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The Effectiveness of Institutional Intervention on Minimizing Demographic Inertia and Improving the Representation of Women Faculty in Higher Education

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ABSTRACT
Women remain under-represented among full time tenured/tenure-track science and engineering faculty at research universities in the United States despite their increasing availability in the employment pool. In response, intervention strategies aimed at boosting their participation have been introduced at university and national levels. Efforts to improve women's representation may be challenged by demographic inertia, the tendency for the maintenance of the entrenched population structure that favors men despite improvements in women's vital parameters. Here, we investigate the effectiveness of the U.S. National Science Foundation's ADVANCE institutional intervention program at curtailing demographic inertia at a research university dubbed 'Snow State University' (SSU). We found that demographic inertia's impact on women's representation was lessened during ADVANCE. Yet to achieve long-lasting improvements in women's representation, universities will need to increase their recruitment of women at the associate and full professor ranks while maintaining promotion and retention probabilities favorable to women over the long-term.

KEYWORDS
Demographic inertia; Matrix population models; Faculty women; Gender inequality; Institutional intervention; Women scientists and engineers; The National Science Foundation's ADVANCE program

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INTRODUCTION AND BACKGROUND

Over the past 40 years, the number of women earning doctoral degrees in Science and Engineering (S&E) fields in the United States has grown steadily with the most recent set of national statistics (2005) indicating that approximately 38% of all S&E doctoral degrees were awarded to women. Given that women received a mere 8% of S&E doctoral degrees in 1966 (U.S. National Science Foundation [NSF], 2007), gains in the number of women obtaining S&E doctorates today is impressive.

Since women constitute a larger proportion of S&E doctoral recipients today, they comprise a larger share of the S&E employment pool than in the past. Despite their increased availability in the employment pool, women remain under-represented in professional S&E positions (Long, 2001). This discrepancy is especially prevalent among full-time tenured/tenure-track academic faculty (Bradburn and Sikora, 2002; Long, 2001; Nettles, Perna and Bradburn, 2000; West and Curtis, 2006). At four year[i] U.S. universities and colleges, women account for 19%, 34% and 42% of full, associate and assistant S&E faculty, respectively (U.S. National Science Board [NSB], 2008). The most severe disparities occur at research universities where the following trend has developed: the number of tenured/tenure-track women faculty decreases, in general, with increasing university prestige, Carnegie classification[ii], and faculty rank, and the more prestigious the institution the less likely it is for a full professor to be a woman (Bradburn and Sikora, 2002; Cataldi, Fahimi and Bradburn, 2005; West and Curtis, 2006). In contrast, women are over-represented among part-time/non-tenure-track academic faculty where they are more likely to be employed today than men (Cataldi, Bradburn, and Fahimi, 2005).

These trends are not unique to the United States. The under-representation of women among faculty at European institutions of higher learning is a consistent trend. Similar to the U.S., the number of women declines with increasing faculty rank prestige. Across the European Union nations, the percent of women full professors ranges from 5% in the Netherlands to 21.5% in Turkey (Osborn, 1998; ETAN, 2000).

The underemployment of professional S&E women translates into a loss of talent, skills, and leadership essential to the continued growth of the U.S.'s science and engineering sectors (Handelsman et al., 2005; Preston, 2004; West and Curtis, 2006). University and national level institutional intervention programs aimed at promoting women scientists such as the U.S. National Science Foundation's ADVANCE program are elucidating the various forces that are responsible for gender inequality in the workplace. Four broad hypotheses have been proposed to explain the scarcity of full time tenured/tenure-track S&E women faculty members: those based on human capital/economic theory, feminist theory, innate biological gender differences, and demographic inertia (see Marschke, 2004; U.S. National Academy of Sciences [NAS], 2006; NSF 2003; Valian, 1998).

Our study examines the demographic inertia hypothesis and its influence on occupational gender segregation in a university setting. Demographic inertia is the tendency for the entrenched employee population structure favoring the majority to be maintained over the long-term, despite changes to the vital parameters intrinsic to the population (Feinberg, 1984; Hargens and Long, 2002). Vital parameters refer to the collective set of rates that describe the movement of employees through their professions. In an academic setting, the vital parameters hypothesized to exert control over the faculty population structure include the composition of the candidate pool, the recruitment rate of new faculty, the promotion rate of existing faculty, and faculty attrition rates. The combination of these parameters is hypothesized to exert strong control over the pace at which a university's faculty gender composition can change by enabling extremely slow faculty turnover so that over the long run, the male-dominated status quo is perpetuated. (Hargens and Long, 2002; Marschke, Laursen, Nielsen and Rankin, 2007).

We hypothesize that demographic inertia has played not only a major role in curtailing women's current representation among academic faculty, but will continue to limit their representation into the foreseeable future. Here, we investigate the efficacy, given demographic inertia, of the National Science Foundation's ADVANCE[iii] program to minimize demographic inertia and improve the recruitment, promotion, and retention of S&E women faculty at a high research activity Carnegie classified university, which we dubbed 'Snow State University' (SSU).

From 2003-2009, Snow State University participated in the National Science Foundation's ADVANCE program which is aimed at promoting and retaining professional women scientists and engineers through institutional transformation. The tenured/tenure-track population structure at SSU is not atypical for a research university in the U.S. in which the majority of full professors are men while the majority of women are employed as assistant professors (Figure 1). As an ADVANCE participant, SSU implemented programs to increase the transparency of the tenure-track promotion system; improve departmental work climates; improve faculty recruitment practices; assist in dual career accommodation; advance collaborative research opportunities; and, improve campus childcare options. We developed four modeling scenarios corresponding to four different sets of population vital parameters to investigate the efficacy of the ADVANCE program. In addition, the scenarios were selected to examine changes in women's representation among tenured/tenure-track S&E faculty in the absence of ADVANCE. These four different modeling scenarios include vital parameters representing: (1) the ADVANCE program years; (2) the pre-ADVANCE program years; (3) an average scenario using vital parameters averaged between the pre-ADVANCE and ADVANCE scenarios; and, (4) the ADVANCE scenario for five years followed by a reversion back to the pre-ADVANCE scenario.

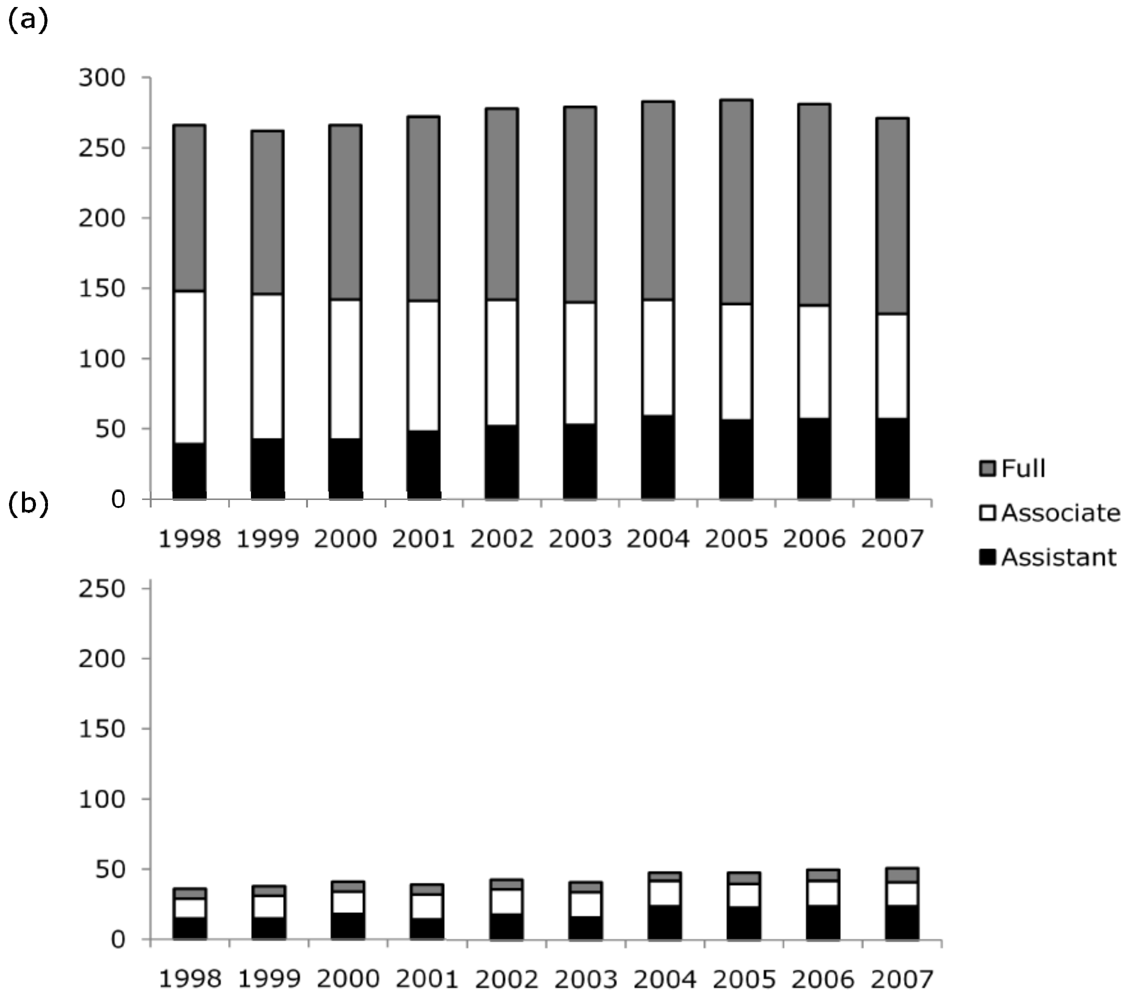


Figure 1. Population structure of male and female science and engineering faculty at Snow State University from 1998-2007.

Demographic Inertia

Only a few other studies have examined the role of demographic inertia on occupational segregation (e.g. Alpert, 1989, Hargens and Long, 2002, Marschke et al., 2007). Feinberg (1984) examined the influence of demographic inertia and the effectiveness of affirmative action programs on the membership of minority employees at the Gramercy metals plant. In Feinberg (1984), models predicted time lags of 31-85 years before racial parity is reached, and the major factors found to contribute to demographic inertia included the availability of minorities in the employment pool and recruitment rate.

Both Hargens and Long (2002) and Marschke et al. (2007) investigated demographic inertia in the context of women's under-representation among academic faculty. Cohort-component models were employed by Hargens and Long (2002) to project the time to reach parity for men and women sociology faculty members under different starting scenarios. By varying the initial age-sex structures of faculty, the rate of faculty new hires, and the gender composition of the employment pool, they found that demographic factors alone can delay equality in the number of total faculty women relative to their availability in the job pool by approximately 35 years. Their analysis identified the availability of women in the employment pool, departmental age structure, faculty attrition rate, and faculty new hire rate as the parameters exerting the greatest influence on the rate of faculty change.

Marschke et al. (2007) used differential equation models to test demographic inertia and the effectiveness of five intervention programs on promoting gender parity among faculty at a large research extensive university, which they titled Mountain University. Their analysis demonstrated the strong control that demographic inertia has on gender integration. The analysis also demonstrated that if recent demographic patterns at Mountain University persist without administrative intervention, it will take over 40 years for women to comprise 34% of all campus faculty members. To minimize demographic inertia, they suggested that the university focus on hiring, promoting, and retaining men and women in equal numbers.

Model and Objectives

We use a matrix population modeling approach to model demographic inertia based on actual university data. Our study builds upon the modeling efforts of Hargens and Long (2002) and Marschke et al. (2007). Matrix population models offer a rigorous, straightforward framework for projecting population growth and change (Caswell, 2001; Keyfitz and Caswell, 2005). Further, perturbation analyses of matrix models reveals the influence that individual model parameters have on population growth, and the potential effects that varying vital parameters has on population change (Caswell, 2001). While Marschke et al. (2007) varied model parameters to reflect hypothetical university intervention strategies, our approach relies on model and perturbation analysis results to inform us of both the actual and potential effectiveness of different institutional intervention strategies, including those implemented by the NSF ADVANCE program at SSU.

Our models build upon earlier demographic inertia models in a number of ways. First, our models are rank classified and not age classified as we feel that rank more accurately represents one's status among faculty than age. Second, in contrast to previous studies, our models assume a growing, rather than static, faculty population size. Despite recent increases in the number of part-time and non-tenure-track faculty members, the total number of full time faculty positions in the U.S. has shown consistent growth over the past century. In addition, given the anticipated retirement of baby boomers[iv], the number of full-time faculty new hires is expected to increase (Lehming, 1998). Finally, our models include recruitment of new faculty at the associate and full professor ranks. Although the majority of new hires enter as junior faculty, recruitment of faculty at senior ranks is not uncommon. Previous studies have not included recruitment at ranks other than assistant professor.

Our study concerns demographic inertia at a single institution. While an investigation such as ours could justifiably include data from multiple institutions, we believe that focusing on a single institution, specifically SSU, is warranted for a number of reasons. First, according to the American Association of University Professor's 2006 report on faculty gender equity indicators (West and Curtis 2006), among all national doctoral granting institutions, SSU ranks just slightly below average in the proportion of women comprising its full-time tenure-track faculty. Inferences based on this study's results, therefore, are potentially relevant to similarly ranked academic institutions. In addition, previous studies of demographic inertia including Feinberg (1984) and Marschke et al. (2007) focused on single institutions. Our synonymous use of data from a single institution allows for between study comparisons with these previous studies. Finally, given the NSF ADVANCE program's ambitious objectives, and the general paucity of published studies investigating its efficacy (but see Plummer, 2006), studies such as ours are needed.

The objectives of our study are to assess: (1) Do the model vital parameters between men and women differ, and what is the impact of ADVANCE on women and men's recruitment, promotion, retention, and attrition rates?; (2) Does demographic inertia behave differently among the four scenarios?; (3) How long will it take for the sex ratios of women to men full time tenured/tenure-track faculty to reach 30%, the proportion of doctoral degrees earned by women nationally in the S&E disciplines at SSU, and 50% at the ranks of assistant, associate and full professor in the four scenarios?; and, (4) What vital parameters do the models and perturbation analysis indicate should be the focus of future institutional level interventions?

METHOD

Data and Transition Tables

The career activity of Snow State University's science and engineering tenured/tenure-track faculty employed during all or part of 1998-2007 was used for estimating the models' vital parameters. Snow State University is a public, high research activity (Carnegie Classification) university located in the western U.S. with a current student body enrollment of approximately 23,000 undergraduate and graduate students. The nineteen science and engineering departments at Snow State University are organized into four colleges and cover the disciplines of mathematics and statistics; life sciences; agricultural sciences; natural resources; applied economics; and, engineering. Psychology and most of the social sciences are not included among SSU's science and engineering fields. Only tenured/tenure-track faculty were included in this analysis, and the employment cycle for SSU tenured/tenure-track faculty is shown in Figure 2 (see the APPENDIX for an explanation of the U.S. and Canadian tenure-track process). During the fall semester of 2007, SSU employed 319 tenured/tenure track faculty in these four colleges, 52 women and 267 men, in three faculty ranks: 149 full professors, 89 associate professors and 81 assistant professors. The database used in our study spans 10 years and includes five years of data representing faculty demography prior to SSU's participation in the ADVANCE program and five years of data covering the period of SSU's ADVANCE participation.

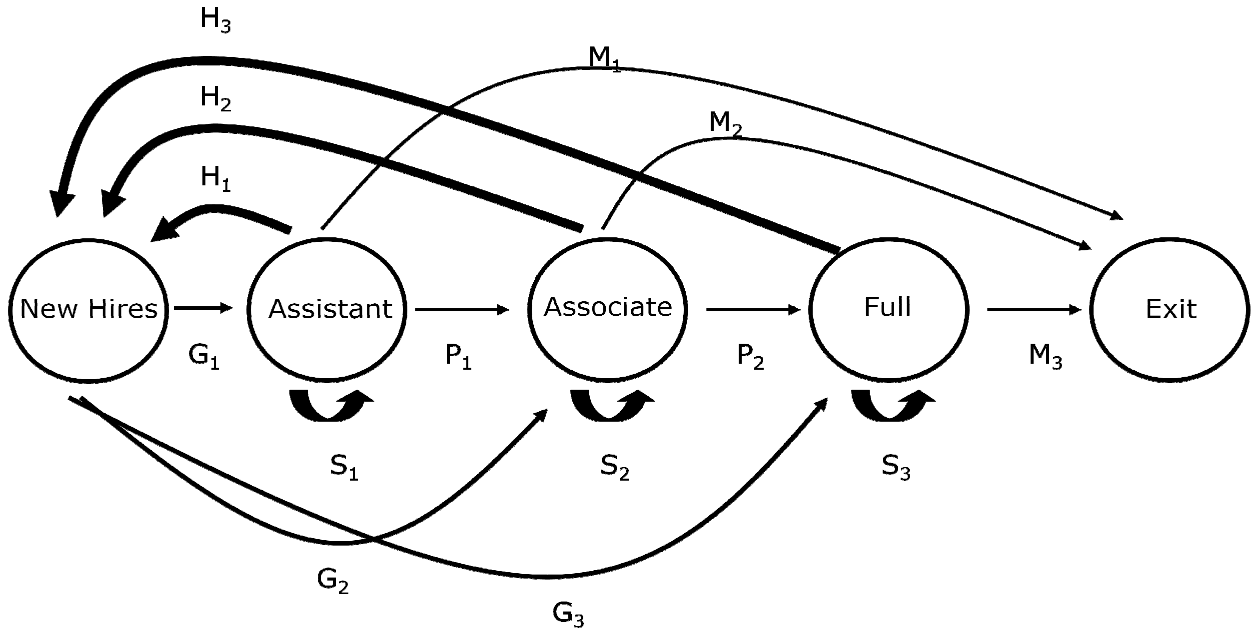


Figure 2. The employment cycle for tenured/tenure-track science and engineering faculty at Snow State University. The circles indicate faculty ranks, and the arrows represent feasible transitions: Distribution probabilities of new hires to faculty ranks (G_i), probability of remaining in rank (S_i), promotion probabilities (P_i), new hire recruitment probabilities (H_i), and attrition probabilities (M_i).The new hire stage is a temporary holding stage where new hires are placed at time t before their distribution into faculty positions at time $t+1$.

Recruitment, promotion, retirement and non-retirement attrition events occurring during this 10 year period were recorded (see Table 1 for new hire and attrition counts).

Men and women were treated as separate populations and were modeled separately. We did not distinguish between exit types in our models, and retirement and non-retirement attrition events were grouped together into a single exit category. Individuals were counted in the exit stage the year following his or her last year of tenure/tenure-track faculty employment at SSU. The demographic data was converted into transition table format, M_{it}, where i = male, female and $t = 1998{,}1999, \ldots ,2007$. From these transition tables, model vital parameters were estimated for constructing separate annual projection/ transition matrices for men and women. From the annual projection/transition matrices, three different sets of mean matrices were formulated representing three of the four scenarios: (1) 'all years', a mean matrix containing vital parameters averaged from all years of data (1998-2007); (2) 'pre-ADVANCE', a mean matrix containing parameters averaged from the pre-ADVANCE program years (1998-2002); and, (3) 'ADVANCE', a mean matrix containing parameters averaged from the ADVANCE program years (2003-2007).

The analysis was conducted in two stages. First, the projection matrices ($\mathbf{A}$, Equation 2) were projected for thirty time steps. The projection matrices were stage classified and included the three employment stages: assistant professor, associate professor, and full professor. Next, transition matrices were formulated by amending the projection matrices to include the exit stages, M_i. The transition matrices were also projected for 30 time steps and their output was used to estimate the average number of years spent by an individual in rank.

Table 1: New hire and attrition counts for male and female S&E faculty at Snow State University from 1998-2007. The 2007 attrition data was not yet available at the time of model formulation.

		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
New Hires											
Men	Assistant	8	12	10	10	15	8	13	13	11	8
	Associate	2	1	3	4	0	0	2	3	1	3
	Full	2	3	2	0	1	2	0	1	1	2
	Total	12	16	15	14	16	10	15	17	13	13
Women	Assistant	4	4	3	1	5	2	9	3	4	3
	Associate	0	0	0	0	1	0	0	0	0	0
	Full	0	0	0	0	0	0	0	0	0	1
	Total	4	4	3	1	6	2	9	3	4	4
Attrition											
Men	Assistant	4	5	1	3	3	2	8	7	4	NA
	Associate	4	3	4	3	2	5	2	3	7	NA
	Full	14	7	4	6	8	5	6	8	11	NA
	Total	22	15	9	12	13	12	16	18	18	NA
Women	Assistant	2	0	2	1	3	0	1	1	2	NA
	Associate	0	0	1	1	0	1	1	0	1	NA
	Full	1	0	0	0	1	1	1	2	1	NA
	Total	3	0	3	2	4	2	3	3	4	NA

The Deterministic Model

A total of six stage classified mean projection/transition matrix models, three male and three female specific models, were formulated as described above: ‘all years’ (1998-2007), pre-ADVANCE (1998-2002) and ADVANCE (2003-2007). The models took the form:

$$\mathbf{n}(t+1) = \mathbf{A}\mathbf{n}(t). \tag{1}$$

where $\mathbf{n}$ is a vector of population sizes by rank and $\mathbf{A}$ is a deterministic projection matrix. An annual time step, t, was used for projecting the models.
The projection matrix, $\mathbf{A}$, contains the population vital parameters described in Figure 2 except for the attrition parameters, M_i, which were only included in the transition matrices.

$$\mathbf{A}_{it} = \begin{pmatrix} 0 & H_1 & H_2 & H_3 \\ G_1 & S_1 & 0 & 0 \\ G_2 & P_1 & S_2 & 0 \\ G_3 & 0 & P_2 & S_3 \end{pmatrix}$$

$$i = \text{men, women};\ t = \text{“All years”, pre} - \text{ADVANCE, ADVANCE} \tag{2}$$

The H_i entries in the projection/transition matrices are the recruitment probabilities or the probability of adding new faculty members, the S_i entries are the retention probabilities or the probability of remaining in the same faculty rank, the P_i entries are the promotion probabilities or the probability of getting promoted from assistant to associate professor or associate to full professor, and the G_i entries are the new hire distribution probabilities or the probability of placing a new hire in the rank of assistant, associate or full professor. The new hire stage is a temporary place holder position where faculty hired at the end of an academic year according to H_i are dispersed into one of three faculty ranks at the beginning of the next academic year according to G_i. For a description of the parameter estimation approach we took, please refer to the appendix.

The transition matrices, $\mathbf{P}_{it}$, contain the M_i parameters which represent the probability of exiting SSU at the assistant, associate and full professor ranks.

$$\mathbf{P}_{it} = \begin{pmatrix} 0 & H_1 & H_2 & H_3 & 0 \\ G_1 & S_1 & 0 & 0 & 0 \\ G_2 & P_1 & S_2 & 0 & 0 \\ G_3 & 0 & P_2 & S_3 & 0 \\ 0 & M_1 & M_2 & M_3 & 1 \end{pmatrix}$$

$$i = \text{men, women};\ t = \text{“All years”, pre} - \text{ADVANCE, ADVANCE} \tag{3}$$

Population Projection
From the projection matrix output, we calculated the women to men sex ratio over thirty years to determine the length of time required for the representation of women assistant, associate, and full professors to match their availability in the job market pool (30%) and exact (50/50) parity with men. Our estimate of women's availability in the S&E job market pool was based on the percentage of total S&E doctoral degrees granted to women according to the most recent set of national statistics (NSF, 2007, Table F-12). The National Science Foundation reports the percentage of doctoral degrees earned by women broken down by discipline; we only included the fields considered S&E at SSU and found the average percent of doctoral degrees earned by women across these disciplines.

The final scenario investigated the consequence of reverting back to pre-ADVANCE vital parameters following an initial projection using the ADVANCE model. In this scenario, referred to as the 'mixed model' scenario, the male and female populations were first projected for 5 years using the ADVANCE model. The population vector at the end of five years was then projected for an additional 25 years using the pre-ADVANCE model and we calculated the change in the ratios of women/men by rank over 30 years.

Population Parameters

Our stage-classified matrix model presented in Equation 1 can take the form of the characteristic equation:

$$\det(\mathbf{A} - \lambda\mathbf{I}) = 0. \tag{4}$$

(Caswell, 2001), where $\mathbf{I}$ is the 4x4 identity matrix. The characteristic equation is of interest because its solution provides the population growth rate, λ_1, as well as the stable population structure, $\mathbf{w}_i$ (see Caswell, 2001 for further details). The average time spent in rank at SSU is found by treating the employment cycle of an individual at SSU in the transition matrices (Equation 3) as an absorbing Markov chain (Caswell, 2001, chapter 5).

Statistical Inference and Sensitivity Analysis

Before a comparison of the different models' vital and population parameters can be conducted, we must quantify the model uncertainty. Confidence intervals and standard errors were estimated via bootstrap resampling (Efron and Tibshirani, 1993; see the APPENDIX for details on the bootstrap approach used).

Perturbation analysis was conducted to investigate the individual-level influence of the vital parameters on the population growth rates in the six projection matrices. Specifically, we examined the sensitivity and elasticity of λ_1 to the vital parameters: recruitment, retention, and promotion probabilities. Sensitivity matrices:

$$\mathbf{S} = \left(\frac{\partial \lambda}{\partial a_{ij}}\right). \tag{5}$$

(Caswell, 2001, pg. 210) were calculated where each entry in the matrix described the absolute response of population growth rate to a change in matrix entry a_{ij} keeping all other vital parameters constant.

RESULTS

In all three models, promotion probabilities (P_i) and the distribution of new hires into associate and full ranks (G_2 and G_3) are generally higher for men than women, with the exception that female associate professors experienced a higher promotion probability during ADVANCE than male associate professors ($P_3 = 0.084$ vs. 0.072, Table 2). Under the ADVANCE scenario, women experience higher promotion probabilities than in either the pre-ADVANCE or 'all years' scenarios. The opposite trend is observed in the men's projection matrices where men have higher promotion probabilities in the pre-ADVANCE than ADVANCE or 'all years' projection matrices. In all three models, men and women assistant professors experience high recruitment probabilities (H_1), while men experience low recruitment probabilities at the ranks of associate and full professor (H_2 and H_3); women experience almost negligible probabilities of recruitment at ranks other than assistant professor. Both men and women experience relatively high retention probabilities (S_i) at all faculty ranks.

Table 2. The vital parameters used in the mean transition matrices*,* P_{it}*,* i *= men, women and* t *= 'all years', pre-ADVANCE and ADVANCE.*

	Men			Women		
Parameter	all years	pre-ADVANCE	ADVANCE	all years	pre-ADVANCE	ADVANCE
G_1	0.779	0.747	0.819	0.981	0.967	1
G_2	0.122	0.143	0.097	0.019	0.033	0
G_3	0.098	0.110	0.084	0	0	0
H_1	0.181	0.180	0.183	0.241	0.243	0.239
H_2	0.029	0.033	0.024	0.002	0	0.005
H_3	0.022	0.026	0.017	0	0	0
M_1	0.082	0.073	0.092	0.072	0.097	0.042
M_2	0.041	0.030	0.054	0.025	0.024	0.028
M_3	0.045	0.044	0.047	0.078	0.029	0.14
P_1	0.102	0.112	0.088	0.075	0.071	0.079
P_2	0.077	0.080	0.072	0.044	0.011	0.084
S_1	0.817	0.814	0.819	0.853	0.832	0.879
S_2	0.882	0.890	0.874	0.931	0.965	0.888
S_3	0.955	0.956	0.953	0.922	0.971	0.86

Note. Mean projection matrices, $\mathbf{A}_{it}$, do not include the attrition vital parameters, M_1, $M_2$and M_3.

The pre-ADVANCE transition matrices (P_{ij}; Equation 3), show that female assistant professors have higher attrition (M_1) and lower promotion probabilities than male assistant professors, while men experience higher attrition probabilities at the associate and full professor ranks than their female colleagues (M_2 and M_3). In the ADVANCE transition matrix, female assistant faculty show a decrease in attrition (M_1) and women full professors show an increase in attrition (M_3) compared to their pre-ADVANCE attrition probabilities. However, it should be noted that during ADVANCE, retirement was the reason for all but one woman full professor's attrition. In the ADVANCE transition matrix, attrition probabilities for male assistant, associate and full professors increased from their pre-ADVANCE matrix values.

During 1998-2007, the total size of the male faculty population grew slightly from 266 in 1998 to 271 in 2007. The total population of women faculty showed consistent growth during the same period from 36 in 1998 to 51 by 2007 (Figure 1).

All three mean projection matrix models predict higher population growth rates for the women's population than men's (Figure 3). The largest and smallest differences in magnitude between men and women's estimated population growth rates are observed in the ADVANCE and pre-ADVANCE models respectively.

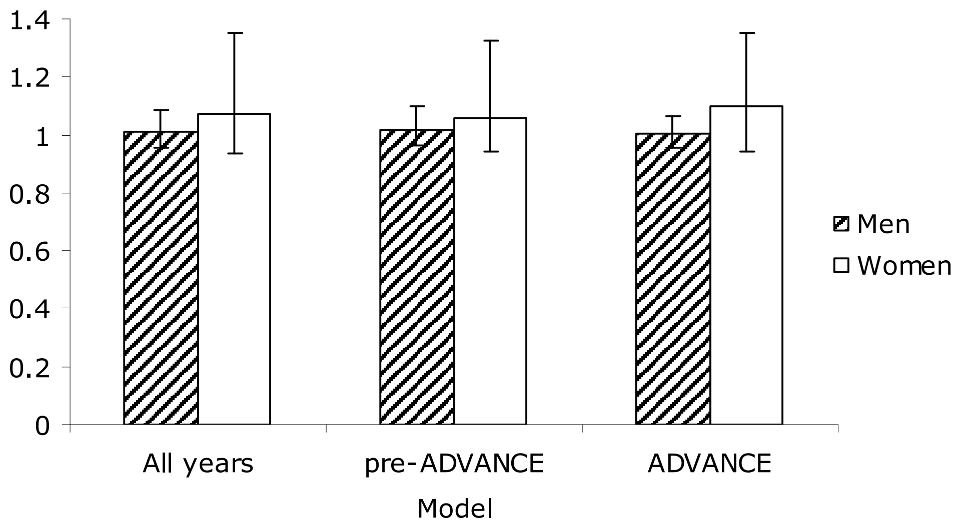


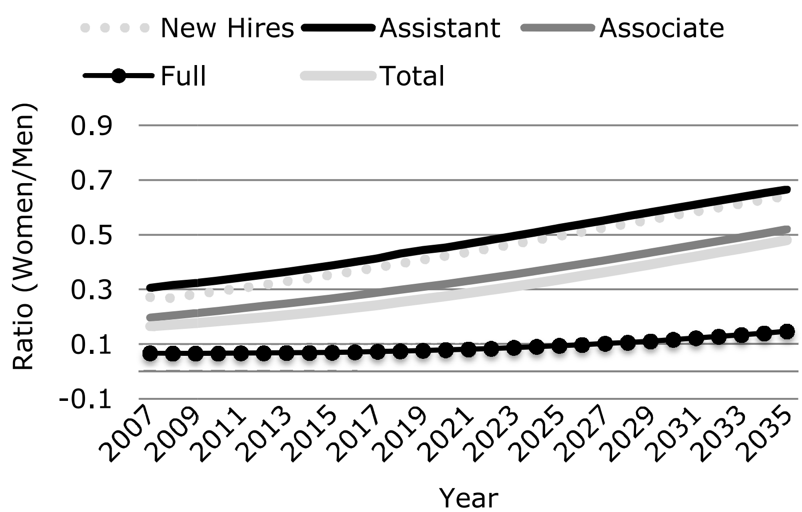
Figure 3. Estimated population growth rate, λ_1, and its bootstrap 95% confidence intervals in three model scenarios. Black and white diagonal stripped bars = male-specific models and solid white bars = female-specific models.

The growth expected in the number of new women faculty and hence the total faculty population will benefit women's overall representation as indicated by increases in the ratio of women/men (Figure 4a, b and c). The rate of change in the ratio of women/men varies by rank and model scenario. The 'all years' model projects lags of 5, 1, and 13 years before the ratio of female to male new hire, assistant, and associate faculty matches their availability in the job pool however, in the 'all years' model the ratio of female to male full professors is not projected to reach 30% within 30 years. The 'all years' model projects lags of 19, 17 and 28 years before parity is achieved at the new hire, assistant, and associate ranks respectively. Equal representation of women and men full professors is not projected in the 'all years' model over the next 30 years.

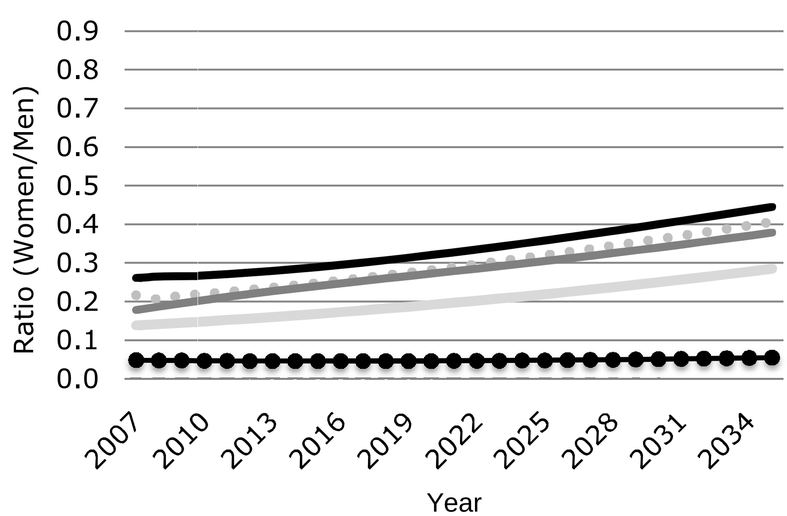
The most conservative changes in women's representation are projected by the pre-ADVANCE models where lags of 17, 11, and 19 years are expected before the proportion of female new hires, assistant and associate professors matches their availability in the employment pool. The pre-ADVANCE projection models do not project the ratio of female full professors to reach 30% within 30 years. The healthiest improvements in women's representation are projected by the ADVANCE model. In this scenario, the ratios of women/men new hires, assistant, and associate professors are projected to match job market availability within 3, 1 and 11 years respectively. Even in the ADVANCE scenario, the ratio of full female/male professors will not reach 30% within 30 years. According to the ADVANCE model, parity between men and women new hires, assistant professors, and associate professors will be achieved in 13, 13 and 22 years respectively.

In the 'mixed model' scenario, the proportion of women assistant, associate and total professors is projected to reach 30% in 1, 12 and 19 years respectively (Figure 4d). The 'mixed model' does not project the representation of women full professors to reach 30% in 30 years, and, in the 'mixed model', exact parity between men and women is achieved within 30 years at the assistant professor rank only.

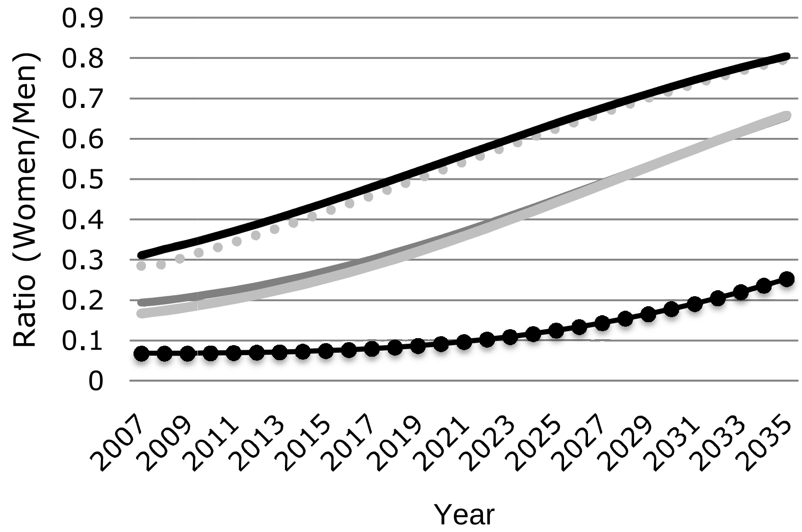
(a. 'All years' scenario)



(b. pre-ADVANCE scenario)



(c. ADVANCE scenario)



(d. 'Mixed-model' scenario)

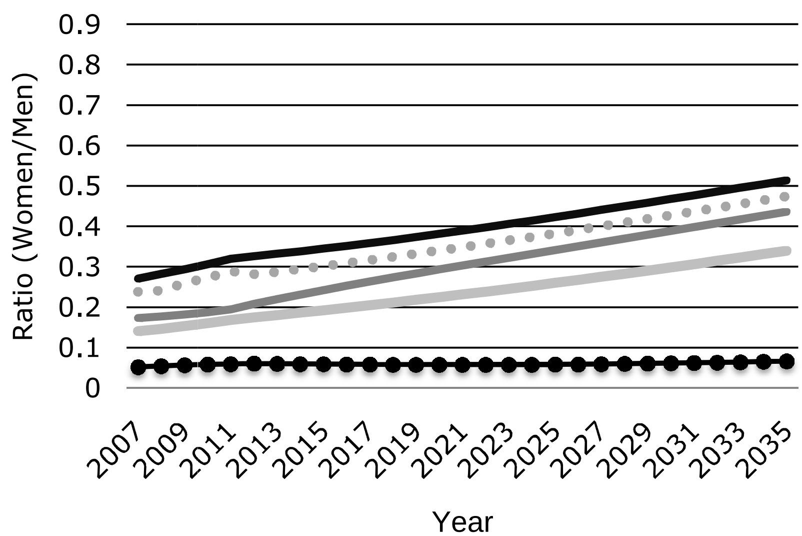


Figure 4. Projected ratios of women/men S&E faculty over 30 years: Light, gray circles = new hires, solid black line= assistant professors, solid dark gray line = associate professors, black line with circle markers = full professors and dashed medium gray line = total professors for the 'all years' (a), pre-ADVANCE (b), ADVANCE (c) and 'mixed model' scenarios (d).

The faculty population structure that is currently established is expected to persist into the foreseeable future (Figure 5). Although women's population is projected to grow, little change is expected in the distribution of women's population across faculty ranks. Improvements to women's representation are projected principally at the rank of assistant professor accompanied by smaller improvements at the ranks of associate and full professor. Men's projected slow population growth will enable the persistence of men's entrenched population structure.

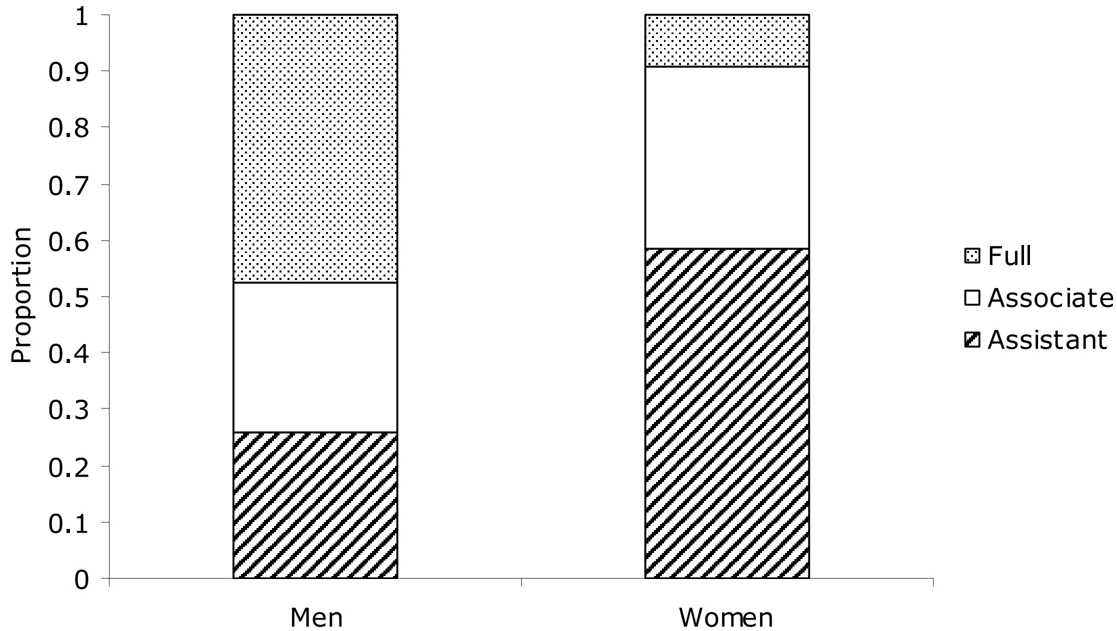


Figure 5. Stable stage distribution of men and women faculty as projected by the 'all years' mean projection matrix. Black and white diagonal stripes = assistant professors, white = associate professors and black dots = full professors. Although not displayed, the pre-ADVANCE and ADVANCE models project equivalent stable stage distributions.

The perturbation analysis indicates that women and men's population growth rates respond differently to changes in the model's vital parameters (Figure 6). Women's population growth rate responds strongest to changes in the retention probabilities of assistant professors and to the recruitment of assistant and associate professors. In contrast, men's population growth rate is more sensitive to changes in the promotion probabilities of assistant and associate professors, and to changes in retention probabilities of assistant and full professors. Men's population growth rate is sensitive to recruitment of faculty at all ranks and especially at the rank of full professor.

In all three models, women spend more time on average in the ranks of assistant and associate professor than their male colleagues (Figure 7a, b and c). The 'all years' model estimates that women spend, on average, 6.8, 7.3 and 4.75 years as assistant, associate and full professors, respectively. Surprisingly, women's estimated time in the assistant rank is 8.25 in the ADVANCE model but only 6 years in the pre-ADVANCE model. The estimated amount of time men spend in the assistant professor rank varies only slightly among the 'all years', pre-ADVANCE and ADVANCE models.

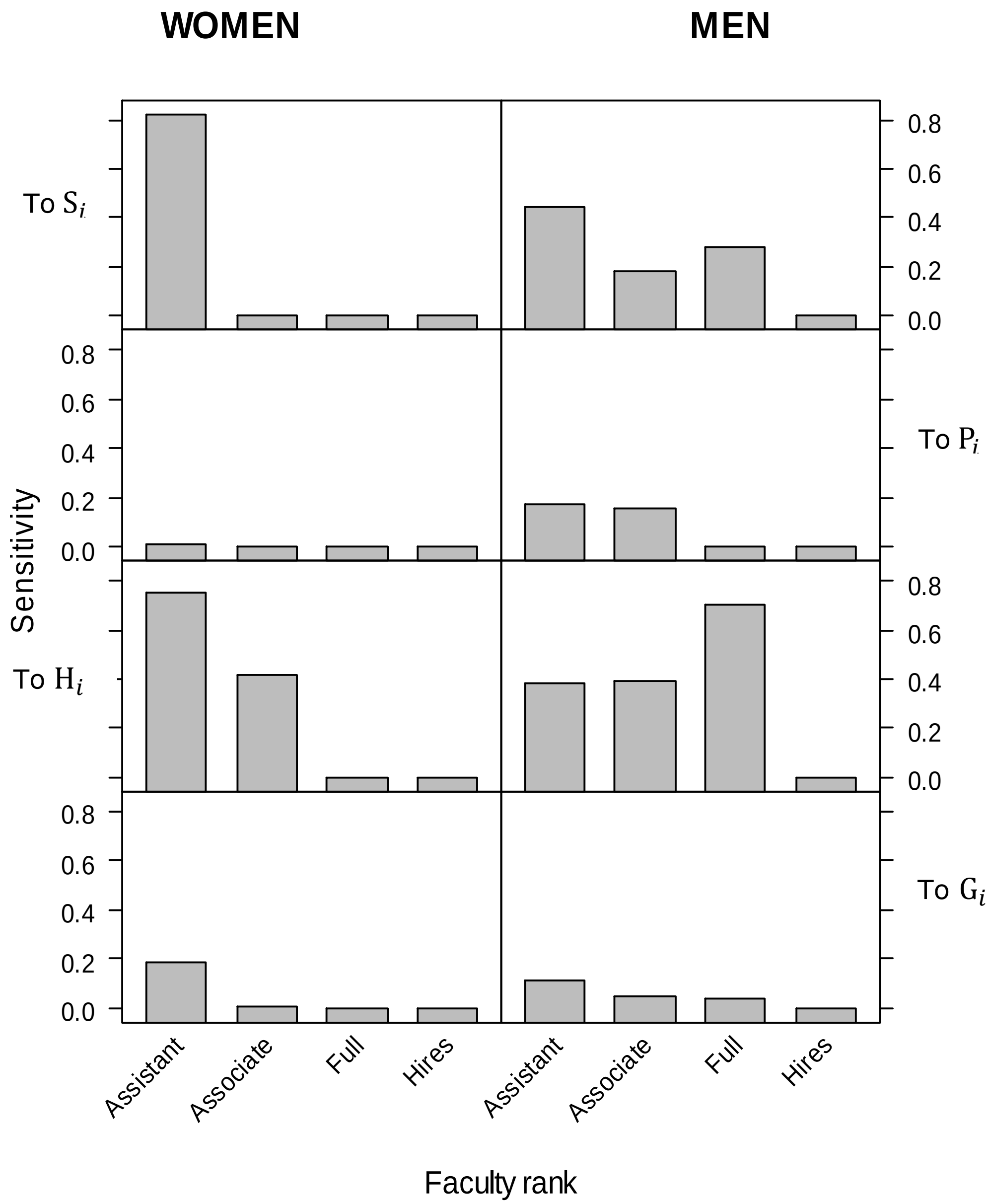


Figure 6. Sensitivity of the 'all years' mean projection matrix's population growth, λ_1, to changes in G_i, H_i, S_i, and P_i.

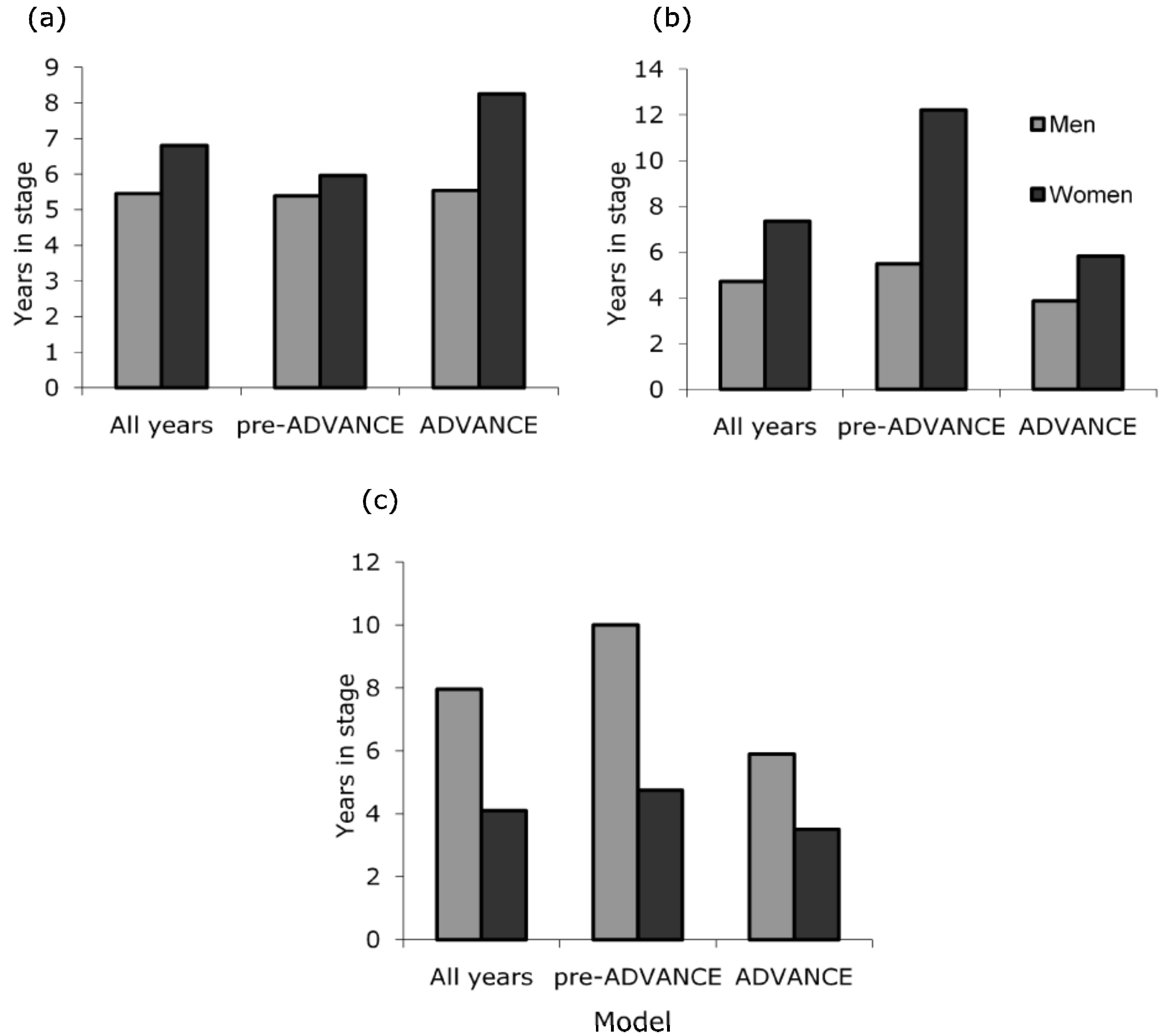


Figure 7. Mean stage durations for male (dark grey) and female (black) faculty as estimated by the 'all years', pre-ADVANCE and ADVANCE projection matrices for assistant (a), associate (b), and full professors (c).

DISCUSSION

Our models indicate that institutional intervention was effective at enhancing women faculty's representation among S&E faculty at SSU. Its long-term efficacy, however, may be challenged by demographic inertia. Demographic inertia controls the pace at which gender equality is achieved through its maintenance of the entrenched faculty population structure. During ADVANCE, many of the female specific vital parameters improved, suggesting that short term intervention strategies such as ADVANCE may be effective for alleviating demographic inertia in a university setting. The total alleviation of demographic inertia at SSU, however, will take decades, as indicated in previous studies (e.g. Hargens and Long 2001; Marschke et al. 2007), and will require that women's improved vital parameters be sustained over the long-term.

Previous studies and reports (e.g. Handelsman et al., 2005; Marschke et al., 2007, NAS, 2006) have suggested ways to improve women's recruitment, retention, and promotion probabilities in a university setting. Here, we provide recommendations aimed specifically at mitigating demographic inertia to improve women's representation among university faculty:

1. Diversify faculty hiring practices by increasing recruitment of women associate and full faculty.
2. Decrease time women spend as assistant and associate professors by increasing their promotion probabilities.
3. Increase retention probabilities of women full professors.
4. Maintain high retention probabilities of women junior faculty.
5. Encourage continued growth in the total number of full time tenured/tenure-track faculty.
6. Following initial improvements in women faculty's vital parameters, maintain beneficial vital parameters over the long term.

Inference derived from the model and sensitivity analyses provides the support for our recommendations as we will discuss below.

The small sample size of women used in this study has direct implications on our findings and on the precision of the model's vital parameters. From 1998-2007, the population size of S&E faculty women at SSU was 1/5 the population size of men, and parameter estimation was based on a small number of recruitment, promotion and attrition events. Therefore, small changes in the number of new hires, promotions or attrition events had large impacts on the vital parameter estimates. Conversely, some of women's vital parameters were zero because of the small number of women in this study and the absence of particular events during the study period. For example, women associate professors were not recruited to SSU during the pre-ADVANCE years and hence in the pre-ADVANCE model, the probability of recruiting a woman associate professor was zero. In reality it is unlikely that there was zero probability of recruiting a woman to the rank of associate professor in the years prior to ADVANCE however, the true probability of recruiting a woman associate professor remains unknown. Also, due to sample size differences, women's vital and population parameter standard errors and confidence intervals were larger than men's. Finally, caution must be used in interpreting output from models projected over long time frames as model precision decreases with increasing projection time; model uncertainty is minimized at the onset of projection. Despite the greater uncertainty associated with women's parameter estimates, we believe that the gender vital parameter and population growth rate comparisons are meaningful.

Recommendations

1. *Diversify faculty hiring practices by increasing recruitment of women associate and full faculty*

Many years of imbalanced hiring and promotion practices at SSU are responsible for current differences in men and women faculty's population structures. Women are hired primarily at the rank of assistant professor while men are recruited at all three faculty ranks. From 1998-2007, growth in the number of associate and full female professors occurred almost exclusively through promotion. In contrast, growth in the number of associate and full male professors occurred through both recruitment and promotion. Currently, men are more evenly distributed among the three faculty ranks than women as a result of different recruitment and promotion practices.

According to our models, women's overall representation is expected to improve under all four scenarios. Despite this, women's population structure will likely continue to exemplify a pyramid shape with the majority of women employed in the rank of assistant professor and fewer women employed in the rank of full professor. In contrast, little change in the shape of men's population structure is expected. Aggressive efforts to recruit women to all three faculty ranks, and especially at the associate and full ranks, will be required to hasten the rate at which men and women's population structures are aligned. Previous studies (Hargens and Long, 2002; Marschke, et al. 2007) overlooked the potential impact that diversified recruitment may have on minimizing demographic inertia.

2. *Decrease time women spend as assistant and associate professors by increasing their promotion probabilities*

Our study reveals differences between men and women faculty in their average time spent in rank. Women labor longer on average as assistant and associate professors at SSU than men, a trend that has been identified at a number of prominent U.S. academic institutions including the University of California at Berkley, Duke University and MIT (NAS, 2006). Hypotheses posited to explain women's slow promotion progression include higher productivity expectations for women than men (Long, Allison, and McGinnis, 1993), and the possibility that women delay their application for promotion because they fear being unprepared (NAS, 2006). In recent years, the productivity gap between men and women, which has been used to explain women's slow progress through the academic pipeline, has narrowed or disappeared completely when confounding factors such as personal characteristics, academic rank and marital status are controlled (Xie and Shauman, 1998).

Women's average duration as associate professor was successfully reduced during ADVANCE due primarily to improvements in the promotion probabilities of female associate faculty. These favorable promotion probabilities must be maintained if equivalency is hoped to be achieved between men and women in their time spent as associate professors.

The attrition pattern of female full professors from 1998-2007 indicates that the majority of full female professors at SSU are nearing the end of their professional careers. Female full professor's average time spent in rank is considerably shorter than their male colleagues', therefore we infer that the few women promoted to full professor in this study received their promotions at the climax of their careers and did not serve as full professors for long.

Although women labor as full professors for considerably shorter periods than their male colleagues, improved associate to full promotion probabilities during ADVANCE helped to increase the time women spend in the rank of full professor. Based on the models, we expect that further improvements in women associate professors' promotion probabilities will enable younger women to enter the rank earlier in their careers, providing them with the opportunity to serve as full professors for longer durations than previously observed at SSU. As university leadership positions are typically filled by senior faculty, the increased availability of younger women in the rank of full professor should lead to their increased participation in university leadership appointments from which they are traditionally absent (NAS, 2006).

Surprisingly, the average time women spend as assistant professors increased during ADVANCE, and we speculate that women's increased use of tenure-clock extensions during ADVANCE may be responsible for this trend. Tenure-clock extensions are available to both women and men however their use is rarely invoked by male assistant professors. Until men's use of tenure-clock extensions is equivalent to women's, the average time women spend as assistant professors is likely to remain markedly longer than men's.

3. *Increase retention probabilities of women full professors*

Female full professor's attrition probabilities were higher during ADVANCE than prior to ADVANCE. During the ADVANCE years, at least one woman full professor left SSU annually. Although all but one of these attrition events was due to retirement, the annual loss of one female full professor limits the growth potential of the rank. High attrition and negligible recruitment of women at the rank of full professor will produce sluggish growth in the rank. Our models also indicated that promotion probabilities of women associate professors were not large enough to overcome the effects of high attrition and negligible recruitment, and therefore little change in the number of women full professors is expected over the next 30 years. A rapid improvement in the representation of female full professors will require the hiring of women at the rank of full professor coupled with high retention of women already in full professor rank. Unfortunately, few women are available at the rank of full professor in the employment pool due to their severe underrepresentation, and high demand. Despite the challenges of recruiting women full professors, our analysis suggests that it is the fastest way to achieve gender equality at the full professor rank.

4. *Maintain high retention probabilities of junior women faculty*

Women's population growth rates are consistently higher than men's population growth rates. The sensitivity analysis suggests that women's higher population growth rate during ADVANCE was due, in large part, to the increased recruitment and retention of female assistant professors. The high recruitment of assistant women professors produced sharp exponential growth in women's overall representation relative to men. Exponential growth occurs in matrix models when the population growth rate is real, positive, and greater than one, and the larger the population growth rate is in magnitude, the sharper the exponential growth.

During ADVANCE, female assistant professor's attrition probability decreased by 50%, and this reduction may be the consequence of programs established at SSU for the purpose of promoting and retaining women faculty. For example, as mentioned earlier, the use of tenure-clock extensions became more common during ADVANCE. Tenure-clock extensions were introduced in an effort to create a supportive work environment for faculty members with young families, with the additional goal of increasing assistant professor's retention probabilities. Although the more wide-spread use of tenure-clock extensions during ADVANCE may have increased the average time women spend as assistant professors, they may also be partly responsible for improvements in female assistant professor's retention probabilities. Therefore, institutions should emphasize recruitment and retention of women junior faculty because high recruitment and retention of women assistant professors will eventually, albeit slowly, lead to improvements in the overall representation of women among S&E university faculty.

5. *Encourage continued growth in the total number of full time tenured/tenure-track faculty*

In all four scenarios, women's representation is expected to improve with time. These improvements depend partly on continuous, positive S&E faculty population growth. Previous studies have examined the pace of change in women's representation given a constant faculty population size. Marschke et al. (2007) showed that, in the absence of continued faculty population growth, it will take over 30 years for women's representation to reach 34%. Our study's more optimistic findings are partly due to our assumption of unbounded population growth. Although the S&E faculty population size at SSU has historically experienced consistent growth, the potential for future growth is unknown and is challenged by current and future economic uncertainty and changes in the availability of tenured/tenure-track faculty positions. Beginning in the early 1990's, because of wide-spread financial challenges, many universities in the U.S. restructured the composition of their departmental faculty by reducing the number of full time tenured/tenure-track faculty and increasing the number of part-time and adjunct faculty (Conley, 2008; Conley and Leslie, 2002; Ehrenberg, 2006). The number of tenured/tenure-track faculty at SSU has not yet undergone wide spread reductions, however, should it restrict or plateau, our models' projections may prove overly optimistic.

6. *Following initial improvement in women faculty's vital parameters, maintain improved recruitment, retention and promotion probabilities over the long term*

The 'mixed model' scenario examined the impact of a short term boost in women's vital parameters on the projected representation of women over the long-term. This modeling scenario was motivated by recent events at the Massachusetts Institute of Technology (MIT) in their efforts to diversify their S&E faculty. MIT's 1996 report, 'A Study on the Status of Women Faculty in Science at MIT' (MIT, 1999) described the situation for women science faculty at MIT at the time and marks the first time a prestigious U.S. research institution recognized and responded to inequalities between men and women faculty. They acknowledged that from 1975 to 1996 growth in the number of women science faculty at MIT had stalled, and in response, they enacted aggressive administrative reforms to promote the recruitment of women junior faculty. The institutional intervention executed by upper MIT administration in the School of Science quickly proved effective at recruiting qualified women scientists for junior faculty positions. However, in 2000, after five years of improvements in women's representation among science faculty, new MIT science administrators relaxed some of the more progressive policies, and once again the number of female science faculty stagnated (Hopkins, 2006). The situation at MIT exposes the vulnerability of achieving lasting improvements in women's representation while begging the question, "What long-term improvements in women's representation are feasible given short-term institutional intervention?" When we addressed this question at Snow State University we found that despite initial gains in women's representation at the ranks of assistant and associate professor during the five years of ADVANCE, following a reversion back to the pre-ADVANCE scenario, the pace of improvement in women's representation slowed down. Over the long run, this scenario projects negligible change in the representation of full female faculty and sluggish improvements in the representation of assistant and associate faculty following initial gains during ADVANCE. Our findings suggest that there is little reason to assume that the phenomenon experienced at MIT is unique to that institution. We show how a similar situation might play out at SSU and demonstrate the long-term maintenance of vital parameters beneficial to women is required to ensure long-term improvements in their representation. We feel that it is vital for institutions to acknowledge the potential limitations of short-term institutional intervention.

Conclusions

This study corroborates results from previous studies by Hargens and Long (2002) and Marschke et al. (2007) that found demographic inertia to be a barrier preventing improvements in women faculty's representation. Our projections are more optimistic than either Hargens and Long (2002) or Marschke et al. (2007) because of our inclusion of continuous faculty population growth. In the Marschke et al. (2007) study, they found that the pace to equality can be accelerated by hiring, promoting and retaining men and women faculty at identical rates.

We also found that overcoming demographic inertia requires improvements to women's vital parameters. However, where previous studies manually manipulated the vital parameters in their models, our matrix population model approach allowed us to pin-point the influence of specific vital parameters on population change, growth and gender representation.

Finally, our models are stage classified, not age classified, which allowed us to investigate changes in the representation of women at specific faculty ranks. This is important since the under-representation of women full professors is especially pronounced. By stage classifying, we were not limited to developing broad suggestions regarding intervention strategies effecting the overall population of female faculty. Instead, we could focus on specific faculty rank level issues and extrapolate the implications that changes to rank level vital parameters will have on woman's overall representation. Such information can be used for formulating both rank specific and overall population level intervention strategies to achieve faculty gender equality.

In conclusion, our study found that demographic inertia limits women's representation at SSU. We examined the effectiveness of ADVANCE at promoting and retaining women scientists and engineers at SSU and posit that intervention strategies such as ADVANCE help overcome demographic inertia. To optimize the rate of change, we argue for both increased recruitment of women at the ranks of associate and full professor, and for continuous growth in the total S&E faculty population. In addition, once favorable recruitment, promotion and retention probabilities are established for women, they must be maintained over the long-run. Although combating demographic inertia will take time, when enacted over the long term, we believe that institutional intervention presents an effective counteraction strategy.

ENDNOTES

[i] A four-year university refers to an institution that grants bachelor's degrees in liberal arts and/or science. A bachelor's degree typically requires four years of instruction to receive.

[ii] The Carnegie Classification of Institutions of Higher Education was first implemented by the Carnegie Foundation in 1970 to classify all accredited, degree-granting U.S. academic institutions based on their function and role (e.g. teaching, research, service etc.). For more information on the Carnegie Classification system, visit http://classifications.carnegiefoundation.org

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[iii] For more information concerning the National Science Foundation's ADVANCE program, participating institutions and project details, visit http://www.nsf.gov/crssprgm/advance/index.jsp.
[iv] The United States Census Bureau defines a "baby boomer" to be someone born during the post-World War II demographic birth boom of 1946-1964.

ACKNOWLEDGEMENTS
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APPENDIX

U.S. and Canada university tenure process

The academic faculty tenure process has been adopted at many colleges and universities in the U.S. and Canada. Academic tenure grants its recipients a lifetime level of protection from job termination without just cause. To receive tenure, an individual is first recruited as an assistant/junior professor to a position that is on a 'tenure-track' and typically remains in this position for 4-7 years. During this period which is commonly referred to as the 'tenure-clock', the assistant professor is expected to demonstrate a high level of success in publishing, teaching and service activities. After 4-7 years, the junior faculty member's performance is reviewed by a group comprised of his or her peers. Given a satisfactory level of performance, the assistant professor is granted tenure and is promoted to the rank of associate professor. Promotion to the rank of full professor does not occur until an associate professor is again able to demonstrate a high level of productivity during the period following tenure promotion to a committee comprised of his or her peers. Non-tenure track academic faculty positions also exist in the U.S. and Canada. These positions in which no guarantee of job protection exists beyond those made in contractual agreements include adjunct, lecturer and research faculty positions.

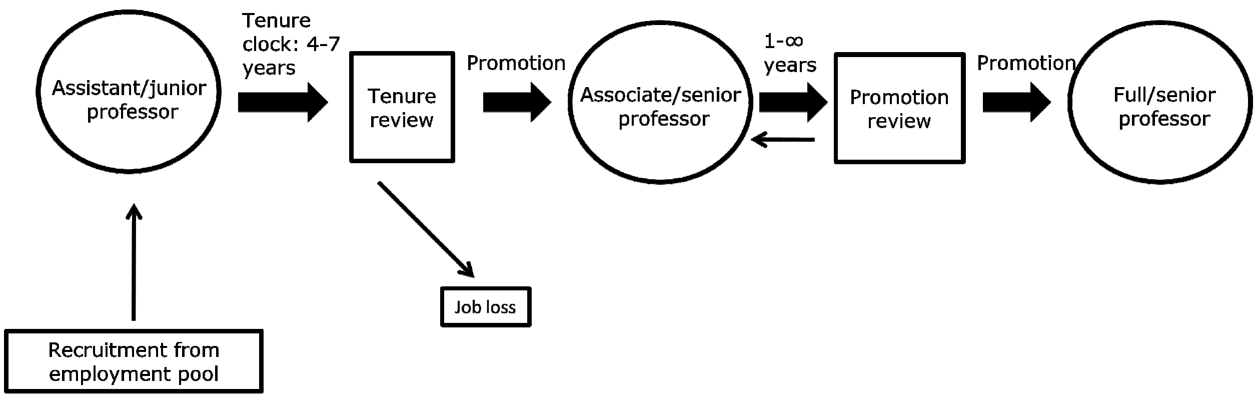

Figure A1. Description of the current faculty tenure-track process in the U.S. and Canada.

Parameter estimation

Retention (S_i), promotion (P_i) and attrition (M_i) probabilities were calculated using maximum likelihood estimation. The annual G_i probabilities were estimated as a function of the proportion of new male and female faculty hired in each faculty rank at the end of an academic year given by:

$$\widehat{\mathrm{G}}_i = \frac{m_j}{\mathrm{N}}. \qquad (6)$$

where m_j is the number of new faculty hired in rank j and N is the total number of new hires for a given year, this value is equivalent to h_i in the new hire (recruitment) rate function described below. This approach assumes that the number of new hires distributed into rank j in year $t+1$ is determined in year t when the $t+1$ new hire cohort is added to the population vector n_t in the new hire 'place holding' stage. At the $t+1$ time step, the new hire population at step t is distributed among the three faculty rank stages according to G_i.

We chose to model recruitment probability, H_i, in a manner akin to 'anonymous' reproduction in ecological population studies (e.g. Caswell, 2001; Ripley and Caswell, 2006). Here, the number of new hires at each time step is a function of the proportional sizes of each faculty stage. For our model,

$$n_1(t+1) = \sum_i \mathrm{H}_i \mathrm{N}_i(t). \qquad (7)$$

so the new hire population, n_1, at time $t+1$ is related to the size of the total faculty population through H_i, the new hire probability, which varies by rank. Since university faculty hiring practices are likely influenced by total faculty population size as well as the number of faculty members in each rank, H_i is related to both the average number of new faculty hires as well as the relative sizes of the faculty population at each rank:

$$H_i = \overline{\mathrm{H}} h_i \text{ where } \sum_i h_i = 1 \text{ and } \overline{\mathrm{H}} = \frac{n_1(t+1)}{\sum_i h_i \mathrm{N_i}(t)}. \qquad (8)$$

In this form, $\overline{\mathrm{H}}$ relates the total number of new hires to both the number of new hires at each rank and the total size of the faculty at each rank at time t. By modeling new hire probability in this fashion, there is no upper limit on faculty population growth. We feel that this assumption is justified given both SSU's continuous student and faculty growth since its founding.

Bootstrap resampling

The bootstrap resampling method was applied to find confidence intervals and standard errors for the population level parameter λ_1, and all lower vital parameters, H_i, S_i, G_i, M_i and P_i. Estimation of the S_i, M_i and P_i vital parameters along with their associated confidence intervals and standard errors required resampling with replacement of the original transition table data with resampling size equal to the faculty population size N_{it} where i = men, women and $t = 1998, 1999, \ldots, 2007$. Bootstrap estimates of new hire recruitment, H_i, and new hire distribution, G_i, probabilities involved the resampling with replacement of their lower level parameters m_j, h_i and $\overline{\mathrm{H}}$ where the resampling size was 10, the number of total data collection years. The resampling scheme was repeated 2000 times for each bootstrap sample and from each bootstrap sample a calculation of the original estimator was made. The empirical distribution of the bootstrap estimates was used for finding the mean and standard errors of each vital parameter, a_{ij}. Population growth rate, λ_1, standard errors were estimated by reshuffling and bootstrapping the original annual projection matrix vital parameters. Since we could not assume that our bootstrap samples come from a normal distribution, 95% confidence intervals were computed as percentiles of the empirical bootstrap distribution.