	3	18 (12.2)	0.319	0.162
	Stereotypes and social norms that foster gender discrimination and hinder women academics in fulfilling their potential by limiting choices and opportunities				
4	Gender roles in management	3	13 (8.8)	0.084	0.079
	How gender roles and expectations affect women being on boards and in senior management positions				
5	Mentorship	3	20 (13.6)	0.176	0.114
	Women's mentoring experiences in academic careers and students' experiences of having mentors of their own race and gender				
6	Mobility of women academics	3	17 (11.5)	0.149	0.110
	Movement of women academics or students to another institution within or outside their own country to study or teach for a limited time				
7	Racial discrimination at universities	4	23 (15.6)	0.360	0.095
	Experiences of black and ethnic minority academics and the issue of being under-represented in academia				
8	Work-life balance in academia	8	34 (23.1)	0.536	0.120
	How different aspects of an academic career make it difficult for women to manage their responsibilities outside their academic work				
9	Academic career in sociology	2	9 (6.1)	2.987	0.222
	Difficulties faced by women in academic careers in the field of sociology				
10	Gender issues in geography	3	31 (21.1)	0.097	0.090
	Female representation and gender inequalities in geography higher education institutions				

* Note that the total number of documents is higher than the number of documents per period. Because clusters were calculated from the keywords of papers, each document can appear in more than one cluster. Percentage was calculated based on the total number of documents per period

previous period. It was now relocated to the lower-left quadrant, suggesting that it is either an emerging or a disappearing theme. In contrast, "*Sex differences in promotion*" (C2) and "*Gender discrimination in labor markets and universities*" (C1), which became "*Gender stereotypes and discrimination*" (C3) in this second period, showed an increase in density and a lower percentage of documents compared with the previous period, and they were relocated to the upper-left quadrant as specialized themes with a higher conceptual development but weak external interconnections with other themes.

Compared with the previous period, the number of emerging (or disappearing) themes increased from two to six. In addition to "*Mobility of women academics*" (C6), five new themes appeared: "*Gender roles in management*" (C4), "*Mentorship*" (C5), "*Racial discrimination at universities*" (C7), "*Work-life balance in academia*" (C8), and "*Gender issues in geography*" (C10).

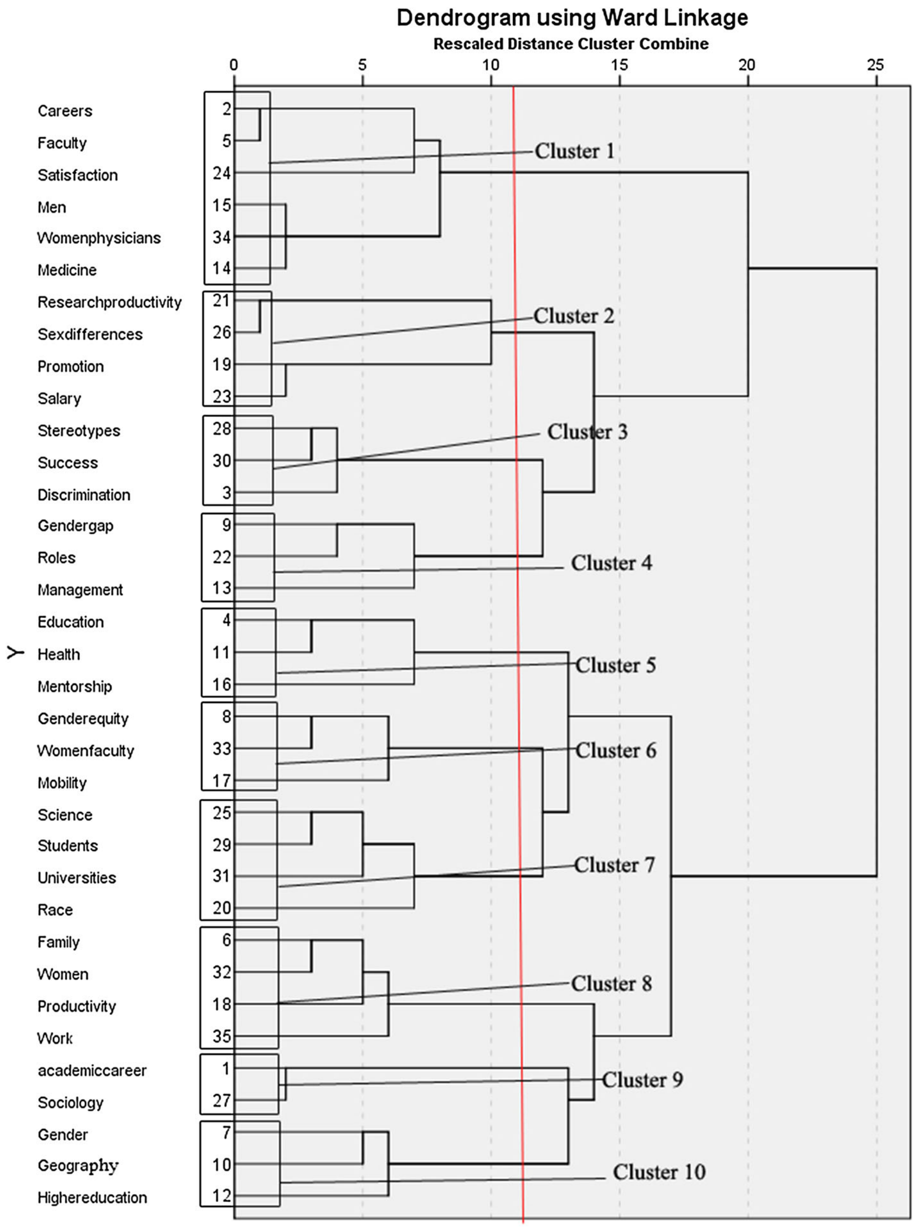


Fig. 4 Dendrogram for the second sub-period (2002–2007)

Period 3: 2008–2012

Based on the hierarchical clustering of 106 keywords, 16 clusters of keywords (themes) were identified in the last period, as shown in Table 3. The dendrogram of the cluster analysis and the strategic diagram are shown respectively in Figs. 6 and 7. The origin of the strategic diagram is based on the centrality value (1.500) and density value (0.099).

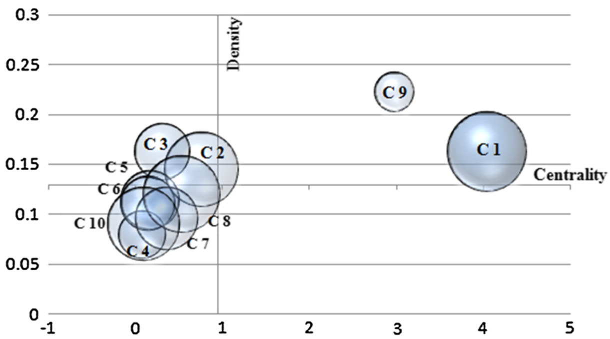


Fig. 5 Strategic diagram for the second sub-period (2002–2007)

In this period, just one motor theme was found: "*Advancement in academic medicine*" (C9). This theme includes articles related mainly to success and progression in medicine. This cluster is similar to the cluster labeled "*Career satisfaction in medicine*" (C1), identified in the second period as a motor theme. "*Gender discrimination in labor markets and universities*" (C1), which was present as a motor theme in the first period and as a specialized theme in the second, reappeared in this third period, where it showed a decrease in the percentage of documents compared with the previous periods and an increase in centrality with respect to the second period. Therefore, it moved from the upper-right quadrant in the first period to the upper-left quadrant in the following two periods as specialized themes with a peripheral character. Additionally, six new themes appeared in this quadrant as specialized themes: "*Gender differences in productivity*" (C2), "*Employment stratification*" (C3), "*Personal factors*" (C5), "*Stereotypes in mathematics*" (C7), "*Institutional issues*" (C10), and "*Women's studies*" (C15). "*Institutional issues*" (C10), which appeared as an emerging theme in the first period but was absent in the second period, reemerged in the third period as a specialized theme, although it had a lower percentage of documents.

The theme of "*Mobility, career choice, and sex composition*" (C6), similar to "*Mobility of women academics*", had been present in the two previous periods and appeared again in the third period. It corresponded to a similar percentage of documents in the three periods, although it went from being a specialized theme in the first period to an emerging or disappearing theme in the second and third periods.

"*Senior positions in medicine*" (C12) and "*Bibliometric indicators*" (C14) were new themes which also appeared in this quadrant as emerging or disappearing themes.

Finally, five themes, namely "*Glass ceiling barriers*" (C4), "*Work-life balance in engineering*" (C8), "*Climate and staff composition in academia*" (C11), "*Inequality and diversity in higher education*" (C13), and "*Work-life balance in psychology*" (C16), appeared in the lower-right quadrant.

It is interesting to see how the theme "*Work-life balance in academia*" (C8), which was present in the second period, reappears twice in the third period and in the same quadrant in the form of "*Work-life balance in psychology*" (C16) and "*Work-life balance in engineering*" (C8), indicating that the topic of work-life balance has attracted the attention of researchers from different research fields.

Finally, "*Inequality and diversity in higher education*" (C13), similar to the cluster labeled "*Racial discrimination at universities*" in the second period, showed a significant

Table 3 Descriptive values of clusters for the third sub-period (2008–2012)

Cluster number	Name of cluster	No of keywords	No of documents (%)	Centrality	Density
1	Gender discrimination in labor markets and universities	3	23 (6.7)	0.881	0.270
	Challenges and gaps that still hinder women's full participation in the labor market generally and in the academic labor market specifically				
2	Gender differences in productivity	4	47 (13.8)	0.733	0.140
	Research performance differences, productivity, and publication disparities between male and female researchers				
3	Employment stratification	4	22 (6.5)	0.759	0.143
	Differences in employment of women and men and the degree to which jobs and the occupational status that women and men hold differ				
4	Glass ceiling barriers	15	112 (32.9)	3.658	0.032
	Institutionalized barriers against women accessing male-dominated positions and upper echelons, which are nearly impossible to break through				
5	Personal factors	4	23 (6.7)	0.411	0.103
	Factors caused by women themselves not by their organization. These are related to issues such as lack of confidence, empathy or motivation; stress; and individual personality and abilities				
6	Mobility, career choice, and sex composition	7	28 (8.2)	1.289	0.069
	Sex differences in preferences for certain kinds of careers and career mobility, and how they have an impact on the gender composition of occupations				
7	Stereotypes in mathematics	5	35 (10.2)	1.415	0.129
	Beliefs and stereotypes that have an effect on inspiring women and girls to enter the field of math and on their math performance in academia				
8	Work-life balance in engineering	10	96 (28.2)	1.875	0.045
	How different aspects of an academic career in the engineering field make it difficult for women to manage their responsibilities outside their academic work				
9	Advancement in academic medicine	8	46 (13.5)	4.551	0.102
	Challenges female faculty physicians and non-physicians face in receiving recognition, including salary, promotion, rank, seniority, etc. in academic medicine				
10	Institutional issues	4	17 (5)	0.391	0.102
	Issues caused by organization such as working hours, organizational structure, retention and exclusion, etc				
11	Climate and staff composition in academia	6	34 (10)	1.617	0.097
	How organizational culture and structure cause gender disparities in the composition of academic staff				
12	Senior positions in medicine	8	66 (40.2)	0.906	0.047
	Obstacles women in academic medicine face in relation to obtaining top positions and leadership				
13	Inequality and diversity in higher education	10	230 (67.6)	2.751	0.056
	Gender and other types of inequalities (such as race, people with disabilities, etc.) in higher education, as well as the diversity issues related to the participation of these groups in the academic system				
14	Bibliometric indicators: Research productivity, impact, and collaboration	5	62 (18.2)	0.793	0.098
	How the participation of women and men in research is different in terms of bibliometric indicators				

Table 3 continued

Cluster number	Name of cluster	No of keywords	No of documents (%)	Centrality	Density
15	Women studies	3	15 (4.4)	0.143	0.102
	Issues and controversies addressed in women's studies, also known as feminist studies				
16	Work-life balance in psychology	10	59 (17.3)	1.877	0.045
	How different aspects of an academic career in the field of psychology make it difficult for women to manage their responsibilities outside their academic work				

* Note that the total number of documents is higher than the number of documents per period. Because clusters were calculated from the keywords of papers, each document can appear in more than one cluster. Percentage was calculated based on the total number of documents per period

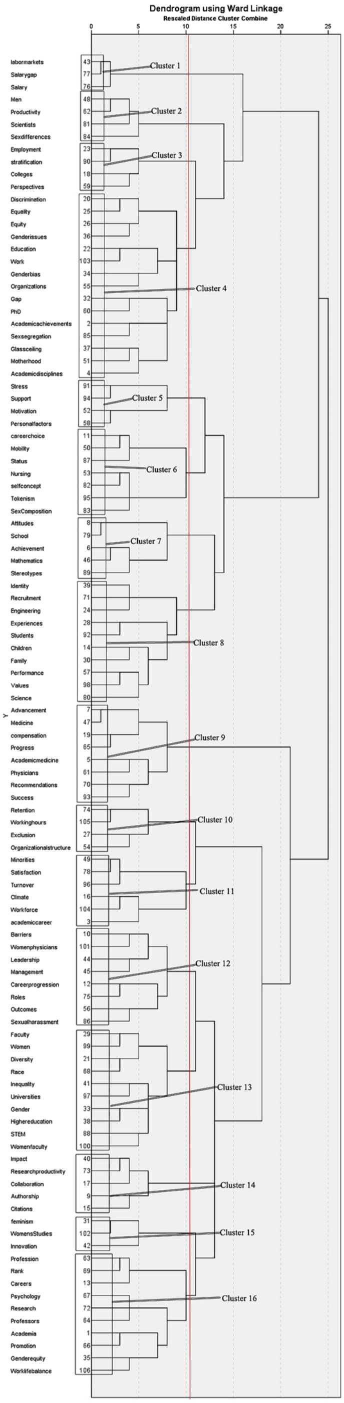
increase both in centrality and the percentage of documents compared with the previous period. Consequently, it was relocated to the lower-right quadrant. As can be seen in Fig. 7, this theme had the largest number of documents among all themes in all periods.

Conclusion and discussion

Using co-word analysis, the present study describes the evolution and current state of the literature on gender differences in higher education and science, and more specifically of those papers that deal with factors that cause these differences. It also examines the evolution of this topic by dividing the literature into three sub-periods (i.e., 1991–2001, 2002–2007, and 2008–2012). Regarding the evolution of the number of documents, the results reveal that more than fifty percent of the total body of literature was published in the last five years (2008–2012), suggesting that this is a current topic which has aroused the interest of researchers. Specifically, "*Inequality and diversity in higher education*" is the theme with the largest number of documents over this period. This broad topic addresses gender and other types of inequalities in higher education, as well as diversity issues. While some papers in this cluster mainly evidence gender and race inequalities related to academic degree, salary, socio-economic status, disciplines, rank, tenure, or mentoring etc., others focus on the potential value of diversity in terms of enhancing work processes and organizational mechanisms through the incorporation of women and members of other underrepresented groups such as racial/ethnic minority groups (Homan et al. 2008; Gonzalez and DeNisi 2009; Rosser 2012).

The results also showed that the number of themes has increased significantly over the years, ranging from four in the first period to ten in the second and sixteen in the third period. This suggests a greater interest in the study of factors related to gender differences in higher education and science, as well as a diversification and specialization of the research field over time. "*Work-life balance in academia*" provides a good illustration of the latter issue: this theme appeared for the first time in the second period, mainly in relation to the issue of work-life balance in universities, while in the third period it became specialized and was covered by specific fields of study such as engineering and psychology (i.e. "*Work-life balance in engineering*" (C8) and "*Work-life balance in psychology*" (C16)). The relevance of this topic has recently been underlined in the latest release of *Education at a Glance* by the OECD (2013). According to this report, the issue remains a key element for achieving gender equality, since women still bear the main burden of care and domestic work.

Fig. 6 Dendrogram for the third sub-period (2008–2012)



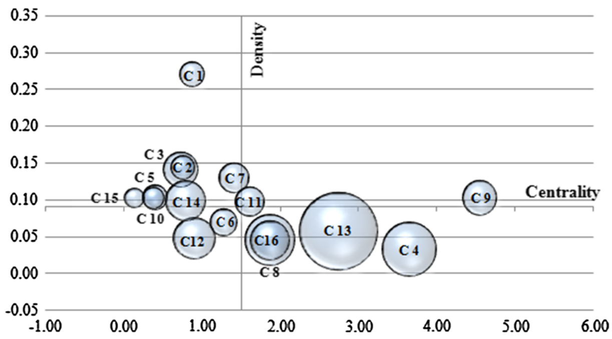


Fig. 7 Strategic diagram for the third sub-period (2008–2012)

In terms of trends in the evolution of themes, the strategic diagrams reveal that many themes are still immature in the studied field. Only four motor themes appeared in the upper-right quadrant of the diagrams, the location for those that could be regarded as mature and well-developed themes. The specific themes in each period were "*Gender discrimination in labor markets and universities*" in the first period, "*Career satisfaction in medicine*" and "*Academic career in sociology*" in the second period, and "*Advancement in academic medicine*" in the third period. Moreover, only two themes, "*Mobility of women academics*" and "*Gender discrimination in labor markets and universities*", were present in all three periods. Some themes emerged and remained in subsequent periods: "*Work-life balance in academia*" and "*Advancement in academic medicine*" appeared in both the second and third periods, while "*Sex differences in promotion*" appeared in both the first and second periods. Other themes such as "*Institutional issues*" emerged (first period), disappeared (second period), and then reemerged (third period).

The results also indicate that gender differences in higher education and science have been considered by specific research disciplines such as medicine, psychology, geography, sociology, engineering, and mathematics, suggesting important research-field-specific variations. Indeed, after the second period a number of specific research disciplines can be seen to show an interest in gender issues. Notably, medicine is a discipline that appears in both of the two most recent periods (2002–2007 and 2008–2012) as a motor theme related to satisfaction and success in an academic medical career. Furthermore, an additional cluster in the field of medicine appears in the third period as an emerging theme related to senior positions in medicine. Particular research fields related to STEM disciplines, such as mathematics and engineering, also appear in the third period. It is worth noting that while in engineering and mathematics the main problem is located at the entry point (i.e., a problem of convincing girls to undertake these studies and embark on a research career), the challenge in the humanities and social and health sciences is not so much one of attraction but of retention, such that in these research fields the particular pipeline is relatively more leaky (LERU 2012).

It is worth mentioning that although the study aims to identify the main explanatory factors that could account for gender differences in higher education and science, several of the themes identified refer to the differences themselves rather than explanatory factors. For instance, "*Sex differences in promotion*" and "*Gender discrimination in labor markets*" correspond to differences described in the literature; but actually, they are not factors related to gender differences. In our view, this result could have two main reasons: the topic of the papers and the selection of keywords. On the one hand, most of the papers in the sample focus on the analysis of gender differences (e.g., salary, promotion, publication rates, etc.) and they sought to explain these differences via some possible factors. On the other hand, authors need to summarize their research in a limited number of keywords, and this point is in fact the biggest problem that is attributed to co-word analysis (He 1999). In co-word analysis, the keywords used for the description of the content of a publication are used as the unit of analysis to map the research field structure. Law and Whittaker (1992), indeed, point out that some keywords are too general and that indexers sometimes put the wrong emphasis on keywording; this has been called the "indexer effect". However, as Courtial et al. (1984) note there is a general structure in each specific field which underlies the co-occurrence of the keywords, and this structure does not seem to be sensitive to variations or redundancies of terms used by indexers. In order to partially solve this issue and to improve the validity of the data, the recommendation is to normalize the keywords or to use a combination of words from abstracts, title words or full-text (He 1999, Wang et al. 2012).

In our view, the evidence presented in this paper allows the most prominent themes at different time periods to be identified together with possible gaps in the literature. For instance, "*Teaching load differences*" and "*Funding support*" are examples of institutional factors that do not appear in our results, indicating that these issues generate little interest among researchers, despite the fact that some studies report clear gender differences based on these issues (LERU 2012).

To the best of our knowledge, this is the first bibliometric study based on co-word analysis to have focused on gender differences in science. The results obtained through the cluster analysis and strategic diagrams complement and confirm previous findings (LERU 2012; European Commission 2013), adding new information and bringing a new perspective to the subject. The value of the strategic diagrams is that they identify the motor themes for the topic and also provide information about the less visible and emerging themes. Furthermore, studying the evolution of results across the three considered periods provides information about specific transient trends, for example, themes that have emerged, then disappeared, and perhaps emerged again. These data illustrate the utility of co-word analysis for understanding the dynamic structure of a subject, and they could serve to anticipate future development or to identify gaps that can be taken into account when setting out the priorities for research policy. In this sense, researchers, governments, and funding agencies could draw upon this type of analysis in order to promote research in emerging areas.

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