Title

- Full Title: Decoupling of the minority Ph.D. talent pool and assistant professor hiring in medical school basic science departments in the US
- Short title: Biomedical Faculty Diversity

Authors

Kenneth D. Gibbs, Jr. [1*], Jacob Basson[1], Imam Xierali[2], and David A. Broniatowski[3]

Affiliations

[1]Office of Program Planning, Analysis and Evaluation, National Institute of General Medical Sciences, 45 Center Drive, Bethesda, Maryland, United States of America, 20892

[2]Public Health and Diversity Initiative, Association of American Medical Colleges, 655 K St NW, Washington, DC, United States of America, 20001

[3]Department of Engineering Management and Systems Engineering, The George Washington University, 800 22nd St NW, Washington, District of Columbia, United States of America, 20052

*****To whom correspondence should be addressed.
Kenneth D. Gibbs, Jr., Office of Program Planning, Analysis and Evaluation, National Institute of General Medical Sciences, 45 Center Drive, Bethesda, Maryland, United States of America, 20892. Ph: 301-594-3901. E: kenneth.gibbs@nih.gov

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Abstract

Faculty diversity is a longstanding challenge in the US. However, we lack a quantitative and systemic understanding of how the career transitions into assistant professor positions of Ph.D. scientists from underrepresented minority (URM) and well-represented (WR) racial/ethnic backgrounds compare. Between 1980 and 2013, the number of PhD graduates from URM backgrounds increased by a factor of 9.3, compared with a 2.6-fold increase in the number of PhD graduates from WR groups. However, the number of scientists from URM backgrounds hired as assistant professors in medical school basic science departments was not related to the number of potential candidates ($R2=0.12$, $p>0.07$), whereas there was a strong correlation between these two numbers for scientists from WR backgrounds ($R2=0.48$, $p<0.0001$). We built and validated a conceptual system dynamics model based on these data that explained 79% of the variance in the hiring of assistant professors and posited no hiring discrimination. Simulations show that, given current transition rates of scientists from URM backgrounds to faculty positions, faculty diversity would not increase significantly through the year 2080 even in the context of an exponential growth in the population of PhD graduates from URM backgrounds, or significant increases in the number of faculty positions. Instead, the simulations showed that diversity increased as more postdoctoral candidates from URM backgrounds transitioned onto the market and were hired.

MAIN TEXT

Introduction

Enhancing the diversity of research workforce has been a longstanding priority of scientific funding agencies [1-4]. Scientists from certain underrepresented minority (URM) racial/ethnic backgrounds—specifically, African American/Black, Hispanic/Latin@, American Indian, and Alaska Native—receive 6% of NIH research project grants [5-7] despite having higher representation in the relevant labor market [8], and constituting 32% of the US population [7]. The vast majority of NIH funding—approximately 83%—is awarded to investigators at extramural institutions, many of whom serve as faculty members at academic and research institutions [9]. In particular, MD-granting medical schools and their affiliates (henceforth, medical schools) that belong to the Association of American Medical Colleges (AAMC) receive 67% of NIH extramural funding, and comprised the entire top 20 of NIH-funded institutions in FY2015 [10]. As a result, the goal of diversifying the biomedical investigator pool necessitates diversifying the professoriate generally, and in medical schools specifically.

Faculty members play critical and unique roles within the scientific enterprise, shaping the national research agenda, and cultivating the next generation of scientists and scholars [11, 12]. However, a 2011 report from the National Academies of Sciences said “diversifying faculties is perhaps the least successful of the diversity initiatives” [13]. Student protests on college campuses across the country in the 2015 academic year often centered on the need for more faculty diversity, and highlighted the lack thereof, especially in scientific disciplines [14]. As the nation continues to diversify, broadening participation within the research enterprise and professoriate is believed to be critically important for maintaining an adequate domestic scientific workforce, and ensuring the research enterprise effectively meets the needs of the entire population [7, 13].

This work focuses on three possible reasons for the low number of scientists from URM backgrounds in the professoriate relative to their peers from well-represented (WR) backgrounds

(specifically, White, Asian, and all other non-URM groups) that are amenable to intervention by the scientific community: (i) the size of the URM Ph.D. talent pool, (ii) the number of available faculty positions, and (iii) the transition of the available URM Ph.D. and postdoctoral talent pool onto the faculty job market, and their subsequent hiring. Educational disparities between students from URM and WR backgrounds begin early in life, and accumulate from K-12 through early independence [7, 15]. Thus, it is possible that the cumulative impact of these disparities is the URM Ph.D. and postdoctoral talent pool that is too small to sustain meaningful levels of faculty diversity [16]. If so, intervention strategies would need to focus primarily on building the talent pool.

Additionally, current faculty diversity efforts occur against the backdrop of systemic changes within biomedicine. Following the NIH budget doubling of 1998, there was a significant increase in the number of Ph.Ds. awarded, without commensurate increase in the number of faculty positions [17, 18]. This led to labor market imbalances in which there are significantly more scientists who desire faculty positions than the supply of such positions. Further, it is estimated that fewer than 11% of all life science Ph.Ds. enter faculty positions in any institution type [19]. This raises the possibility that the low number of faculty from URM groups is mainly a function of broader stresses on the faculty job market or changes in the overall labor market for Ph.Ds. [20]. If so, intervention strategies could focus on expanding the number of new faculty positions available, thus creating more opportunities for scientists from all backgrounds.

Beyond the number of faculty positions available, there is evidence that graduate students and postdocs from all backgrounds lose interest in faculty careers in research-intensive universities as their training progresses [21-23]. Moreover, at Ph.D. completion URM men and women report lower levels of interest in faculty positions at research-intensive universities than their WR counterparts, even when controlling for career interests at Ph.D. entry, scholarly productivity, mentorship or research self-efficacy [24]. Thus, part of the lack of representation could be due to disproportionately low application rates by URM Ph.D. graduates and postdocs for these

positions for reasons ranging from values misalignment [25], implicit and explicit biases [26, 27], or perceptions of hypercompetition within academic research that makes the positions particularly unattractive in the current funding climate [28].

Increasing diversity in the applicant pool and equitable evaluation in the hiring process are strategies that promote faculty diversity [29-32]. While systematic data are not available on the demographics of faculty applicants, the chair of a recent faculty search in systems biology at Harvard university reported very low numbers of applications from women and scientists from URM backgrounds [33], lending credence to the notion that faculty applicant pools lack diversity. If this is the case, intervention strategies could focus on enhancing diversity in the applicant pool and ensuring equitable evaluation to increase faculty diversity.

The static nature of faculty diversity, especially in research-intensive environments, suggests that new approaches are necessary for achieving the goal of workforce diversity. In particular, computational modeling approaches such as System Dynamics (SD) have been used to examine the macro-scale impacts of potential policy interventions on the biomedical postdoctoral workforce [34], and new faculty hiring [35]. The goal of this work is to:

1. Provide a systematic and quantitative perspective on changes in the numbers of biomedical Ph.Ds., and assistant professorships in medical school basic science departments by scientists from URM and WR backgrounds between 1980-2014.

2. Build and validate a System Dynamics (SD) model that can capture major trends in the career progression of Ph.D. scientists from URM and WR backgrounds into this segment of the professoriate.

3. Utilize the SD model to test the impact of various intervention strategies to faculty diversity in the short-term (through 2030) and long-term (through 2080). Specifically, we model the impact on faculty diversity at the assistant professor stage by increasing: (i) the

size of the talent pool of Ph.Ds. from URM backgrounds, (ii) the number of assistant professor positions available, or (iii) the rate of transition of Ph.Ds. from URM backgrounds into the applicant pool of assistant professorships.

We focus on medical school basic science departments because of the availability of comprehensive, longitudinal demographic data (in contrast to the broader biomedical workforce, where career outcome data are lacking [36, 37]). Our goal is that these analyses can provide an example for other areas of the scientific community working to address their own diversity challenges.

Results

Trends in Ph.D. Graduation and Assistant Professorship Growth: 1980-2014

Figure 1 shows how the representation of scientists from URM and WR backgrounds in the populations of biomedical Ph.D. graduates, and assistant professors in medical school basic science departments has changed from 1980-2014 (complete data are available in Figure 1-source data 1). These analyses include the annual population (Figure 1Ai, Bi), population growth relative to 1980 (Figure 1Aii, Bii), and the percentages of scientists from each population from each group (Figure 1Aiii, Biii). Data on the populations of Ph.D. graduates and assistant professors in medical school basic science departments were obtained from the National Science Foundation Survey of Earned Doctorates (as compiled by Federation of American Societies for Experimental Biology), and the AAMC Faculty Roster, respectively (please see methods section for more information).

For both URM and WR populations, there was significant growth in the number of Ph.D. graduates, and significant yet slower growth in the population of assistant professors (Figure 1). However, there were differences in the magnitudes of these changes across time. The annual number of URM Ph.D. graduates grew more than nine-fold from 1980-2013 (from n=93 to n=868), whereas the population of URM assistant professors grew 2.6-fold (from n=132 in 1980 to n=341 in 2014; Figures 1Ai-ii). In comparison, for scientists from WR backgrounds

158 growth in assistant professors was more closely aligned with growth in Ph.D. graduates–there
159 was a 2.2-fold increase in the annual number of Ph.D. graduates (from n=3989 in 1980 to
160 n=8789 in 2013; Figures 1Bi-ii), and a 1.7-fold increase for population of assistant professors
161 (n=3246 in 1980 to n=5562 in 2014; Figures 1Bi-ii). While the population of Ph.D. graduates
162 grew more quickly than that of assistant professors for all groups over time, this difference
163 was greater in the URM population than the WR population. That is, there was a statistically
164 significant interaction between URM status and position (β=1.60; p=3.6*10^{-7}; Ph.D. graduates
165 relative to assistant professors), above the impacts URM status (β=0.0602, p=0.005), position
166 alone (β=0.229, p=0.28), or the increases that occurred as the system grew through time
167 (β=0.0895, p=2*10^{-16}).
168
169 Figures 1Aiii and 1Biii show the proportions of URM and WR Ph.D. graduates in the overall
170 pool (solid lines) and among U.S. citizens and permanent residents (dotted lines). Among the
171 pool of U.S. citizens and permanent residents, the proportion of URM Ph.D. graduates grew
172 from 2.5% in 1980 to 13% in 2013, whereas in the overall pool the proportion of URM Ph.D.
173 graduates grew from 2.3% in 1980 to 9% in 2013. In contrast, the percentage of URM
174 assistant professors grew from 3.9% in 1980 to 5.8% in 2014 (Figure 1Aiii).
175
176 Between 2005-2013, a total of 5,842 biomedical Ph.Ds. were awarded to scientists from URM
177 backgrounds; however, there were six *fewer* URM assistant professors in basic science
178 departments in 2014 than in 2005 (n=341 in 2014 versus 347 in 2005). For scientists from
179 WR backgrounds, there was 31% growth in the annual number of Ph.D. graduates (n=8789 in
180 2013 compared to n=6703 in 2005) and 8.6% growth in the population of assistant professors
181 (n=5562 in 2014 compared to n=5122 in 2005). Thus, while the populations of Ph.D.
182 graduates and assistant professors has grown since 1980 for scientists from all backgrounds,
183 the magnitude of the growth of Ph.D. graduates relative to assistant professors differed
184 greatly between URM and WR scientists.

Hiring Patterns of URM & WR Assistant Professors in Basic Science

The patterns of assistant professor hiring differed across populations. For scientists from URM backgrounds, there was a 7.6-fold increase in the size of the potential candidate pool (Figure 2Ai); however, the size of the potential URM candidate pool was not significantly correlated with the number of URM assistant professors hired each year (R^2=0.12, p=0.07; Figure 2Aii). In contrast, for scientists from WR backgrounds there was a 2.2-fold growth in the size of the candidate pool (Figure 2Bi), and the size of the potential candidate pool was significantly correlated with the number of assistant professors hired (R^2=0.48, p=$2.54*10^{-5}$; Figure 2Bii). For scientists from URM backgrounds, the proportion of the candidate pool hired into assistant professor positions decreased from year to year (β=-0.14, p=$9.6*10^{-4}$), while for scientists from WR backgrounds the proportion of the potential candidate pool hired did not change significantly over time (β=0.004, p=0.77). Thus, despite growth in the pools of potential URM and WR candidates, the nature of entry into assistant professor positions differed significantly between the two populations, with little connection between the size of the URM available candidate pool, and the numbers entering into assistant professor positions (full data are available in Figure 2-source data 1 and 2).

System Dynamics Model Development and Calibration

We created a System Dynamics model capturing the flows of Ph.D. graduates from URM and WR backgrounds into assistant professor positions. This abstract model [38] expands on the traditional “pipeline” view of assistant professor hiring (Figure 3A), and is calibrated with the empirical data mentioned above (Figure 3B for intermediate conceptual model, and Figure 3C for final model; the source code provides the model software file). Hiring trends (e.g. growth in pool size, relationship between potential candidate pool and number of assistant professors hired) were largely consistent across the intersections of gender and URM or WR status (Figure 2-figure supplement 1). Thus, for modeling, we focused only on URM/WR status, and not their intersections with gender.

The core assumptions of the model are that the number of assistant professors hired is based on: 1) the number of positions available, and 2) the number of candidates pursuing these positions. Candidates on the market are composed primarily of the subset of postdoctoral scientists pursuing faculty careers in medical school basic science departments (evidence suggests that the rates of transition into postdoctoral training are comparable between URM and WR Ph.D. graduates [39]). Based on market hiring conditions, one-fifth of the candidates on the market drop out of the market annually. That is, if the probability of being hired is relatively high (>20%) all candidates remain on the market that year; otherwise, one-fifth of the available pool drops out of the system. Thus, the average "half-life" of a candidate on the market who is not hired is five years (similar to the period of postdoctoral training for candidates pursuing faculty positions in research-intensive environments [37]).

The model also posits that URM and WR candidates are hired in direct proportion to their representation on the market. That is, the model's output assumes that that racial bias does not impacts hiring. Further, the model assumes that differences in relative strength on the job market across URM status do not impact hiring, because URM Ph.D. graduates have lower interest in faculty careers in research-intensive environments than WR Ph.Ds. graduates even if they have graduated from the same institutions and have the same levels of scholarly productivity [22, 24].

Based on the analyses presented above, the career pathways for scientists from URM and WR backgrounds were represented separately, but were linked based on the total number of assistant professor slots available. Within each population, we assumed a fixed proportion of graduates would pursue and enter faculty positions in research-intensive environments (i.e. "faculty aspire"). The size of the "faculty aspire" pool was based on hiring trends 1980-1997, before the NIH budget doubling and subsequent expansion of the biomedical Ph.D. pool. All other Ph.Ds. would pursue other careers (i.e. "other aspire"). Without intervention, the "faculty

aspire" and "other aspire" populations grow in proportion to the total number of Ph.D. graduates (i.e. "baseline Ph.D. graduate growth rate"). We further assumed that efforts by the scientific community to enhance the diversity of the Ph.D. pool ("URM target growth rate") would increase the pool of URM "other aspire" Ph.Ds., some of whom will then transition to the faculty market. Key variables—including baseline Ph.D. graduate growth rate, URM target growth rate, proportions of URM or WR scientists pursuing faculty positions, and the number of positions available—were derived from national survey data, while the transition rate represented a free parameter for analysis. Full details of the model are provided in the methods section and model equations and parameter values are presented in Appendix-Tables 1 and 2.

We calibrated our model against empirical trends in Ph.D. graduations (R^2=0.99, p<0.0001; Figure 4Ai) and chose the number of available slots to match empirical assistant professor hiring trends (R^2=0.96, p<0.0001; Figure 4Aii). The resulting model output captured 79% of the variance in overall assistant professor hiring (R^2=0.79, p<0.0001; Figure 4Aiii). When disaggregated by URM and WR status, the model captures 51% of the variance in URM hiring (Figure 4Biii; R^2=0.51, p<0.0001), and 78% of the variance in WR assistant professor hiring (R^2=0.78, p<0.0001; Figure 4Ciii). Thus, the model captures major trends in URM and WR hiring rates, over and above what is captured by just examining the size of the talent pool (Figure 2B).

Intervention Strategies to Increasing Assistant Professor Diversity

We used the model to test the impact of three different intervention strategies on the diversity of the assistant professor pool in the short-term (through 2030; Figure 5A), and long-term (through 2080, Figure 5B). These strategies were: (i) increasing the size of the talent pool of Ph.Ds. from URM backgrounds (given the current transition rate), (ii) increasing the number of assistant professor positions available (given the current transition rate), or (iii) increasing the rate of transition of Ph.Ds. from URM backgrounds into the applicant pool of assistant

269 professorships (with subsequent hiring). Unlike a "facsimile model" that would be designed to
270 explicitly predict precise values of outcome metrics (in this case, precise numbers of PhD
271 graduate and assistant professor ratios), our model is an "abstract model," meaning that
272 simulations are intended to examine the qualitative behavior associated with hypothetical policy
273 outcomes, assuming that the system continues to follow its historic behavior [38]. Specifically,
274 from 1980-2013, the number of URM Ph.D. graduates grew at an exponential rate. Therefore, all
275 model runs assumed continued exponential growth of URM Ph.D. graduates (lower growth rates
276 of PhD graduates did not change the qualitative behavior of our model's output).
277
278 In 2014, 5.8% of assistant professors in basic science departments were from URM
279 backgrounds. This level of representation is consistent with a transition rate of 0.25% of
280 "other aspire" URM Ph.Ds. onto the market (Figure 5-source data 1). Given a 0.25% transition
281 rate, short-term simulations (Figure 5A) show that, increasing the size of URM talent pool or the
282 numbers of assistant professor positions available were not sufficient to increase faculty
283 diversity. Specifically, the model predicted that by 2030, 13.8% of biomedical Ph.Ds. would be
284 URMs, but that only 5.9% of assistant professors would be URMs whether the number of
285 assistant professor positions remained the same (Figure 5Ai) or grew by 100 positions annually
286 beginning in 2015 (Figure 5Aii). Put another way, the model predicted that growing the URM
287 Ph.D. pool 53% above current levels (i.e. 13.8% v. the current 9%) would result in a less than 2%
288 increase in the representation of URM assistant professors. Thus, in the presence of a low
289 transition rate, the model predicted that increasing the size of the talent pool or the number of
290 available positions would not lead to a significant increase in the representation of URM assistant
291 professors through 2030.
292
293 Instead, the simulations predicted that increased diversity would result from increased transition
294 of candidates onto the market and their subsequent hiring. Increasing the transition rate to 10%
295 increased URM representation in the assistant professor pool to between 12.4-12.5% in 2030
296 given the same (Figure 5Aiii) or increased number of positions available (Figure 5Aiv). That is,

297 increasing the transition rate, increased URM faculty representation by more than two-fold above
298 what would be predicted from simply increasing the number of URM scientists exponentially
299 through 2030.
300
301 To test if there was a threshold above which the URM Ph.D. talent pool was sufficient to result in
302 increased faculty diversity, we conducted simulations through 2080 (with the caveat that as the
303 time horizons extend unforeseen external factors are likely to arise that could attenuate
304 predictive power). The model predicted if the URM Ph.D. population continued to grow at an
305 exponential rate through 2080, 73% of Ph.Ds. would be URMs (at which point these populations
306 would no longer be underrepresented). However, in the presence of the 0.25% transition rate,
307 the model predicted that in 2080 fewer than 10% of assistant professors would be URMs, no
308 matter the number of positions available (Figures 5Bi and 5Bii). In contrast, the simulations
309 predicted that if the transition rate increased to 10%, URM assistant professor representation
310 would be between 56.5-58.3% given the same (Figure 5Biii) or increased number of positions
311 available (Figure 5Biv). Thus, these model simulations indicate that in the short and long-term,
312 given the low transition rate, the size of the URM talent pool, and number of available positions in
313 the overall market had a minimal impact on faculty diversity (even in the absence of labor market
314 discrimination). Instead, increased faculty diversity resulted from ensuring the growing URM
315 Ph.D. and postdoctoral pools transitioned onto the job market and were hired (the impact of other
316 transition rates are shown in Figure 5-source data 1 and 2). These simulations assume no
317 racial bias in hiring; the presence of discrimination against URM scientists would attenuate any
318 increases in faculty diversity.
319

320 **Discussion**

321 Increasing faculty diversity in academic science departments has been a long-standing
322 challenge and has received renewed attention in recent years [5, 6, 14, 40, 41]. Here, we
323 used data from medical school basic science departments to highlight the impact of potential
324 intervention strategies on the diversity of assistant professors. By illuminating some of the

325 dynamics with respect to faculty diversity in medical schools, we aim to better understand
326 diversity challenges in other segments of the scientific enterprise (including other university
327 settings, industry, and government).
328
329 Although the dearth of URM faculty members in medical schools typically has been framed as a
330 "pipeline" problem—i.e. a lack of available URM talent—our analysis shows that the rate of Ph.D.
331 production for scientists from URM backgrounds has increased significantly over the past 33
332 years, and at a faster rate than that of WR scientists. Despite this progress, there was no
333 statistical linkage between the size of the pool of URM talent, and the number of URM assistant
334 professors hired in basic science departments of medical schools (Figure 2; imputed values
335 assuming 6-year turnover in assistant professor population; findings hold for longer periods of
336 turnover). These findings suggest a decoupling of Ph.D. production and faculty attainment in
337 these environments for scientists from URM backgrounds. In contrast, WR assistant professor
338 hiring numbers were more closely related to the total number of WR Ph.D. graduates. Therefore,
339 broader changes in the biomedical academic labor market—i.e., more trainees than faculty
340 positions, elongated pathways to independence, and declining research funding [18, 28, 42]–are
341 insufficient to explain differences in faculty attainment between postdoctoral scientists from URM
342 and WR backgrounds.
343
344 Obtaining an assistant professorship position requires, at a minimum: (i) a position to be
345 available; (ii) a candidate to be interested in and apply for the position; and (iii) the applicant
346 to be favorably evaluated, offered the position and ultimately accept the position. Systematic
347 data on the applications, evaluations, offers and acceptances for assistant professor
348 candidates in any academic discipline are not typically made available (due to privacy and
349 confidentiality laws), thus we were unable to include this information in the model. However, a
350 recent study has shown that inequality and hierarchy characterize assistant professor hiring
351 across disciplines, and that prestige of doctoral institution plays a major role in who is hired
352 [11]. While 80% of Black and Hispanic science Ph.D. graduates obtain their degrees from

Carnegie classification research universities (high or very high research activity), this number is lower than the proportion of White and Asian Ph.D. graduates from these institutions (90%) [39]. Thus, it is possible that part of the difference can be attributed to the nature of the assistant professor hiring process itself, which emphasizes training background. A more in-depth analysis of this aspect of faculty hiring the biomedical sciences remains a topic for future work.

Beyond institutional pedigree, previous work has shown that interest in assistant professor careers at research-intensive universities such as medical schools declines as training progresses [21, 23], and these declines are larger for Ph.Ds. and postdocs from URM backgrounds relative to their WR counterparts [22, 24]. Importantly, differences in interest in these assistant professor positions between URM and WR scientists remained when controlling for first-author publication rate, advisor relationships, Ph.D. training institution, research self-efficacy, and training experiences [24]. This suggests that there are fundamental aspects of the environment, or nature of faculty work in research-intensive universities that cause otherwise equally qualified URMs to differentially choose other career paths.

Indeed, prominent scientists from URM backgrounds have written about the unique experiences, challenges, and biases (implicit and explicit) faced while conducting science in these environments [26, 27]. Further, there is an emerging body of literature on the distinct values that motivate many scientists from URM backgrounds to pursue scientific careers (e.g. giving back to or serving as a role model in their community of origin), the importance of congruence between personal values and career opportunities to fulfill them for scientists of all backgrounds, and the perception that faculty environments at research-intensive institutions such as medical schools may not enable sufficient engagement with the distinct values of URM scientists [25, 43-46].

The modeling data we presented indicate that given current rates of transition from Ph.D. to assistant professorship among URMs, the percentage of URM assistant professors in basic

381 science departments of U.S. medical schools could remain below 10% in the short- and long-
382 term (i.e. by 2080), even in the context of exponential growth of the URM Ph.D. and postdoctoral
383 pool and the absence of discrimination. Thus, faculty diversity efforts that rely primarily on
384 enhancing rates of Ph.D. graduates (i.e. "filling the pipeline") can only have their desired impact if
385 they are coupled with efforts to get these candidates on the market and hired. This would require
386 making faculty positions and work environments attractive and supportive to these scientists,
387 ensuring the proper types of support (e.g. funding, mentorship and sponsorship) to allow URM
388 postdocs to effectively progress to independence [47], and ensuring institutional faculty
389 recruitment, evaluation, and retention processes support scientists from all backgrounds [48].
390 Such efforts would have to take into account factors such as the broader landscape in which
391 scientists from all backgrounds have greater career options [49], and the specific career
392 development of women from URM backgrounds [24, 25, 50] who make up the majority of URM
393 biomedical Ph.D. graduates [39].
394
395 While the challenge of achieving faculty diversity has been longstanding, with concerted and
396 targeted effort, the numeric realities of assistant professor hiring and turnover mean that higher
397 diversity could be achieved relatively quickly among junior faculty. On average, the pool of
398 assistant professors turns over every six years. The analysis presented here demonstrated that
399 in recent years, assistant professor hiring has been relatively stable at around 1000 positions
400 each year (or roughly 7 assistant professors per institution across all basic science departments
401 annually). Thus, to achieve parity with the pool of Ph.D. graduates (estimated to grow to 10%
402 URM in 2016) would require hiring around 100 URM assistant professors annually at medical
403 schools. Put another way, if roughly two-thirds of medical schools hired (and retained) just one
404 faculty member from an URM background annually for the next six years, the system would
405 reach parity with the Ph.D. pool within one tenure cycle. While this would still not reflect the
406 proportion of people from URM backgrounds in the overall population (currently greater than
407 30%), this would represent a meaningful first step to addressing the longstanding goal of
408 enhancing scientific excellence by increasing faculty diversity.

Materials and Methods

Data Sources

Biomedical Ph.D. attainment data were obtained from the National Science Foundation's Survey of Earned Doctorates (SED), an annual census of individuals receiving research doctorates from accredited U.S. institutions [51], as compiled by the Federation of American Societies for Experimental Biology (FASEB) [52]. FASEB tallies and publishes annually the number of Ph.Ds. granted in biomedical disciplines (including those who earned Ph.Ds. as a single degree or in combination with an MD) from 1980-2013. To calculate the total number of Ph.D. graduates in the U.S., we added together the number of biomedical Ph.Ds. awarded to U.S. Citizens and permanent residents, temporary residents, and individuals with unknown citizenship. To calculate the number of Ph.D. graduates from URM backgrounds, we added together the number of U.S. citizen and permanent resident Ph.D. graduates who identified as one of the following: "Black/African-American (non-Hispanic/Latino)," "Hispanic/Latino," or "American Indian or Alaska Native" [3]. Ph.D. graduates from all non-URM backgrounds (White, Asian or Pacific Islander, "Other," "Unknown" and non-citizens) were called "well represented" (WR). These data are shown in Figure 1-source data 1.

To determine trends in representation of faculty in medical school basic science departments, we obtained faculty data from the AAMC Faculty Roster, 1980-2014 [53]. The AAMC Faculty Roster has collected comprehensive information on the characteristics of full-time faculty members at accredited allopathic U.S. medical schools since 1966. We focused specifically on assistant professors in basic science departments because on average 88% of the faculty members in these departments have earned Ph.Ds. (either as a single degree or in combination with and MD). For consistency, assistant professors who identified as "Black," "Hispanic/Latino," and "American Indian or Alaska Native" were considered URM. Assistant professors from all other backgrounds were considered WR. These data are also shown in Figure 1-source data 1.

Assistant Professor Hiring Trends

To calculate the aggregate number of assistant professors hired each year, we made two assumptions: (i) the length of time that an individual occupied the position of assistant professor was six years based on traditional academic promotion cycles [54, 55], and similarly, (ii) one-sixth of the WR and URM assistant professors left the rank of assistant professor in 1980 (either to become associate professors, or pursue other career options). The numbers of assistant professors hired were then imputed based on real changes in the populations of URM and WR assistant professors each year. For example, if the assistant professor population changed from n_1 in year one to n_2 in year two, and the number of assistant professors leaving in year one was l_1, then the number of assistant professors hired in year two (h_2) equaled $(n_2-n_1) + l_1$. Thus, using real data showing that there were $n_1=132$ assistant professors from URM backgrounds in 1980, and $n_2=129$ in 1981, we assumed that one-sixth of the assistant professors left the rank in year 1980 ($l_1=22$), and thus $h_2=19$. These data are shown in Figure 2-source data 1.

Available evidence indicates that scientists who pursue faculty careers in the biomedical sciences remain in postdoctoral training for five or more years [37]. To estimate the pool of potential candidates for assistant professor positions, we assumed that Ph.D. graduates (postdocs) remained in the pool of potential candidates for a total of five years, including the year in which they graduated (similar results were found when the length of time in the pool was four or six years). To calculate the pool of available candidates, we totaled the number of Ph.D. graduates in the preceding five years, and subtracted the total number of assistant professors hired in medical school basic science departments in the preceding four years. For example, the pool of available candidates in the year 2010 equaled the sum of the Ph.D. graduates from 2006-2010 less the candidates hired from 2006-2009. The percentage of the pool hired was derived by dividing the number of assistant professors hired each year by the size of the available pool. These data are shown in Figure 2-source data 2. These

calculations were used to understand the current landscape and the connection between the available talent pool and faculty hiring, but were not used in the system dynamics model described below.

To determine the relationships between various constructs, we performed statistical analysis in R (version 3.2.2) [56]. Specifically, we used a linear regression model to compare the growth of Ph.D. graduates relative to the growth of assistant professors between URM and WR populations, where population relative to 1980 levels was the dependent variable, and independent variables included time (i.e. year), URM status (0= well-represented, 1=underrepresented minority), position (0=assistant professor, 1=PhD graduate), and the interaction between URM status and position. We also calculated Pearson's correlation coefficient between the size of the candidate pools and the number of assistant professors hired in each group. Finally, we examined how the proportion of the pool hired varied across time using a linear model with proportion assistant professors hired as the dependent variable and year as the independent variable, for scientists from URM and WR backgrounds. All figures were made in GraphPad Prism (version 6) and Adobe Illustrator (version 16.0.4).

System Dynamics Model of Assistant Professor Hiring

We used System Dynamics (SD) to create an abstract model [38] that could adequately explain macro-scale trends in the transition from the biomedical Ph.D. pool into assistant professor positions in basic science departments at medical schools, and be used to predict the impacts of potential intervention strategies for increasing faculty diversity. We focused on entry into assistant professor positions since these positions turn over more rapidly than the overall faculty pool, and generally pull from recent Ph.D. graduates and postdocs. All other areas of the workforce (i.e. faculty positions in other university contexts, research positions in industry or government, non-research positions occupied by Ph.Ds.) as well as longitudinal tracking of individual career transitions are beyond the scope of the model.

493 SD is a modeling framework that emphasizes the role of a system's structure on its ultimate
494 behavior [57, 58], and has been used along with other approaches to model other aspects of
495 the biomedical workforce and faculty hiring [34, 35, 59]. SD models implement these "loop-
496 driven" dynamics through three basic types of elements: (1) stocks, which represent the
497 accumulation of a quantity (e.g. assistant professors) and are represented by boxes; (2) flows,
498 which represent the rate of change in a quantity (e.g. hiring rate for assistant professors), and
499 are represented by hourglasses; and (3) variables, representing factors that can interact with
500 stocks and flows in complex ways (e.g. number of assistant professors slots available),
501 represented by words that have thin, blue causal arrows. In SD diagrams, clouds represent
502 factors that are outside the system boundary, i.e., that extend beyond the range of the model.
503 All modeling was done using Vensim PLE.
504
505 Our model extends beyond the standard "pipeline" conceptualization of faculty hiring (Figure
506 3A). There are three stocks accounting for progress from Ph.D. graduation through assistant
507 professor hiring: number of Ph.D. graduates, number of candidates on the market (i.e., those
508 Ph.D. graduates who become postdoctoral scientists and pursue faculty careers), and number
509 of assistant professors. Candidates on the market are hired into the stock of assistant
510 professors at a rate equal to the total number of slots available. New assistant professors
511 remain in the position for six years, at which point they leave the system boundary either
512 through promotion or contract termination ("assistant professor tenure or leave"). Thus, the
513 overarching structure of this model is that the number of assistant professors hired is based
514 on the number of slots available, and the number of candidates pursuing these positions.
515
516 We expanded upon this standard model in a number of ways (See Figure 3B for intermediate
517 conceptual model, and Figure 3C for final model structure). All equations and initial
518 parameter values are shown in Appendix-Tables 1 and 2, and the final model is in the source
519 code. Based on the analysis presented in Figure 2, and the distinct underlying patterns with
520 respect to assistant professor position attainment after Ph.D. completion, we separated the

521 pathways for the career progression of URM and WR scientists. Further, for both URM and
522 WR scientists, we assumed there was a fixed proportion of people who would pursue and
523 enter assistant professor positions in medical school basic science departments (called
524 "faculty aspire"), and all other Ph.Ds. would pursue careers in other sectors (called, "other
525 aspire"; this can include research careers outside of academia, faculty careers in teaching-
526 intensive environments, or careers away from bench research) [21, 22, 25].
527
528 The number of "faculty aspire" candidates is based upon the number of URM and WR
529 assistant professors hired in the period of 1980-1997 (prior to the NIH budget doubling which
530 lead a significant expansion in the number of biomedical Ph.Ds.). Without intervention, as the
531 total number of Ph.D. graduates grows, the pools of "URM faculty aspire," "URM other aspire,"
532 "WR faculty aspire," and "WR other aspire" are expected grow proportionally. The overall
533 Ph.D. graduate growth rate is represented as a variable termed "baseline Ph.D. graduate
534 growth rate." This is a piecewise linear function that mirrors the actual growth in the overall
535 number of Ph.D. graduates from 1980- 2013.
536
537 The model assumes all Ph.D. graduates in the "faculty aspire" stock pursue assistant
538 professorships in research-intensive environments. The remaining graduates pursue other
539 careers and depart the system. Each year, the system attempts to fill all "slots available."
540 Further, depending on market hiring conditions, 20% of the candidates on the market drop out
541 of the market annually. That is, if the probability of being hired is relatively high (>20%) all
542 candidates remain on the market that year. Otherwise, one-fifth of the available pool drops out
543 of the system. Thus, the "half-life" of a candidate on the market who is not hired is 5 years
544 (similar to the current period of postdoctoral training for candidates pursuing faculty positions in
545 research intensive environments [37]).
546
547 Candidates are chosen from the stocks of WR and URM candidates in proportion to their
548 respective representations on the market. For example, if there are 100 slots available, and

549 25% of the candidates on the market are from URM backgrounds and 75% are from WR
550 backgrounds, then 25 slots will be filled by URMs and 75 slots will be filled by WRs. Although
551 the career development pathways for WR and URM students are separate, the total number
552 of assistant professor slots available links them. If there are not enough candidates to fill all
553 slots, these slots are removed from the system. Specifically, we posit that candidates in a
554 specific group (URM or WR) are hired with likelihood proportional to their representation on
555 the market. That is, the model posits no hiring bias.
556
557 Beyond the baseline student growth rate, "URM target growth rate" (Figure 3C) is a variable
558 that represents the concerted effort of the scientific community (e.g. funders, institutions,
559 scientific societies) to increase the representation of scientists from URM backgrounds in the
560 Ph.D. pool over and above what would occur with natural system growth. This growth rate
561 increases exponentially throughout the duration of the model, matching the empirical trend of
562 URM biomedical Ph.D. population growth from 1980-2013. The "URM target growth rate" is
563 conceptualized as the result of external intervention; thus, these additional URM scientists are
564 initially added to the "URM other aspire" stock. For model simulations, the overall number of
565 scientists in the "URM other aspire" stock is the greater of either the baseline growth rate, or
566 the URM target growth rate. A proportion of URM Ph.D. graduates who begin in the "other
567 aspire" stock may then choose to pursue a faculty career. The "transition rate" is a free
568 parameter that represents the proportion of URM "other aspire" graduates that choose to
569 pursue faculty careers Because there has not been similar intervention to increase the
570 number of scientists from WR backgrounds entering the Ph.D. pool and faculty market, they
571 do not have a transition rate. Thus, the total number of URM candidates on the market is
572 equal to the number who would have entered the market in proportion to the overall growth of
573 the system (i.e. "URM Faculty Aspire"), and the number who entered as a result of external
574 intervention and then chose to pursue faculty careers (i.e. "URM Other Aspire" scientists who
575 transition) minus those who have dropped out of the market ("URM Market Dropout").
576

To determine the initial number of faculty aspire candidates for both URM and WR scientists ("Faculty Aspire P_0") we used the average number of assistant professors hired from 1980-1997, corresponding to the period before the NIH budget doubling, which drove significant growth of the biomedical enterprise [9]. The value of "URM Faculty Aspire P_0" is 34.4, and "WR Faculty Aspire P_0" is 567.7. The growth rates for each population (UR or WR) were then scaled to match empirical trends, resulting in numbers of Ph.D. graduates. The patterns of growth differed between scientists from WR and URM backgrounds (piecewise linear and exponential respectively). Thus, for scientists from WR backgrounds, we used the difference between the 1980 population of Ph.D. graduates and "WR Faculty Aspire" candidates to calculate the "WR other aspire P_0." For URM scientists, we fit an exponential function to URM student growth data and used the associated coefficient to derive the "URM other aspire P_0".

Finally, the number of assistant professor "slots available" is a piecewise function fit to data imputed from historical counts of assistant professors. Specifically, we made the simplifying assumption that there were a fixed number of slots available per year (i.e., flat hiring), with a step increase in 1998, when the NIH budget-doubling lead to an era of expansion in the biomedical sciences. Thus, the numbers of slots available from 1980-1997 (n=602.1 slots), and 1998-2013 (n=1064.7 slots) represent the average number of total assistant professors hired during these periods. The final model structure is shown in Figure 3C (the source code has model file).

Limitations

There are a number of limitations to the analyses presented. Postdoctoral training has become an almost uniform prerequisite to obtaining a faculty position in biomedical research. There are no reliable estimates on the number of postdocs in the US (currently or historically), thus these data were not included in the model [60]. However, available data suggest comparable postdoctoral transition rates across race/ethnicity for Ph.D. graduates [39]. Further, we recognize that scientists from URM and WR groups are not all uniform (i.e. there

605 are differences across race/ethnicity groups, and between them by dimensions including but
606 not limited to socioeconomic background). However, the small numbers of scientists from any
607 individual URM group on the faculty did not allow for further disaggregation and separate
608 modeling of URM populations. Additionally, some scientists (from all racial-ethnic
609 backgrounds) complete their training outside of the U.S., and then obtain faculty positions
610 within the U.S. For example, a Black or Hispanic scientist who completed their training
611 outside of the U.S., and then obtained a faculty position within the U.S. would be counted as a
612 URM faculty member, even though they were not part of the URM Ph.D. pool (which only
613 includes U.S. Citizens and Permanent Residents who completed their training within the U.S.).
614 There are no systematic data available on the numbers of scientists from either WR or URM
615 racial-ethnic backgrounds who fit this category [37], thus these data were not included in the
616 model. From the perspective of examining the transition from Ph.D. to assistant professor in
617 medical school basic science departments, a central focus of this work, the entry of scientists
618 that identify as being part of an URM group into faculty positions but who were not trained in
619 the U.S. would lead to an overestimation of the proportion of URM Ph.D. graduates hired as
620 assistant professors. Finally, between the period of 1980-2013, many universities adopted
621 policies that allow for flexibility in the traditional six-year tenure clock [61]. Thus, our
622 assumption of a fixed, six-year tenure clock may also lead to an overestimation of the number
623 of assistant professors hired each year, but it is consistent with the standard timeframe used
624 by number of leading institutions [54, 55].

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Competing interests: The authors declare no competing financial interests.

Data and materials availability: All data used in the analysis are available in the supplement.

Supplementary Materials

Figure 1-source data 1. Ph.D. Graduates and Assistant Professors (Total, URM and WR): 1980-2014
Figure 2-source data 1. Assistant Professor Hiring and Leaving (Total, URM and WR): 1980-2014
Figure 2-source data 2. Candidate Pool and Fraction Hired (URM and WR): 1980-2014
Figure 2-figure supplement 1. Candidate Pool Size, Hiring and Utilization of URM and WR Assistant Professors in Basic Biomedical Science Departments: By Gender.
Source Code File. System Dynamics Model of Assistant Professor Hiring (Vensim File).
Figure 5-source data 1. Model Predictions: Percentage URM Assistant Professors by Transition Rate: 1980-2080 (current number of assistant professor positions)
Figure 5-source data 2. Model Predictions: Percentage URM Assistant Professors by Transition Rate: 1980-2080 (100 new assistant professor positions, annually, beginning in 2015)
Appendix-Table 1. Model Formulation and Equation Notation
Appendix-Table 2: Initial Parameter Values

658 **References and Notes**

659 1. Tabak LA, Collins FS. Weaving a richer tapestry in biomedical science. Science.
660 2011;333(6045):940-1. Epub 2011/08/20. doi: 333/6045/940 [pii]
661 10.1126/science.1211704. PubMed PMID: 21852476.
662 2. Valantine HA, Collins FS. National Institutes of Health addresses the science of diversity.
663 Proc Natl Acad Sci U S A. 2015;112(40):12240-2. doi: 10.1073/pnas.1515612112. PubMed
664 PMID: 26392553; PubMed Central PMCID: PMCPMC4603507.
665 3. National Institutes of Health. Notice of NIH's Interest in Diversity 2015 [cited 2015
666 November 4]. Available from: https://grants.nih.gov/grants/guide/notice-files/NOT-OD-15-053.html.
667 4. National Institute of General Medical Sciences. National Institute of General Medical
668 Sciences 5-Year Strategic Plan 2015 [cited 2016 February 1]. Available from:
669 https://publications.nigms.nih.gov/strategicplan/NIGMS-strategic-plan.pdf.
670 5. Ginther DK, Kahn S, Schaffer WT. Gender, Race/Ethnicity, and National Institutes of
671 Health R01 Research Awards: Is There Evidence of a Double Bind for Women of Color?
672 Academic medicine : journal of the Association of American Medical Colleges. 2016;91(8):1098-
673 107. doi: 10.1097/ACM.0000000000001278. PubMed PMID: 27306969; PubMed Central
674 PMCID: PMCPMC4965301.
675 6. Ginther DK, Schaffer WT, Schnell J, Masimore B, Liu F, Haak LL, et al. Race, ethnicity,
676 and NIH research awards. Science. 2011;333(6045):1015-9. Epub 2011/08/20. doi:
677 333/6045/1015 [pii]
678 10.1126/science.1196783. PubMed PMID: 21852498; PubMed Central PMCID: PMC3412416.
679 7. National Institutes of Health. Draft Report of the Advisory Committee to the Director
680 Working Group on Diversity in the Biomedical Research Workforce. 2012.
681 8. Heggeness ML, Evans L, Pohlhaus JR, Mills SL. Measuring Diversity of the National
682 Institutes of Health-Funded Workforce. Academic medicine : journal of the Association of
683 American Medical Colleges. 2016. doi: 10.1097/ACM.0000000000001209. PubMed PMID:
684 27224301.
685 9. Johnson JA. Brief History of NIH Funding: Fact Sheet Washington, DC: Congressional
686 Research Service, 2013.
687 10. National Institutes of Health. Research Portfolio Online Reporting Tools (RePORT): NIH
688 Awards by Location & Organization 2016 [cited 2016 February 1]. Available from:
689 https://report.nih.gov/award/index.cfm.
690 11. Clauset A, Arbesman S, Larremore DB. Systematic inequality and hierarchy in faculty
691 hiring networks. Sci Adv. 2015;1(1):e1400005. doi: 10.1126/sciadv.1400005. PubMed PMID:
692 26601125; PubMed Central PMCID: PMCPMC4644075.
693 12. Leggon CB. Diversifying Science and Engineering Faculties: Intersections of Race,
694 Ethnicity, and Gender. American Behavioral Scientist. 2010;53(7):1013-28. doi: Doi
695 10.1177/0002764209356236. PubMed PMID: ISI:000274409900006.
696 13. National Academy of Sciences. Expanding underrepresented minority participation.
697 Washington, DC: National Academies Press; 2011. xv, 269 p. p.
698 14. Griffin KA. Reconsidering the Pipeline Problem: Increasing Faculty Diversity Higher
699 Education Today: American Council on Education; 2016 [cited 2016 March 14]. Available from:
700 http://higheredtoday.org/2016/02/10/reconsidering-the-pipeline-problem-increasing-faculty-diversity/.
701 15. Garrison H. Underrepresentation by race-ethnicity across stages of U.S. science and
702 engineering education. CBE Life Sci Educ. 2013;12(3):357-63. doi: 10.1187/cbe.12-12-0207.
703 PubMed PMID: 24006384; PubMed Central PMCID: PMCPMC3763003.
704 16. Ginther DK, Schaffer WT, Schnell J, Masimore B, Liu F, Haak LL, et al. Diversity in
705 Academic Biomedicine: An Evaluation of Education and Career Outcomes with Implications for
706 Policy 2009 [cited 2016 October 15]. Available from: http://www.people.ku.edu/~dginther/working
707 papers/Ginther_etal_Diversity2009.pdf.

17. Stephan P. How Economics Shapes Science. Cambridge, Massachusetts: Harvard University Press; 2012.
18. Alberts B, Kirschner MW, Tilghman S, Varmus H. Rescuing US biomedical research from its systemic flaws. Proc Natl Acad Sci U S A. 2014. doi: 10.1073/pnas.1404402111. PubMed PMID: 24733905.
19. National Science Board. Science and Engineering Indicators 2014. Arlington, VA: National Science Foundation (NSB 14-01), 2014.
20. Zolas N, Goldschlag N, Jarmin R, Stephan P, Smith JO, Rosen RF, et al. Wrapping it up in a person: Examining employment and earnings outcomes for Ph.D. recipients. Science. 2015;350(6266):1367-71. doi: 10.1126/science.aac5949. PubMed PMID: 26659054; PubMed Central PMCID: PMCPMC4836945.
21. Fuhrmann CN, Halme DG, O'Sullivan PS, Lindstaedt B. Improving graduate education to support a branching career pipeline: recommendations based on a survey of doctoral students in the basic biomedical sciences. CBE Life Sci Educ. 2011;10(3):239-49. Epub 2011/09/03. doi: 10/3/239 [pii]
10.1187/cbe.11-02-0013. PubMed PMID: 21885820; PubMed Central PMCID: PMC3164563.
22. Gibbs KD, Jr., McGready J, Griffin K. Career Development among American Biomedical Postdocs. CBE Life Sci Educ. 2015;14(4):ar44. doi: 10.1187/cbe.15-03-0075. PubMed PMID: 26582238; PubMed Central PMCID: PMCPMC4710405.
23. Sauermann H, Roach M. Science PhD career preferences: levels, changes, and advisor encouragement. PLoS One. 2012;7(5):e36307. Epub 2012/05/09. doi: 10.1371/journal.pone.0036307
PONE-D-12-04251 [pii]. PubMed PMID: 22567149; PubMed Central PMCID: PMC3342243.
24. Gibbs KD, Jr., McGready J, Bennett JC, Griffin K. Biomedical Science Ph.D. Career Interest Patterns by Race/Ethnicity and Gender. PLoS One. 2014;9(12):e114736. doi: 10.1371/journal.pone.0114736. PubMed PMID: 25493425.
25. Gibbs KD, Jr., Griffin KA. What do I want to be with my PhD? The roles of personal values and structural dynamics in shaping the career interests of recent biomedical science PhD graduates. CBE Life Sci Educ. 2013;12(4):711-23. doi: 10.1187/cbe.13-02-0021. PubMed PMID: 24297297; PubMed Central PMCID: PMC3846521.
26. Colon Ramos DA, Quiñones-Hinojosa A. Racism in the Research Lab New York Times2016 [cited 2016 August 5]. Available from: http://kristof.blogs.nytimes.com/2016/08/04/racism-in-the-research-lab/.
27. Jarvis ED. Surviving as an underrepresented minority scientist in a majority environment. Mol Biol Cell. 2015;26(21):3692-6. doi: 10.1091/mbc.E15-06-0451. PubMed PMID: 26515973; PubMed Central PMCID: PMCPMC4626054.
28. McDowell GS, Gunsalus KT, MacKellar DC, Mazzilli SA, Pai VP, Goodwin PR, et al. Shaping the Future of Research: a perspective from junior scientists. F1000Research. 2014;3:291. doi: 10.12688/f1000research.5878.2. PubMed PMID: 25653845; PubMed Central PMCID: PMC4304227.
29. Turner C. Diversifying the Faculty: A Guidebook for Search Committees. Washington, D.C.: Association of American Colleges and Universities; 2002.
30. Sheridan JT, Fine E, Pribbenow CM, Handelsman J, Carnes M. Searching for excellence & diversity: increasing the hiring of women faculty at one academic medical center. Academic medicine : journal of the Association of American Medical Colleges. 2010;85(6):999-1007. doi: 10.1097/ACM.0b013e3181dbf75a. PubMed PMID: 20505400; PubMed Central PMCID: PMCPMC4128022.
31. Moody J. Faculty Diversity: Problems and Solutions. New York: RoutledgeFalmer; 2004.
32. Smith DG. Diversity's Promise for Higher Education: Making It Work (Second Edition). Baltimore: Johns Hopkins University Press; 2015.

33. Eddy S. Our faculty search so far 2015 [cited 2016 February 1]. Available from: https://cryptogenomicon.org/2015/12/15/our-faculty-search-so-far/.
34. Ghaffarzadegan N, Hawley J, Desai A. Research Workforce Diversity: The Case of Balancing National versus International Postdocs in US Biomedical Research. Syst Res Behav Sci. 2014;31(2):301-15. doi: 10.1002/sres.2190. PubMed PMID: 25368504; PubMed Central PMCID: PMCPMC4215734.
35. Larson RC, Diaz MG. Nonfixed Retirement Age for University Professors: Modeling Its Effects on New Faculty Hires. Serv Sci. 2012;4(1):69-78. doi: 10.1287/serv.1120.0006. PubMed PMID: 23936582; PubMed Central PMCID: PMCPMC3737001.
36. Polka JK, Krukenberg KA, McDowell GS. A call for transparency in tracking student and postdoc career outcomes. Mol Biol Cell. 2015;26(8):1413-5. doi: 10.1091/mbc.E14-10-1432. PubMed PMID: 25870234; PubMed Central PMCID: PMCPMC4395122.
37. National Institutes of Health. Biomedical Research Workforce Working Group Report 2012.
38. Gilbert N. Agent Based Models. Los Angeles: SAGE Publications, Inc.; 2007.
39. National Science Foundation. Women, Minorities, and Persons with Disabilities in Science and Engineering (NSF 15-311). Arlington, VA: 2015.
40. Duehren AM, Muluk SL. Medical Students Petition Faust to Increase School's Diversity 2016 [cited 2016 March 14]. Available from: http://www.thecrimson.com/article/2016/1/28/hms-students-petition-diversity/.
41. Myers SL, Jr., Fealing KH. Changes in the representation of women and minorities in biomedical careers. Academic medicine : journal of the Association of American Medical Colleges. 2012;87(11):1525-9. doi: 10.1097/ACM.0b013e31826d7189. PubMed PMID: 23018333.
42. Larson RC, Ghaffarzadegan N, Xue Y. Too Many PhD Graduates or Too Few Academic Job Openings: The Basic Reproductive Number in Academia. Syst Res Behav Sci. 2014;31(6):745-50. doi: 10.1002/sres.2210. PubMed PMID: 25642132; PubMed Central PMCID: PMCPMC4309283.
43. Estrada M, Woodcock A, Hernandez PR, Schultz Pw. Toward a Model of Social Influence That Explains Minority Student Integration into Scientific Community. Journal of Educational Psychology. 2011;103(1):206-22.
44. Thoman DB, Brown ER, Mason AZ, Harmsen AG, Smith JL. The Role of Altruistic Values in Motivating Underrepresented Minority Students for Biomedicine. Bioscience. 2015;65(2):183-8.
45. Smith JL, Cech E, Metz A, Huntoon M, Moyer C. Giving back or giving up: Native American student experiences in science and engineering. Cultur Divers Ethnic Minor Psychol. 2014;20(3):413-29. doi: 10.1037/a0036945. PubMed PMID: 25045952.
46. Powers BW, White AA, Oriol NE, Jain SH. Race-Conscious Professionalism and African American Representation in Academic Medicine. Academic medicine : journal of the Association of American Medical Colleges. 2016. doi: 10.1097/ACM.0000000000001074. PubMed PMID: 26760060.
47. Valantine HA, Lund PK, Gammie AE. From the NIH: A Systems Approach to Increasing the Diversity of the Biomedical Research Workforce. CBE Life Sci Educ. 2016;15(3). doi: 10.1187/cbe.16-03-0138. PubMed PMID: 27587850.
48. Gasman M. An Ivy League professor on why colleges don't hire more faculty of color: 'We don't want them' The Washington Post2016 [cited 2016 October 18]. Available from: https://www.washingtonpost.com/news/grade-point/wp/2016/09/26/an-ivy-league-professor-on-why-colleges-dont-hire-more-faculty-of-color-we-dont-want-them/?tid=a_inl.
49. Nature. There is life after academia. Nature. 2014;513(7516):5. doi: 10.1038/513005a. PubMed PMID: 25186866.

50. National Research Council. Seeking Solutions: Maximizing American Talent by Advancing Women of Color in Academia: Summary of a Conference. . Washington, D.C.: 2013.
51. National Science Foundation. Survey of Earned Doctorates 2015 [cited 2015 December 1]. Available from: http://www.nsf.gov/statistics/srvydoctorates/.
52. Garrison HH, Campbell E. Education and Employment of Biological and Medical Scientists 2015: Data from National Surveys: Federation of American Societies For Experimental Biology; 2015 [cited 2015 December 1]. Available from: http://www.faseb.org/Science-Policy-and-Advocacy/Federal-Funding-Data/Education-and-Employment-of-Scientists.aspx.
53. Association of American Medical Colleges. Reports: U.S. Medical School Faculty. 1980 through 2013 2015 [cited 2015 November 9]. Available from: https://services.aamc.org/famous/.
54. Stanford University. FACULTY HANDBOOK, Chapter 2: Appointments, Reappointments and Promotions in the Professoriate 2016 [cited 2016 August 1]. Available from: https://facultyhandbook.stanford.edu/ch2.html.
55. Yale School of Medicine. Faculty Affairs: Ladder Faculty 2014 [cited 2016 August 1]. Available from: http://medicine.yale.edu/facultyaffairs/appts/ap_procedures/ladder.aspx.
56. R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2015 [cited 2015 September 1]. Available from: https://www.R-project.org/.
57. Homer JB, Hirsch GB. System dynamics modeling for public health: background and opportunities. Am J Public Health. 2006;96(3):452-8. doi: 10.2105/AJPH.2005.062059. PubMed PMID: 16449591; PubMed Central PMCID: PMCPMC1470525.
58. Meadows DH. Thinking in Systems: A Primer Chelsea Green Publishing 2008.
59. Ghaffarzadegan N, Hawley J, Larson R, Xue Y. A Note on PhD Population Growth in Biomedical Sciences. Syst Res Behav Sci. 2015;23(3):402-5. doi: 10.1002/sres.2324. PubMed PMID: 26190914; PubMed Central PMCID: PMCPMC4503365.
60. National Academy of Sciences NAoE, and Institute of Medicine. The Postdoctoral Experience Revisited. Washington, D.C.: 2014.
61. American Association of University Professors. Stopping the Tenure Clock 2004 [cited 2016 April 26]. Available from: http://www.aaup.org/issues/balancing-family-academic-workstopping-tenure-clock.

841 **Figures**
842
843 **Figure. 1. Temporal Trends in the Populations of Biomedical Underrepresented Minority**
844 **(URM) and Well-Represented (WR) Ph.D. Graduates and Assistant Professors, 1980-**
845 **2014.** Line charts showing the (i) annual population, (ii) population growth relative to 1980,
846 and (iii) percentage representation of Ph.D. graduates and assistant professors in basic
847 science departments in medical schools for scientists from (A) URM and (B) WR racial-ethnic
848 backgrounds. Data on the populations of Ph.D. graduates and assistant professors in medical
849 school basic science departments were obtained from the National Science Foundation
850 Survey of Earned Doctorates (as compiled by Federation of American Societies for
851 Experimental Biology), and the AAMC Faculty Roster, respectively (please see methods
852 section for more information). Grey lines represent Ph.D. graduates, and black lines
853 represent assistant professors. In panels Aiii and Biii, solid grey lines represent the
854 percentages of URM and WR Ph.D. graduates among all students who receive Ph.Ds. in the
855 U.S. (U.S. citizen, permanent resident, and international), and dotted lines show percentages
856 among Ph.D. graduates who are U.S. citizens and permanent residents. The relative growth
857 of Ph.D. graduates from URM backgrounds to assistant professors is greater than the same
858 comparison among scientists from WR backgrounds (i.e., there was a significant interaction
859 between the URM status and position, β=1.60; $p=3.6*10^{-7}$; panels Aii and Bii). Data are
860 available in Figure 1-source data 1.

Figure 2. Candidate Pool Size, Hiring and Utilization of URM and WR Assistant Professors in Basic Biomedical Science Departments. Scatter plots showing the (i) pool of potential candidates for assistant professor positions, (ii) annual number of assistant professors hired, and (iii) percentage of the potential candidate pool hired annually for scientists from (A) URM and (B) WR backgrounds. R^2 values in panels Aii and Bii are derived from correlating number of URM or WR assistant professors hired with the size of their respective pool of potential candidates. β in panels Aiii and Biii reflect the yearly percentage change in the fraction of the pools of URM and WR scientists hired into assistant professor positions. Asterisks represent significant values ($p<10^{-4}$). Data are available in Figure 2-source data 1 and 2.

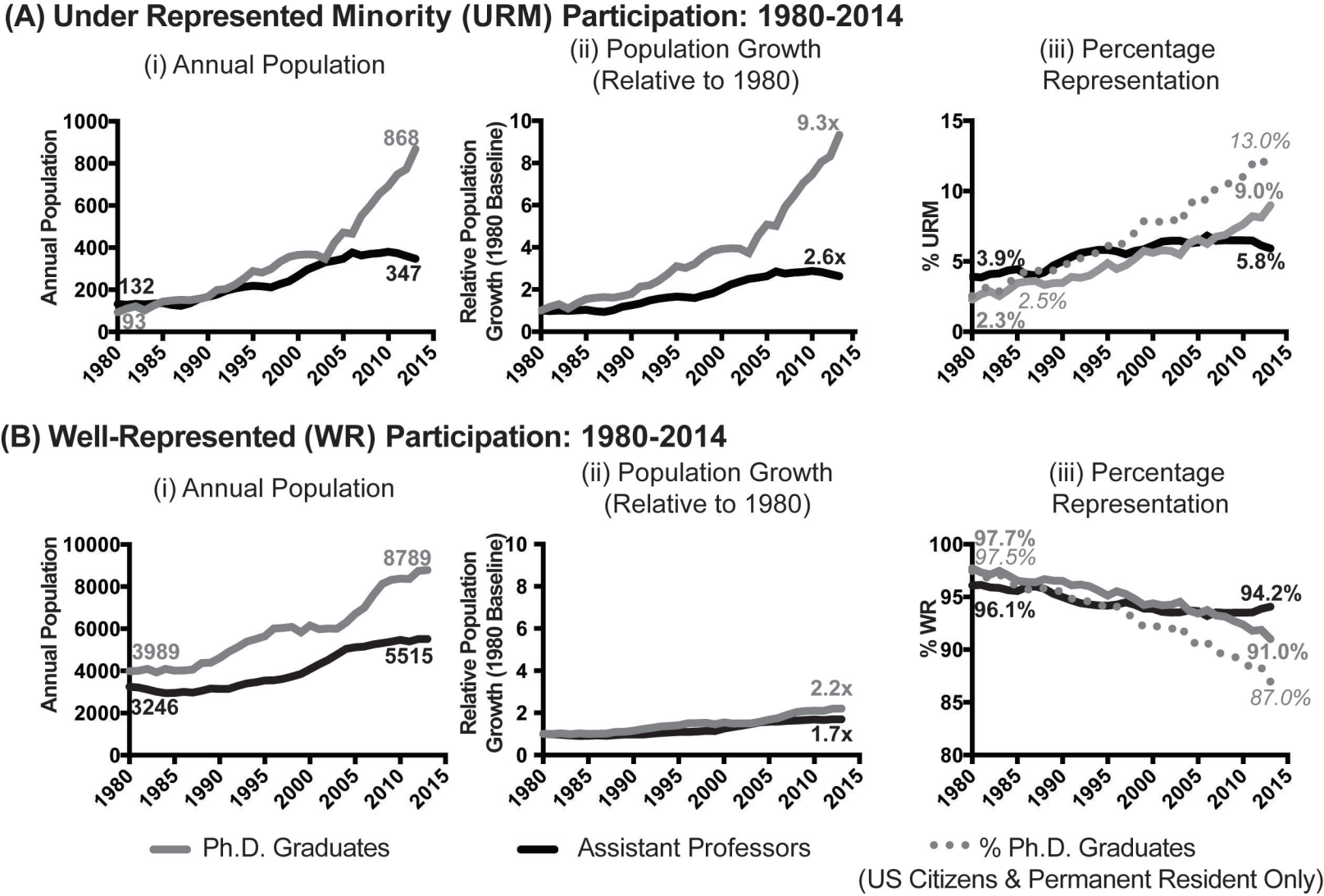
Figure 3. **System Dynamics Model of Assistant Professor Hiring.** (A) A traditional "pipeline" view of faculty hiring. A fraction of the total stock of Ph.D. graduates pursues faculty positions, and thus become candidates on the market. Candidates on the market are composed primarily of the subset of postdoctoral scientists pursuing faculty careers in medical school basic science departments but can include those who have non-traditional career paths such as the rare Ph.D. student who proceeds directly to the faculty job market. Each year, candidates on the market are hired into the stock of assistant professors at a rate equal to the total number of slots available ("slots available"), and candidates who are not hired remain in the pool conditional on hiring probability ("market dropout"). After six years, assistant professors leave the system (either via promotion or contract termination, "Assistant Professor Tenure or Leave"). Boxes represent stocks (quantities), hourglasses represent flows (rates; writing italicized), variables are bolded, blue arrows represent causal connections between factors, and clouds represent system boundaries (B) Intermediate conceptual model. The pool of Ph.D. graduates is separated into two groups: those who will pursue and enter faculty positions in research-intensive environments ("Faculty Aspire"), and those who will pursue other career interests ("Other Aspire"). All "Faculty Aspire" graduates enter the academic job market ("Candidates on the Market") and remain based on hiring probability, while the "Other Aspire" scientists depart the system. As the total number of Ph.D. graduates grows ("Baseline Ph.D. Graduate Growth Rate"), the populations of "Faculty Aspire" and "Other Aspire" graduates are expected to grow equally (i.e. they maintain the same, fixed proportions with respect to one another). Initial populations (P_0) of "Faculty Aspire" and "Other Aspire" candidates represent scaling factors that, together with the baseline growth rate, produce the number of Ph.D. graduates in each stock. Candidates on the market are hired into the stock of assistant professors at a rate equal to the total number

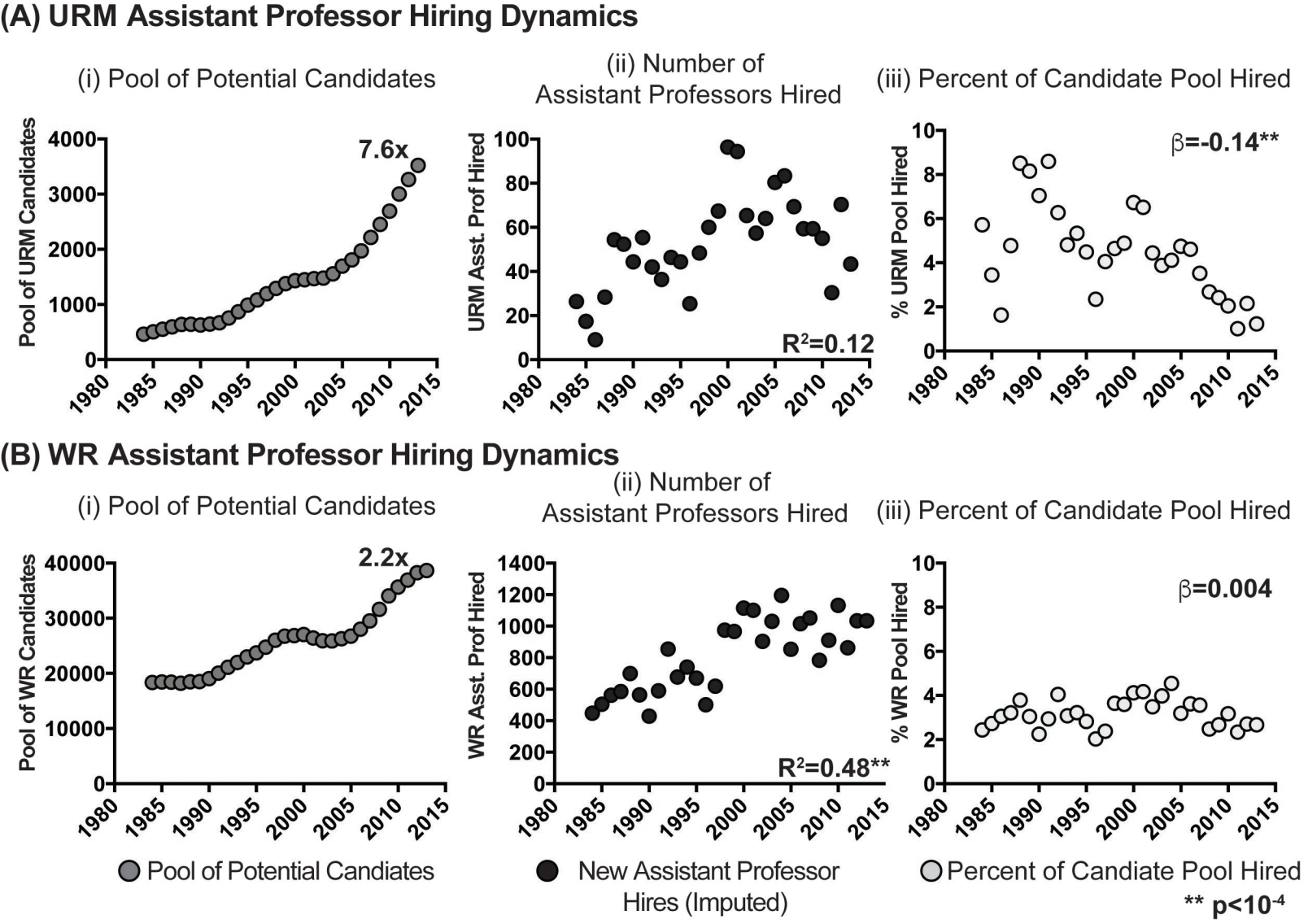
904 of slots available, and then depart the system six years later. (C) Elaborated model of faculty
905 hiring for Ph.D. scientists from WR and URM backgrounds with intervention to enhance
906 workforce diversity. The career pathways of URM and WR scientists are conceptualized as
907 independent, but are linked with respect to assistant professor hiring by the number of
908 assistant professor slots available. URM and WR candidates are hired based on the number
909 of slots available, and in proportion to their representation on the market (hence the
910 influence of WR candidates on the URM hiring rate and vice versa). That is, the model posits
911 no bias in hiring. In addition to baseline growth, the variable "URM Target Growth Rate"
912 represents efforts from the scientific community to enhance workforce diversity. These
913 additional URM scientists are initially added to the "URM other aspire" stock. The "transition
914 rate" represents the percentage of URM other aspire scientists that enter the faculty market.
915 As this rate increases, more URM candidates enter the academic job market. Candidates
916 hired leave the system after six years, and the initial populations (P_0) are derived from
917 empirical data as described in methods.
918
919

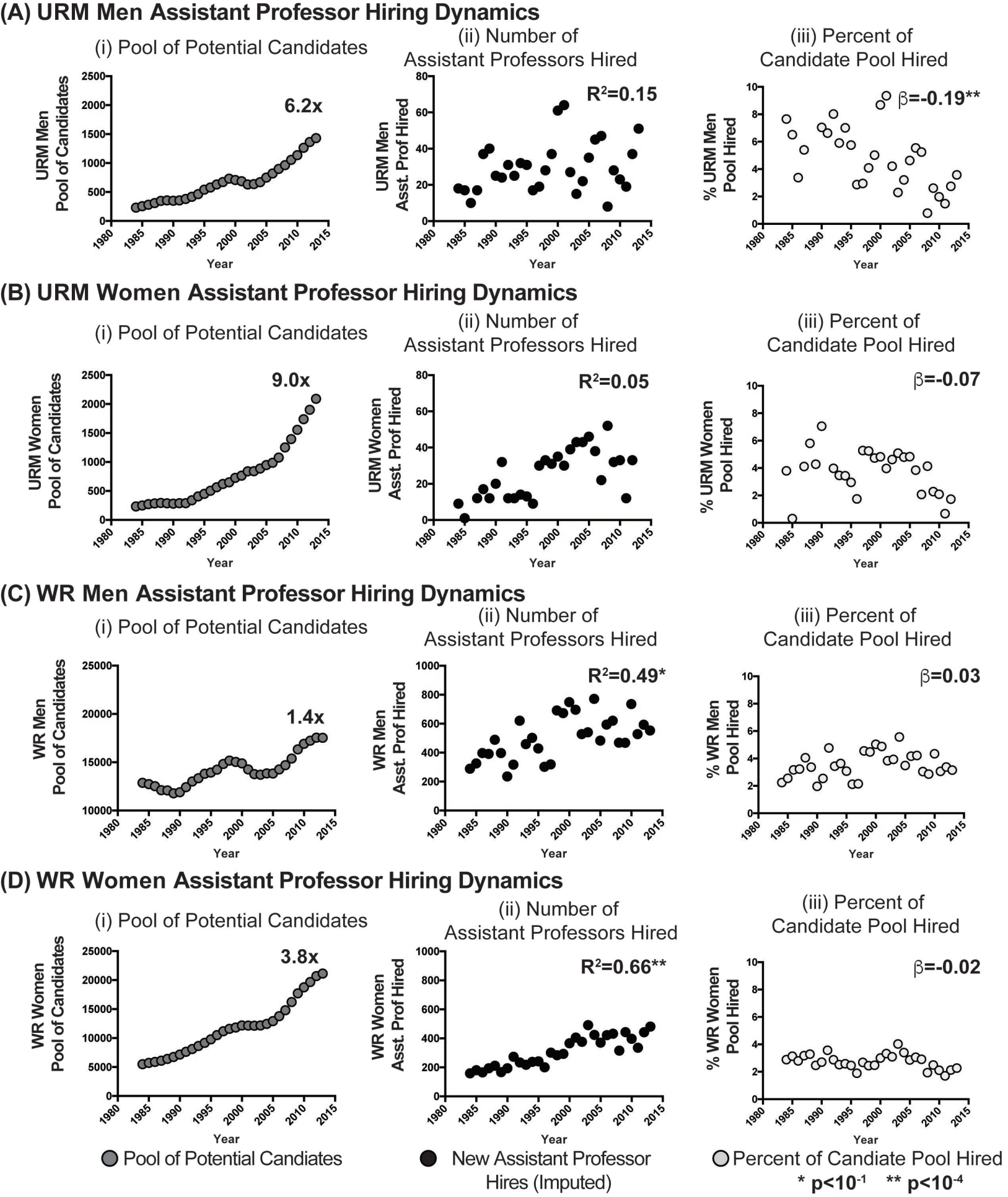
Figure 4. Model Simulation: 1980-2013. Scatter plots showing the performance of the model (open circles) compared to input data (filled circles) for the populations of (i) Ph.D. graduates, (ii) assistant professors, and (iii) newly hired assistant professors for the (A) overall pool, (B) pool of URM scientists, and (C) pool of WR scientists. All R^2 values are significant at the $p<0.0001$ level.

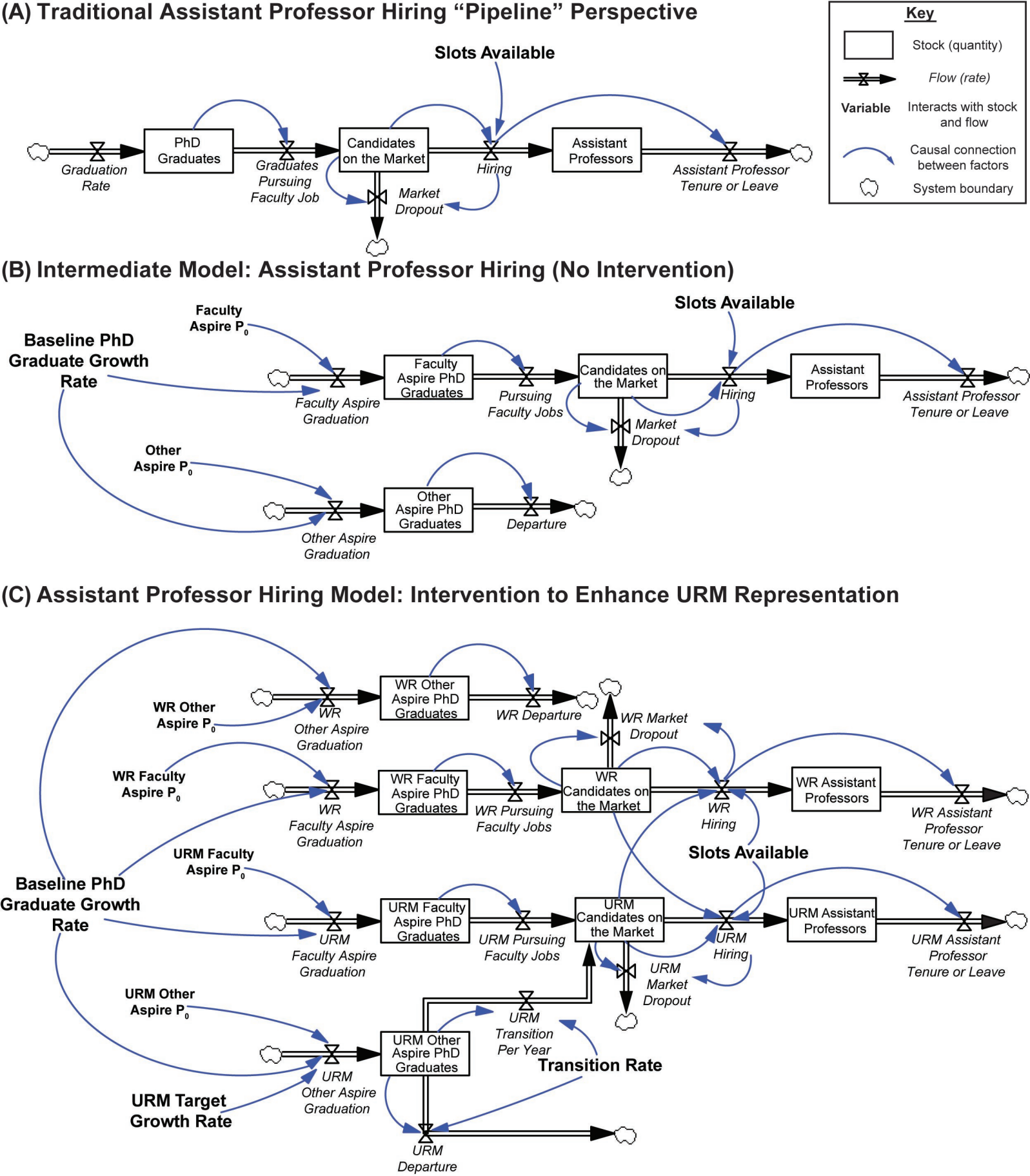
927
928
929 **Figure 5. Model Predictions of URM Assistant Professor Attainment.** Line graph showing
930 model predictions for the percentage of URM Ph.D. graduates (grey), and the corresponding
931 percentages of URM assistant professors (black) as a function of various intervention
932 strategies to increase faculty diversity in (A) short-term, through 2030, and (B) long-term,
933 through 2080. All model runs assume an exponential increase in the number of Ph.Ds. from
934 URM backgrounds. Thus, in all runs, the percentage of Ph.D. scientists from URM
935 backgrounds is 13.8% in 2030 and 73% in 2080. Simulations: (i) No change in transition rate
936 (0.25%) or number of assistant professor positions. (ii) No change in transition rate (0.25%),
937 increase the number of assistant professor positions by 100 per year, beginning in 2015. (iii)
938 Increase transition rate to 10%, and no change in the number of assistant professor positions.
939 (iv) Increase transition rate to 10% and increase the number of assistant professor positions by
940 100 per year, beginning in 2015.

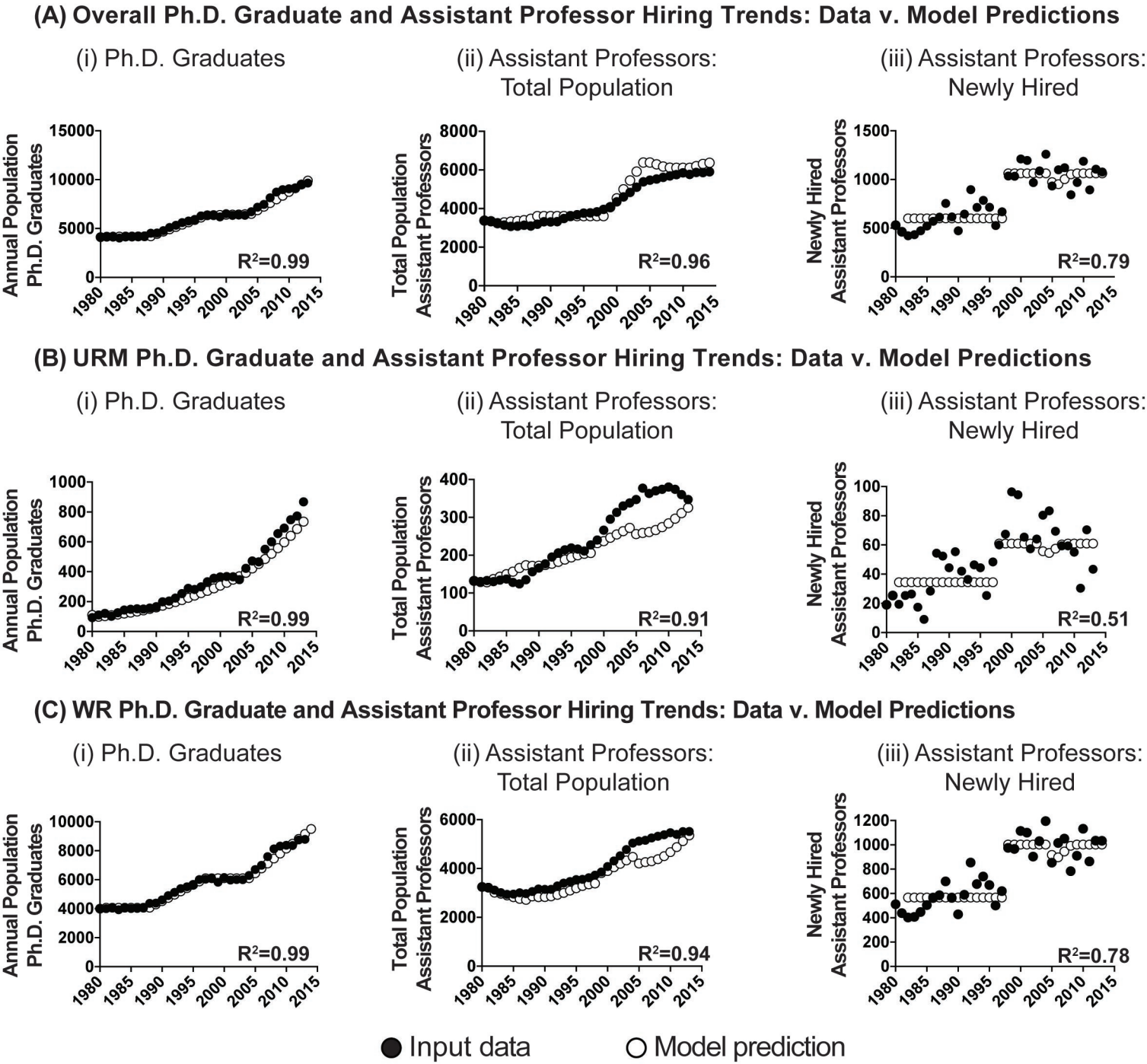
941 **Figure 2-figure supplement 1. Candidate Pool Size, Hiring and Utilization of URM and WR**
942 **Assistant Professors in Basic Biomedical Science Departments: By Gender**. Scatter plots
943 showing the (i) pool of potential candidates for assistant professor positions, (ii) annual number
944 of assistant professors hired, and (iii) percentage of the potential candidate pool hired annually
945 for (A) URM Men, (B) URM Women, (C) WR Men, and (D) WR women. R^2 values in panels A-
946 Dii were derived from correlating number of URM or WR assistant professors hired with the size
947 of their respective pool of potential candidates. β in panels A-Diii reflect the yearly percentage
948 change in the fraction of the pools of URM and WR scientists hired into assistant professor
949 positions. Asterisks represent significant values ($p<10^{-4}$). Data are available in Figure 2-source
950 data 1 and 2.
951
952 **Source Code File.** Vensim file containing the final system dynamics model of assistant
953 professor hiring in basic science departments of medical schools.

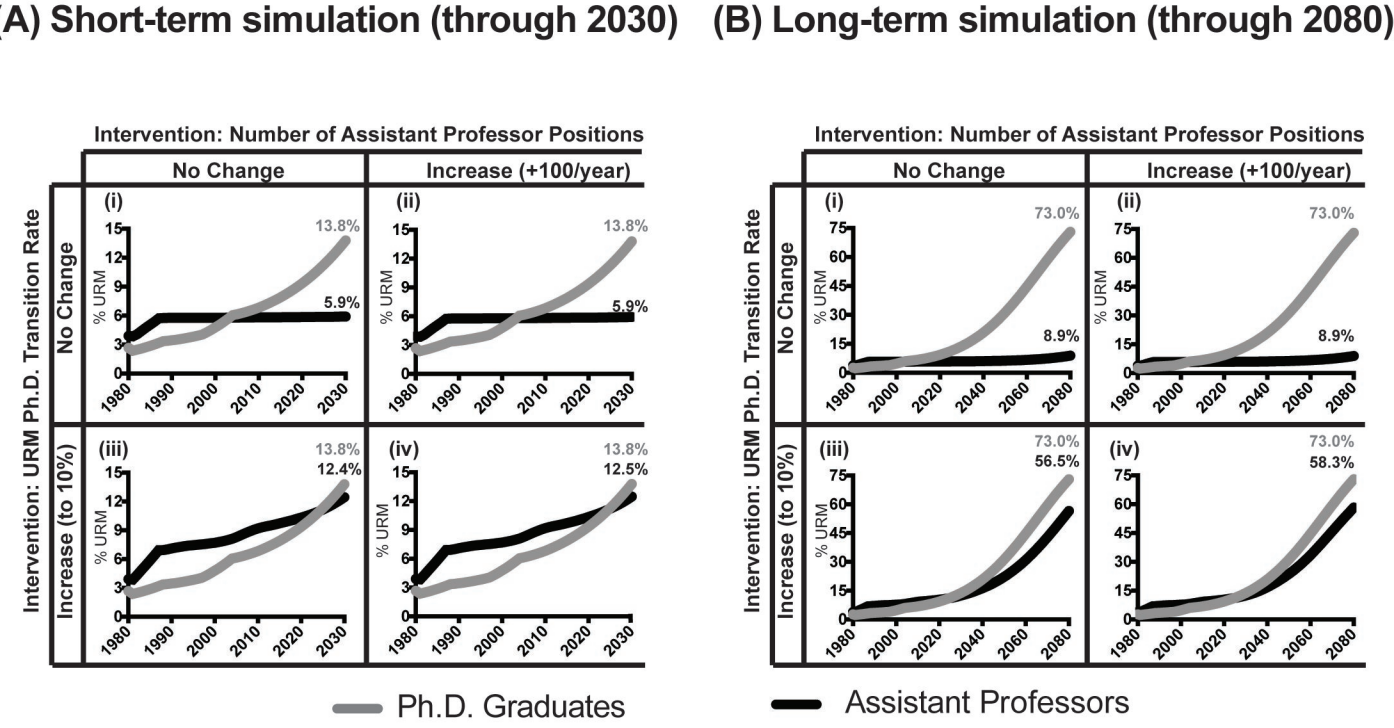

(A) Under Represented Minority (URM) Participation: 1980-2014
(i) Annual Population
Annual Population
868
132
93
347
(ii) Population Growth (Relative to 1980)
Relative Population Growth (1980 Baseline)
9.3x
2.6x
(iii) Percentage Representation
% URM
13.0%
9.0%
3.9%
5.8%
2.5%
2.3%
(B) Well-Represented (WR) Participation: 1980-2014
(i) Annual Population
Annual Population
8789
3989
5515
3246
(ii) Population Growth (Relative to 1980)
Relative Population Growth (1980 Baseline)
2.2x
1.7x
(iii) Percentage Representation
% WR
97.7%
97.5%
96.1%
94.2%
91.0%
87.0%
Ph.D. Graduates
Assistant Professors
% Ph.D. Graduates (US Citizens & Permanent Resident Only)


(A) URM Assistant Professor Hiring Dynamics
(i) Pool of Potential Candidates
(ii) Number of Assistant Professors Hired
(iii) Percent of Candidate Pool Hired
Pool of URM Candidates
7.6x
URM Asst. Prof Hired
R²=0.12
% URM Pool Hired
β=-0.14**
(B) WR Assistant Professor Hiring Dynamics
(i) Pool of Potential Candidates
(ii) Number of Assistant Professors Hired
(iii) Percent of Candidate Pool Hired
Pool of WR Candidates
2.2x
WR Asst. Prof Hired
R²=0.48**
% WR Pool Hired
β=0.004
Pool of Potential Candiates
New Assistant Professor Hires (Imputed)
Percent of Candiate Pool Hired
** p<10⁻⁴


(A) URM Men Assistant Professor Hiring Dynamics
(i) Pool of Potential Candidates
URM Men Pool of Candidates
6.2x
Year
(ii) Number of Assistant Professors Hired
URM Men Asst. Prof Hired
R²=0.15
Year
(iii) Percent of Candidate Pool Hired
% URM Men Pool Hired
β=-0.19**
Year
(B) URM Women Assistant Professor Hiring Dynamics
(i) Pool of Potential Candidates
URM Women Pool of Candidates
9.0x
Year
(ii) Number of Assistant Professors Hired
URM Women Asst. Prof Hired
R²=0.05
Year
(iii) Percent of Candidate Pool Hired
% URM Women Pool Hired
β=-0.07
Year
(C) WR Men Assistant Professor Hiring Dynamics
(i) Pool of Potential Candidates
WR Men Pool of Candidates
1.4x
Year
(ii) Number of Assistant Professors Hired
WR Men Asst. Prof Hired
R²=0.49*
Year
(iii) Percent of Candidate Pool Hired
% WR Men Pool Hired
β=0.03
Year
(D) WR Women Assistant Professor Hiring Dynamics
(i) Pool of Potential Candidates
WR Women Pool of Candidates
3.8x
Year
(ii) Number of Assistant Professors Hired
WR Women Asst. Prof Hired
R²=0.66**
Year
(iii) Percent of Candidate Pool Hired
% WR Women Pool Hired
β=-0.02
Year
Pool of Potential Candiates
New Assistant Professor Hires (Imputed)
Percent of Candiate Pool Hired
* p<10⁻¹ ** p<10⁻⁴


(A) Traditional Assistant Professor Hiring "Pipeline" Perspective
Key
Stock (quantity)
Flow (rate)
Variable
Interacts with stock and flow
Causal connection between factors
System boundary
Slots Available
PhD Graduates
Graduation Rate
Graduates Pursuing Faculty Job
Candidates on the Market
Market Dropout
Hiring
Assistant Professors
Assistant Professor Tenure or Leave
(B) Intermediate Model: Assistant Professor Hiring (No Intervention)
Slots Available
Faculty Aspire P0
Baseline PhD Graduate Growth Rate
Faculty Aspire Graduation
Faculty Aspire PhD Graduates
Pursuing Faculty Jobs
Candidates on the Market
Hiring
Assistant Professors
Assistant Professor Tenure or Leave
Market Dropout
Other Aspire P0
Other Aspire Graduation
Other Aspire PhD Graduates
Departure
(C) Assistant Professor Hiring Model: Intervention to Enhance URM Representation
WR Other Aspire P0
WR Other Aspire Graduation
WR Other Aspire PhD Graduates
WR Departure
WR Market Dropout
WR Faculty Aspire P0
WR Faculty Aspire Graduation
WR Faculty Aspire PhD Graduates
WR Pursuing Faculty Jobs
WR Candidates on the Market
WR Hiring
WR Assistant Professors
WR Assistant Professor Tenure or Leave
Slots Available
URM Faculty Aspire P0
Baseline PhD Graduate Growth Rate
URM Faculty Aspire Graduation
URM Faculty Aspire PhD Graduates
URM Pursuing Faculty Jobs
URM Candidates on the Market
URM Hiring
URM Assistant Professors
URM Assistant Professor Tenure or Leave
URM Market Dropout
URM Other Aspire P0
URM Transition Per Year
URM Other Aspire PhD Graduates
Transition Rate
URM Other Aspire Graduation
URM Target Growth Rate
URM Departure


(A) Overall Ph.D. Graduate and Assistant Professor Hiring Trends: Data v. Model Predictions
(i) Ph.D. Graduates
(ii) Assistant Professors: Total Population
(iii) Assistant Professors: Newly Hired
Annual Population Ph.D. Graduates
Total Population Assistant Professors
Newly Hired Assistant Professors
R²=0.99
R²=0.96
R²=0.79
(B) URM Ph.D. Graduate and Assistant Professor Hiring Trends: Data v. Model Predictions
(i) Ph.D. Graduates
(ii) Assistant Professors: Total Population
(iii) Assistant Professors: Newly Hired
R²=0.99
R²=0.91
R²=0.51
(C) WR Ph.D. Graduate and Assistant Professor Hiring Trends: Data v. Model Predictions
(i) Ph.D. Graduates
(ii) Assistant Professors: Total Population
(iii) Assistant Professors: Newly Hired
R²=0.99
R²=0.94
R²=0.78
Input data
Model prediction


(A) Short-term simulation (through 2030)
(B) Long-term simulation (through 2080)
Intervention: Number of Assistant Professor Positions
No Change
Increase (+100/year)
Intervention: URM Ph.D. Transition Rate
No Change
Increase (to 10%)
(i)
(ii)
(iii)
(iv)
% URM
13.8%
5.9%
12.4%
12.5%
73.0%
8.9%
56.5%
58.3%
Ph.D. Graduates
Assistant Professors

Appendix-Table 1. Model Formulation

Notation	Description	Formulation
UTG	URM Target Growth Rate	$\exp(t * C_{UTG})$
$GR_{WR,Other}$	WR Non-Faculty Student Growth Rate	BSG * $P_{0,WR,Other}$
$GR_{WR,Faculty}$	WR Faculty Student Growth Rate	BSG * $P_{0,WR,Faculty}$
$GR_{URM,Other}$	URM Non-Faculty Student Growth Rate	BSG * $P_{0,URM,Other}$
$GR_{URM,Faculty}$	URM Faculty Student Growth Rate	MAX(BSG * $P_{0,URM,Faculty}$, UTG * $P_{0,URM,Faculty}$)
$PHD_{WR,Other}$	WR Non-Faculty PHD Graduates	$PHD_{WR,Other,0} + \int GR_{WR,Other} - DR_{WR,Other} dt$
$PHD_{WR,Faculty}$	WR Faculty Student PHD Graduates	$PHD_{WR,Faculty,0} + \int GR_{WR,Faculty} - MR_{WR,Faculty} dt$
$PHD_{URM,Other}$	URM Non-Faculty PHD Graduates	$PHD_{URM,Other,0} + \int GR_{URM,Other} - DR_{URM,Other} dt$
$PHD_{URM,Faculty}$	URM Faculty PHD Graduates	$PHD_{URM,Faculty,0} + \int GR_{URM,Faculty} - MR_{URM,Faculty} - TR_{URM,Faculty} dt$
$DR_{WR,Other}$	WR Non-Faculty Student Departure Rate	$PHD_{WR.Other}$
$MR_{WR,Faculty}$	WR Faculty Student Market Entrance Rate	$PHD_{WR.Faculty}$
$DR_{URM,Other}$	WR Non-Faculty Student Market Entrance Rate	$PHD_{WR.Other}$
$MR_{URM,Faculty}$	WR Faculty Student Market Transition Rate	C_{UTR}*$PHD_{URM.Faculty}$
$TR_{URM,Faculty}$	WR Faculty Student Departure Rate	(1-C_{UTR})*$PHD_{URM.Faculty}$

PD_{WR}	WR Candidates on the Market (e.g., Postdocs)	$PD_{WR,0} + \int MR_{WR,Faculty} - HR_{WR} - DR_{WR,Faculty} dt$
PD_{URM}	URM Candidates on the Market (e.g., Postdocs)	$PD_{URM,0} + \int MR_{URM,Faculty} - HR_{URM} - DR_{URM,Faculty} dt$
π_{URM}	Proportion of URM candidates on the market	$PD_{URM}/(PD_{URM} + PD_{WR})$
HR_{WR}	Hiring rate of WR candidates	$MIN[PD_{WR}, S*(1-\pi_{URM})]$
HR_{URM}	Hiring rate of URM candidates	$MIN(PD_{URM}, S*\pi_{URM})$
$DR_{WR,Faculty}$	WR Faculty Student Departure Rate	$\begin{cases} 0 & if\ HR_{WR} < \frac{PD_{WR}}{5} \\ \frac{PD_{WR}}{5} & otherwise \end{cases}$
$DR_{URM,Faculty}$	URM Faculty Student Departure Rate	$\begin{cases} 0 & if\ HR_{URM} < \frac{PD_{URM}}{5} \\ \frac{PD_{URM}}{5} & otherwise \end{cases}$
AP_{WR}	WR Assistant Professors	$AP_{WR,0} + \int HR_{WR} - HR_{WR,t-6} dt$
AP_{URM}	URM Assistant Professors	$AP_{URM,0} + \int HR_{URM} - HR_{URM,t-6} dt$

Note: $HR_{.,t-6}$ denotes hiring rate of assistant professors delayed by six time steps (i.e., the length of a tenure cycle). For timesteps <7, $HR_{.,t-6}$ is calculated by amortization of the initial value of assistant professors $AP_{.,0}$

1 **Appendix-Table 2. Parameters and Exogenous Variables**

2

Notation	Description	Value	Source
$P_{0,URM,Faculty}$	URM Faculty Student Growth Rate Multiplier	34.44	**AAMC Faculty Roster** (Imputed values, URM hiring 1980-1997)
$P_{0,URM,Other}$	URM Non-Faculty Student Growth Rate Multiplier	64	**AAMC Faculty Roster** (Exponential fit of URM Ph.D. graduate growth and imputed URM hiring 1980-1997)
$P_{0,WR,Faculty}$	WR Faculty Student Growth Rate Multiplier	566.67	**AAMC Faculty Roster** (Imputed values, WR hiring 1980-1997)
$P_{0,WR,Other}$	WR Non-Faculty Student Growth Rate Multiplier	3500	**AAMC Faculty Roster** (Linear fit of WR Ph.D. graduate growth and imputed WR hiring 1980-1997)
C_{UTG}	URM Target Growth Constant	0.0728	**FASEB** (Author estimation based on exponential fit to URM Ph.D. graduation rate 1980-2013)
$PHD_{WR,Other,0}$	Initial WR Non-	3570	**FASEB** (Author

	Faculty PhD Graduates		estimation based on number of WR Ph.D. graduates)
$PHD_{WR,Other,0}$	Initial WR Faculty PhD Graduates	438	**FASEB** (Author estimation based on number of WR Ph.D. graduates)
$PHD_{WR,Other,0}$	Initial URM Non-Faculty PhD Graduates	84.6	**FASEB** (Author estimation based on number of URM Ph.D. graduates)
$PHD_{WR,Other,0}$	Initial URM Faculty PhD Graduates	25.4	**FASEB** (Author estimation based on number of URM Ph.D. graduates)
C_{UTR}	URM Transition Rate Constant	0.0025	**AAMC Faculty Roster** (Author estimation based on % URM Assistant Professor 2014)
$PD_{WR,0}$	Initial WR Candidates on the Market	511	**AAMC Faculty Roster** (Imputed Hiring Value)
$PD_{URM,0}$	Initial URM Candidates on the Market	19	**AAMC Faculty Roster** (Imputed Hiring Value)
S	Faculty Slots Available per Year	Step function time series: $S = \begin{Bmatrix} 601.11 & t \in [0,18) \\ 1063.67 & t > 18 \end{Bmatrix}$	**AAMC Faculty Roster** (average of imputed hiring values: 1980-1997; 1998-2013)
$AP_{WR,0}$	Initial WR Assistant Professors	3246	**AAMC Faculty Roster**

$AP_{URM,0}$	Initial URM Assistant Professors	132	**AAMC Faculty Roster**

3
4