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Gendered knowledge in fields and academic careers

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ABSTRACT

Women and men often contribute differently to research knowledge. Do differences in these contributions partially explain disparities in academic career outcomes? We explore this by looking at how gender is embodied in research language, and then ascertain whether the adoption of more gendered research language affects career outcomes beyond the researcher's attributes. We identify different forms of gendered knowledge—gender referents (explicit references to sex and gender) and gender-associated terms (words that are implicitly associated with women or men researchers)—by applying natural language processing techniques to nearly one million doctoral dissertations published in the United States between 1980 and 2010. We then determine whether employing gender referents and gender-associated terms affects the course of PhDs' ensuing careers. We find women researchers have lower chances of securing academic positions than men in every field; explicit references to women as research subjects are modestly rewarded in comparison to references to men; and more career opportunities are afforded to research knowledge associated with men. These results suggest that academia is slowly correcting the traditional and explicit bias of studying men at the exclusion of women. Still, there remains a stronger implicit bias against knowledge associated with women scholars. We discuss relative differences between humanities and social sciences versus natural sciences, technology, engineering, and math, as well as potential treatments for offsetting bias in those fields.

1. Introduction

Although women now outnumber men in many doctoral programs (Buchmann and DiPrete, 2006; England et al., 2007), gender-based disparities persist in the professoriate (Charles and Grusky, 2005; Glazer-Raymo, 2008). These disparities arise at various career junctures and accomplishments: women have lower tenure rates (Agathangelou and Ling, 2002), lower pay (Smith-Doerr et al., 2019), fewer authorships (D'Amico et al., 2011), fewer grants, patents, and fellowships (Mutz et al., 2012; Primack et al., 2009; Whittington and Smith-Doerr, 2008), and fewer academic leadership positions than men (Dreher, 2003). This literature often identifies structural barriers that women face in academia, such as having lower salaries and being concentrated in lower ranks of the academic hierarchy or in fields and institutions with lower rates of promotion (Crasnow et al., 2018: 10–11; Ginther, 2004; West and Curtis, 2006: 12). Such an explanation focuses on the systematic outflow of women from academe as they approach tenure, sometimes referred to as the "leaky pipeline" (Anders, 2004; Goulden et al., 2011; White, 2004). Other work identifies cultural barriers that women (and non-dominant genders) face in academia. For instance, even women with tenure-track positions often experience a "chilly climate" in academic workplaces—such as being excluded from informal mentoring and networking, saddled with heavy advising and undergraduate teaching loads, allocated to administrative positions with little decision-making power, and subjected to gendered evaluations that attribute women's accomplishments to luck and men's accomplishments to hard work (Crasnow et al., 2018; Sandler, 1986; Wylie et al., 2008). These cultural barriers are consistently found to lower retention among tenured women (Britton, 2016; Dreher, 2003; Morris and Daniel, 2008). Together, the literature on structural and cultural barriers in the academy partly explains why women are persistently underrepresented despite the ever-growing share of women doctoral candidates.

While prior work sheds light on the cultural and structural barriers women continue to face, scant attention has been given to the role women's research itself has in the persistent underrepresentation of women in the academy. To be sure, we know much about the processes that tend to disproportionately sort women out of science, technology, engineering, and mathematics fields (Charles and Bradley, 2002; Gerber

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and Cheung, 2008). Thanks to a growing body of empirical literature, we know that women's increased inclusion in these fields—and in all research domains—expands the scope of scientific knowledge by drawing attention to traditionally overlooked topics, especially those concerning women as subjects, such as women's health (Schiebinger, 1999; Nielsen et al., 2017). Yet, we also know women tend to specialize less and correspondingly choose research that is more interdisciplinary and more applied (Leahey, 2007). Even within a field, women and men choose different research subjects and employ different methodologies, with women adapting more qualitative approaches to social science and studying domains related to development, health, and family (Key and Sumner, 2019; Nielsen and Börjeson, 2019; Grant et al., al.,1987; Bayer and Rouse, 2016). Women are more likely to select into research designs and knowledge domains the academy systematically devalues (Key and Sumner, 2019). And we know that women continue to receive less credit and make less impact with their research: they have less visibility, receive less credit as authors no matter what position their names appear in published research, and their work is cited less than men's (Leahey, 2007; Beaudry and Larivière, 2016; Frietsch et al., 2009). But we do not know why their research is less valued. Women's research in the academy—their traditions of intellectual labor and knowledge work within and across fields—in other words, might be an important, though overlooked, piece to the puzzle of women's comparatively grimmer fate in the academy.

Might the routine and systematic, if implicit, devaluation of women's research be a factor in their continued underrepresentation in today's professoriate? Indeed, less emphasized in the literature on gender-based disparities in higher education is how research itself might become gendered and whether that gendered character of research may bias its evaluation. Prior work on gender perceptions in consumer goods and creative writing has demonstrated that individuals routinely associate objects with gender (Tak et al., 2019; Childress and Nault, 2019). For instance, Tak et al. (2019) highlight contextual and cognitive associations people have with cultural products, linking cupcakes with women and beer with men. Through similar associations, research might become gendered (Code, 1991. 1993). Early childhood education research might be more associated with women, while mechanical engineering might be more associated with men, because a preponderance of women and men, respectively, have traditionally contributed to each of these fields. Moreover, investigations into the different ways gender manifests in empirical research show that women scientists tend to signal their own gender identities by more frequently including gender referents (e.g., woman, man) in their research (Schiebinger, 1989, 1999). So, research becomes gendered merely by way of the author's attentiveness to gender and sex in research designs.

The latently gendered character of research could matter in important ways. Societal beliefs, preferences, and tastes about women and men, however implicit, may be transferred to scientific knowledge and its subsequent evaluation (Ridgeway, 2011). Such a dynamic may favor men over women as research subjects, or it may favor research areas that men traditionally work on (Tak et al. 2019, Key and Sumner 2019, Ridgeway and Correll 2004). Identifying whether such bias exists and understanding its dynamic role within and across research fields could clarify how gender inequities in academia persist. Yet, such a perspective on the gendered character of research content raises complex theoretical and methodological questions: What constitutes women's research as separate from men's? If it exists, how would we determine whether it affects women's academic careers?

To begin to answer those questions, we analyze text data on the dissertations of a nationally representative sample of nearly one million PhD graduates from U.S. doctoral programs between 1980 and 2010. Building on prior published work (Galvez et al., 2020; Hofstra et al., 2020), we follow PhDs' careers and ascertain whether they become faculty advisors and/or continue to conduct research. The doctoral thesis is a rite of passage and contribution to academic knowledge that all PhDs make, and we explore whether the content of their dissertations is gendered and whether this has repercussions for whether doctorates become faculty advisors and/or continue publishing research. We conceptualize two ways dissertation research could be gendered: (1) by the use of explicit references to sex and gender (gender-referenced research), and (2) by the use of constructs, methods, and frames that have historically been associated with one or the other gender (gender-associated research). We use natural language processing to measure the gendered character of dissertations and we use statistical models to analyze PhD students' subsequent chances of getting an academic job as a function of the gendered character of their dissertations.

We find women PhDs have lower chances of securing academic positions than men in every field; explicit references to women as research subjects are only modestly rewarded in comparison with references to men; and more career opportunities are afforded to research associated with men. These results suggest academe is slowly correcting the traditional and explicit bias of studying men at the exclusion of women. However, structural barriers remain and a stronger implicit bias against knowledge associated with women scholars persists. We find structural barriers are stronger in natural sciences, technology, engineering, and math fields while issues of implicit bias are stronger in humanities and social science fields.

While not without limitations, our findings foreground the need for research policies across the wider academy and within universities to consider the ways that gender bias manifests in the evaluation of research. To this end, we offer several suggestions to promote the academic career chances among emerging scholars, such as actively including and elevating more diverse research at conferences, in journals, and within university programs and research centers. We also suggest providing expanded implicit bias training to faculty hiring committees.

2. Gendered dissertation content and its relationship with later career outcomes

2.1. How doctoral research gets gendered

2.1.1. Research that references gender and sex

Historically, universities have neglected research on sex and gender (Gumport, 2002; Rossiter, 1986). However, after the advances of the women's rights movements of the late twentieth century, universities have increasingly welcomed dissertations designed to address research problems about gender and sex identity. In turn, this has resulted in the development of programs and areas of specialization dedicated to the specific needs of females, women, and other gender- and sex-diverse populations, driving further demand for dissertations designed around the explicit study of gender- and sex-specific research problems in the contemporary university (Boxer, 1982, 2001; Handelsman et al., 2005). In this way, many PhD students now choose topics or labs[1] centered around problems related to gender and sex identity to forge their academic careers, and their dissertations in turn substantively engage with explicitly gendered content. We seek to measure this substantive engagement with gender and sex identity and to understand the ways it

[1] Choosing a doctoral program or research lab usually happens before deciding on and proposing a specific research problem for the dissertation. While the former is unambiguously a choice of the incoming or rotating PhD student, the dissertation research problem is likely an outcome of more than that student's initial preferences. For example, in the natural, biological, and physical sciences dissertation topics are governed by the principal investigator's (lab director's) research program and priorities. In the humanities and social sciences, a dissertation topic is often the students' choice. Still, we observe that the initial choice of a doctoral program or lab has an important relationship with the final dissertation content, even if the topic is influenced by lab hierarchy. In Section 5.1, we discuss the NSTEM PI's discretion in assigning dissertation topics as one possible mechanism for sustained gendered traditions within fields.

may be related to academic job outcomes.

2.1.2. Research that is associated with gender

Even though the explicit focus on gender and sex identity has recently achieved widespread legitimacy in the academy, we argue research can be gendered in more implicit ways. Historically, for both structural and cultural reasons cited in the introduction, women have often studied different domains than men (Lerchenmueller and Sorenson, 2018; Key and Sumner, 2019). For instance, women have been systematically excluded from the natural science, technology, engineering, and math fields (NSTEM). Even within specific fields, cultural and structural conditions bring into relation certain topics with specific genders (Leahey and Guo, 2001; Reay et al., 2005; Rhoten and Pfirman, 2007; Nielsen and Börjeson, 2019; Key and Sumner, 2019). For example, within the field of Computer Science, substantially fewer women study artificial intelligence and more women study human-computer interaction (Element, 2019). Within Economics, fewer women study asset pricing, monetary economics, and economic fluctuation and growth while many more women study children, developmental economics, and health economics (Chari and Goldsmith-Pinkham, 2017). Within mathematics, much fewer women PhDs study analysis, probability, and number theory while many more study math education, optimization, and statistics/biostatistics (Brisbin and Whitcher, 2015). What this means is that, even if a cross-section of today's fields shows reduced disparity among men and women in the topics they study, by accrued precedent, traditions of women's research have nonetheless been established within fields. We argue that when PhD students evoke this tradition of women's research in their dissertations, their work may be implicitly gendered. We aim to understand what role this implicit gendered character might play in a woman's chance in getting an academic job.

2.2. Why gendered research might matter for getting an academic job

2.2.1. Evaluation of research that is explicitly gender-biased

While many doctoral students study problems about gender and sex (U.S. Department of Education. National Center for Education Statistics 2021), strikingly little is known about whether—and to what extent—this explicit specialization affects academic job outcomes. We argue that such gender-referenced doctoral research could be rewarded, on average, in the academy writ large based on the widespread cultural changes that emphasize the importance of sex and gender diversity in and for research (Klein et al., 2015; Woitowich and Woodruff, 2019). From this view, PhD students who study research problems about women and females as subjects are more likely to get a job because they meet a compensatory need for the academy to realign itself with equitable principles of inclusion and to overcome historical injustices; their inclusion also leads to better science (Schiebinger, 1999; Antonio and Muñiz, 2007; Nielsen et al., 2017; Hofstra et al., 2020):

***Hypothesis 1 (Gender-referenced research)**: PhD students whose dissertations explicitly reference women (gender-referenced research) have higher chances of getting an academic job than those whose dissertations explicitly reference men.*[2]

We acknowledge that writing a dissertation on sex, gender, and sexuality might be differentially received depending on the dissertation writer's gender identity and whether the dissertation is more associated with men or women. For example, in particular, women PhDs are noted for having a better understanding of their own gender (Crasnow et al., 2018: p. 57–59), as compared to men. Furthermore, women who write about their own gender are better received than men who write about women (Scott, 1989: p. 690). Indeed, men writing on men likely do not have the same advantage, because such work was done historically, often in a woman-excluding fashion. Along this line of reasoning, we argue that women who write dissertations referencing women, females, and other femme sex and gender referents would, on average, have better chances at getting an academic job compared to women and men who do not. This expectation is aligned with policy arguments in higher education that call for deeper expertise based on the lived experiences of alternative and diverse viewpoints (Schiebinger, 1989; Longino, 2017; Witteman et al., 2021). To the extent that these arguments hold, women who study femme sex, gender, and sexuality would be seen as contributing deep expertise, as well as alternative viewpoints and epistemologies. Therefore, they would be more sought after in the academic job market:

***Hypothesis 1a (PhD gender & gender-referenced research)**: Women whose dissertations explicitly reference women (gender-referenced research) have even higher chances of getting an academic job than men whose dissertations explicitly reference women.*[3]

2.2.2. Evaluation of research that is implicitly gender-biased

Still less is known about whether and to what extent evoking research traditions associated with women in one's dissertation translates to better or worse job outcomes (Rhoten and Pfirman, 2007). Such traditions and specific lines of thought are pursued by both men and women researchers. Yet, the language constituting them may take on a gendered character over and beyond their substantive focus through accrued historical precedent of a preponderance of either women or men working on them (England et al., 2007; Marini and Brinton, 1984). We argue that this is a critical gap in the literature, as it could constitute an important source of implicit gender stigma that results in the undervaluation of scholarship associated with women. In turn, this stigma could perpetuate worse outcomes for women, giving them a double disadvantage (i.e. in facing structural and cultural barriers and in aligning with stigmatized topics).

There is reason to believe that research topics and language associated with women are devalued and have lesser returns to academic careers, as compared to research associated with men (Steinpreis et al., 1999; Larivière et al., 2013; Bornmann et al., 2007; Karlin et al., 2002; Pfeffer and Blake, 1987). Historically, occupations and research traditions that have been more accessible to women have also had lower status (Leslie et al., 2015; Foschi, 2000). Research traditions may also become devalued when more women associate with them as a result of implicit and indirect biases against women (England et al., 2007; Roos, 1997; Mandel, 2013). PhD students who draw on language, topics, and ideas that are historically associated with women signal their scholarly allegiance with gendered traditions (Stinchcombe, 1982). If these traditions are subject to gendered stigma, PhD students evoking them may struggle to get an academic job:

***Hypothesis 2 (Gender-associated research)**: PhD students whose dissertations implicitly evoke a tradition of women's research (gender-associated research) have lower chances of getting an academic job than those whose dissertations implicitly evoke a tradition of men's research.*

Studies suggest that when women conform to gender stereotypes in professional settings, they are perceived as more likeable but less competent (Heilman, 2012; Lueptow et al., 2001; Arkkelin and O'Connor, 1992). In conforming, women comply with notions of what women ought to do. Those norms often position women as subordinate to (and lesser than) men. So, women scholars who do woman-typed research may experience benevolent sexism: they are well-liked but also dismissed (Krefting, 2003). Along this line of reasoning, women PhDs who evoke traditions of women's research in their dissertations might

[2] In all ensuing hypotheses, we use "women" to represent research on both women and females (gender and sex) and "men" to represent research on both men and males. We note that gender and sex are distinct and each nonbinary.

[3] For this secondary hypothesis and all the other "a" hypotheses, we empirically test their inverses, too: men whose dissertations explicitly reference men and males have even higher chances of getting an academic job, as compared to women whose dissertations explicitly reference women and females, and so on.

implicitly indicate allegiance with a gendered tradition already beleaguered with negative bias. Evoking these gendered traditions of research might worsen women PhDs' chances of getting an academic job by further accentuating their implicitly stigmatized gender identity (Key and Sumner, 2019):

Hypothesis 2a (PhD gender & gender-associated research): *Women whose dissertations implicitly evoke a tradition of women's research (gender-associated research) have even lower chances of getting an academic job than men whose dissertations implicitly evoke a tradition of women's research.*

2.3. How academic fields structure job opportunities

We recognize that PhD students write their dissertations within and for specific academic fields and audiences, and these fields vary in ways important to understanding doctoral students' chances of getting an academic job (Abbott, 2001; Clauset et al., 2015). For our conceptual arguments here, we focus on four mechanisms relevant to persistent gender-based disparities.

2.3.1. Fields with a preponderance of work about women and female research subjects

Many PhD students write dissertations in programs, departments, and fields that have been purposely erected to institutionalize the study of research problems related to gender and sex (e.g., urology, gynecology, feminist studies). In the aggregate, these fields are more explicitly gendered than other fields, such as entomology or numismatics. On the one hand, fields that focus on women as subjects may have been historically studied by women. As we note above, these fields may be of lower status, have fewer institutional resources, and exhibit lower demand. If this were the case, then we would expect that PhDs who write dissertations in these fields would have lower chances of getting an academic job, as compared to PhDs in traditionally male-dominated fields. On the other hand, women-oriented fields are also seen as contributing to more complete, better science (Nielsen et al., 2017; Tannenbaum et al., 2019). If this were the case, then PhDs in these fields would have better chances of getting an academic job because their areas of expertise would be in high demand and command significant institutional resources. Because of this ambivalence, we contend that fields concerning women and females as subjects of study may afford no greater or lesser career chances:

Hypothesis 3 (Gender-referenced fields): *PhD students whose dissertations are in fields where women tend to be the subject of study (gender-referenced research fields) have the same chances of getting an academic job as those whose dissertations are in fields where men tend to be the subject of study.*

While fields concerning women and females as a subject likely do not afford greater or lesser academic career opportunities, we argue that PhDs writing within these fields whose dissertations are better aligned to the specialized focus on women and females—dissertations that employ explicit referents to women and females within fields concerning women and females as subjects—are more likely to get a job. On the one hand, this is a matter of writing in-field, suggesting an appropriate level of esoteric field knowledge (Saks, 2012; Fleck, 2012; Goode, 1960). On the other hand, it suggests that specialization results in higher chances of better outcomes (Leahey and Reikowsky, 2008; Leahey et al., 2017):

Hypothesis 3a (Gender-referenced research & gender-referenced fields): *PhD students whose dissertations explicitly reference women (gender-referenced research) in fields where women tend to be the subject of study (gender-referenced research fields) have even higher chances of getting an academic job than those in these same fields whose dissertations explicitly reference men.*

2.3.2. Fields with a tradition of women's research

Though less formally identifiable within university organizational charts, fields with established traditions of women's research might nonetheless be distinguished. As noted above, examples would be the subfields of development economics or statistics within the academic fields Economics and Mathematics, respectively (Chari and Goldsmith-Pinkham, 2017). Within the humanities, traditions of women's research include cultural/ethnic studies and literature, as opposed to the male-dominated fields of philosophy and religion (Humanities Indicators, 2015). Traditions of women's research can also extend to more fine-grained cases, such as issues of fairness in artificial intelligence. Historically, fields with traditions of women's research have been fewer, smaller, more poorly compensated, and less acclaimed (Weeden et al., 2017; Schlenker, 2020). Therefore, we expect PhD students who align with these traditions to have lower chances of getting an academic job, relative to other students:

Hypothesis 4 (Gender-associated fields): *PhD students whose dissertations are in fields with a tradition of women's research (gender-associated research fields) have lower chances of getting an academic job than those whose dissertations are in fields with a tradition of men's research.*

Implicit biases against women's research coupled with lower availability of jobs in fields with traditions of women's research makes it especially unlikely that PhD candidates whose dissertations evoke women's traditions will secure an academic job. Indeed, in contrast to signaling field alignment of expertise and area knowledge (Hypothesis 3a), we contend that such dissertations may instead elicit stigmas associated with women's research where they are most strongly institutionalized, thusly making it all the more difficult to get an academic job:

Hypothesis 4a (Gender-associated research & gender-associated fields): *PhD students whose dissertations implicitly evoke a tradition of women's research (gender-associated research) in fields with a tradition of women's research (gender-associated research fields) have even lower chances of getting an academic job than those in these same fields whose dissertations implicitly evoke a tradition of men's work.*

2.3.3. Humanities and social sciences (HSS) versus natural sciences, technology, engineering, and mathematics (NSTEM)

Our conceptualization of gendered research is relative to academic fields, writ large. Nonetheless, we would be remiss not to consider how complex ontological, epistemological, and organizational differences across the HSS and NSTEM fields (Snow, 2001; Kagan, 2009) may translate to differences in academic job chances for women PhDs. On the one hand, women have been—and continue to be—more underrepresented in NSTEM fields than in HSS fields (Beede et al., 2011), suggesting a particularly critical need to better understand possible mechanisms of persistent gap between HSS and NSTEM fields. On the other hand, the very nature of doctoral work varies dramatically between HSS and NSTEM fields. Questions about when, where, and how research is performed are not uniformly relevant in HSS and NSTEM fields. For this reason, we interrogate the above expectations first across academe as a whole and then more narrowly within these two academic cultures of research. Given the variation between HSS and NSTEM, we do not have any formal expectations. Rather, we compare how our main arguments manifest across the HSS-NSTEM divide.

3. Research design

3.1. Data

To test our hypotheses, we use the ProQuest dissertation database. These data concern PhD recipients from 225 U.S. colleges and universities that granted PhD degrees between 1980 and 2010. The database includes detailed information about PhD students, such as the departments from which they graduated, the years they received their degrees, the names of their dissertation chairs, their dissertation abstracts, and so forth. The total number of awarded doctorates in the database is 1,036,687, reflecting a majority (85.6%) of the doctoral recipients from U.S. universities between 1980 and 2010 (National Science Foundation, 2018). Using data from the National Center of

Education Statistics (NCES), which includes a census of degrees awarded by U.S. institutions, we create data weights: the number of students in a university-year relative to the total in the ProQuest database, divided by that same fraction for the entire doctorate population. These weights enable us to generalize our sample's results to the population of U.S. doctoral students during this period. Dissertations are ideal to study gendered reproduction in the academy because they represent a rite of passage into the academic community and form the basis of PhD students' scholarly identity (Galvez et al., 2020).

The ProQuest database has strengths over other databases used in recent research about the relationship between gender and academic career outcomes (e.g., Huang et al. 2020). First, it does not overrepresent fields that value journal articles. For instance, it includes doctorates earned in fields that are "slow" (i.e. value books) and "fast" (i.e. value conference proceedings). Second, it is not disproportionately focused on biomedicine. ProQuest captures most U.S. doctorates in each field and follows the population as reported in the NCES census. Therefore, the data reported in this article are a relatively unbiased and representative sample of U.S. PhDs in all fields. Finally, the ProQuest database includes dissertations written by a range of students, not only students who went on to have successful academic careers.[4]

3.2. Outcome variable: academic careers

We use a conservative proxy to measure the outcome of getting an academic job: whether or not a PhD graduate ever becomes a primary faculty advisor to another PhD student in a U.S. PhD-granting university. In the ProQuest database, each dissertation lists the primary dissertation advisor. This primary advisor is typically a tenured professor in the student's degree-granting department. So, if a given PhD graduate is, at a later point in time, listed as a primary advisor on a student's dissertation, we assume that the PhD graduate successfully transitioned into a tenure-line faculty role. We analyze the dissertations of PhDs who graduated between 1980 and 2010. To track whether these PhD students eventually become primary advisors, we examine advisor data from 1980 to 2015. We find that 6.3% of PhD graduates ultimately become primary advisors. This relatively low percentage partially reflects the scarcity of research faculty positions in U.S. PhD-granting institutions (Weissmann, 2013).

This measure of a "successful" academic career is somewhat limited because it only counts cases where PhD graduates become dissertation chairs. This metric signifies the attainment of an elite (i.e., being at U.S. PhD-granting universities) faculty position. Advising a PhD student to their completed doctorate requires several years of continuous employment in the university. Dissertation chairs often exert great influence on PhD students' choice of topics. They also publish articles, write grants, and define research priorities. Thus, dissertation chairs are "successful" because they influence academic activities in many ways. However, defining "success" as chairing a dissertation is conservative because it excludes individuals employed by other types of research institutions or who hold other positions at PhD-granting universities.

Indeed, we acknowledge that PhD graduates may have highly successful careers outside of PhD-granting universities, such as at community colleges or in private and government research agencies. To validate our measure of a "successful" academic career, we perform a robustness check with another measure of success: the publication of at least one paper 10 or more years after graduation. This robustness check, which we perform using data from Web of Science, shows that our results are insensitive to a more inclusive outcome variable (see Appendices F). In other words, our results hold even when we define "success" using a measure of research work done outside of PhD-granting universities (e.g., at think tanks, undergraduate institutions, or community colleges). For parsimony, we present our results that were generated with the more conservative proxy of academic job success (i.e., becoming a faculty advisor).

3.3. Key independent variables

3.3.1. Gender of PhD graduates

Because there are no self-reports of gender in the ProQuest database, we infer a PhD graduate's gender from the first name filed on their PhD dissertation using algorithms developed by Hofstra et al. (2017) and Genderize.io (https://genderize.io). We exclude 69,315 PhDs (6.7%) for whom we are unable to classify their gender. More details are included in Appendices A.1. In total, 389,540 PhDs (41%) are classified as women and 551,130 as men (59%).[5]

3.3.2. Gender-referenced dissertation research

We use the text of dissertation abstracts[6] to measure how often a thesis uses gender-referents and how much it is gender-associated. We see abstracts as a stylized expression of the knowledge contained in the dissertation. It concentrates the contents of the dissertation research — including research topic, sources and data, arguments, contributions, conclusions, among other important features of doctoral research — in highly regularized ways that are widely legible across fields. By analyzing the abstracts, we can study dissertations more efficiently and with greater comparability than if we studied whole dissertations, which often vary incommensurably in form across fields (e.g., mathematical proofs versus historical monographs).

We identify the terms that are direct gender referents in dissertations by using Linguistic Inquiry and Word Count 2015 (LIWC, see Pennebaker et al. 2015). For each dissertation abstract, we compute the percentage of words that refer to woman (124 words: "women," "girls," "her," etc.) and man (116 words: "man, "boy," "his," etc.). More examples and details are in Appendices B.[7] In general, gender-referents are uncommon. On average, woman referents are used 0.22 times per 100 words, and man referents are used 0.20 times per 100 words. Next, we subtract man referents from woman referents. We then weight the counts of gender referents by the inverse of the total word count of each abstract and transform standardized counts by taking the square root of the variable to account for the right-hand skewing of the distribution. Next, we grand-mean center the average level of gender referents at the field-level and group-mean center at the individual-level. Together, these field-level and individual-level indicators of the prevalence of gender referents in dissertation texts allow us to study whether and how dissertations explicitly about gender or sex might be differentially evaluated, depending on the extent to which fields incorporate sex and gender into their research paradigms.

3.3.3. Gender-associated terms in dissertation research

To investigate how the content of PhD graduates' research may be gender-associated, we focus only on the terms that substantively relate to research content (i.e., interests, topics) and research design (e.g.,

[4] Data sources such as CVs or bio sketches in journals might overrepresent scholars with successful careers.

[5] These percentages exclude missing cases.

[6] We dropped 5,582 records (0.5%) that did not have abstract data.

[7] Gender referents, particularly woman referents, are associated with woman scholars. When women scholars evoke woman subjects in their research, "woman" is not only a gender referent but also a gender-associated term (Schiebinger, 1999). As we note earlier, because the valuation of a gender-associated text might be different from gender referents, we simultaneously include both specifications of gendered knowledge in the statistical model and examine the impact of each.

"autoethnography") and ignore generic terms (e.g., "the").[8] We operationalize the gendered character of terms by linking them to the gender of the authors that have historically used them in past dissertations. In so doing, we find terms associated with one gender but not with another. For example, "war" and "machine learning" are terms predominantly adopted by and associated with men authors while "parenting" and "children" are disproportionately associated with women authors. These terms might not explicitly refer to the concept of man or woman but are reflective of the extent to which terms are either feminized or masculinized. We call these "feminized terms" and "masculinized terms." We identify these feminized and masculinized terms by using a log odds ratio (Monroe et al., 2008).[9] According to 2010 data, woman-associated terms are used 30.7 times per 100 words in dissertation abstracts, whereas man-associated terms are used 34.8 times per 100 words.[10] Thus feminized and masculinized terms are used more frequently than gender-referents.

Fig. 1 illustrates the frequency and z-scores of gender-associated terms from dissertation abstracts written in 2010.[11] (See Appendices C.3 for more examples.) The *z*-score (*y*-axis) represents the degree of exclusive term usage by one gender over another. Terms that are more distinctively used by women include "women," "student," "children," terms related to education, child rearing, or the private sphere. In contrast, terms that are more frequently used by men are "model," "system," "algorithm." Masculinized terms generally relate to topics in engineering, computing, or quantitative experiments.

To determine each dissertation abstract's overall level of feminization or masculinization, we sum each abstract's feminized and masculinized term z-scores. When we compute the sum, we use the terms' relative feminized or masculinized z-score values observed in the year prior to when the current dissertation was submitted.[12] Next, we subtract the sum of masculinized terms from feminized terms to have a single measure of relative feminization. Finally, we divide the sum by the number of words in the abstract to create a measure of its degree of gender association (gender-associated text). A large, positive value of gender-associated text indicates that the document mostly utilizes words that have been used by women. On the contrary, a large, negative value implies that the abstract mostly includes words frequently used by men.

In our operationalization of gender-associated terms, we do not consider field boundaries because academic writing is (ideally) not constricted by field. This is not the case, in reality. Thus, our decision inevitably causes feminized (or masculinized) knowledge to be predominant in fields where, respectively, women (or men) are dominant.

Fig. 2 summarizes how gendered texts vary across- and within-field.[13] HSS fields (black lines) have higher averages of gendered text than NSTEM fields (grey lines). The 95% range of within-field variation is sometimes as wide as across-field variation. While field averages roughly range from −2 to 2.5, within-field variation is notably higher in HSS fields than in NSTEM fields.

Because there is variation in gender-associated text both across and within fields, we analyze our data at the field- and individual-level. We grand-mean center our gender-associated text metrics on the field-level (across fields) and group-mean center on the individual-level (within fields). The field-level gender-associated text then defines how much the field in which the student receives a degree employs gender-associated language in comparison to other fields. For example, in Fig. 2, sociology uses more feminized terms, while mechanical engineering uses more masculinized terms. This field-level measure enables us to model variation in women's career chances as an outcome of the relative degree of feminization versus masculinization of their respective dissertation fields compared to other fields.

We also measure the individual-level gender-association of the dissertation text. This indicates how feminized or masculinized dissertations are relative to their field. This is key because what is considered feminized or masculinized differs by field. For example, a feminized sociology dissertation abstract in our dataset, written in 2010, describes how gender and racial dynamics shape the socialization process in schools. A masculinized sociology abstract, written in the same year, describes the social structure of labor movements. In the NSTEM realm, we find a feminized cell biology dissertation abstract about how social context influences patients' experiences with diseases. A masculinized abstract in that field summarizes the tools or methods that help advance the treatment of illness. This individual-level measure enables us to capture this important variation and model whether and how women's career chances are an outcome of the degree of feminization of their dissertations relative to others in the same field. As such, this setup can capture the multi-layered impact of gender segregation on women's academic careers.

3.4. Control variables

We control for a set of factors that relate to both gendered knowledge and academic jobs. First, we control for the race/ethnicity of PhD graduates. We infer this using the same method used for inferring gender. We use four race/ethnicity categories: white, underrepresented minorities (URMs), Asian, and unknown (see Appendices A.2. for more details.) Next, we control for the fact that hiring outcomes are partially driven by the prestige of the PhD's university (Burris, 2004; Jacobs and Frickel, 2009). We divide departments into four ranking groups (1 – "top 10," 2 – "top 11–50," 3 – "top rest," and "unknown"). These rankings are based on a combination of the National Research Council and U.S. World News & World Report rankings from 2010. We keep constant the year when the degree was awarded. We also include a square term of the graduation year, ranging from 1 (i.e., 1981) to 30 (i.e., 2010) to account for the fact that time has a non-linear relationship to the probability of becoming a faculty member (i.e., the chances of getting an academic job do not monotonically increase or decrease with each passing year after graduation).

In addition, we include measures of PhD graduates' marketability and their advisors' reputation within academia. To measure student

[8] We use terms under the assumption that a term is an independent unit of text. This assumption does not account for context. While advanced natural language processing techniques such as word embeddings account for context (e.g., Kozlowski et al. 2019 and Garg et al. 2018), we choose a simpler method that assumes independence among terms. Our assumption is reasonable to make because our main goal is to trace dissertation-level associations by gender group, not word-level relationships. Also, our method captures annual changes in word-level gender associations. Thus, with a preference for simplicity, we treat terms as independent.

[9] This approach reduces the overrepresentation of infrequent terms or those that are exclusively used by one group. It also limits the misrepresentation of words that lack specific meanings. (See Appendices C.1 and C.2 for methodological details).

[10] We use *z*-scores of 2 for feminized terms and −2 for masculinized terms. *Z*-scores help us to show when one gender group is more likely to use the term than the other, significant at an alpha level of .05.

[11] Fig. 1 does not include one outlier in each panel: "studi" from feminized terms (frequency = 63888, *z*-score = 20) and "use" from masculinized term (frequency = 67480, *z*-score = 8). Because we compute the level of gender association each year, terms have different levels of gender association across years. This figure includes examples from the most recent year of observations.

[12] We drop observations from 1980 because we do not have the measure of gendered terms from 1979. In total, we remove 21,120 PhDs (2.0%) from the dataset.

[13] We infer the field of PhDs based on the subject field that PhDs enter when they upload their dissertation to ProQuest. However, the original entry of subjects often has multiple field names affixed, thus we infer the primary field where the PhD is granted. Based on 85 distinct National Research Council disciplines, first, we hand labeled information on primary field for a subset of dissertations. With this information, we developed a classifier that sorts fields into the primary field with approximately 96% accuracy.

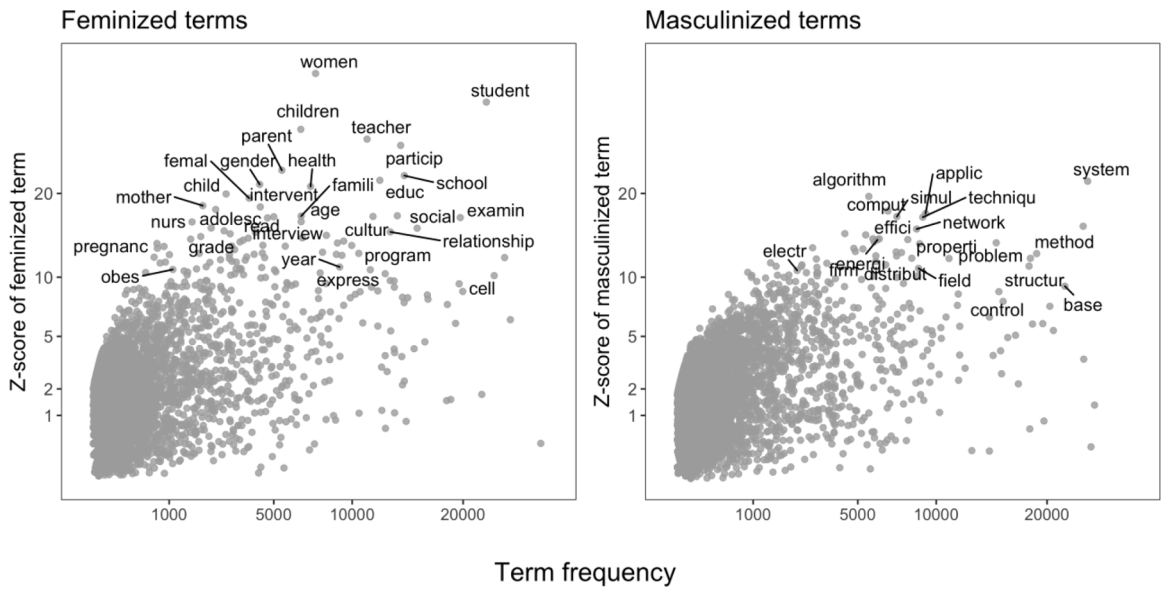

Fig. 1.. The frequency and z-score of feminized and masculinized research terms in all dissertation abstracts submitted in 2010. The square roots are taken on the *x*- and *y*-axes.

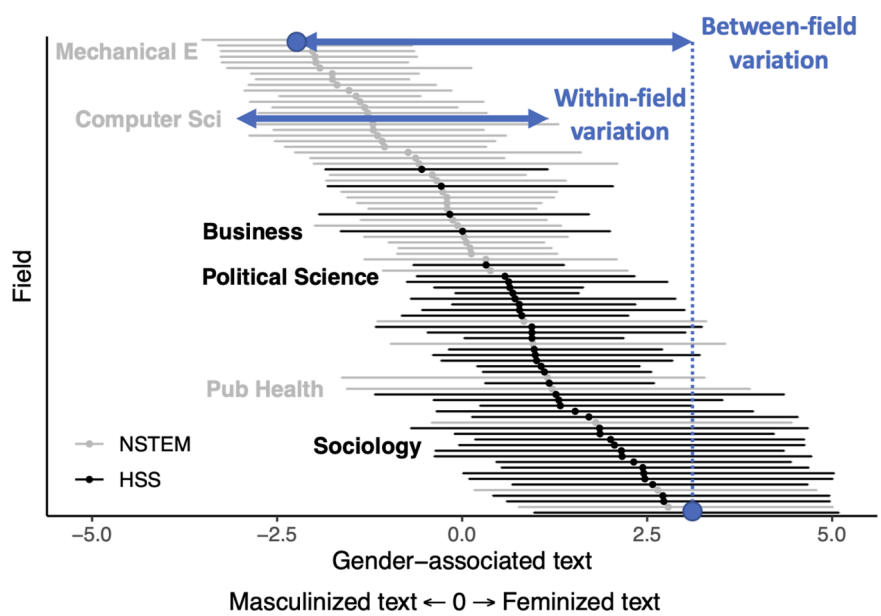

Fig. 2.. Across- and within-field difference in gendered text. Each horizontal line covers 95% of the observations per field. The center point is the average of gendered text per field. Black lines show fields in HSS, and grey lines show fields in NSTEM.

proficiency or visibility (Leahey, 2007), we count the number of publications—books and journal articles found in the Web of Science database—that PhDs produce up to two years after they graduate.[14] We trace a PhD's name in the Web of Science database and generate a single record for each PhD that includes their full name, institution, field, and text similarity between abstracts. As a measure of an advisor's reputation, we count the number of cumulative publications that they have published up to two years after a PhD student graduates. This allows us to measure the advisor's influence at the time when their advisee is on the job market. We count both solo-authored and co-authored publications. We calculate the log of the publication count of PhDs and advisors. Finally, we include the percentage of woman PhDs in each field, to control for the field's gender representation. Descriptive statistics of variables are in Appendices D.1.[15]

[14] We examine citation counts as well, but this variable has a high correlation with the publication count ($r = 0.76$) and does not make a difference in the results of the final model.

[15] The VIF of all independent and control variables in the model is under 2 except for the percentage of women PhDs in the field (7.2) and the field-level gender-associated dissertation text (7.2).

3.5. Methods

Using mixed-effects logistic regression analysis with two levels[16] (the field- and individual-level) and sample weights, we test how a PhD graduate's gender and gendered dissertation both separately and together relate to the likelihood of becoming an academic. Studying the field- and individual-level separately allows us to address different analytical questions. For example, if sociology is more feminized than computer science, does sociology's comparative feminization diminish the PhD student's chances for an academic job, irrespective of their dissertation? Conversely, within sociology, does the comparative feminization of a dissertation (e.g., on socialization in school) diminish the PhD student's chances compared to another (e.g., on new empirical methods)?

Our hypotheses concern the direct relationship of gendered knowledge on academic jobs (H1, H2, H3, H4) and whether that relationship depends on other independent variables (H1a, H2a, H3a, H4a). Therefore, we build our model in a stepwise fashion to test each set of expectations, respectively.

We first estimate Model 1 to evaluate how the gender of PhD graduates relates to their career outcomes:

Model 1: Log odds ratio (hired as a faculty advisor) = $\beta_0 + \beta_1$ * woman PhD + control variables + field random effects

Based on our review of the literature, we expect β_1 to be negative, indicating woman PhDs have lower chances of getting hired as a faculty advisor.

In Model 2, we add measures for gendered dissertations, separately for the two levels (individual and field levels) and two types (gender-referenced and gender-associated text).[17] Our individual-level indicators (β_2 and β_3) enable us to account for the relative gendered character of the dissertation texts within a field. Field-level indicators (β_4 and β_5) allow us to account for any advantage or disadvantage in terms of getting hired as faculty advisors that is related to writing in a field that is preponderantly feminized or masculinized.

Model 2: Log odds ratio (hired as a faculty advisor) = Model 1 +
β_2 * (individual-level) gender-referenced dissertation text +
β_3 * (individual-level gender-associated dissertation text +
β_4 * (field-level) gender-referenced dissertation texts +
β_5 * (field-level) gender-associated dissertation texts

A positive coefficient of the gender-referenced text (β_2) would confirm our hypothesis that writing dissertations with woman referents is rewarded within the field (H1). In contrast, a negative coefficient of gender-associated text (β_3) would confirm our hypothesis that dissertations with woman-associated knowledge are penalized and those with man-associated knowledge are rewarded within the field (H2). At the field level, we expect to see no effects for gender-referenced text (β_4, H3), but negative effects for gender-associated text (β_5, H4). Overall, we expect to see evidence of efforts to offset explicit bias of women in academia, but evidence of implicit bias toward woman-associated knowledge.

In Model 3, we test Hypotheses 1a to 4a by adding interaction effects. First, to test if woman PhDs who write dissertations about women have an advantage (H1a), we add to Model 2 the interaction between the gender of the PhD (a binary indicator of being a woman) and the individual-level gender-referenced text (β_6). Statistically significant positive coefficients would confirm our expectation (H1a) and indicate an advantage for woman PhDs who write about women, meaning that their lived experience and expertise is valued on the job market. However, a negative coefficient on the interaction effect of a woman dummy variable and the individual-level gender-associated text (β_7) will confirm our hypothesis (H2a) that women writing woman-associated dissertations have a disadvantage, due to their association with a stigmatized gender and sex identity (H2a).

Model 3: Log odds ratio (hired as a faculty advisor) = Model 2 +
β_6 * (individual-level) gender-referenced text × Woman PhD +
β_7 * (individual-level) gender-associated text × Woman PhD +
β_8 * (field-level) gender-referenced texts × (individual-level) gender-referenced text +
β_9 * (field-level) gender-associated texts × (individual-level) gender-associated text

Finally, we include two interaction effects between field-level and individual-level gender-referenced and gender-associated text to test whether PhD graduates who write about women are differentially rewarded, depending on their field of study. A positive coefficient for β_8 would indicate that PhDs who write about women in fields where women tend to be subjects of study have a better chance at getting an academic job (H3a). Conversely, a negative coefficient on β_9 would confirm H4a, which states that doing woman-associated research in fields with traditions of women's research is disadvantageous.

As the last step, we test the relationship between gendered knowledge and academic careers varies across HSS and NSTEM. We interact the field-level dummy variable indicating whether a field is categorized as NSTEM or not with the variables from Model 3. By doing so, we seek to understand whether NSTEM and HSS fields—which exhibit ontological, epistemological, and organizational differences—place different value on gendered knowledge.

4. Results

4.1. The impact of gendered knowledge on career outcomes

We report our findings in Table 1. (See Appendices E.1 for the full model.) Our results from Model 1 indicate that both men and women have low odds of becoming a faculty advisor. However, men have a 0.25 odds of becoming faculty (exp(−1.38)) whereas women have a 0.20 odds (exp(−1.38 + −0.21). The resultant odds ratio is 0.20/0.25. That is, women are around 20% less likely to become a faculty advisor, as compared to men. This finding is consistent with prior work that shows prospective woman academics are disadvantaged on the job market.

In Model 2, we find evidence for Hypothesis 1, which predicts an advantage in becoming a faculty advisor for PhDs who write dissertations that explicitly refer to gender and sex. Our data show that PhDs who use more woman and female referents than is typical in their field are more likely to get an academic job (stdb = 0.22). Next, we test whether woman- or man-associated dissertations result in different chances of becoming a faculty advisor. We find evidence consistent with Hypotheses 2: writing dissertations that evoke a tradition of women's research within fields lowers one's chances for success on the academic job market (stdb = −0.26).

Consistent with Hypothesis 3, our results show that PhDs in fields where women tend to be the focus of study have the same chances of getting an academic job as PhDs in fields that typically study men. In contrast, in line with Hypothesis 4, we find that writing dissertations in more feminized fields lowers PhDs' chances for an academic career (stdb = −0.77).

In Model 3, we find no evidence that a PhD graduate's gender relates to the value of their dissertation's gendered knowledge on the academic job market (H1a, H2a). That is, men and women are equally rewarded for discussing woman referents and are equally penalized for associating

[16] We include field random effects in the model. We compare coefficients from two different models, one with field fixed effects and another with random effects. The model with field fixed effects assumes that all fields have unique effects on hiring outcomes, while the random effects model assumes that effects are structural and do not differ by field. Because the coefficients of two models only differ slightly, we choose the random effect model to test the influence of field-level variables.

[17] While the variables of gender-referenced and gender-associated texts are related to each other, their correlations are relatively low. The correlation matrix of all variables of gendered knowledge in field- and individual-levels can be found in Appendices D.2.

Table 1.
The impact of an author's gender and gendered text on becoming a faculty advisor.

Variables	Model 1		Model 2		Model 3	
	β (SE)	std(β)	β (SE)	std(β)	β (SE)	std(β)
Intercept	−1.38*** (0.11)	—	−1.77*** (0.22)	—	−1.79*** (0.22)	—
Woman PhD	−0.21*** (0.01)	−0.42	−0.20*** (0.01)	−0.40	−0.20*** (0.01)	−0.40
Individual-level Predictors						
(H1) Gender-referenced text (higher = more woman and female referents in dissertation)			.10*** (0.01)	.22	.11*** (0.01)	.24
(H1a) Gender-referenced text × Woman PhD					−0.02 (0.02)	−0.03
(H2) Gender-associated text (higher = more feminized dissertation)			−0.07*** (0.01)	−0.26	−0.06*** (0.01)	−0.22
(H2a) Gender-associated text × Woman PhD					.01 (0.01)	.03
Field-level Predictors						
(H3) Gender-referenced texts (higher = more research on women and females in field)			−0.07 (0.22)	−0.03	−0.07 (0.22)	−0.00
(H4) Gender-associated texts (higher = more feminized field)			−0.12* (0.06)	−0.77	−0.12* (0.06)	−0.77
Cross-level Predictors						
(H3a) (Field-level) Gender-referenced texts × (Individual-level) Gender-referenced text					−0.08 (0.05)	−0.03
(H4a) (Field-level) Gender-associated texts × (Individual-level) Gender-associated text					−0.03*** (0.00)	−0.19
Model fit (AIC)	370,856		370,631		370,569	
N (PhD)	940,670					

Note: Standard errors in parentheses. * $p < .05$; ** $p < .01$; *** $p < .001$ (two-tailed tests); multilevel mixed-effects logit regression (N of fields = 85); the coefficients of control variables and variable description are in Appendices E.1. Standardized beta (stdb) refers to the impact of one standard deviation change of an independent variable on the standard deviation change of a dependent variable. Model 2 with variables of gendered texts fits significantly better than Model 1 (LR test, $p < .001$). Model 3 with interaction effects fits significantly better than Model 2 (LR test, $p < .001$).

with feminized topics. We also test whether dissertation research that is about women and females (referent) or that evokes women's research traditions (associated) is valued differently depending on the field's relative degree of feminization. We find that PhD students writing woman-associated dissertations are even less likely to secure academic jobs if they are in fields associated with women's research traditions (H4a).

Fig. 3 illustrates the interaction effect in H4a. It shows that two PhDs, one writing on relatively feminized research topics and another one on masculinized topics,[18] have different likelihoods of becoming a faculty advisor. Those differences are related to the degree to which their research topics are gender-associated within their fields. Overall, for PhDs doing relatively feminized or masculinized dissertation research, the probability of becoming a faculty advisor is lower in fields with traditions associated with women. However, the impact of doing masculinized research is weaker, as suggested by the gradual decrease in the dotted line in Fig. 3. In the most masculinized fields, we find no notable difference in career chances for PhDs writing masculinized and feminized dissertations. However, in feminized fields, PhDs writing on masculinized topics are about two times more likely to get an academic job, as compared to PhDs writing on feminized research topics (See right hand side of Fig. 3). In other words, writing a dissertation in feminist studies that uses machine learning (masculinized) techniques is twice as advantageous than writing a feminist studies dissertation that uses a qualitative (feminized) approach.

[18] Relatively feminized dissertations are 2 standard deviations above average and relatively masculinized dissertations are 2 standard deviations below average.

Fig. 4 visually compares the magnitudes and confidence intervals of the standardized coefficients in Model 3. While we confirm the positive impact of referencing women at the individual-level (H1), woman-associated dissertations within field (H2) and woman-associated fields (H4) have a negative impact on PhD graduates' chances of becoming a faculty advisor. An explicit focus on women as the subject of dissertations is associated with higher chances of obtaining academic careers. Yet, woman PhDs who do research associated with women are still penalized. In other words, the positive valuation of explicit woman referents is not enough to reverse either structural disadvantages or the implicit devaluation of woman-associated knowledge within and across fields.

Our results also imply that gendered dissertation content has independent additive effects in addition to moderating existing gender inequality. Overall, our results show that signaled or symbolic gender alignments exacerbate bias and devalue PhD graduates' dissertation research, regardless of their own gender or sexual identity.

4.2. Does the impact of gendered knowledge differ by HSS and NSTEM fields?

Finally, we consider how the coefficients for variables presented in Fig. 4—being a woman PhD, individual-level gender-referenced text (H1), gender-associated dissertation text (H2), and gender-associated field (H4)—differ between the HSS and NSTEM fields. Fig. 5 compares the magnitudes of the standardized coefficients for those variables, for HSS and NSTEM.

Our results in Fig. 5 show that women are confronted with greater structural inequality in NSTEM than HSS. The standardized coefficient of being a woman PhD is −0.17 in HSS, but it is 1.4 times higher in

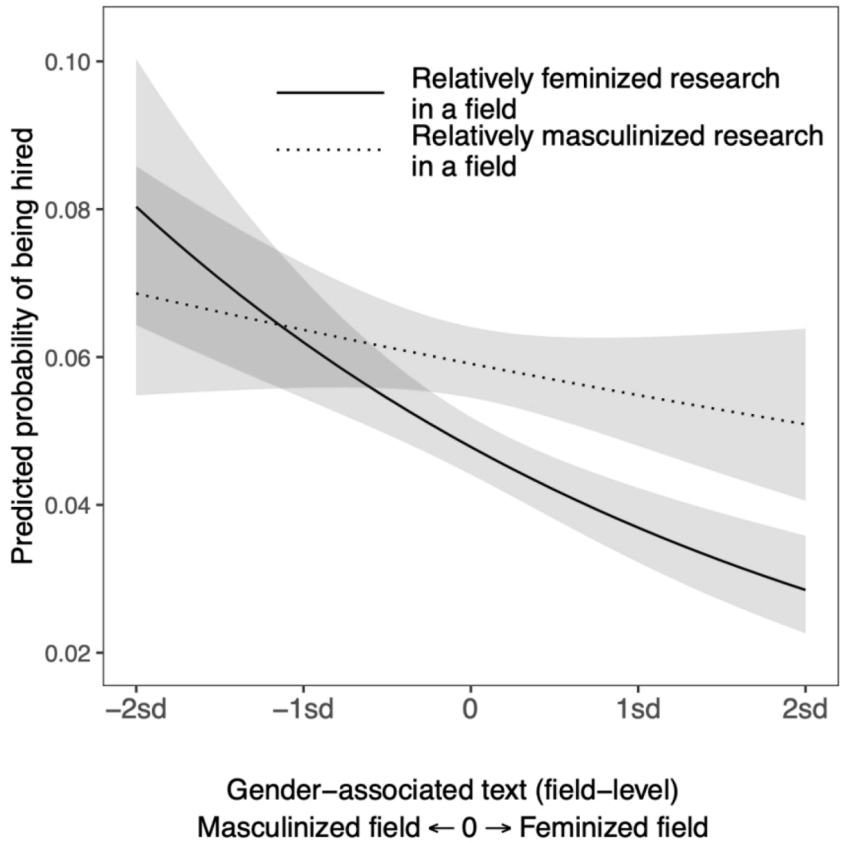

Fig. 3.. The predicted probability of being hired (=becoming a faculty advisor) for masculinized and feminized research, relative to field average by gender-association. 95% confidence interval for shaded areas.

NSTEM (stdb = −0.24). However, HSS and NSTEM fields place similar value on gender-referenced (H1) and gender-associated (H2) dissertations. That is, both HSS and NSTEM positively value dissertation research with women as the subject matter and negatively value dissertations that evoke woman-associated research traditions.

In HSS, PhDs in woman-associated fields (e.g., feminist studies) are more penalized in terms of academic job opportunities than those in man-associated fields (e.g., economics). It is important to note, however, that although the standardized coefficient for HSS is large, the confidence interval is wide.[19] In contrast, the standardized coefficient for field-level gender-association for NSTEM is relatively small and not statistically significant. This indicates that PhDs in woman-associated fields of NSTEM (e.g., biology) are not penalized on the academic job market any more than PhDs in man-associated fields (e.g., mechanical engineering).

Our findings suggest that gender inequality exists in both HSS and NSTEM fields yet manifests differently. Systemic inequality is worse in NSTEM fields than in HSS. Although the explicit barrier of entry into academia for women is lower in HSS than in NSTEM, the field-level devaluation of woman-associated knowledge is greater in HSS.[20]

5. Discussion and conclusion

We set out by asking whether gender inequality extends beyond structural factors to gender's symbolic embodiment in research language. Our intuition is that what people write about can be gender-related in some ways, and this gender relation is explicitly and implicitly valued and thereby influences employment outcomes, often further contributing to the reproduction of gender inequities. We examine this by measuring gender-typing of academic research using two variables: (1) gender-referenced text and (2) gender-associated text. We use natural language processing techniques to identify these gendered forms of knowledge in nearly a million dissertations in the U.S. from 1980 to 2010. Our efforts result in one of the first large-scale empirical studies that identifies how gender inequality is reproduced by gendered representations of knowledge. Our approach empirically identifies how explicit references to women in research get modestly rewarded as a corrective to their past exclusion (Nielsen et al., 2017), but that more implicit forms of bias overwhelm this "corrective": research that is associated with women and their research traditions is strongly devalued. In making a theoretical and empirical distinction between reference to and association with gender, we disentangle the mechanisms that continue to disadvantage women on the academic job market.

Overall, our examination of gendered knowledge suggests that academia is making modest, explicit efforts to include women and female referents, yet there still exists a bias favoring research traditions

[19] The negative devaluation of woman-associated fields in HSS might be due to women's concentration in applied doctoral degrees such as the Doctor of Education (EdD) or the Doctor of Psychology degree (PsyD). However, our data do not provide information on PhD students' degree type. Instead, we test the same model after excluding fields known to have a high proportion of applied degrees (e.g., education, clinical counseling, and applied psychology). Using this approach, the strength of the evidence for the difference between HSS and NSTEM coefficients becomes weaker (*p*-value increases from .0032 to .0204).

[20] We explore fine-grained gender differences by testing whether Hypotheses 1a and 2a yield different results in HSS/NSTEM. Those results can be found in Appendices E.3.

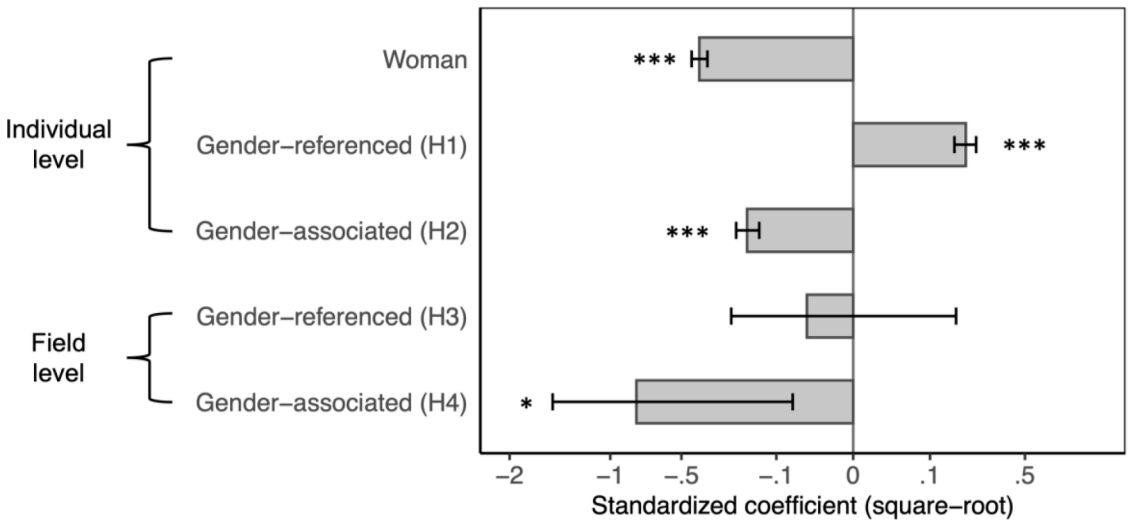

Fig. 4.. The standardized coefficients of being a woman and gendered knowledge variables (Model 3). The horizontal line represents the 95% confidence interval for each standardized coefficient. The standardized coefficients of interaction variables are calculated assuming that all other variables are set to the average. Asterisks show p-value of the statistical test of coefficients ($\beta = 0$); *** $p < .001$ ** $p < .01$ * $p < .05$. See Appendices E.4 for robustness calculations.

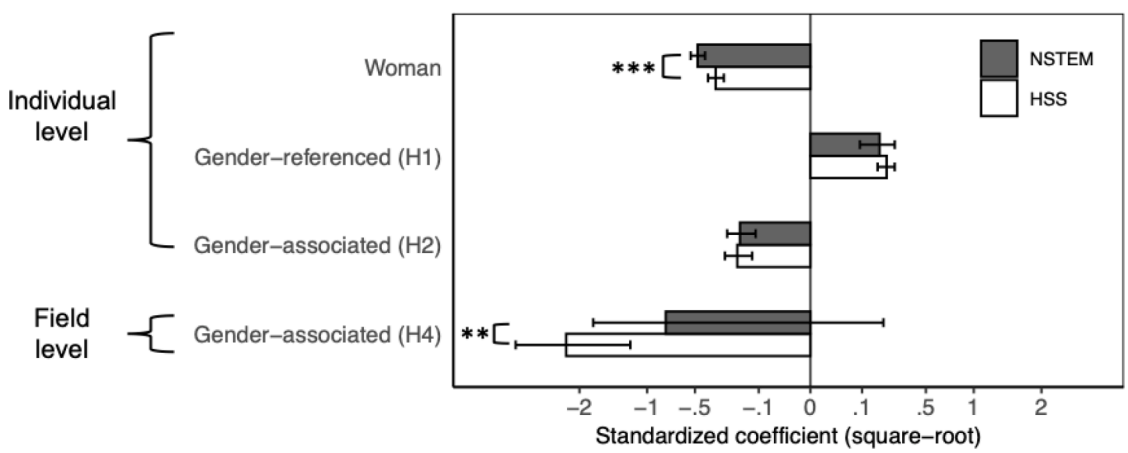

Fig. 5.. The standardized coefficients of being a woman and gendered knowledge variables by NSTEM and HSS (see Appendices E.2 for full model results.) The horizontal line represents the 95% confidence interval for each standardized coefficient. Asterisks show p-value of the statistical test comparing coefficients between HSS and NSTEM ($\beta_{\text{HSS}} = \beta_{\text{NSTEM}}$); *** $p < .001$ ** $p < .01$ * $p < .05$.

and dissertation topics associated with men. As a consequence, the science that emerges from PhD graduates' dissertations is not always equally valued. This valuation reinforces gender stratification in science because research interests of PhDs are often gendered. These findings confirm that the man-dominated culture in academia partly extends to the valuation of academic knowledge as it partly translates to later career outcomes among PhD students. We see this as a critical but worrisome component of reproduced gender-based disadvantage in the research process. Not only does the scholar's gender identity matter for their academic career outcomes, but so too does the gender-typing of their research. Often, scholars' gender identity matches the gender of their work, meaning that women are doubly-disadvantaged.

Also, our findings suggest that the devaluation of research associated with women is more prevalent in fields that are themselves more associated with women and less valued. Perhaps facing a legitimacy crisis due to the low career chances of PhDs, these devalued fields likely react by promoting relatively masculinized studies, which are perceived to be more legitimate than feminized work (e.g., see Schuman 2014.) Thus, for those working in fields with a preponderance of research traditionally associated with women, women PhDs are more likely to suffer a triple disadvantage on the job market. They are penalized for: (1) being a woman, (2) not doing a PhD in a masculinized field, and (3) not adopting man-typed research practices and traditions.

Lastly, we show that women PhDs face greater systemic barriers in NSTEM than in HSS. However, writing dissertations on women and woman-associated topics have a similar impact on PhD graduates' academic job prospects in those fields. For PhDs in both HSS and NSTEM who write dissertations with an especially narrow specialization on women and females results in positive career outcomes. PhDs who focus more than their same-field peers on woman-associated topics, however, do not fare especially well on the academic job market. We also find weak evidence that woman-associated fields in HSS afford PhDs lower chances of becoming faculty advisors, as compared to woman-associated fields in NSTEM. The gender-association variable had no association in NTSEM.

In sum, we find evidence that the scholarly community is attaining modest success in fixing manifest gender bias. For example, we show that studying women as the subject of research (in contrast to men) is welcomed in the academic job market. This tendency to favor women subjects counteracts the historical inclination to value studies centered on dominant groups (Menand, 2010). Yet, we contend that gender bias implicit in the evaluation of academic research is an important and

insidious source of persistent gender inequality.

5.1. Limitations and future directions

Our dataset and the approaches we took are likely imperfect, so here we describe potential limitations and the strategies we used to address them. In addition, we explain how our findings can inform future research. One limitation is that the ProQuest dissertation database includes abstracts rather than full text. While full text would be ideal, prior work argues the abstract concisely summarizes the core features of the research undertaken in the full text (Hofstra et al., 2020; Yu, 2006; Lin, 2009). Even so, an avenue for future research would be to model the full dissertation text. This future research could complement our current findings either by corroborating the impact of gendered knowledge on PhDs' careers or by identifying differences in how dissertation abstracts and full texts embody gendered knowledge and, subsequently, operate differently but in conjunction as signals on the academic job market.

Second, we analyze data on the US-based academic careers of PhD graduates of US universities. Many PhDs have successful research careers elsewhere, including at international universities, colleges and community colleges, government agencies, think tanks, and research divisions of companies. Our focus on US-based universities helps us avoid biased representation of international universities as well as non-academic research careers (e.g., there is no census of international faculty or PhD recipients' domestic and international research careers). We do, however, explore whether our findings might hold in these alternative settings. To infer career outcomes of US PhDs outside of research universities in the US, we track the names of PhD recipients in the Web of Science database and see whether they continue research ten years after graduation. Our key findings remain robust with this approach. (See Appendices F.) Future research could use more comprehensive data on non-academic research career outcomes to explore whether and how differential evaluation of gendered knowledge might result in persistent gender disparities in sectors outside of academia.

Third, our analyses focus on how the dissertation topic affects PhDs' chances of getting a faculty position. We do not examine the research topics that PhDs study during their postdoctoral programs, even though the postdoctoral fellowship is an increasingly critical step on the way to becoming a faculty member. Notably, our data cover 1980–2010, a period before the broad-based mainstreaming of the postdoc across the academy (Brischoux and Angelier, 2015). Nonetheless, our analytic strategy recognizes that some PhDs will carry a significant part of their research interests to the postdoc period. We do this by introducing a two-year buffer[21] following the PhD student's graduation when measuring their productivity during this early career stage. This helps us to avoid attributing undue influence to the dissertation and PhD lab work for early-career scientists who increasingly rely on the postdoc to establish themselves in academia. By including the two-year buffer, we account for potentially important differences both in their research productivity and agendas that may influence their chances of getting an academic job.

Future work can improve on ours in multiple ways. For example, our work adopts a relatively simple and direct approach to identifying gender-associated and gender-referenced research by focusing only on the terms researchers choose, not on how they use them. We removed English stop words—including auxiliary verbs and function words—as well as word suffixes, retaining just the stem for analysis. This process makes it impossible to identify the different uses of adjectives or adverbs. We thus do not trace degrees of "politeness" (Brown and Levinson, 1987) or sentiment (Lerchenmueller et al., 2019), both of which might be related to the gendered character of these texts. Future research could investigate how gender manifests in writing style and how style impacts PhD graduates' chances of getting an academic job.

Our work investigates how women and men in NSTEM and HSS fare on the job market depending on how much they draw on gendered knowledge. Our auxiliary analyses point to important variation across these fields (see Appendices E.3.). Future scholars might study how and why the impact of gendered knowledge on women's academic career outcomes varies across epistemic cultures. For example, the mechanism that causes feminized fields to have worse academic career outcomes than masculinized fields is currently unknown. We do know that it is not uncommon for feminized fields to have fewer resources (Dominguez-Villegas et al., 2020). One possibility is that fields associated with men are perceived to be more prestigious, harder, more demanding of "talent" (Leslie et al., 2015), and therefore more deserving of resources. Another explanation is that man-associated fields are regarded as facilitating more innovation than woman-associated fields. Consequently, more resources are allocated to those fields. It would be fruitful to study the decision-making process of budget allocation across fields, both at the national and institutional level.

It is also important to understand the mechanisms by which certain research traditions become and remain—subtly and stubbornly—associated with one or another gender. For example, in NSTEM fields, one possible hypothesis is that principal investigators assign dissertation research topics based on implicit gender biases and related notions of PhD student interest and aptitude. If this is the case, women PhDs might be disproportionately assigned to potentially devalued topics within fields. As a result, women might have fewer opportunities in the long run. This type of analysis could highlight current research policies that sustain gender inequality in academia.

When we control for race/ethnicity in our models, we very narrowly focus on the gender of PhD students. While this enables us to understand the average disadvantage women face on the academic job market compared to men, we do not explore how such disadvantage compounds due to other dimensions of identity that intersect with gender. For example, Black scientists and Black women scientists are multiply marginalized in many domains in American society with real consequences for the academic job market (West, 1993; Croom 2017; Buchanan, 2020). Future work could build on ours in this regard. For example, future work could explore whether race/ethnic minority PhD students have different chances in securing a job when they write comparatively feminized dissertations. Does the potentially feminized knowledge that Black PhD students produce result in even lower job chances? Other work could also identify traditions of research associated with Black, Latinx, and other race/ethnic minority scientists. In a similar spirit to the present work, this future work could investigate whether there is double disadvantage (penalties for being minority and writing in traditions of minority scholars' work) or even a triple advantage (additional penalties for being women, as well).

Lastly, future work should consider gender as continuous and should, whenever possible, utilize the self-reported gender identities of PhD students. Our work leverages the traditional gender binary to identify gender-based inequities. We fully recognize that gender identity can be nonbinary, but data limitations prevent us from applying this more inclusive view of gender. We believe that other non-dominant genders are likely experiencing similar inequities or worse. As such, our results are arguably conservative and underestimate biases toward other gender-minority groups.

5.2. Research policy implications

While the culture in academia is often perceived as meritocratic, our results suggest that the system is a tilted ground that values the research associated with men more highly than women. Understanding this

[21] The median length of postdoctoral period in science and engineering fields is about 3 years for researchers in the 1980s and 1990s (Stephan and Ma, 2005). The actual median length of all PhDs during that period is lower, considering that this statistic excludes PhDs who have not been a postdoc. We therefore argue that a two-year buffer will be sufficient to measure productivity during the postdoc period, at list for the period covered by the data.

implicit bias is urgent and important because we may be neglecting the unconventional and diverse perspectives raised by minorities in academia (Hofstra et al., 2020; Akerlof, 2020; Corsi et al., 2019). This slows down innovation in research and, therefore, inhibits the economic value of scholarship.

Some may infer from our results that conducting research traditionally associated with men might be an effective strategy for women to successfully navigate the tilted academic job market. However, we are reticent to adopt this stance and believe young scholars should pursue their interests. Instead, we suggest that educators should encourage women (and men) to navigate research agendas without being tied to gender stereotypes.

Perhaps the problem lies more with the system's implicit bias against certain types of research rather than assuming that some types of research are inherently more valuable than others. To reduce implicit bias, decision-makers with the power to make a difference in academia can promote, expand, and invest in a wide scope of research. For example, university administrators should promote new research initiatives and establish new centers and programs that value research by and about women. Additionally, members of the profession who are in leadership roles, such as professional association presidents and editorial boards, should consider whether their tacit bias is affecting their agendas. Together, these efforts would promote the opportunities of early-career academics to contribute to their fields and could help to attenuate the systemic devaluation of research traditionally associated with women.

Moreover, our research reinforces the need for implicit bias training in the faculty hiring and promotion process.[22] Faculty recruitment is one of the keys to solving the problem, as the breadth of innovation through teaching and research is determined by representation (Koning et al., 2021). Through implicit bias training, committee members will become aware of how the research topics of women, under-represented minorities, or non-dominant genders are systematically undervalued. In a more direct approach, hiring candidates who research topics traditionally undervalued is also helpful in expanding the breadth of diversity what we address in our research. Only then will we be able to pursue research that lives up to the values of universalism and fairness espoused long ago (Merton, 1945). By recognizing that research is imbued with social value, we both identify the means by which our values can be undermined but also potentially fulfilled.

CRediT authorship contribution statement

Lanu Kim: Conceptualization, Methodology, Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Daniel Scott Smith:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Bas Hofstra:** Conceptualization, Methodology, Validation, Data curation, Writing – review & editing, Software. **Daniel A. McFarland:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Project administration, Funding acquisition, Data curation, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[22] For example, Stanford has a program that attempts to educate hiring and promotion committees about issues of bias (https://facultydevelopment.stanford.edu/recruitment/recruitment-overview).

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Supplementary materials

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