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Leaks in the pipeline: separating demographic inertia from ongoing gender differences in academia

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Identification of the causes underlying the under-representation of women and minorities in academia is a source of ongoing concern and controversy. This is a critical issue in ensuring the openness and diversity of academia; yet differences in personal experiences and interpretations have mired it in controversy. We construct a simple model of the academic career that can be used to identify general trends, and separate the demographic effects of historical differences from ongoing biological or cultural gender differences. We apply the model to data on academics collected by the National Science Foundation (USA) over the past three decades, across all of science and engineering, and within six disciplines (agricultural and biological sciences, engineering, mathematics and computer sciences, physical sciences, psychology, and social sciences). We show that the hiring and retention of women in academia have been affected by both demographic inertia and gender differences, but that the relative influence of gender differences appears to be dwindling for most disciplines and career transitions. Our model enables us to identify the two key non-structural bottlenecks restricting female participation in academia: choice of undergraduate major and application to faculty positions. These transitions are those in greatest need of detailed study and policy development.

Keywords: academic hiring; gender bias; women in science

1. INTRODUCTION

The prevalence and persistence of inequalities in academia is an important yet volatile issue. Despite widespread support for equality [1], women and many racial and ethnic minorities are under-represented in academia relative to their proportion in the general population [2]. Numerous studies have uncovered evidence for historical and continuing gender- and ethnicity-based differences in academia, attributed to various causes such as innate differences between the sexes [3], differences in career goals and interests [4–6], and explicit and implicit bias against female or minority academics [7–9]. The scale of these differences and their quantifiable impact on the demographic composition of academia remain controversial [10–13]. Although it may be tempting to infer bias when current minority proportions in academic positions are below parity (in the case of gender discrimination) or below the proportions in the overall human population [14], such a comparison fails to account for enduring effects of historical inequalities. Because the time spent in each stage of an academic career lasts of the order of years to decades, changes in hiring practices or improvements of retention of under-represented groups may not lead to immediate, or even rapid, rectification of inequalities. This results in demographic inertia where a time lag is to be expected before the full effects of changes are seen [14,15]. In conservatively organized institutions such as academia, demographics can be the main promoter of structural changes (e.g. hiring policies, staff benefit plans, etc.), and thus demographic inertia has the additional potential to reinforce structural inertia [16,17]. Legal measures to guard against discrimination have been in place for decades in many countries, and yet the allegations of gender and racial bias remain. Here, we make use of a common idealization of the 'typical' academic career to create a baseline expectation for gender equity in academia, accounting for demographic inertia. This baseline allows for the easy identification and quantification of particular career transitions and academic disciplines in which gender differences and/or discrimination may still play an important role.

We illustrate this framework by examining the participation of women in the natural and social sciences in the USA, using publicly available data from the National Science Foundation (NSF). The discussions of the seeming under-representation of women in academic careers have been fraught with conflicting views of the causes and solutions [11,12,14,15], without clear definitions of a null baseline that accounts for inertial effects. The lack of a baseline makes it difficult to assess the extent to which gender-based differences have persisted since the introduction of fair hiring legislation (e.g. the Equal Employment Opportunity Act of 1972). Although we have chosen to focus on gender equity in US academia in this paper, the framework is easily applicable to minorities and/or other countries.

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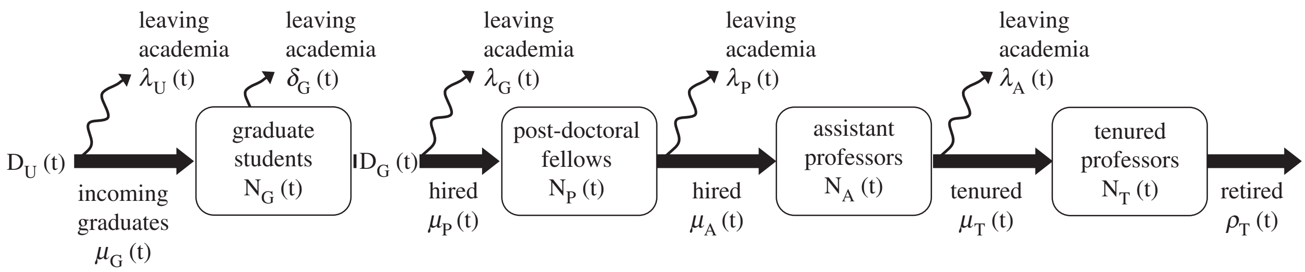

Figure 1. Schematic of academia as a 'leaky pipeline', where individuals either progress through the series of academic stages, or leave academia altogether.

2. THE PIPELINE MODEL

Academia is often metaphorically described as a pipeline [18], alluding to the notion that an academic career can be idealized as a linear progression from undergraduate education to tenured professorship (figure 1). The academic career pipeline is conceived of as consisting of five discrete stages: undergraduate studies, graduate studies, post-doctoral fellowships, assistant professorship (tenure track) and tenured professorship. This pipeline is often referred to as 'leaky'; that is, individuals may leave academia at various stages in the process. Although obviously a simplification, the pipeline metaphor provides an excellent framework for establishing a model of academia within which the effects of gender-based differences may be tested. The career path of any individual academic may be more tortuous, and influenced by numerous non-academic events [19] but this does not undermine the heuristic usefulness of the pipeline idealization. A simple general model can identify otherwise obscure broad patterns and trends whose specific causes can be identified through more detailed studies.

We constructed such a model (see electronic supplementary material for details), allowing us to establish a baseline free of gender-based differences while accounting for lags induced by historically low female participation in academia. Similar Markov modelling approaches have been applied to educational careers in a more limited scope; past studies have developed a model of high-school and undergraduate education [20], and used a comparable framework to explore the outcomes of various policy scenarios at a single university [21]. Age-structured models have also been applied to this problem; however, policies often target particular career moments rather than specific ages, making such an approach less helpful for the examination of specific policy impacts. We demonstrate how our more general model can be used to test for the presence and extent of gender-based differences in academia in the USA, across several decades and a wide range of scientific disciplines. We compare model output for each career stage to data collected by the NSF over a 28-year period (1979–2006). Gender inequalities that are not explained by the time lags in the model are indicative of gender-based differences or discrimination, allowing the rapid identification of key career stages and transitions for effective policy application.

3. PERFORMANCE OF THE PIPELINE MODEL

We calibrated and ran the pipeline model to examine female participation in academia (defined as the proportion of individuals in a pool that are female) across science and engineering in general, as well as for six disciplines (agricultural and biological sciences, engineering, mathematics and computer sciences, physical sciences, psychology, and social sciences) chosen to represent a variety of discipline sizes and ranging from male-dominated to female-dominated undergraduate pools.

Several factors may limit the realism of our model. Academic careers are not necessarily linear progressions within universities alone, and individuals may leave and return at various stages. Although it might seem that this would increase the lag associated with career transitions, it does not in fact affect the applicability of the model. What is important is the comparison of the gender composition of a career stage to the potential applicants, which will be unaffected by career detours during that transition. If there are gender differences in the likelihood of spending time away from academia during a particular career transition, these will be assessed as part of the overall gender difference associated with said transition.

There is some variance in the duration of various career stages, such as the time spent in graduate studies [22], post-doctoral employment [23,24] or the age of retirement [22]. Realistic variation in the duration of career stages did not qualitatively affect the outcome of the model. We varied the average length of time spent both as an assistant (4–8 years [25]) and tenured professor (20–30 years [22]), and although the final outputs differ (shaded areas in figure 2), the predicted null female proportion of professors consistently exceeded actual demographics. Varying the length or number of postdoctoral fellowships taken by each individual had even less effect on final outcomes.

Many academics are highly internationally mobile. Many American academics have spent significant portions of their career abroad, and many foreign-born academics may spend parts or all of their careers in the USA [22]. Non-American academic institutions can have significantly different gender composition, and our model is unable to account for these effects. We therefore assume that the percentage of female foreign hires is the same as that within the US system.

4. INERTIA IS NOT THE WHOLE STORY

The model predicted steady increases in female participation over time in all stages of academia. These increases are driven by a strong increase in the proportion of female undergraduate students in the majority of scientific disciplines (figure 2). Increases in female proportions are slow under the no gender-based differences conditions of the model, reflecting demographic inertia slowing the rate of demographic change.

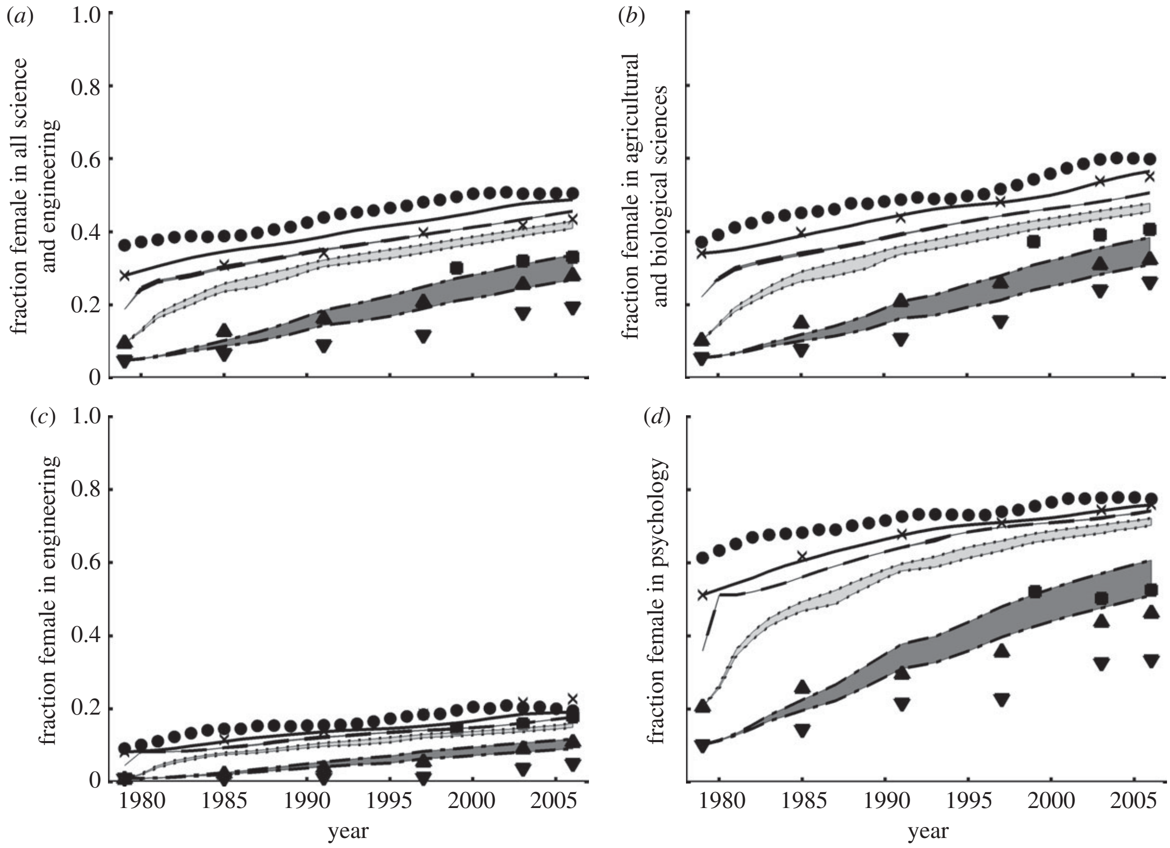

Figure 2. Comparison of female participation (female academics as a percentage of the academic population) as predicted under a null model (lines: solid lines, graduate; dashed lines, post-doctorate; dotted lines, assistant professor; dash-dotted lines, tenured professor) versus actual NSF data (symbols: circles, undergraduate; cross symbols, graduate; squares, post-doctorate; triangles, assistant professor; inverted triangles, tenured professor) for (*a*) all of science and engineering, (*b*) agricultural and biological sciences, (*c*) engineering, and (*d*) psychology. Shaded areas reflect the variation in model output under slightly different model structures (see text for details).

Although demographic inertia slows the rate at which parity is attained, actual demographic data also consistently diverged from the baseline predicted by the model, suggesting that gender-based differences also play a role. In all disciplines, including those with greater-than-parity female participation at some career stages (agricultural and biological sciences, and psychology), female participation was lower than expected under complete gender neutrality (figure 2).

5. UNDERGRADUATE ENROLMENT AND FACULTY HIRE: A BIMODAL ACADEMIC BOTTLENECK

To get a sense of the relative importance of demographic inertia compared with all other gender-based differences, we calculated the amount of the divergence between current demographics and parity that can be attributed to demographic inertia (i.e. accounted for by the pipeline model; see electronic supplementary material for details). The value, which we term the inertial effect (IE), can be calculated for each career transition (table 1). An IE value equal to 1 indicates that actual female participation within a class and discipline exactly matches that predicted by inertia alone, while a value less than 1 indicates that women are less represented than would be expected by demographic inertia, and a value greater than 1 indicates that they are more represented.

Paradoxically, career stages with lower female participation often showed greater demographic inertia effects. For example, essentially all of the current deviation from parity among tenured professors is explained by the earlier female proportion of assistant professors combined with inertia in the granting of tenure, with the exception of faculty in mathematics and computer sciences (table 1, AP to TP). Some disciplines with low numbers of female undergraduates (engineering, mathematics and computer sciences) have IE values well over 1 for the transition to graduate school (table 1, UG to GR), suggesting that female undergraduates are more likely to pursue graduate studies than their male counterparts. This pattern disappears entirely for academic retention after graduate school, for which these disciplines exhibit the greatest non-inertial gender differences.

Across all disciplines, the career transition divergence least explained by demographic inertia effects is that from graduate student or post-doctoral researcher to the professoriate. This is a career transition that has been identified as difficult by other authors [26–28], and frequently coincides with family formation for educated professionals [18], as well as the highest degree transferable to non-academic professions (e.g. industry).

6. STEADY BUT INCOMPLETE IMPROVEMENT THROUGH TIME

We also looked at how IE values have changed over the past 30 years. The IE value for most transitions and disciplines shows a tendency to approach a value of 1,

Table 1. The proportion of female individuals in each class in the year 2006 from NSF data and our model predictions, as well as the inertial effect (IE): how much can be accounted for by demographic inertia in the transitions between classes. Results are shown for all of S&E (science and engineering) and by discipline: BIO, agricultural and biological sciences; ENG, engineering; MAT, mathematics; PHY, physical sciences; PSY, psychology; SOC, social sciences.

	S&E	BIO	ENG	MAT	PHY	PSY	SOC
undergraduate studies (UG)	0.51	0.60	0.20	0.27	0.42	0.77	0.54
graduate students (GR)							
data	0.43	0.55	0.23	0.37	0.33	0.76	0.54
model	0.49	0.56	0.19	0.31	0.41	0.76	0.52
post-doctoral fellows (PD)							
data	0.33	0.41	0.18	0.22	0.21	0.53	0.46
model	0.42	0.53	0.22	0.37	0.31	0.76	0.54
assistant professors (AP)							
data	0.28	0.32	0.11	0.17	0.17	0.46	0.34
model	0.39	0.48	0.19	0.37	0.28	0.73	0.51
tenured professors (TP)							
data	0.19	0.26	0.05	0.09	0.08	0.33	0.23
model	0.18	0.22	0.05	0.10	0.08	0.32	0.21
IE in transitions between classes							
UG to GR	0.89	0.97	1.19	1.19	0.80	1.00	1.04
GR to PD	0.79	0.77	0.82	0.59	0.68	0.69	0.86
GR to AP	0.71	0.67	0.57	0.47	0.60	0.64	0.66
AP to TP	1.09	1.18	1.03	0.86	0.98	1.04	1.07

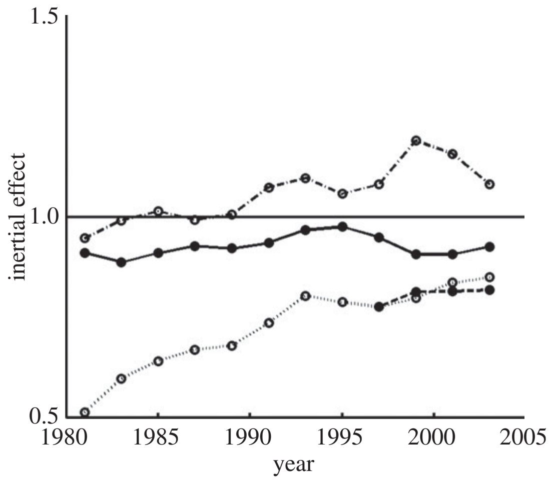

Figure 3. The IE over time for each transition in the academic pipeline for science and engineering. Solid line, UG to GR; dashed line, GR to PD; dotted line, GR to AP; dashed-dotted line, AP to TP.

suggesting that they have become increasingly egalitarian over time (see figure 3; electronic supplementary material, table S1). Admission to graduate school and granting of tenure do not seem to have been associated with strong gender differences in the past, and currently closely resemble the predictions of a null model, with the possible exception of the granting of tenure in mathematics and computer sciences.

The greatest gender difference, both historically and currently, is in the continuation of an academic career after graduate school. The gender difference associated with the transition has decreased considerably since the beginning of the available dataset in the 1970s, with particularly strong gains made in engineering and physical sciences. In mathematics and computer sciences, although much progress has been made, gender differences remain comparable with those in many other disciplines 30 years ago.

The strong gains in female participation in academia over recent decades lend support to the notion that cultural and societal pressures, rather than inherent biological differences, were responsible for historically low participation of women in science. They are probably also evidence of (partially) successful measures to increase fairness of hiring. There is little indication that an equilibrium has been reached, as IE values continue to change, in particular for the transition to faculty positions.

7. WHY DO DIFFERENCES PERSIST?

Much of the current underparticipation of women in academia can be explained by the time lags associated with overcoming historically very low representation. However, although gender differences associated with academic career transitions have diminished, they remain significant, and two transitions are particularly problematic: enrolment in undergraduate majors in some disciplines and retention in academia after a graduate degree.

Female enrolment in science and engineering undergraduate majors has greatly increased over recent decades; however, the increase has not affected all disciplines equally. Agricultural and biological sciences, social sciences and psychology now have female undergraduate enrolment exceeding 50 per cent, but numbers of female students remain low in engineering, mathematics and computer science, and physical sciences. Low numbers of female undergraduate majors will have lasting repercussions for the gender composition of faculty in those disciplines, even when there are minimal gender differences associated with later career transitions. The proportion of female starting university students intending to study these disciplines is much lower than that of male students, suggesting that factors prior to university are likely to be as or more important than attrition during the undergraduate studies [29]. This gender difference is absent in disciplines such as agricultural and biological science and social sciences. Male high-school students tend to be more proficient in mathematics and science by some metrics [22]; however, the differences are marginal and hardly account for the differences seen at the undergraduate level. This would suggest that the differences in undergraduate enrolment are not caused by differences in innate ability.

The most difficult academic transition for women (when compared with men) appears to be retention in academia after the doctorate. This has been true historically, and although the gender gap appears to be closing in most disciplines, it remains a problematic stage. Unfortunately, our model cannot distinguish among the potential gender-based differences, and although possible causes have been discussed in depth by numerous authors [5,6,8,9,27,30], they remain controversial. One study that examined the composition of applicants for faculty positions found no evidence of discrimination in the choice of interviewees or hires, and even found that women were slightly more likely to be interviewed and hired [28]. This same study found that the fraction of female applicants was much lower than the fraction of graduating female PhDs, suggesting that the gender difference lies primarily in the decision to apply for an academic position [28]. However, others have reported perception biases at this stage, as measured by differences in likelihood of hiring [8] and recommendation letter content [9], by applicant gender. It is perhaps telling that the two most problematic transitions are associated with the largest shifts in institutional roles. Transitioning to university from high school and seeking a faculty position involve taking on novel roles and responsibilities, making them stages at which positive role models and societal pressures can be particularly important.

8. CONCLUSIONS

Inequalities in hiring and retention can take numerous forms, and varied personal experience can colour the interpretation of the current state of women in academia. We propose that the use of a simple model can help identify general trends, and separate the demographic effects of historical discrimination from ongoing gender differences. This approach is also applicable to other historically underrepresented groups in academia, and can help provide a context for more detailed examination of the causes of and solutions to particularly differentiating career transitions.

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