

Analysis of NIH K99/R00 Awards and the Career Progression of Awardees

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Abstract

Many postdoctoral fellows and scholars who hope to secure tenure-track faculty positions in the United States apply to the National Institutes of Health (NIH) for a Pathway to Independence Award. This award has two phases (K99 and R00) and provides funding for up to five years. Using NIH data for the period 2006-2022, we report that ~230 K99 awards were made every year, representing ~\$25 million annually. About 40% of K99 awardees were women and ~89% of K99 awardees went on to receive an R00 award annually. Institutions with the most NIH funding produced the most recipients of K99 awards and recruited the most recipients of R00 awards. The time between a researcher starting an R00 award and receiving a major NIH award (such as an R01) ranged between 4.6 and 7.4 years, and was significantly longer for women, for those who remained at their home institution, and for those hired by an institution that was not one of the 25 institutions with the most NIH funding. Shockingly, there has yet to be a K99 awardee at a historically Black college or university. We go on to show how K99 awardees flow to faculty positions, and to identify various factors that influence the future success of individual researchers and, therefore, also influence the composition of biomedical faculty at universities in the US.

eLife assessment

This study follows the career trajectories of the winners of an early-career funding award in the United States, and finds that researchers with greater mobility, men, and those hired at well-funded institutions experience greater subsequent funding success. Using data on K99/R00 awards from the National Institutes of Health's grants management database, the authors provide **compelling** evidence documenting the inequalities that shape faculty funding opportunities and career pathways, and show that these inequalities disproportionately impact women and faculty working at particular institutions, including historically black colleges and universities. Overall, the article is an **important** addition to the literature examining inequality in biomedical research in the United States.

Introduction

Postdoctoral research fellows are a driving force of the academic biomedical research enterprise. They typically have doctorate (i.e., PhD) or medical degrees (i.e., MD or DVM) which means they have completed a significant amount of education, training, and publishing.^{1–4} Postdoctoral fellows aspiring to continue in academic research typically seek tenure-track faculty appointments.⁴ Despite recent trends of new doctoral degree holders seeking private sector positions,⁵ tenure-track academic faculty positions are highly coveted and competitive due to the increasing number of PhD graduates but stagnant number of tenure-track faculty positions.^{3,6} Obtaining such positions requires consistent access to opportunities for success such as attending doctoral programs at perceived prestigious institutions, publishing manuscripts at the undergraduate, graduate, and postdoctoral levels, and receiving extramural grant funding throughout one's career.^{7–10} University prestige has significant impacts on resources,¹¹ paper acceptance rates,¹² citations,¹³ and awards.¹⁴ There is also significant bias against women, LGBTQIA+, and other systematically marginalized groups at all levels, which results in underrepresentation in STEM fields and fewer R01 awards compared to white/men counterparts.^{15–18} To combat these biases, the NIH developed funding mechanisms, such as the K99 MOSAIC and K12 IRACDA awards, to promote scientists from diverse backgrounds into tenure-track faculty positions. In addition, other non-federal grant mechanisms exist, such as the Gilliam Fellowships for Advanced Study from the Howard Hughes Medical Institute which began in 2004. The success of these programs at addressing bias or improving equity for systematically marginalized groups in the tenure-track ranks is currently unclear because the programs are either too new (MOSAIC) or data are not publicly available (HHMI Gilliam Fellowships).

Within the United States, one of the most lucrative award mechanisms to facilitate the transition from postdoctoral fellow to tenure-track faculty member in the biomedical sciences is the NIH Pathway to Independence Award (K99/R00).¹⁹ Launching in 2006, this award provides salary support for postdoctoral fellows for two years during the K99 phase and \$250,000/yr for 3 years during the R00 phase.^{20,21} The candidate benefits directly through funding, visibility, and protected time.^{1,21} Having a K99/R00 award also demonstrates to hiring institutions that the candidate has a track record of receiving extramural funding which is a requirement for future success in academic research careers.²² Roughly 89% of K99 awardees received R00 funding on a rolling yearly basis, which indicates having obtained a faculty position although factors such as publications, presentations, interpersonal skills, choice of advisor, and others also contribute to securing faculty positions. Of those that secure faculty positions, many factors influence postdoctoral researchers in their decision of which position to choose including career-oriented factors like department, support, colleagues, and personal factors such as family and location. About 50% of R00 awardees subsequently attain R01 funding²³ which is a higher success rate than other NIH career development grants such as K01, K08, and K23.^{19,24} although having any K-award tends to increase future funding success.²⁵ The specific and cumulative factors that influence future NIH funding success for R00 awardees has not been examined.

Individuals from marginalized communities are typically at a disadvantage when applying for research grants such as R01s. For example, men typically experience 2-3% greater funding success rates; however, in 2019 women had an advantage in funding success rates for NIH research project grants (21% versus 20%).²⁶ Men also receive an average of \$35,000-\$45,000 more NIH funding per grant than women or other gender identities,^{17,26,27} however, some report no difference.²⁸ Women have been reported to have a disadvantage in transitioning from K-awards to R-awards from the NIH.²⁹ Racial and ethnic minorities are also at a disadvantage in receiving R01 funding compared to white counterparts.^{30,31} The institution itself also influences R01 funding success. Here, we explore the conversion of K99 to R00 awards by year, gender identity, and institutions (other demographic data are not publicly available) to demonstrate the flow of

K99/R00 awardees from postdoc to faculty positions. We also determine whether these influence future NIH funding success for K99/R00 awardees. These findings have the potential to influence how and where career development awards are made, how potential candidates are supported, and how grant reviewing practices may be changed to be more equitable and inclusive.

Methods

Data acquisition and analysis

Raw K99/R00 data examined in this manuscript is publicly available from the NIH Reporter (<https://reporter.nih.gov/>). Filtered data and annotated data used to generate **Figures 1-5** and **Tables 1 & 2** are available in the Supplemental Tables. Names have been removed; however, the corresponding author will provide the identified data upon reasonable request. All data for K99 awardees, R00 awardees, and matched K99/R00 awardees is included in Supplemental Tables 1-3. The data used to generate **Figure 6** and **Supplemental Figures S1** and **S2** were generated by Wapman et al. and are available on Zenodo at <https://doi.org/10.5281/zenodo.6941651>. K99 and R00 data were downloaded from NIH Reporter using the “Advanced Search” function to include only the year range (2006-2022) and only the grant of interest (i.e., K99 or R00). Duplicate values containing additional awards for the same contact PI (i.e., supplemental awards or multiple years of the same award) were removed. The latest available fiscal year for the K99 award was used and the earliest available fiscal year for the R00 was used. The K99 and R00 institution were aligned and confirmed that the contact PI name was identical before removing the contact PI name from the dataset. The institutions were analyzed using Microsoft Excel and Graphpad Prism (version 9.4.1). Data on doctoral degree university and subsequent faculty position are from Wapman et. al, 2022 and are available at <https://larremorelab.github.io/us-faculty/>. We included the following fields from this dataset: Anatomy, Animal Sciences, Biochemistry, Biological Sciences, Biomedical Engineering, Biophysics, Biostatistics, Environmental Health Sciences, Exercise Science, Kinesiology, Rehab, Health, Health, Physical Education, Recreation, Human Development and Family Sciences, Immunology, Microbiology, Molecular Biology, Neuroscience, Nursing, Nutrition Sciences, Pathology, Pharmaceutical Sciences, Pharmacology, Pharmacy, Physiology, Psychology, Public Health, and Veterinary Medical Sciences. We examined the Historically Black Colleges and Universities from this dataset. The list of K99 institutions and R00 institutions and HBCU institutions were plotted as Sankey diagrams using the “gvisSankey()” function in the “googleVis” package in R (version 2022.07.1, Build 554). Interactive versions of the K99 to R00 Sankey plot is available at: https://k99tor00.shinyapps.io/K99-R00_Sankey/ with data available here: <https://zenodo.org/records/10005359> and code available here: <https://github.com/chsolis/K99toR00SankeyNetwork2007-2022>. Interactive versions of the HBCU Sankey plots (**Fig. 7**) are available at: <https://dantyr.github.io/html/>. The K99 and R00 location maps were generated on ObservableHQ using a map layer and overlaying heatmap dot plot by latitude and longitude coordinates from the NIH Reporter dataset. Data on R01, DP2, and R35 awards were exported from NIH Reporter using the list of K99 to R00 transfers for each year from 2007 to 2023 and the time from each candidate’s first R00 budget start date to R01, DP2, and R35 budget start date was calculated.

Institutional classification

Institutions were classified as either “highest NIH funding” or “lower NIH funding” based on 2022 NIH funding levels and included the 25 institutions with the most NIH funding. The institutions included in this list in order from most funding to least are: Johns Hopkins University, University of California, San Francisco, University of Pittsburgh at Pittsburgh, Duke University, University of Pennsylvania, Stanford University, University of Michigan at Ann Arbor, Washington University, Columbia University Health Sciences, University of California, San Diego, University of California Los Angeles, Yale University, University of Washington, Univ of North Carolina Chapel Hill,

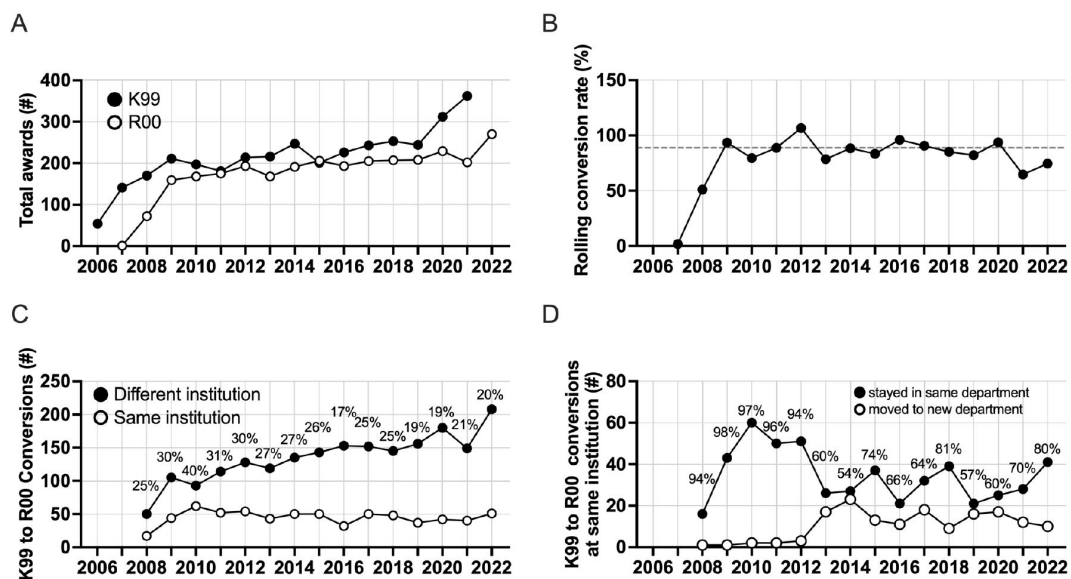


Figure 1

Rate of K99 and R00 awards and conversion by year. A) Total extramural K99 awards and R00 awards made by year. B) Annual rolling conversion rate of R00 award activation compared to the number of K99 awards activated in the prior year. Average rolling retention rate (89%) from 2008-2020 shown in dashed line. C) Total number of extramural K99 to R00 conversions per year at the same institution or different institution. For each year, numbers represent the percentage of K99 awardees that stayed at the same institution for the R00 activation. D) Within the K99 to R00 conversions at the same institution, the number of K99 to R00 conversions either in the same department or different department, by year. For each year, numbers represent the percentage of K99 awardees that stayed in the same department.

Massachusetts General Hospital, Emory University, Icahn School of Medicine at Mount Sinai, University of Minnesota, Fred Hutchinson Cancer Center, Northwestern University at Chicago, Brigham and Women's Hospital, New York University School of Medicine, Vanderbilt University Medical Center, and University of Wisconsin-Madison. Leidos Biomedical Research, Inc. is also included in this list but does not have any K99 or R00 awardees.

Binary name-to-gender classification

Name-based ascription tools for gender and for race/ethnicity are inherently biased and these biases occur unevenly across groups.³² A name-to-gender assignment tool (GenderAPI, <https://gender-api.com/>) was used to assign a binary gender (man/woman) to K99/R00 awardees. GenderAPI was chosen based on its low rate of mis-classifications and non-classifications.³³ It assigns gender identity as either men, women, or unknown. Because the terms male and female typically refer to biological sex, the terms man/men or woman/women are utilized here. However, it is important to note that gender identity is a social construct that is non-binary and non-static. Individuals identifying as transgender, non-binary, or gender non-conforming, or whose gender identity has changed since the time of receiving the K99 or R00 award are at risk of being misgendered. We acknowledge this remains a major limitation of this type of name-to-gender methodology and we hope it changes in the future to be more inclusive.

Results

K99 to R00 conversions are increasing in time

K99 awards provide funding for 2 years and awardees generally can accept faculty positions within the second year. From the total of 3475 extramural K99s awarded from 2006 through 2021 (Fig. 1A), 2703 extramural K99 awardees that converted to R00 awards by the end of 2022 (Fig. 1B). Thus, a total of 78% of K99 awardees converted to the R00 phase but on a rolling basis excluding the first 2 years and last 2 years of the program, ~89% of K99 awardees go on to receive the R00 award. From 2007-2022, there were a total 2847 R00 awards (Fig. 1A), and thus we conclude that the remaining 144 R00 awardees with no matching K99 data are likely intramural NIH K99 awardees. There is no public data on intramural K99 awards in NIH Reporter. This means that there are 772 scientists with K99 awards did not get R00s. 468 of these K99 awards were from 2020 or later and may still convert to the R00 phase; however, 304 were from 2019 or earlier, which suggests they have not and will not convert to the R00 phase. Where those scientists went and why they did not convert the K99 grant into an R00 is unknown. From 2008 through 2021, there were an average of 234 K99 awards/year, and from 2009 to 2022, an average of 198 K99 awardees converted to R00 awards/year (Fig. 1B). In the early years of the K99/R00 program, around 30% of R00 awardees had been hired at the same institution. From 2012 to 2016, the proportion of awardees that stayed at the same institution declined to about 20% where it has remained consistent (Fig. 1B). In the beginning of the K99/R00 program, nearly all the awardees that stayed at the same institution also stayed in the same department; however, from 2013 onward a greater number moved to new departments (Fig. 1C). This is in line with what Pickett reports that ~20% of K99 recipients received their first R01 award at the same institution where they had a K99 award.²³ In general, the majority of K99 awardees in recent years move to new institutions to activate the R00 phase and begin faculty positions.

Geographic localization of K99 awards are at a more concentrated set of institutions whereas R00 awards are more dispersed

K99 awards have been granted to individuals at 256 different institutions and R00 awardees represented 357 unique institutions. Strikingly, 54% of all K99 awardees were at 10% of all institutions, while 46% of all R00 awardees were at 10% of institutions. K99 and R00 awards were both most frequent in parts of the country containing a high concentration of research

universities (e.g. the Bay Area in California and Boston Area in Massachusetts) (**Fig. 2** [↗](#)). Three institutions had more than 75 K99 awardees through the end of 2022 (Stanford [237], University of California San Francisco [116], and Massachusetts General Hospital [93]), and 73 institutions had just one, with the median being four awards per institution. Remarkably, Stanford had more awards than the 134 institutions with the fewest number of awards (**Figure 2** [↗](#)). R00 awards were dispersed across more institutions than K99 awards, with the maximum number being 60: three institutions had more than 50 (Massachusetts General Hospital [60], University of Pittsburgh [58], and University of Michigan [54]), and 116 institutions had just one (**Figure 2** [↗](#)). K99 awards are more concentrated in East and West coast states than R00 awards (73% vs 55%). California (n=491), Massachusetts (n=348), and New York (n=121) had the largest proportion of K99 relative to R00 awards, and Texas (n=48), Ohio (n=46), Michigan (n=33), and Arizona (n=31) received the greatest number of R00 awardees relative to K99 awards. These data indicate that while more K99 awards are physically located on the East and West coast universities, the R00 awardees are distributed more evenly throughout the geographic location of the United States.

Institutions with the most NIH funding tend to hire K99/R00 awardees from other institutions with the most funding

We next analyzed the flow of awardees from K99 institution to R00 institution (n=2703 individuals) (**Fig. 3** [↗](#)). We coded the 25 institutions that received the most NIH funding in the year 2022 as “1” and the rest as “2”; however, Leidos Biomedical Research, Inc. is included in the highest funded institutions but has no K99 or R00 awardees. The institutions that produce the highest number of K99 awardees also tend to hire the most R00-awardees and also tend to receive the most NIH funding (**Fig. 3** [↗](#)). Most K99 awardees attain faculty positions at private institutions (62%) compared to public institutions (38%). Private institutions with the highest NIH funding generally hire R00 faculty from other private institutions whether they are in the top NIH funding category (31.2%) or not (46.9%). The public institutions with the highest NIH funding and private institutions that do not have the highest NIH funding also tend to hire R00 faculty more from private institutions categorized as both top NIH funding (20.3% and 22.5%, respectively) and lower NIH funding (27.2% and 41.3% respectively). Notably, the public and private institutions with the largest NIH funding portfolios and other private institutions have hired only 26% of K99 awardees from public institutions with smaller NIH portfolios. In contrast, these public institutions with smaller NIH funding portfolios have hired 74% of all K99 awardees from similar institutions (**Table 1** [↗](#)).

K99/R00 awardee self-hires are more common at institutions with the top NIH funding

We also demonstrate the number of self-hires of K99/R00 recipients from within institutions. A mean of 27% of K99 awardees remain at their home institution during the R00 phase; however, this differs based on institutional type and NIH funding portfolio size. At private institutions with large NIH funding portfolios, 36% of those stay at the same institution for the R00 phase. Fewer individuals stay at the same institution from public institutions with large NIH funding portfolios (30.9%), private smaller NIH funding portfolios (23.3%), and public smaller NIH funding portfolios (18.5%). 70% of the R00 awardees recruited by Massachusetts General Hospital were self-hires. Of the remaining 17 individuals, 8 were from other Harvard-associated institutions (Brigham and Women’s Hospital, Dana Farber Cancer Institute, Broad Institute). There are other institutions that have higher relative proportions of K99 awardees remain for the R00 phase (i.e., University of Pittsburgh, Johns Hopkins University, and Brigham and Women’s Hospital). In contrast, some institutions recruit more of their R00 awardees from external institutions (i.e., Northwestern University, University of Texas Southwestern, University of Utah, and Yale University).

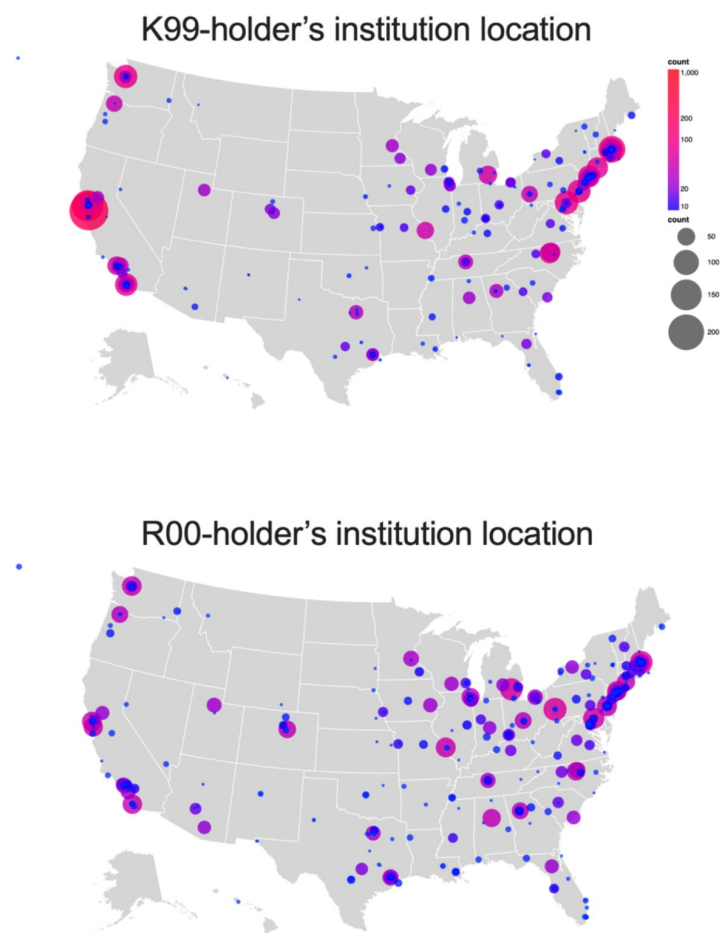


Figure 2

Cartographic representation of the number of K99 and R00 awards by institutional location and state from 2007-2008 through 2021-2022. Note no individual award or grant is counted more than 1 time.



Figure 3

Sankey diagram of all successful K99 to R00 award transfers from 2007-2022 with the K99 institution on the left and R00 institution on the right. An interactive version of this figure can be found at: [Interactive Sankey diagram can be found at: https://k99tor00.shinyapps.io/K99-R00_Sankey/](https://k99tor00.shinyapps.io/K99-R00_Sankey/)

	Top NIH funding, private R00 n(%)	Top NIH funding, public R00 n(%)	not Top NIH funding, private R00 n(%)	not Top NIH funding, public R00 n(%)
Top NIH funding, private K99	295 (56.0%) 105 (31.2%)*	71 (20.3%)	179 (22.5%)	196 (19.0%)
Top NIH funding, public K99	47 (8.9%)	152 (43.5%) 44 (18.3%)*	94 (11.8%)	174 (16.9%)
not Top NIH funding, private K99	157 (29.8%)	95 (27.2%)	437 (55.0%) 252 (41.3%)*	251 (24.3%)
not Top NIH funding, public K99	28 (5.3%)	31 (8.9%)	85 (10.7%)	411 (39.8%) 220 (26.2%)*
Column total	527 (100%)	349 (100%)	795 (100%)	1032 (100%)

Table 1

Number and frequency of R00 faculty hires from specific types of K99 institutions from 2006-2022. Note, each column sums to 100%. *=excluding self-hires to the same institution.

More K99 awardees are men than women

We performed a name-to-gender classification using binary terms of man and women. This type of classification is inherently biased unevenly across demographics and groups (please see Methods).³² Using this methodology, we found that men make up the majority of K99 (n=2028, 58%) and R00 (n=1655, 58%) awardees. The same percentages of men and women K99 awardees convert their K99 awards to R00 awards (Table 2). Since the beginning of the K99 award mechanism in 2006, men have received more K99 awards than women each year; however, the percentage of women receiving K99 awards has risen slightly in the most recent decade (Fig. 4).

K99 and R00 awards are concentrated within the highest funded institutions

The majority of K99 awardees were at private institutions with 28% from the top 25 highest funded institutions and 35% from other private institutions. The remaining 37% of K99 awardees were from public institutions (Fig. 5 and Table 4). In contrast, the majority of R00 awardees were at public institutions outside of the top 25 highest funded (38%). The second largest group of R00 awardees were at private institutions outside of the top 25 highest funded (29%) (Fig. 5 and Table 4). To further put this in context, we examined the composition of institutions represented by both K99 awards and R00 awards. We found that 45% of K99 awards were made to the top 25 highest funded institutions which represents while 55% of K99 awards were made to 226 lower-funded institutions (Fig. 5). R00 awards were distributed slightly more evenly with only 32% of R00 awards going to the top 25 highest-funded institutions and 68% going to lower funded institutions which represents 327 institutions. This means that the top 25 highest funded institutions had an average of 65.5 K99 awards and 38.2 R00 awards per institution. In contrast, the lower-funded institutions had an average of 8.4 K99 awards and 5.8 R00 awards per institution. While a greater percentage of both K99 and R00 awards are made at lower-funded public and private institutions, the top 25 highest funded institutions clearly receive and retain a far greater share of both K99 and R00 awardees.

Being female, staying at the same K99 and R00 institution, and activating the R00 at a lower-funded institution are disadvantages to future funding success

We sought to determine which factors impacted whether K99/R00 awardees received major subsequent extramural funding in the form of an NIH R01, DP2, or R35 MIRA grant. We refer to these as “major awards” as they fund a similar total cost, timeframe, and hold similar weight for tenure and promotion considerations. Thus, we calculated a Cox proportional hazard model which includes whether the K99/R00 awardees stayed at the K99 institution for the R00 phase or left, were men or women, whether the K99 or R00 institutions were private or public, and whether the K99 and R00 institutions were one of the top 25 institutions for NIH funding in 2022 (Fig. 6). Individuals that stayed at the same institution for the K99 and R00 phase were at the greatest disadvantage for receiving future funding (HR: 0.7095, $P < 0.0001$). The next strongest factor in receiving future R01 funding was whether the R00 institution was in the top 25 largest NIH funding portfolios ($P < 0.0001$). The third factor was whether the candidate was a man or woman ($P = 0.001$), consistent with previous findings that women are at a disadvantage in academic career placement.³⁴ The NIH funding portfolio of the K99 institution and whether the K99 institution was private or public did not impact success in receiving future R01 funding.

The similarity in effect sizes suggests a cumulative advantage, or disadvantage, model. K99/R00 awardees that were men and moved to a new institution with large NIH funding portfolios for the R00 phase of the award have the shortest median time to receiving a subsequent major NIH award (median 4.6 years from the R00 budget start date to major award budget start date) as well as

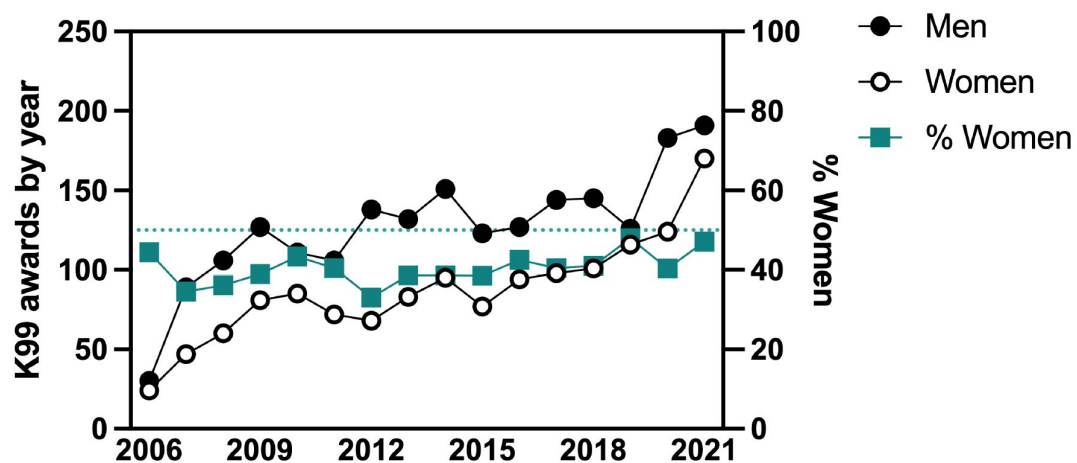


Figure 4

Number of K99 awards per year to either men or women (left Y axis) and the percentage of K99 awardees that are women (right Y axis).

	N	%
K99 Recipients	3474	100
Men	2028	58
Women	1395	40
Unknown	51	1
R00 Recipients	2843	100
Men	1655	58
Women	1142	40
Unknown	46	1
Successful K99-R00 Transition	2703	100
Men	1575	58
Women	1090	40
Unknown	38	1

Table 2

Number and frequency of men and women receiving K99 and R00 awards and whether they successfully converted K99 to R00 awards from 2006-2022.

	N	%
K99 recipient institution	3473	100
Top funded Private	990	28.5
Top funded Public	582	16.8
Lower funded Private	1212	34.9
Lower funded Public	689	19.8
R00 recipient institution	2842	100
Top funded Private	549	19.3
Top funded Public	368	12.9
Lower funded Private	831	29.2
Lower funded Public	1094	38.5
Successful K99-R00 transition K99 institution	2703	100
Top funded Private	741	27.4
Top funded Public	467	17.3
Lower funded Private	940	34.8
Lower funded Public	555	20.5

Table 3

Number and frequency of K99 and R00 awardees and which type of institution they received the award at. Successful K99-R00 transitions show the K99 award institution from 2006-2022. The 2842 R00 recipients includes recipients of NIH intramural K99 awards.

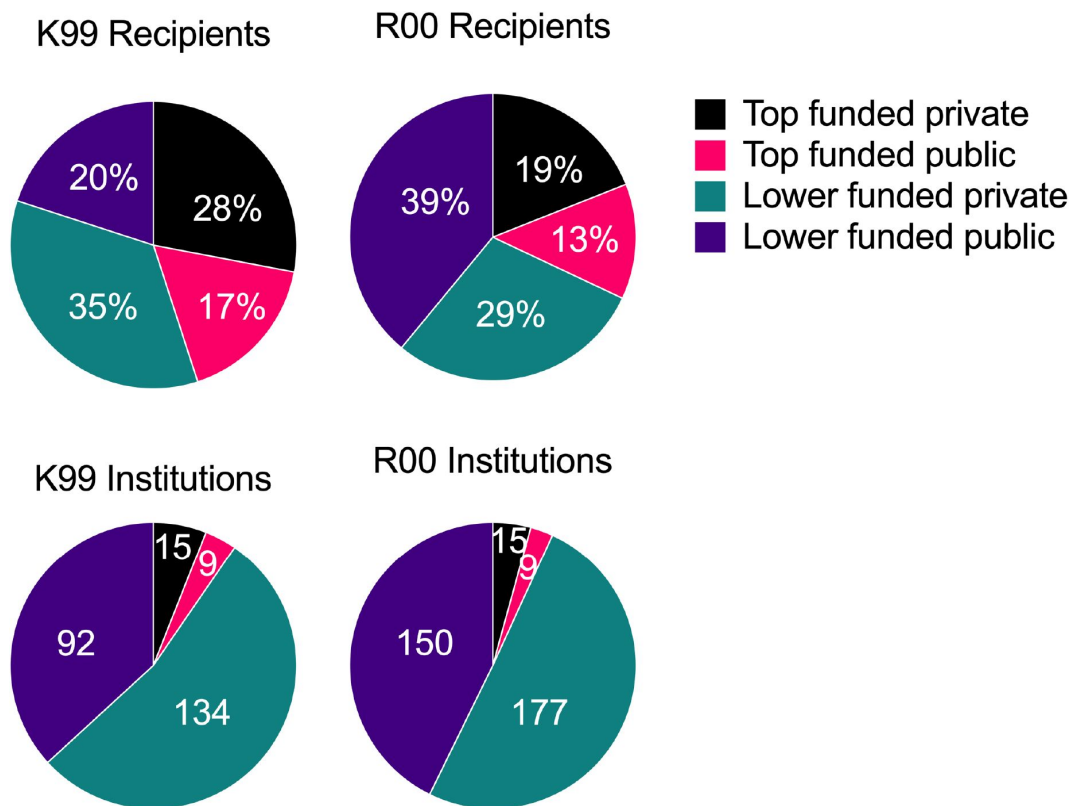


Figure 5

The percentage of K99 and R00 recipients by the institution type and the number of each institution type that has received K99 and R00 awards from 2006-2022.

	N	%
K99 recipient institution	250	100
Top funded Private	15	6.0
Top funded Public	9	3.6
Lower funded Private	134	53.6
Lower funded Public	92	36.8
R00 recipient institution	351	100.0
Top funded Private	15	4.3
Top funded Public	9	2.6
Lower funded Private	177	50.4
Lower funded Public	150	42.7

Table 4

Number and frequency of institution type that received K99 and R00 awardees from 2006-2022.

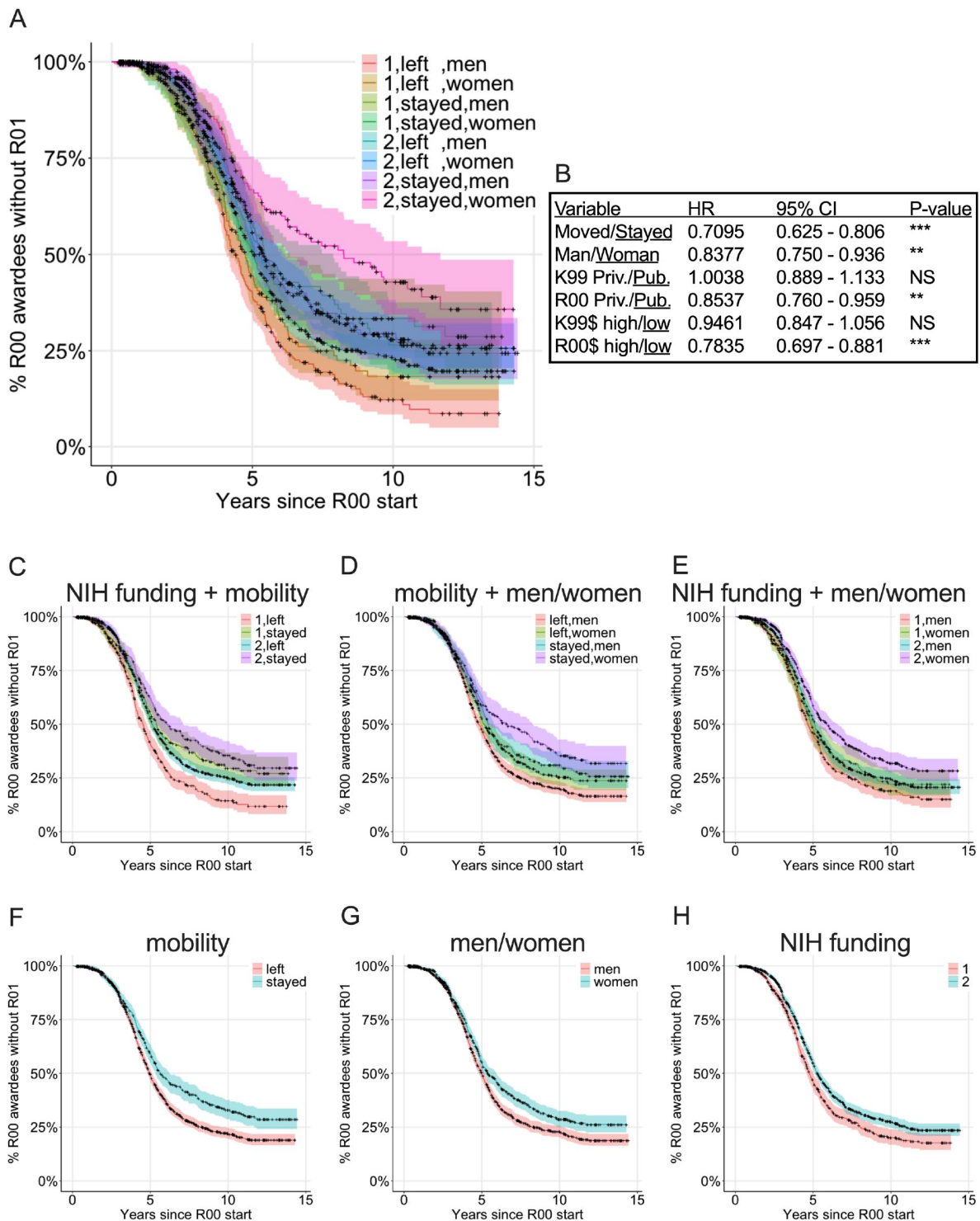


Figure 6

Cox proportional hazard model examining K99/R00 awardees success at receiving subsequent major extramural NIH awards by mobility, classified as women or men, and R00 institutional NIH funding level. Mobility is classified whether the K99 awardee moved to a new institution for the R00 award activation or stayed at the same institution. Classification of women or men was determined by name (see Methods for description and limitations). R00 institution funding level is classified as: 1 = 25 highest NIH funded institutions in 2022 and 2: all other institutions. A) Survival curve demonstrating all 8 possible classifications. B) Cox proportional hazard model hazard ratio, 95% confidence interval, and P-value. Survival plots showing the individual components of the full model including C) NIH funding + mobility, D) mobility + women/men, E) NIH funding + women/men, F) mobility, G) women/men, and H) NIH funding.

greater overall percent chance of ever receiving a major award (84.6%; [Fig. 6](#)). Each cumulative disadvantage increased the median time to receive a major NIH award by about 6 months and reduced the overall chance to receive subsequent major NIH award by 5-6%. The median time to receive subsequent major NIH awards for K99/R00 awardees that were women that stayed at an R00 institution with smaller NIH funding portfolios is 7.4 years and there is only a 60% chance to receive any major NIH award. This amounts to 2.8 years longer and 24.6% lower chance to receive any subsequent major funding compared with men who move to institutions with the largest NIH funding portfolios for the R00 phase of the award. This length of time is critical for tenure-track faculty who typically have between 6-7 years to earn tenure which often hinges on receipt of a major research grant for research-intensive faculty.

Faculty at HBCUs mostly have doctoral degrees from HBCUs and public and private institutions outside of the top 25 NIH funding category

It is clear that diversity in all metrics is beneficial for scientific progress. We sought to examine the rates of funding for those at historically under-funded institutions. We examined HBCUs in NIH Reporter, we found that there were 8 active R01 awards at Morehouse School of Medicine, 9 at Howard, 5 at Meharry Medical College, and 5 at Jackson State University in April 2023. Strikingly, of all 2703 K99 awardees that transitioned to R00 awards, no K99 awardees were from HBCUs, and only 2 K99 awardees activated R00 awards at HBCUs. Thus, there are not enough data available to determine how the classification of HBCU impacts future R01 funding success; however, Wapman and colleagues have made an extensive dataset of all United States faculty from 2010 to 2020 and where they received their doctoral degrees publicly available¹⁵. Wapman et al., did not demonstrate doctoral degrees or faculty hiring practices at HBCUs. This prompted us to examine faculty flow at HBCUs. We examine where faculty with doctoral degrees from HBCUs ended up for their faculty career ([Fig. 7A](#)) and where faculty members at HBCUs received their doctoral degrees ([Fig. 7B](#)) specifically related to biological and biomedical faculty. We included only biology, biomedical, and health related fields (see Methods) which excluded fields such as computer science, business, language, etc., which resulted in a total of 65,120 faculty flows from doctoral degree programs.

Out of the 65,120 total faculty flows, there are data on 296 faculty members with doctoral degrees from HBCUs with a known doctoral degree granting institution. There were 529 faculty at HBCUs with a known doctoral degree granting institution. Those with doctorates from primarily-underrepresented minority-serving institutions are less likely to be in academic positions³⁵. The HBCU granting the most doctoral degrees that went on to receive faculty appointments in the United States were from Howard University with 116 individuals. The majority of these are working as faculty members at Howard (56). The HBCU with the next most doctoral degrees in faculty positions is Florida A&M with 44 and the bulk of these (32) are employed at Florida A&M. Most of the institutions with faculty that have doctoral degrees from HBCUs are other HBCUs and public and private institutions. Notably there are very few HBCU doctoral degree holders working at public or private institutions within the top 25 NIH funding category ([Fig. 7A](#)). When examining faculty flows to HBCU's it is apparent that the HBCU faculty ranks employ a large number of faculty with HBCU doctoral degrees ([Fig. 7B](#)). There are more faculty at Howard University with doctoral degrees from a range of different types of institutions which are primarily public and private and institutions outside of the top 25 NIH funding category; however, there are some (9 from University of Michigan, 1 from Vanderbilt, 4 from University of Wisconsin, and 3 from UNC). For the other HBCUs, the faculty ranks are dominated primarily by faculty with doctoral degrees from other HBCUs and public universities, primarily outside of the top 25 NIH funding category. These data highlight stark differences in hiring practices between HBCUs and institutions that hire significant numbers of R00 awardees. We quantified where faculty at a subset of institutions received their doctoral degrees with annotations for the top 15 institutions (Supplemental Fig. S1).

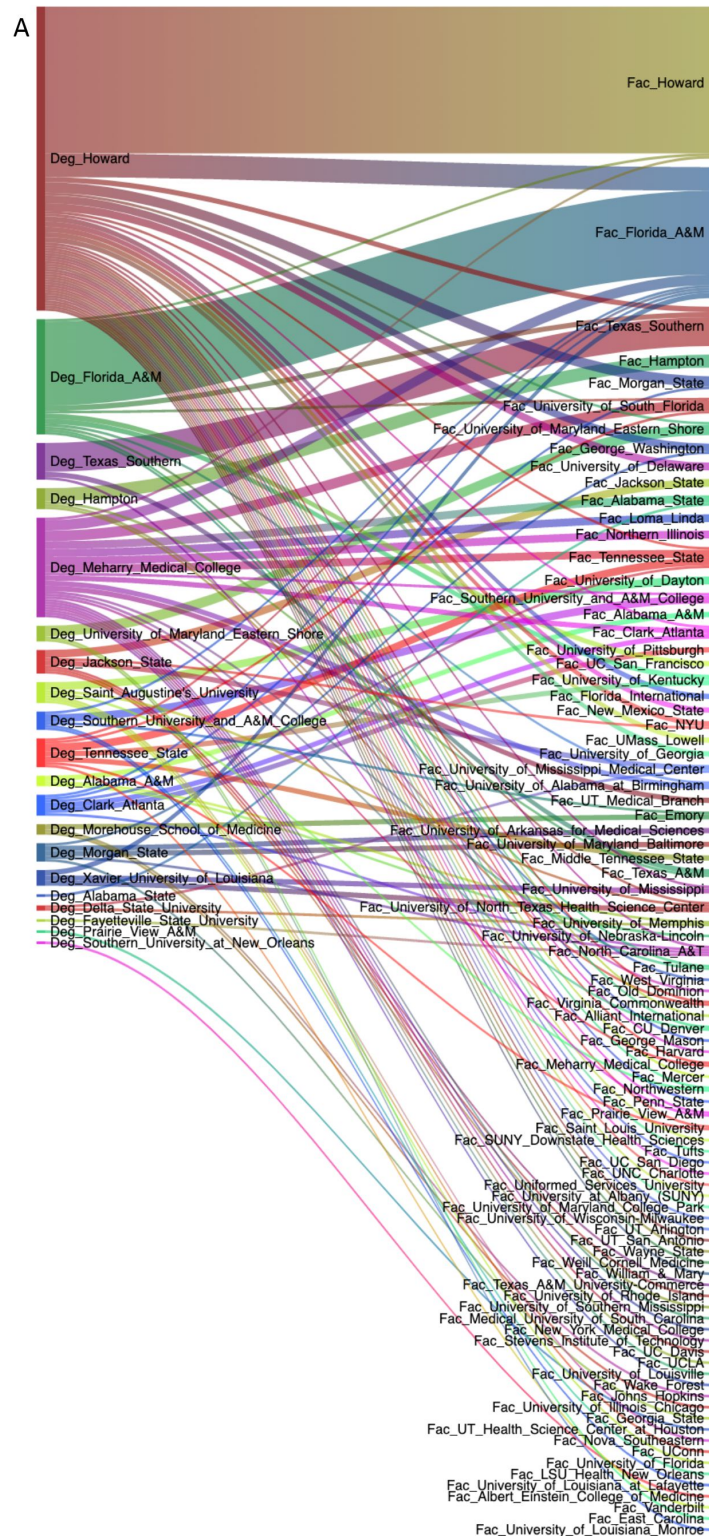


Figure 7

A) Sankey diagram of faculty members that received doctoral degrees from HBCUs (on left) and the faculty institution they moved to (on right). B) Sankey diagram of faculty members at HBCUs (on right) and where they received their doctoral degrees (on left). Interactive versions of these figures can be found at: https://dantyrr.github.io/K99-R00-analysis/HBCU_deg.html for **Figure 7A** and https://dantyrr.github.io/K99-R00-analysis/HBCU_faculty.html for **Figure 7B**.

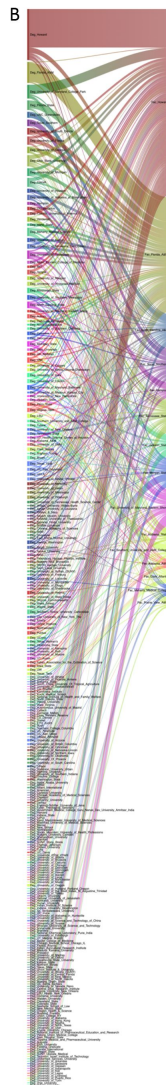


Figure 7 (continued)

Self-hiring and regional hiring of faculty is ubiquitous

Some institutions tend to hire more faculty with doctoral degrees from the same institution (i.e., self-hires). A quarter of faculty at USC have USC doctoral degrees (Supplemental Fig. S1). In contrast, only ~10-12% of faculty at Duke and Yale have doctoral degrees from Duke and Yale (Supplemental Fig. S1). In contrast, at Princeton, there are relatively few faculty with Princeton doctoral degrees. Certain institutions (Harvard, Columbia, U Penn, Stanford, Johns Hopkins, University of Michigan, UC Berkeley, Duke, and UNC) are nearly ubiquitous in the top 15 doctoral degrees for faculty at many institutions. There is also regional bias where institutions in the same region or city are more heavily represented. For example, doctoral degree holders from Tufts and Boston University are common for Harvard Faculty. A significant number of faculty at University of Michigan have doctoral degrees from Wayne State University, which is in Detroit, Michigan. The faculty at southeastern institutions have greater representation from Vanderbilt, Emory, Duke, University of North Carolina, and Washington University in St. Louis compared with the rest of the country. Similarly, the University of California system institutions have greater representations from other UC system affiliates including UC Berkeley, UCSD, UCSF, UCLA, USC, and Caltech (Supplemental Fig. S1).

Institution faculty hiring is consistent with institution type

We also examined the type of institutions that faculty received their doctoral degrees at (see Fig. 3). Massachusetts General Hospital, Yale, and Stanford are private institutions with large NIH funding portfolios along with public institutions like UCSF and U of Michigan. We compare these with historically Black colleges and universities and foreign institutions. The faculty at private institutions with large NIH funding portfolios tend to have degrees from other well-funded private institutions (Supplemental Fig. S2). The faculty at public institutions with large NIH funding portfolios (i.e., UCSF and University of Michigan) tend to have doctoral degrees from other public institutions with large NIH funding portfolios. Similarly, faculty at public institutions with smaller NIH funding portfolios have degrees from other public institutions with smaller NIH funding portfolios (Supplemental Fig. S2). The faculty at HBCU's tend to have doctoral degrees from public institutions with smaller NIH funding portfolios as well as other HBCUs (Supplemental Fig. S2). Faculty members with doctoral degrees from HBCUs are rare and do not exceed more than 2% of the total faculty except at other HBCUs and Middle Tennessee State University which has 3.9%. In general, the practice of self-hiring contributes to institutions having faculty with the same doctoral degree-type as the institution they are employed at.

Discussion

It has previously been shown that a minority of institutions populate the faculty ranks of the bulk of other institutions along prestige hierarchies across fields and disciplines.^{7,15} These findings are in-line with the Matthew effect whereby success early on increases the chance of success in the future.^{36,37} Our analyses focus on the K99/R00 career development award. We demonstrate there are significant disadvantages associated with mobility, gender identity, type of R00 institution, and whether faculty candidates move from the K99 institution or stay at the same institution. In the context of the Matthew effect, there are significant advantages for receiving the K99 award at a highly funded institution or for being classified as a man or having mobility in the choice of an R00 institution. Scientists are often the most mobile at the earliest stages of their careers whether by choice or necessity.³⁸ Academic mobility, especially in early stage investigators has been described as “coerced movement from job to job” and has also been termed “forced mobility”.³⁹ International post-doctoral fellows may have a cultural reasons for moving to the United States based in perceived bias regarding the United States’ scientific training.⁴⁰ Our analysis also demonstrates that K99 to R00 faculty flow generally follows similar hierarchies with some deviation for specific institutions. We find that a minority of private and public institutions with the largest NIH funding portfolios produce the majority of K99 awardees, and

there are a handful of private and public institutions with the largest NIH funding portfolios that recruit the most R00 awardees. Many K99 awardees from institutions with the largest NIH funding portfolios move to public institutions and institutions with smaller NIH funding portfolios for the R00 phase of the award. These also happen to be less concentrated on the East and West coast. This supports the universal core-periphery structure of hiring that Wapman and colleagues conceptualized but suggests that prestige hierarchies in academic biomedical science align with NIH funding portfolio size.¹⁵ Despite this, there are also K99/R00 awardees that move up the prestige hierarchy to public and private institutions with the largest NIH funding portfolios and some individuals that stay within the same category for both K99 and R00 award phase. There are stark differences in future major NIH grant funding depending on several factors including NIH funding portfolio size of R00 institution, gender identity, and whether the awardee moved or stayed at the K99 institution.

Notably, whether the K99 institution was private or public or the size of the NIH funding portfolio did not impact future funding success except when considering whether the candidate eventually moved for the R00 phase of the award. One key component of activating the R00 award is to demonstrate independence from the candidate's postdoctoral advisor because the candidate will need to establish independence from the postdoctoral advisor to be competitive to receive future NIH funding. Moving to a new institution clearly establishes independence; however, there are many pressures to stay at the K99 institution including familiarity with the institution, location, and family. K99/R00 awardees that stay at the same institution have an increase in the median time to future major NIH funding (either R01, DP2, or R35 MIRA) and have a reduced overall chance to receive any major NIH award. This may be due to reduced start-up packages for internal candidates, which could leave them less well-suited to perform the necessary research to be competitive for R01 funding. Candidates that remain at the same institution may also have additional duties in service work that drain their time. They may have more work on committees given the knowledge, experience, familiarity, and institutional history. Alternatively, this may be an internal bias of candidates within the institution or of grant reviewers who do not view the candidate as truly independent from their postdoctoral advisor. There are also cultural biases that largely reward white and Asian male academics by perceiving them to be more productive and devaluing work done by non-white and non-Asian men.^{41,42} These data bring to light several factors that affect the scientific human experience. Moving institutions throughout one's academic career can cause significant hardship on anyone. First generation scientists and those in systematically marginalized groups may lack support systems that those from non-marginalized groups have. Familial/friendships ties play important roles in the happiness, support, and productivity in the lives of scientists. Compounding the burden of first-generation scientists and systemically marginalized scientists with the burden of moving away from supports offered by family and friends may have a significant negative impact on those scientists. The second is that obtaining K99 funding and staying at the same institution comes with inherent biases within the system designed to support scientific talent. How these two factors are at odds with each other is of significant note to the wider scientific community. Ameliorating these disparities to increase equity should be of future focus.

Additional disadvantages to future funding success of K99/R00 awardees is whether the candidate is a man or a woman and whether the candidate is from an institution with a large NIH funding portfolio. Each of these factors can prolong the median time to future funding by about half a year and reduces the overall chance of securing future funding by ~5.5%. These cumulative disadvantages may contribute to lower likelihood of receiving promotion and tenure and may contribute to the gender disparities in faculty ranks and in leadership positions. The United States has a more even gender balance for tenure-track positions than some other countries including Japan and South Korea⁴³; however, it is apparent that women are at a disadvantage compared with men despite this. There may also be additional disadvantages for K99/R00 awardees who identify as transgender, gender non-binary, or non-conforming, or for individuals from

systematically marginalized groups, or those with disabilities. There have been recommendations to promote a sustainable biomedical research enterprise.⁴⁴ Future work is needed to examine how intersectional identities impact scientific success within the academic workforce.

We can speculate why K99 awards most often go to individuals at institutions with the largest NIH funding portfolios; however, data on individual K99/R00 applications that were not funded are not publicly available. Our data show that 772 scientists with funded K99 awards did not get R00 awards and 302 of these were from 2019 or earlier. Those made from 2020 onward may still have the possibility to convert to the R00 phase, even after the 2-year K99 period with a 1-year no-cost extension. The factors that prevented the other 302 K99 awardees from 2019 and earlier unable to convert their K99-R00 grants is cause for concern within our greater academic community. Possible explanations include leaving the biomedical workforce, accepting tenure-track positions or other positions abroad, or by simply not successfully securing a tenable tenure-track offer. Of the funded K99/R00 awardees, we can make the assumption that candidates at institutions with large biomedical research portfolios and built-in support to write competitive grant applications that may be lacking at institutions with smaller research enterprises. Institutions with the largest NIH funding portfolios may facilitate greater access to making scientific discoveries. Movement of postdocs from these institutions to independent faculty positions at institutions with the smaller NIH funding portfolios, may increase the effectiveness of the faculty at those institutions. We must also consider that senior faculty themselves review and score K99/R00 award applications, and by doing so, determine which candidates ultimately receive these awards. A contrary perspective is that K99/R00 awardees at institutions perceived as more prestigious receive their awards in part because of the name and reputation of their institution. Thus, the interpretation of our data is that the system of reviewing and scoring grants has inherent bias towards less prestigious institutions which is currently being reviewed at the NIH. We can extend this speculation of bias to explain why men who receive R00-awards and move to institutions with the largest NIH funding portfolios are the most successful at securing subsequent major NIH awards in contrast to women, people who stay at the same institution for the R00 phase, and individuals at institutions with smaller NIH funding portfolios.

Of note, no K99 award has been made to a candidate at an HBCU, and only 2 awardees activated R00 awards at HBCUs. Most HBCUs specialize in undergraduate education; however, several perform biomedical research. Thus, we used a different dataset of faculty institutions and doctoral degree institutions to examine how faculty hiring practices differ between institution types, in particular, HBCUs. In agreement with others, we also found that self-hiring is common.⁴⁵ The self-hiring rate generally between 10-20% most institutions including HBCUs. One stark difference between HBCUs and all other US research institutions is that HBCUs appear to be the only institution type that hires faculty with doctoral degrees from other HBCUs. For example, of the 938 biomedical faculty members at Harvard, only 1 has a doctoral degree from an HBCU. Some institutions have lower rates of self-hiring. For example, Princeton faculty have degrees primarily from other Ivy league institutions but doctoral degrees from Princeton only represent the 14th most common for biomedical sciences. In agreement with the known and described systemic inequalities within the academic system we have highlighted in this article, self-hiring within HBCUs may occur to enable survival of these institutions. Although many HBCUs focus primarily on undergraduate education, several have large biomedical research enterprises, and it is shocking that no K99 awardees have ever been from HBCUs. The K99 MOSAIC program, established in 2020 may increase equity; however, an effort to fund career development awards specifically at HBCUs may also increase equity in this area.

We do not know how many un-funded K99 applications may have originated from HBCUs. A freedom of information act request in 2018 by Dr. Pickett (request # 47950) for fiscal years 2007-2017 for K99/R00 awardees found that the successful award rate for white K99 applicants was 31.0% which was higher than both Asian (26.7%) and Black (16.2%) applicants. Total successful R00 transition rates were also higher among white K99 applicants (77%) compared to Asian

(76.1%) and Black (60.0%) awardees.⁴⁶ Although data on specific applicants is not available to determine trajectories from specific institution types, these data demonstrate that while improvements in equity to male and female applicants have improved; there is still a significant racial equity gap.

These analyses exclude those that received a K99 but were either unable to transition to an R00 award for various reasons including receiving a faculty position in the United States without needing the R00, receiving a faculty position outside of the United States, pursuing another line of work, or other unknown reasons. Furthermore, these analyses are limited to academic institutions in the United States and do not examine academic centers in other countries. When interpreting these data, it is important to consider that each data point corresponds to an individual with unique motivations for choice of postdoctoral research advisor, institution, and laboratory as well as autonomy in whether to pursue a faculty position and where that may be. Complex consideration of start-up package, institutional clout, and individual motivations factor into this decision. In addition, the choice to give K99/R00 awards and subsequent NIH awards lies mostly with grant reviewers who are generally mid-to senior-career faculty that may have different levels of conscious or unconscious bias for or against various factors that contribute to the overall score given. This dataset does not account for the motivation behind these complex decisions, and an understanding of these motivating factors would be enlightening.

It is important to note the limitations of this study. The present study is focuses on K99/R00 awardees and is limited to faculty flows within the United States. While similar practices may exist in other countries, there are likely significant differences also. Another limitation due to our focus on K99/R00 awardees, is that scientists without K99/R00 awards are excluded from our analyses. Further, the public data on K99/R00 awardees does not provide demographic details including self-identified gender, race, ethnicity, age, and degree type. The gender identity used here was assigned as a binary man or woman gender based on the first name of the candidate. If these demographic data were available, a critical analysis of bias and how these impact outcomes could be made. For our analysis of K99 awardees, we do not have information on the doctoral degree granting institution, and for our exploration of where faculty members at HBCUs received their doctoral degrees, we do not have information on their postdoctoral research experience. If we had these details, we could make a more complete examination of flow from doctoral degree institution to postdoctoral institution to faculty institution and then to determine outcomes based on each of these. Future research should aim to complete a more comprehensive assessment of faculty flows and outcomes.

Here we demonstrate the complex nature of faculty hiring within the NIH grant system that exists today in the biomedical sciences and related fields. The K99/R00 award mechanism undoubtedly increases awardees' chance of securing a faculty position. As one of the most coveted NIH grants for postdocs, we have examined the flow of K99 awardees to R00 institutions and how these flows impact future NIH award funding. Many factors besides those considered and quantified here contribute to where K99 awardees choose to begin their faculty careers, and the K99 award itself does not guarantee securing a faculty position. Despite this, we have identified factors that pose significant disadvantages to future funding success for K99/R00 awardees which likely influence funding success more broadly. Future work must examine the role of ethnic and racial bias in these domains. As the K99 MOSAIC program becomes more established, a comparison of this program and the K99 grant mechanism explored here may reveal whether the MOSAIC strategy is effective at promoting equity for under-represented minorities in the biomedical faculty ranks. By quantifying and understanding these factors, grant reviewers, faculty hiring committees, department chairs, and funding bodies may be able to more equitably award and administer grants and evaluate faculty candidates. Improvements to the faculty hiring process can be achieved centrally through the NIH creating a more equitable grant funding system or within the

many diverse faculty searches.⁴⁷⁴⁸ There is only one NIH and many searches, so systemic change will likely lead to more impactful change; however, both options could be implemented simultaneously for the optimal benefit of the scientific community.

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Disclosures

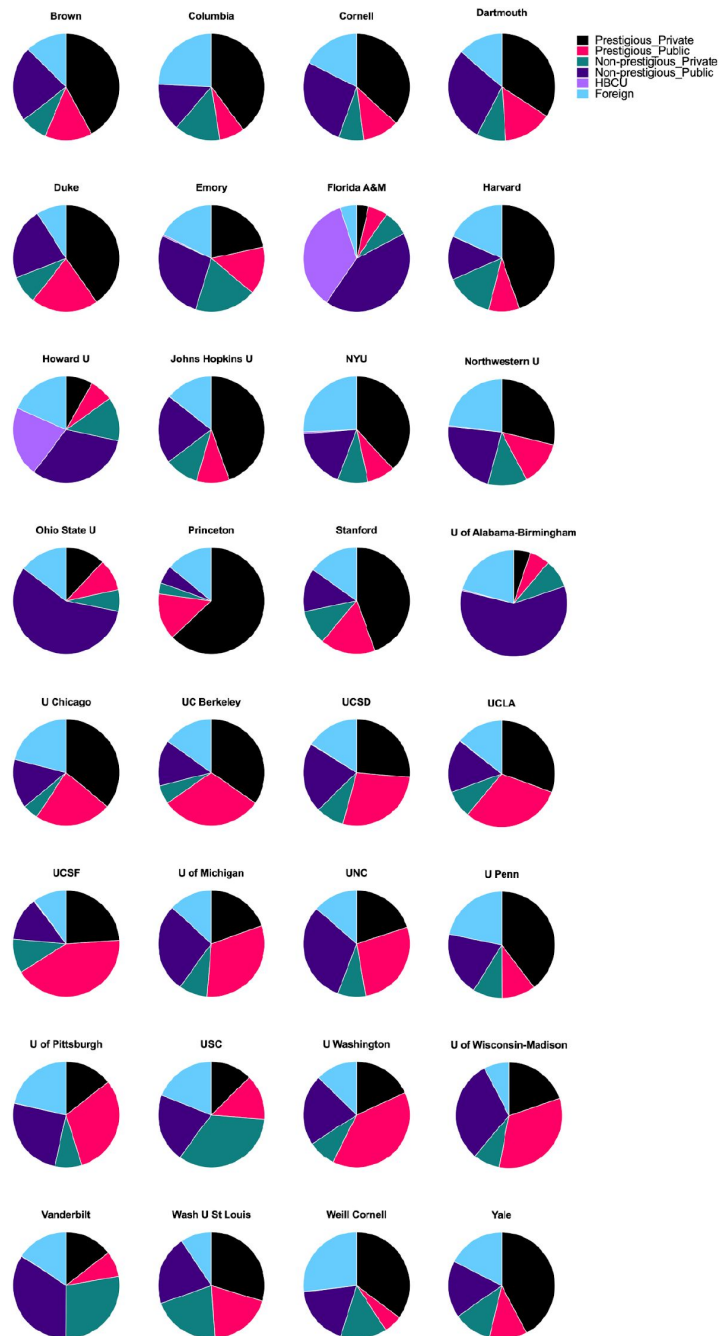
D.J.T., T.V., S.R.H., C.S., J.B., and N.C.W. have no competing interests. D.J.T. was a K99 recipient who transitioned to R00 in the 2021-2022 cycle and is included in this dataset.

Supplemental Materials



Supplemental Figure S1

Pie charts showing where faculty from biology, biomedical, health and related fields from 32 select institutions received their doctoral degrees (from 2010 to 2020) by percentage. Colors were selected as a colorblind safe color scheme.



Supplemental Figure S2

Pie charts showing the type of institution that faculty from biology, biomedical, health and related fields from 32 select institutions received their doctoral degrees (from 2010 to 2020) by percentage. Colors used were selected as a colorblind safe color scheme.

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Editors

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Peter Rodgers

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Reviewer #1 (Public Review):

Summary and strengths

This is an interesting, timely and informative article. The authors used publicly available data (made available by a funding agency) to examine some of the academic characteristics of the individuals recipients of the National Institutes of Health (NIH) k99/R00 award program during the entire history of this funding mechanism (17 years, total ~ 4 billion US dollars (annual investment of ~230 million USD)). The analysis focuses on the pedigree and the NIH funding portfolio of the institutions hosting the k99 awardees as postdoctoral researchers and the institutions hiring these individuals. The authors also analyze the data by gender, by whether the R00 portion of the awards eventually gets activated and based on whether the awardees stayed/were hired as faculty at their k99 (postdoctoral) host institution or moved elsewhere. The authors further sought to examine the rates of funding for those in systematically marginalized groups by analyzing the patterns of receiving k99 awards and hiring k99 awardees at historically black colleges and universities.

The goals and analysis are reasonable and the limitations of the data are described adequately. It is worth noting that some of the observed funding and hiring traits are in line with the Matthew effect in science (Merton, 1968: <https://www.science.org/doi/10.1126/science.159.3810.56>) and in science funding (Bol et al., 2018: <https://www.pnas.org/doi/10.1073/pnas.1719557115>). Overall, the article is a valuable addition to the research culture literature examining the academic funding and hiring traits in the United States. The findings can provide further insights for the leadership at funding and hiring institutions and science policy makers for individual and large-scale improvements that can benefit the scientific community.

Weaknesses

The authors have addressed my recommendations in the previous review round in a satisfactory way.

- <https://doi.org/10.7554/eLife.88984.2.sa2>

Reviewer #2 (Public Review):

Summary and strengths

Early career funding success has an immense impact on later funding success and faculty persistence, as evidenced by well-documented "rich-get-richer" or "Matthew effect" phenomena in science (e.g., Bol et al., 2018, PNAS). In this study the authors examined publicly available data on the distribution of the National Institutes of Health's K99/R00 awards - an early career postdoc-to-faculty transition funding mechanism - and showed that although 89% of K99 awardees successfully transitioned into faculty, disparities in subsequent R01 grant obtainment emerged along three characteristics: researcher mobility, gender, and institution. Men who moved to a top-25 NIH funded institution in their postdoc-to-faculty transition experienced the shortest median time to receiving a R01 award, 4.6

years, in contrast to the median 7.4 years for women working at less well-funded schools who remained at their postdoc institutions.

Amongst the three characteristics, the finding that researcher mobility has the largest effect on subsequent funding success is key and novel. Other data supplement this finding: for example, although the total number of R00 awards has increased, most of this increase is for awards to individuals moving to different institutions. In 2010, 60% of R00 awards were activated at different institutions compared to 80% in 2022. These findings enhance previous work on the relationship between mobility and ones' access to resources, collaborators, or research objects (e.g., Sugimoto and Larivière, 2023, *Equity for Women in Science* (Harvard University Press)).

These results empirically demonstrate that even after receiving a prestigious early career grant, researchers with less mobility belonging to disadvantaged groups at less-resourced institutions continue to experience barriers that delay them from receiving their next major grant. This result has important policy implications aimed at reducing funding disparities - mainly that interventions that focus solely on early career or early stage investigator funding alone will not achieve the desired outcome of improving faculty diversity.

The authors also highlight two incredible facts: No postdoc at a historically Black college or university (HBCU) has been awarded a K99 since the program's launch. And out of all 2,847 R00 awards given thus far, only two have been made to faculty at HBCUs. Given the track record of HBCUs for improving diversity in STEM contexts, this distribution of awards is a massive oversight that demands attention.

At no fault of the authors, the analysis is limited to only examining K99 awardees and not those who applied but did not receive the award. This limitation is solely due to the lack of data made publicly available by the NIH. If this data were available, this study would have been able to compare the trajectory of winners versus losers and therefore could potentially quantify the impact of the award itself on later funding success, much like the landmark paper by Bol et al. (PNAS; 2018) that followed the careers of an early career grant scheme in the Netherlands. Such an analysis would also provide new insights that would inform policy.

Although data on applications versus awards for the K99/R00 mechanism are limited, there exists data for applicant race and ethnicity for the 2007-2017 period, which were made available by a Freedom of Information Act request through the now defunct Rescuing Biomedical Research Initiative (<https://web.archive.org/web/20180723171128/http://rescuingbiomedicalresearch.org/blog/examining-distribution-k99r00-awards-race/>). These results are highly relevant given the discussion of K99 award impacts on the sociodemographic composition of U.S. biomedical faculty. During the 2007-2017 period, the K99 award rate for white applicants was 31% compared to 26.7% for Asian applicants and 16.2% for Black applicants. In terms of award totals, these funding rates amount to 1,384 awards to white applicants, 610 to Asian applicants, and 25 to Black applicants. However, the work required to include these data may be beyond the scope of the study.

The conclusions are well-supported by the data, and limitations of the data and the name-gender matching algorithm are described satisfactorily.

- <https://doi.org/10.7554/eLife.88984.2.sa1>

Reviewer #3 (Public Review):

Summary

The researchers aim add to the literature on faculty career pathways with particular attention to how gender disparities persist in the career and funding opportunities of researchers. The researchers also examine aspects of institutional prestige that can further

amplify funding and career disparities. While some factors about individuals' pathways to faculty lines are known, including the prospects of certain K award recipients, the current study provides the only known examination of the K99/R00 awardees and their pathways.

Strengths

The authors establish a clear overview of the institutional locations of K99 and R00 awardees and the pathways for K99-to-R00 researchers and the gendered and institutional patterns of such pathways. For example, there's a clear institutional hierarchy of hiring for K99/R00 researchers that echo previous research on the rigid faculty hiring networks across fields, and a pivotal difference in the time between awards that can impact faculty careers. Moreover, there's regional clusters of hiring in certain parts of the US where multiple research universities are located. Moreover, documenting the pathways of HBCU faculty is an important extension of the study by Wapman et al. (2022: <https://www.nature.com/articles/s41586-022-05222-x>), and provides a more nuanced look at the pathways of faculty beyond the oft-discussed high status institutions. (However, there is a need for more refinement in this segment of the analyses). Also, the authors provide important caveats throughout the manuscript about the study's findings that show careful attention to the complexity of these patterns and attempting to limit misinterpretations of readers.

Weaknesses

The authors have addressed my recommendations in the previous review round in a satisfactory way.

- <https://doi.org/10.7554/eLife.88984.2.sa0>

Author Response

The following is the authors' response to the original reviews.

Public Reviews:

Reviewer #1 (Public Review):

This is an interesting, timely and informative article. The authors used publicly available data (made available by a funding agency) to examine some of the academic characteristics of the individuals recipients of the National Institutes of Health (NIH) k99/R00 award program during the entire history of this funding mechanism (17 years, total ~ 4 billion US dollars (annual investment of ~230 million USD)). The analysis focuses on the pedigree and the NIH funding portfolio of the institutions hosting the k99 awardees as postdoctoral researchers and the institutions hiring these individuals. The authors also analyze the data by gender, by whether the R00 portion of the awards eventually gets activated and based on whether the awardees stayed/were hired as faculty at their k99 (postdoctoral) host institution or moved elsewhere. The authors further sought to examine the rates of funding for those in systematically marginalized groups by analyzing the patterns of receiving k99 awards and hiring k99 awardees at historically black colleges and universities.

The goals and analysis are reasonable and the limitations of the data are described adequately. It is worth noting that some of the observed funding and hiring traits are in line with the Matthew effect in science (<https://www.science.org/doi/10.1126/science.159.3810.56>) and in science funding (<https://www.pnas.org/doi/10.1073/pnas.1719557115>). Overall, the article is a valuable addition to the research culture literature examining the academic funding and hiring traits in the United States. The findings can provide further insights for the leadership at funding and hiring institutions and science policy makers for individual and large-scale improvements that can benefit the scientific community.

Thank you for these comments. We have incorporated the articles referenced on the Matthew effect into the first paragraph of the Discussion our revised preprint.

Reviewer #2 (Public Review):

Early career funding success has an immense impact on later funding success and faculty persistence, as evidenced by well-documented "rich-get-richer" or "Matthew effect" phenomena in science (e.g., Bol et al. 2018, PNAS). Waitowich et al. examined publicly available data on the distribution of the National Institutes of Health's K99/R00 awards - an early career postdoc-to-faculty transition funding mechanism - and showed that although 85% of K99 awardees successfully transitioned into faculty, disparities in subsequent R01 grant obtainment emerged along three characteristics: researcher mobility, gender, and institution. Men who moved to a top-25 NIH funded institution in their postdoc-to-faculty transition experienced the shortest median time to receiving a R01 award, 4.6 years, in contrast to the median 7.4 years for women working at less well-funded schools who remained at their postdoc institutions. This result is consistent with prior evidence of funding disparities by gender and institution type. The finding that researcher mobility has the largest effect on subsequent funding success is key and novel, and enhances previous work showing the relationship between mobility and ones' access to resources, collaborators, or research objects (e.g., Sugimoto and Larivière, 2023, Equity for Women in Science (Harvard University Press)).

These results empirically demonstrate that even after receiving a prestigious early career grant, researchers with less mobility belonging to disadvantaged groups at less-resourced institutions continue to experience barriers that delay them from receiving their next major grant. This result has important policy implications aimed at reducing funding disparities - mainly that interventions that focus solely on early career or early stage investigator funding alone will not achieve the desired outcome of improving faculty diversity.

The authors also highlight two incredible facts: No postdoc at a historically Black college or university (HBCU) has been awarded a K99 since the program's launch. And out of all 2,847 R00 awards given thus far, only two have been made to faculty at HBCUs. Given the track record of HBCUs for improving diversity in STEM contexts, this distribution of awards is a massive oversight that demands attention.

At no fault of the authors, the analysis is limited to only examining K99 awardees and not those who applied but did not receive the award. This limitation is solely due to the lack of data made publicly available by the NIH. If this data were available, this study would have been able to compare the trajectory of winners versus losers and therefore could potentially quantify the impact of the award itself on later funding success, much like the landmark Bol et al. (2018) paper that followed the careers of winners of an early career grant scheme in the Netherlands. Such an analysis would also provide new insights that would inform policy.

Although data on applications versus awards for the K99/R00 mechanism are limited, there exists data for applicant race and ethnicity for the 2007-2017 period, which were made available by a Freedom of Information Act request through the now defunct Rescuing Biomedical Research Initiative: <https://web.archive.org/web/20180723171128/http://rescuingbiomedicalresearch.org/blog/examining-distribution-k99r00-awards-race/>. These results are not presently discussed in the paper, but are highly relevant given the discussion of K99 award impacts on the sociodemographic composition of U.S. biomedical faculty. From 2007 to 2017, the K99 award rate for white applicants was 31.0% compared to 26.7% for Asian applicants and 16.2% for Black applicants. In terms of award totals, these funding rates amount to 1,384 awards to white applicants, 610 to

Asian applicants, and 25 to Black applicants for the entire 2007-2017 period. And in terms of R00 awards, or successful faculty transitions: whereas 77.0% of white K99 awardees received an R00 award, the conversion rate for Asian and Black K99 awardees was lower, at 76.1% and 60.0%, respectively. Regarding this K99-to-R00 transition rate, Woitowich et al. found no difference by gender (Table 2). These results are consistent with a growing body of literature that shows that while there have been improvements to equity in funding outcomes by gender, similar improvements for achieving racial equity are lagging.

The conclusions are well-supported by the data, and limitations of the data and the name-gender matching algorithm are described satisfactorily.

One aspect that the authors should expand or comment on is the change in the rate of K99 to R00 conversions. Since 2016, while the absolute number of K99 and R00 awards has been increasing, the percentage of R00 conversions appears to be decreasing, especially in 2020 and 2021. This observation is not clearly stated or shown in Figure 1 but is an important point - if the effectiveness of the K99/R00 mechanism for postdoc-to-faculty transitions has been decreasing lately, then something is undermining the purpose of this mechanism. This result bears emphasis and potentially discussion for possible reasons for why this is happening.

Thank you for these insightful comments. We now calculate a rolling conversion rate for K99 to R00 awards which shows there is not as much of a decline in conversion from K99 to R00 (Fig 1B). We still see a slight decline in 2021 and 2022. 468 K99 awards are from 2020 or later so they may still convert to the R00 phase. Thus it is difficult to draw conclusions about 2021/2022 yet. As more time passes, we may better be able to determine whether or not significant alteration from normal occurred in these years, presumably due to pressures from the Covid-19 pandemic. We also thank you for providing the details of the FOIA request. We have included a discussion of these data in the discussion.

Reviewer #3 (Public Review):

The researchers aim add to the literature on faculty career pathways with particular attention to how gender disparities persist in the career and funding opportunities of researchers. The researchers also examine aspects of institutional prestige that can further amplify funding and career disparities. While some factors about individuals' pathways to faculty lines are known, including the prospects of certain K award recipients, the current study provides the only known examination of the K99/R00 awardees and their pathways.

Strengths:

The authors establish a clear overview of the institutional locations of K99 and R00 awardees and the pathways for K99-to-R00 researchers and the gendered and institutional patterns of such pathways. For example, there's a clear institutional hierarchy of hiring for K99/R00 researchers that echo previous research on the rigid faculty hiring networks across fields, and a pivotal difference in the time between awards that can impact faculty careers. Moreover, there's regional clusters of hiring in certain parts of the US where multiple research universities are located. Moreover, documenting the pathways of HBCU faculty is an important extension of the Wapman et al. study (among others from that research group), and provides a more nuanced look at the pathways of faculty beyond the oft-discussed high status institutions. (However, there is a need for more refinement in this segment of the analyses as discussed further below.). Also, the authors provide important caveats throughout the manuscript about the study's findings that show careful attention to the complexity of these patterns and attempting to limit misinterpretations of readers.

Weaknesses:

The authors reference institutional prestige in relation to some of the findings, but there's no specific measure of institutional prestige included in the analyses. If being identified as a top 25 NIH-funded institution is the proximate measure for prestige in the study, then more justification of how that relates to previous studies' measures of institutional prestige and status are needed to further clarify the interpretations offered in the manuscript.

The identification of institutional funding disparities impacting HBCUs is an important finding and highlights another aspect of how faculty at these institutions are under resourced and arguably undervalued in their research contributions. However, a lingering question exists: why compare HBCUs with Harvard? What are the theoretical and/or methodological justifications for such comparisons? This comparison lends itself to reifying the status hierarchy of institutions that perpetuate funding and career inequalities at the heart of the current manuscript. If aggregating all HBCU faculty together, then a comparable grouping for comparison is needed, not just one institution. Perhaps looking at the top 25 NIH funded institutions could be one way of providing a clearer comparison. Related to this point is the confusing inclusion of Gallaudet in Figure 6 as it is not an officially identified HBCU. Was this institution also included in the HBCU-related calculations?

Thank you for this comment. We agree this comparison perpetuates the perception of the prestige hierarchy and is problematic. We now compare all institutions in the top 25 NIH funding category to all HBCUs. Thank you also for identifying our error in mis-coding Gallaudet as an HBCU. We have corrected this in the current version.

There is a clear connection that is missed in the current iteration of the manuscript derived from the work of Robert Merton and others about cumulative advantages in science and the "Matthew effect." While aspects of this connection are noted in the manuscript such as well-resourced institutions (those with the most NIH funding in this circumstance) hire each others' K99/R00 awardees, elaborating on these connections are important for readers to understand the central processes of how a rigid hierarchy of funding and career opportunities exist around these pathways. The work the authors build on from Daniel Larremore, Aaron Clauset, and their colleagues have also incorporated these important theoretical connections from the sociology of knowledge and science, and it would provide a more interdisciplinary lens and further depth to understanding the faculty career inequalities documented in the current study.

Reviewer #1 (Recommendations For The Authors):

Comments to authors:

1. For the benefit of general reader, it would be informative to mention the amount of annual NIH investment in the k99 funding mechanism in the text (230 awards representing a ~ 230 million US dollars investment).

Thank you for this suggestion. We have added that this is ~\$25 million investment annually.

1. It is worth noting that some of the observed funding and hiring traits resemble the Matthew effect, discussed in: *The Matthew effect in science*: <https://www.science.org/doi/10.1126/science.159.3810.56>

The Matthew effect in science funding: <https://www.pnas.org/doi/10.1073/pnas.1719557115>

It would be of value to cite these for further context for the readers.

Thank you for this suggestion. We have included these references and briefly discussed the Matthew effect in the first paragraph of the Discussion.

1. Figs 3, 6 and Fig S1 are hard to read without zooming in due to their format and don't work great within a letter size page but can work if they are also linked to a zoomable web version. It would make sense to have an online navigable/searchable/selectable version. But when the reader zooms out, there are patterns that reflect what points the authors are making (though those could be illustrated differently). These figures are really made for online webapp visualization (such as Shiny in R).

We agree with this comment and have used the “googleVis()” package in R to put together interactive Sankey diagrams. These can be found at: <https://dantyr.github.io/K99-R00-analysis/> and they are referenced in the manuscript.

1. The abstract states 85% of awardees get R00 awards. That appears to come from 198/234 (page 6) though it's not explicitly stated, and other ratios give different answers (e.g., $1-304/3475 = 91\%$) but the 85% seems to be the right one. That first paragraph of the results could be clearer. Also, in the middle of page three the number given is 90% so something is inconsistent. For Figure 1A, given the methodology it should be possible to calculate a rolling conversion rate as “ $R00(t) / K99(t-1)$ ” (and a similarly-calculated cumulative rate).

Thank you for catching these errors. These were introduced because there are R00 awardees that did not have extramural K99 awards. These are intramural NIH K99 awardees but there is no public data on these awardees. The correct number is 78% of K99 awardees that transitioned to the R00 phase. We have also calculated the rolling conversion rate which is 89% if you exclude the first 2 years of the program (when the first awardees were within the 2-yr K99 period) and final 2 years (when most recent K99 awardees were still within their first 2 years of the K99 period).

1. Assuming that 85% is the correct number, is there any information/insight into why ~1/6 of awardees do not continue to R00, which seems high given that only two years passes - that's a lot of awardees not getting R00 positions.

We are unsure of why these don't convert. In the revised version of the manuscript, we speculate on this in the 4th paragraph of the discussion:

The factors that prevented the other 302 K99 awardees from 2019 and earlier unable to convert their K99-R00 grants is cause for concern within our greater academic community. Possible explanations include leaving the biomedical workforce, accepting tenure-track positions or other positions abroad, or by simply not successfully securing a tenable tenure-track offer.

1. It looks like perhaps a non-zero number of K99s are just one year and not two (e.g., see 2006 in Fig 1A, which should not appear if all 2006 awards were 2 years). What is the typical percentage of K99s not activated for a second year, and is this a sizable % of the 15% not converting to R00?

This is an interesting question. We didn't originally look into this and the dataset that we originally downloaded from NIH reporter included a significant number of duplicates for the grants because year 1 of the K99 was listed on its own line and year 2 was listed on a different line. The first step in curating the data was to delete the duplicate values so we only had one entry per person. Unfortunately based on sorting of the data tables, sometimes the year 1 appeared above year 2 and at other times year 2 appeared before year 1. Because none of the data we were interested in are benchmarked to K99 start date, we removed the duplicate values non-specifically. With the dataset we currently have, we would not be able to tell which individuals dropped out (didn't convert to R00) during the first or second year of the K99. In order to do this we would have to download the raw data from NIH reporter again and curate it again. We may do this in the future but for the purpose of publishing the current manuscript we prefer to focus our efforts on other aspects of the revision.

1. Further down page 3, the authors state that "men typically experience 2-3% greater funding success rates" is ambiguous, as rates are themselves a percentage. So, is it 2-3% greater as in 23% vs 20%, or is it 2-3% greater as in 20.6% vs 20%? Please clarify the language.

Thank you for asking for this clarification. We have updated the text here to reflect that we mean "23% vs 20%".

1. Metrics such as time to first R01 are compared internally within the study set, which yields interesting insights, but more could be done to benchmark these metrics to non-K99 scientists.

We agree with the reviewer that this would be ideal; however, we feel that it is out of the scope of this manuscript. We may examine this in the future.

1. In the text, several times percentages are being referred to when the figures cited do not show percentages. For example (page 6) 'proportion of awardees that stayed at the same institution declined to about 20% where it has remained consistent (Fig 1B)' - Figure 1B does not show percentages, instead the reader would need to work out from the raw numbers what the pattern of percentages might look like. It's fine (great even) to provide the raw numbers, but would be great to show the percentages as well. This happened for multiple graphs.

Thank you for this comment. We agree that showing the percentage would be beneficial so we have included the percentages in Figure 1 for the conversion rate. We also added a standalone figure panel for the rolling conversion rate for Figure 1. For Figure 4, we have also included a right Y-axis to better indicate the % women.

1. Figure 4 - putting the %women on a 0-250 scale makes it difficult to see the changes in that curve. Please replot it as a separate graph with an appropriate scale (30-50%? 30-70%?)

Thank you for this comment. We have made this edit.

1. Figure 5 - The table appears inconsistent - the Moved/Stayed HR is 1.411 suggesting that moving is better for reducing time to R01, but then Woman/Man is 1.208, so one of these pairs needs to be written in the opposite order to have the table make sense (intended to be listed as 'better/worse'?)

Thank you for noticing this. In the revised manuscript we have re-run the cox proportional hazard model using the R package “survival” and the function “coxph()”. There were minor differences in the hazard ratios using this package instead of Graphpad prism; however, the R package is much more widely used compared to prism for these types of analysis. We present the new data in the table in Figure 5B in the revised manuscript. We now present the “detrimental” cox hazard value for each variable (i.e. 0.7095 for the mobility [moved/stayed]). We also underlined the variable which was detrimental to receiving an R01 award earlier.

1. *Figure 5's graph appears strange. All the lines have an appearance of stochasticity but are actually multiples of each other, rising exactly in sync. Are these actually modeled lines? If so, why not instead actually draw the lines based on the real data from the real groups depicted, and give the n for each group?*

Thank you for picking this up. The software we originally used to plot the graphs did plot modeled lines instead of the actual data. We have re-run the cox proportional hazard model using the R “survival” package v3.5-5 and the coxph() and survfit() functions. The updated data are in Figure 5 of the revised manuscript.

1. *Table 1 should note that each column sums to 100%.*

This is a good suggestion. In the revised manuscript, we have added a row to the table to indicate the column total N and %.

1. *The authors discuss how k99/R00 grant reviewing process may have to change but the k99 awards also impact the faculty hiring ecosystem as well. There are faculty hiring job ads explicitly requesting or indicating preference towards k99 holders and the results described in this article show that k99 awarding is biased towards particular demographics at select wealthy institutions. Of course, collective/central action is almost always more effective/impactful (especially in shorter time line) than individual elective action. In other words, NIH changing granting patterns would likely work better than encouraging faculty searches to change the weight they give to K99s, because there are many searches and just one NIH. But these are not mutually exclusive and individual action can still help when central action isn't done (if the NIH does not change the k99/R00 grant review process for more inclusive funding and does not increase the number of annual k99 awards hence the annual budget for this award mechanism) and it would be good to have this discussed in the manuscript.*

Thank you for this comment and thoughtful insights. We have included additional discussion on this in the final paragraph of the discussion.

Reviewer #2 (Recommendations For The Authors):

Thank you for conducting this important work. On top of some thoughts I have described in the public review (in particular, Chris Pickett's FOIA data on K99/R00 outcomes by applicant race and ethnicity), I only have a few comments for potential improvements to this paper:

1. The comparison of K99-R00 transition rates by gender was interesting. However, I missed the analysis on the K99-R00 transition rates by institution (by type or by top-25 NIH funded institution versus not). I think this analysis may be buried somewhere in the more nuanced descriptions about faculty flows from one institution type to another, but I was not able to locate it. I wonder if the authors could consider dedicating a subsection to specifically describing the transition rate by institution type, creating a table equivalent to Table 2. This section would probably fit best somewhere before the authors dive into the nuances of self-hires and faculty flows.

Said another way: As I was reading, I felt I was missing an answer to a simple question - are there differences in conversion rates by institution type (however you define institution type, as an MSI or non MSI, or top-25 NIH funded versus not)?

Thank you for this suggestion. We have created the table (Table 3 and Table 4) in the revised manuscript. We also made a new figure (now figure 5 in the revised manuscript). This was an interesting way to look at the data and it is very clear that the number of K99 and R00 awards is heavily concentrated within the institutions that have the highest NIH funding. We have added a paragraph in the results in a new section entitled “K99 and R00 awards are concentrated within the highest funded institutions”.

1. Regarding the comparison of HBCUs and Harvard: this analysis was elucidating, but I am not sure if the framing of this analysis as pertaining to “systematically marginalized groups” - see second sentence in the section, “Faculty doctorates differ between Harvard and HBCUs” is appropriate. While it is true that proportionally more faculty at HBCUs are from marginalized groups, there are also many faculty at HBCUs who are from privileged or advantaged backgrounds (e.g., white, men, educated at elite institutions). It would be more accurate to rephrase the second sentence to say something along the lines of, “We sought to examine the rates of funding for those at historically under-funded institutions.” I recommend that the authors comb the paper for any other potential places in the text that conflate systemic marginalization with institution type, and rephrase as needed for accuracy.

Thank you for pointing this out. This is an extremely important point and we have removed any instances we could find where we conflate systemically marginalized groups with institution type.

1. I strongly recommend Sugimoto and Larivière (2023)'s new book, *Equity for Women in Science*, which has an entire section dedicated to previous work investigating how researcher mobility impacts access to resources, collaborations, et cetera (Chapter 5 on Mobility; other chapters on Funding are also relevant but I hone in on Mobility since this is such a key result of this work). I think this chapter would provide significant food-for-thought and background that could strengthen the Discussion section of the paper.

Thank you for this suggestion. We have added some discussion of mobility in the first paragraph of the Discussion.

1. I appreciated the subsection headings that described key results (e.g., "Institutions with the most NIH funding tend to hire K99/R00 awardees from other institutions with the most funding"; "K99/R00 awardee self-hires are more common at institutions with the top NIH funding.") This paper structure made it easier for me to ensure that I was getting the intended takeaway from a figure or section. But partway through the paper, the subheadings changed to being less declarative and therefore less informative (e.g., "Gender of K99/R00 awardees"; "Factors influencing K99/R00 awardee future funding success"). It would be great to rephrase these boilerplate subsection headers to be more declarative, like earlier subsection headings. For example, maybe say "Men receive the majority of K99 awards" or "No gender difference in the rate of conversion from K99 to R00" or something to that effect, depending on what result the authors wish to emphasize.

Thank you for this comment. This is a very good point. We have re-worded the more generic headings in the revised version.

1. Lastly, I would like to share a question that came to my mind that involves an additional analysis, but is work that is (probably) out-of-the-scope of this paper, but could instead be a separate paper or product. Circling back to Chris Pickett's FOIA-ed data on K99/R00 funding outcomes by applicant race and ethnicity (<https://web.archive.org/web/20180723171128/http://rescuingbiomedicalresearch.org/blog/examining-distribution-k99r00-awards-race/>): Given that Pickett's numbers provide incontrovertible information on the number of awards to various racial and ethnic groups, I wonder if it is possible to use this information as an "answer key" to (1) check the accuracy of an algorithm that assigns race based on name for applications in your analysis but for 2007-2017 period, and, (2) if the results are reasonable, then examine the dataset with race and ethnicity information. Some recent papers performing large-scale bibliometric analyses have applied such algorithms (e.g., see Kozłowski et al. 2022 PNAS Intersectional inequalities in science) and I wonder if they could be useful, or at least tested, here. Again, Pickett's data would serve as the benchmark to see if the algorithm produces numbers that are consistent with the actual funding outcomes; if they're not wildly off, or perhaps accurate for some groups but not others, there might be something here.

This is a really insightful comment. We have discussed whether we could assign ethnicity based on an algorithm and check based on Chris Pickett's data. We agree that it is beyond the scope of this article, but has potential for future research.

Reviewer #3 (Recommendations For The Authors):

-In the methods section, it would be helpful to provide an overview of the number of universities, departments, and faculty represented in the data analyzed in the study.

Thank you for this comment. We agree with the reviewer. We have added a section to the results discussing the distribution of different types of institutions. We also added Table 3 and Table 4 and a new Figure 5 describing these. Regarding the faculty, we have discussed the demographics of the K99 and R00 awardees as best as we could. We do not have data on which faculty laboratories the K99 awardees were in when they received their awards. This information is not available through NIH reporter.

-I would consider incorporating, or at least citing, Jeff Lockhart and colleagues' recent paper *Nature Human Behavior* article "Name-based demographic inference and the unequal distribution of misrecognition" about to provide readers with an additional resource and more information about the likelihood of misattribution and general

cautionary notes about using gender and race/ethnicity ascription/imputation approaches and tools for research.

Thank you for bringing this reference to our attention. We have incorporated this into the methods section describing our name-based gender determination.

-In the next to last sentence under the final paragraph of the methods section, there looks to be a typo as it should read "K99 or R00," not "K00" as currently written.

Thank you for catching this. We have now corrected it.

-Clarifying some of the data and measures used are necessary to limit confusion and misinterpretations of the study's findings.

Thank you. We have significantly updated the revised manuscript and hope that it is more clear.

-Elaborating more on the gender inequality notable in the Cox proportional hazard model would strengthen the authors' point about persistent gender inequalities within the K99/R00 funding mechanism and pathways. In its current iteration, the findings are somewhat buried by the discussion of institutional differences, but when we look at the findings and the plot associated with the model, we notice that men have more advantages than women in funding and institutional location.

Thank you for highlighting this. This is true and we have elaborated on the gender inequality in the revised version of the manuscript.

-Also for the Cox proportional hazard model, I would consider exploring the inclusion of data that can further clarify the biomedical research infrastructure of institutions. For example, in the conversation about the differences between Princeton and other universities including other Ivies, it's important to note that Princeton does not have a medical school. Moreover, other institutions do not operate or are affiliated with a hospital. Adding more data to the model that can better contextualize the research infrastructure around researchers with NIH awards beyond the size of the NIH portfolio can shed light on possibly other important institutional differences that undergird these inequalities.

Thank you for this comment. We have added additional details about the institutional type; however, to examine whether institutions are attached to a hospital (or are themselves as hospital like MGH etc.) or whether institutions include a medical school may be difficult. We would have to manually code these and then determine whether or not the award recipient was affiliated with a department within that entity or not. We believe that this is a fascinating question but that it is out of the scope of the present manuscript. This is something that we will look into for potential future publications.

-Throughout the manuscript there's usage of "elite" and "prestigious" that are somewhat ambiguous regarding what exactly they are referring to about institutional characteristics. This is a common issue in the literature, but trying to clarify what these terms specifically mean for the current study and checking for consistent usage with limited interchangeability that can add confusion for readers about what is being referred to would give added strength to the conversation provided by the authors.

Thank you for this suggestion. Based on these comments and those by the other reviewers, in the revised version of the manuscript, we have limited the use of “elite” and “prestigious” to

describe institutions in order not to perpetuate biases toward certain institutions.

-In relation to the discussion at the end of the manuscript of the longer time to award noted for researchers who stay at the same institutions, another possibility for the disparity could be their reliance for service work (e.g., hiring committees, departmental committees, supporting graduate students through mentoring and/or dissertation committee work, etc.) in their institutions given their knowledge of and experience within it.

Thank you for this suggestion. We have added 2 sentences to the discussion reflecting this possibility.

*-Engaging with how STEM professional cultures can perpetuate these funding disparities and related hiring and career outcomes could enhance the contributions of the study. In relation to STEM professional cultures, engaging with the work of Mary Blair-Loy and Erin Cech in their recent book, *Misconceiving Merit*, could help provide additional insights for readers.*

Thank you for these comments. We have incorporated edits to the revised manuscript reflecting the work of Erin Cech and Mary Blair-Loy.