Analysis of NIH Biomedical Faculty K99 Awards, Transitions, and R00 Outcomes

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Abstract

Postdoctoral fellows and scholars are highly skilled and trained researchers within the academic biomedical research workforce. Those that aspire to continue academic research careers typically seek tenure-track faculty positions as a principal investigator. In the United States, the National Institutes of Health (NIH) Pathway to Independence Award (K99/R00) is designed to facilitate the transition from postdoctoral fellow to faculty by providing up to 5-years of funding support. Using data for K99 recipients from 2006 to 2021, we find that 40% of awardees are women, 58% of awardees are men, and each year an average of 234 K99 awards are made and an average of 198 K99 awardees convert to R00 which amounts to 2703 successful K99 to R00 conversions. Between 20-35% of K99 awardees stay at the same institution for the R00. Our analyses show institutions with the most NIH funding produce the most K99 recipients and recruit the most R00 awardees. As of the end of 2022, 51.8% of R00 awardees obtained a major NIH award. Overall, the median time to a major NIH award (e.g., R01) from the start of R00 is from 4.6 to 7.4 years depending on certain factors including gender, moving to new institution, and institutional funding level. It took significantly longer (up to 2.8 yrs longer) to obtain a subsequent major NIH award for women R00 awardees, those that remained at their home institution, and those that were hired at institutions outside of the 24 institutions with the most NIH funding. Shockingly, there has yet to be a K99 awardee at a historically black college or university (HBCU) and only 2 K99 awardees have ever been recruited by HBCUs for the R00 phase of the award. Together, our analyses show how K99 awardees flow to faculty positions and identify factors related to their future success, influencing the composition of US academic biomedical faculty ranks.

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 prestigious doctoral programs, 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/male 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 prestigious 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, prestige, 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 90% of K99 awardees received R00 funding, 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 funding[23] 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 XX-XX% greater success than women or other gender identities.[17,26,27] however, some report no difference.[28] Racial and ethnic minorities are also at a disadvantage in receiving R01 funding compared to white

counterparts.[29,30] Institutional prestige 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 will be deposited on Zenodo upon publication. K99 and R00 data were downloaded from NIH Reporter using the "Advanced Search" function to include only the year range (2007-2022) 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/.[15] 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 manually identified whether institutions were public, private, and which country they were located in. The list of K99 institutions and R00 institutions were plotted as Sankey diagrams using SankeyMATIC. The images are exported as SVG files to allow zooming in and out to read the text. 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.

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, 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.

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[31]. It assigns gender identity as either male, female, 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 K00 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. There were a total of 3475 extramural K99s awarded from 2006 through 2021 and 2847 R00 awards from 2007 through 2022 (Fig. 1A). There were 2703 extramural K99 awardees that converted to R00 awards by the end of 2022 (Fig. 1B). The remaining 144 R00 awardees with no matching K99 data are likely intramural NIH K99 awardees with no public data on NIH Reporter. Roughly 85% of K99 awardees successfully converted to the R00 phase

and about 15% of K99 awardees did not convert to the R00 phase. That means that 772 scientists with K99 awards did not get R00s. Many 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.

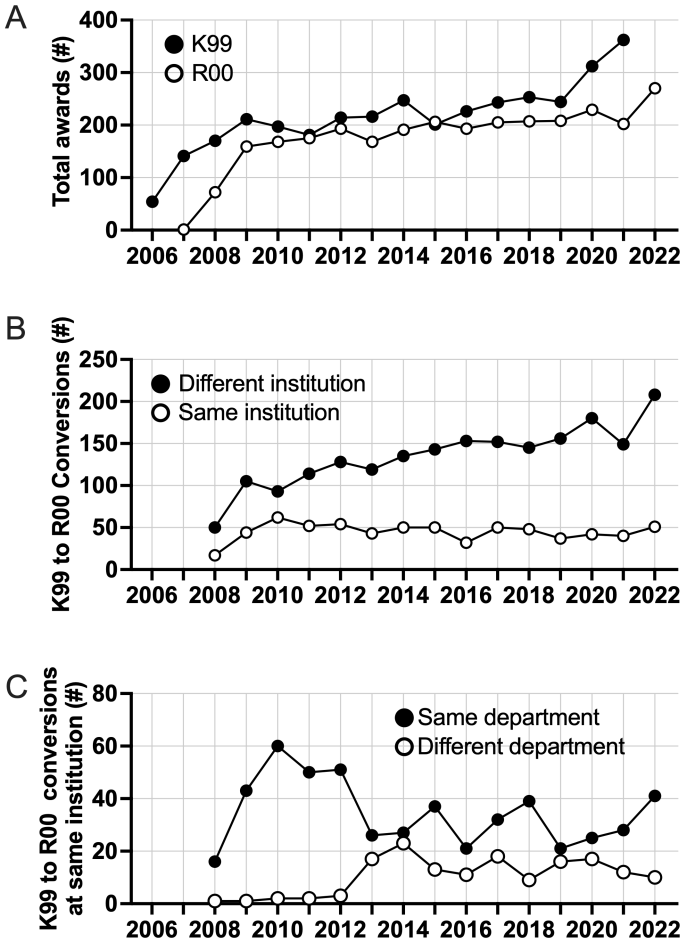


Figure 1: Rate of K99 and R00 awards and conversion by year. A) Total extramural K99 awards and R00 awards made by year. B) Total number of extramural K99 to R00 conversions per year at the same institution or different institution. C) Within the K99 to R00 conversions at the same institution, the number of K99 to R00 conversions either in the same department or different department, by year.

Geographic localization of K99 awards are located at an exclusive set of institutions whereas R00 awards are dispersed across all institutions.

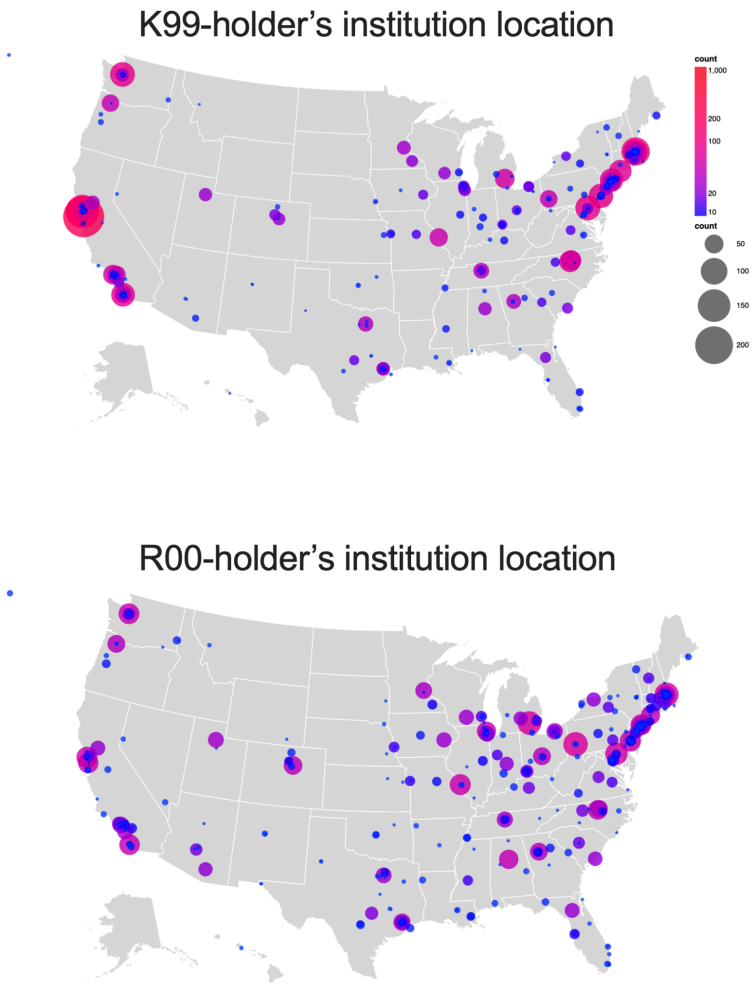


Figure 2: Cartographic representation of the number of K99 and R00 awards by institutional location and state from 2007-2008 through 2021-2022. Note no individual award or grant is counted more than 1 time.

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. Thus, K99s are awarded to a smaller number of institutions than those which K99 awardees go on to work. 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). There were 237 K99 recipients at Stanford University, which is 59-fold greater than the median of 4 awards per institution. More than the 134 institutions that received the fewest (1-4) K99 awards (Fig. 2). There were 73 institutions with only 1 K99 awardee. R00 awards were dispersed across more institutions than K99 awards, although many of these schools only had 1 (n=116) or 2 (n=47) R00 awardees. Three institutions had >100 K99 awards through the end of 2022 (Stanford, University of California San Francisco, and Massachusetts General Hospital). However, no institution exceeded 62 R00 awardees and only 4 institutions had >50 recipients (University of Pittsburgh, Massachusetts General Hospital, University of Michigan, and Johns Hopkins University; Fig. 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

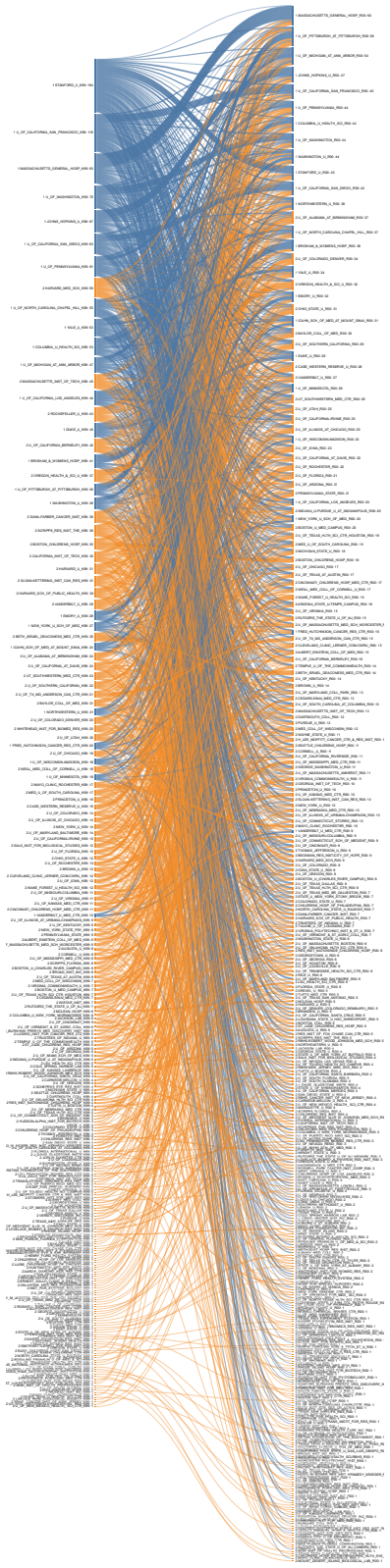
(n=121) had the largest proportion of K99 relative to R00 awards, and Texas (n=48), Ohio (n=46), Michigan (n=33), and Arizona (n=31) received the greatest number of R00 awardees relative to K99 awards. These data indicate that while more K99 awards are physically located on the east and west coast universities, 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 this included Leidos Biomedical Research, Inc. which did not have any 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 amount 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%). Of individual institutions, Massachusetts General Hospital has the highest rate of K99 awardees staying for the R00 phase with 42 of the 93 K99 awardees (45.2%).



Massachusetts General Hospital has recruited a total of 60 R00 awardees from 2007-2022 and 71.7% of these had K99's at Massachusetts General Hospital. 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 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 prestigious 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 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. Institutions are ranked by number of K99 awards on the left and number of R00 awards on the right. The 25 institutions with the largest NIH funding portfolios in 2022 are coded blue and all others are coded orange. High resolution image can be found at: https://sites.uab.edu/tyrrelllab/about/k99-to-r00-transfers/

	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%)*

Table 1: Number and frequency of R00 faculty hires from specific types of K99 institutions.
*=excluding self-hires to the same institution.

Gender of K99/R00 awardees

Overall, 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).

	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	2698	*100*
Men	1575	*58*
Women	1090	*40*
Unknown	33	*1*

Table 2: Number and frequency of men and women receiving K99 and R00 awards and whether they successfully converted K99 to R00 awards.

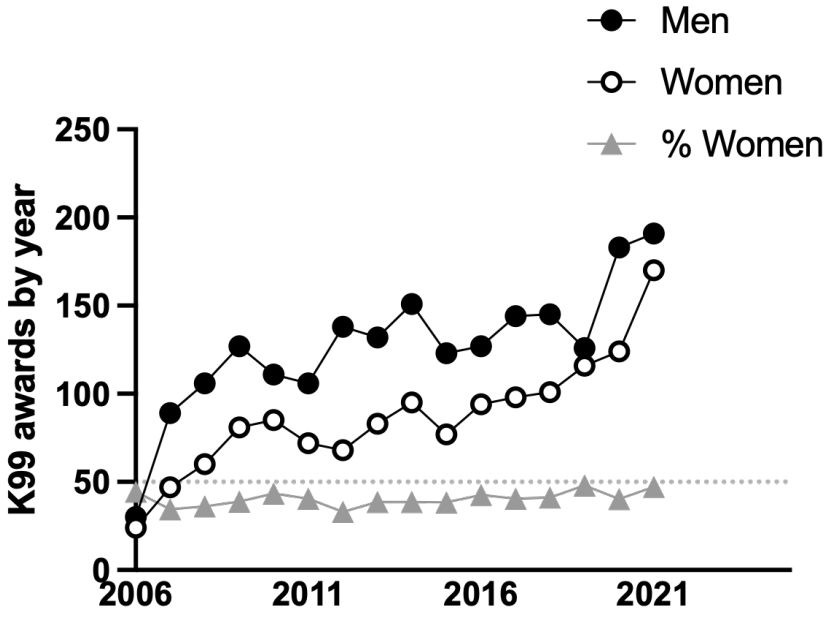
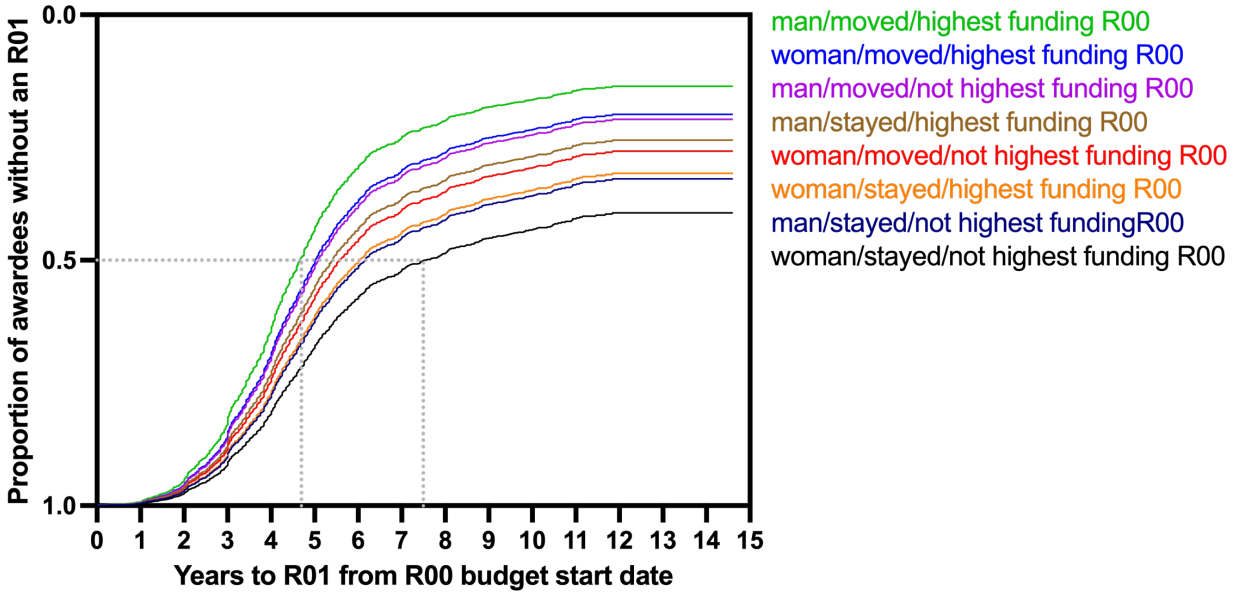


Figure 4: Number of K99 awards per year to either men or women and the percentage of K99 awardees that are women.

Factors influencing K99/R00 awardee 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

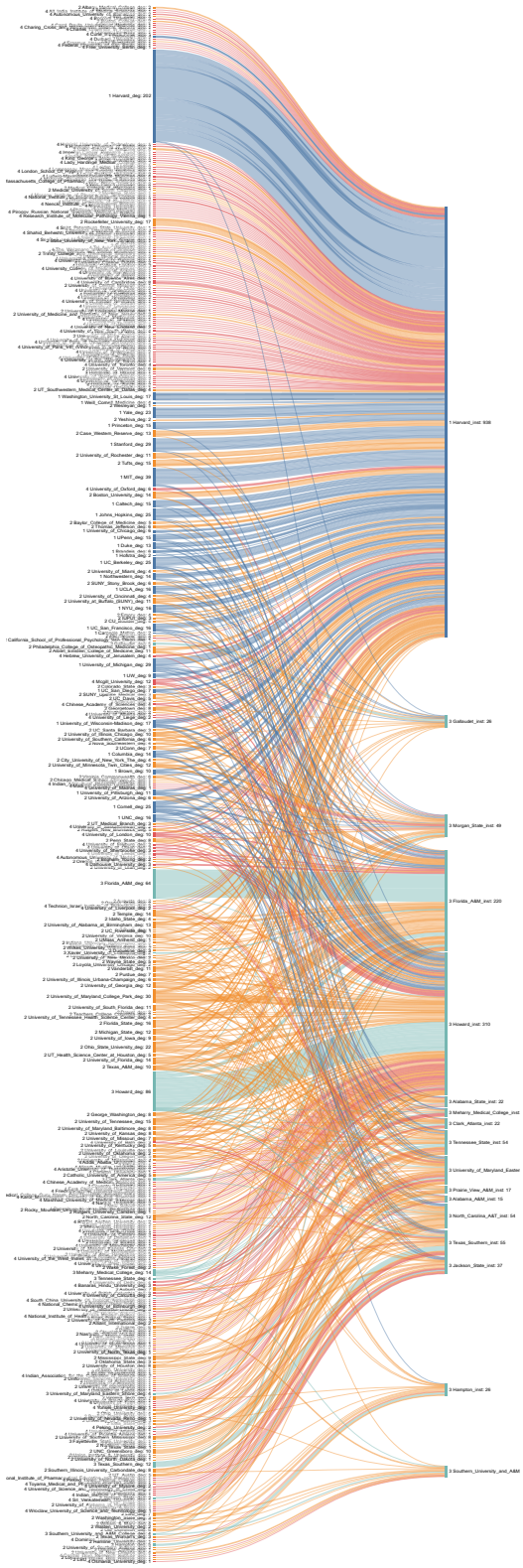
which includes whether the K99/R00 awardees stayed at the K99 institution for the R00 phase or left, were male or female, whether the K99 or R00 institutions were private or public, and whether the K99 and R00 institutions were one of the top 25 institutions for NIH funding in 2022 (Fig. 5). The factor that impacted the hazard ratio the most was whether an individual stayed at the same institution for the K99 and R00 phase or moved to a new institution (P<0.0001). The next strongest factor in receiving future R01 funding was whether the candidate was a man or woman (P=0.0008), consistent with previous findings that women are at a disadvantage in academic career placement.[32] The next factor was whether the R00 institution was in the top 25 largest NIH funding portfolios. 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, once accounting for R00 institution prestige.



Hazard ratios (variable)	Estimate	95% CI	P-value
Moved/Stayed	1.411	1.245 - 1.604	<0.0001
Female/Male	1.208	1.082 - 1.350	0.0008
K99 NIH funding	1.015	0.9481 - 1.182	0.3099
R00 NIH funding	1.246	1.106 - 1.401	0.0003
K99: Private/Public	0.9914	0.8789 - 1.119	0.8889
R00: Private/Public	1.151	1.023 - 1.294	0.0194

Figure 5: Cox proportional hazard model examining K99/R00 awardees success at receiving subsequent major extramural NIH awards by whether they stayed at the same institution for K99 and R00 or moved to a new institution, whether they were male or female, and whether they were at a prestigious institution for the R00 phase or other institution.

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 greater overall percent chance of ever receiving a major award (84.6%; Fig. 5). 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.

Figure 6: Sankey diagram of faculty members at Harvard (top right) and all HBCUs (bottom right) and the doctoral degree-granting institution for each (on left). Institutions with the highest prestige coded blue, HBCUs coded turquoise, foreign coded red, and all others coded orange.

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 doctorates differ between Harvard and HBCUs

Enhancing equity and representation in science is important. Thus, we examined the rates of funding for those in historically marginalized groups. It is

unequivocal that diversity in all metrics is beneficial for scientific progress. Therefore, 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. Strikingly, of all 2704 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 available.[15] Wapman et al., do not demonstrate doctoral degrees or faculty hiring practices at specific institutions or at HBCUs. This prompted us to examine faculty flow to HBCUs compared to other types of institutions, specifically related to biological and biomedical faculty. We included only biology, biomedical, and health related fields 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 901 faculty members 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 positions.[33] Here, we explore the doctoral degree granting institution for the 901 faculty members at HBCUs and the 938 faculty at Harvard with known doctoral degree granting institutions (Fig. 6). There is a stark difference in where faculty from Harvard received their doctoral degrees compared with the faculty ranks at HBCUs. When examining faculty flows to HBCU's it is apparent that Florida A&M, Howard, and Texas Southern have a significant number of faculty with doctoral degrees from Florida A&M, Howard, and Texas Southern respectively. Within the HBCUs, both Howard and Meharry Medical College produce a significant number of doctoral degree holders which populate the other HBCUs (Fig. 6). Each of the HBCUs, except Prairie View A&M and Southern U A&M College have at least 1 faculty member from an institution considered prestigious. Howard has the largest faculty and the most faculty from prestigious institutions (n=47) which accounts for 15.1% of their faculty ranks with biomedical doctoral degrees. 21.3% of the faculty at Howard and 35.4% of the faculty at Florida A&M have doctorates HBCUs. Other HBCUs appear to hire faculty with foreign doctorates more such as Meharry (38.9%) and Jackson State (27%) whereas other rely more on institutions classified as less-prestigious such as Prairie View A&M (88.2%) and North Carolina A&T (85.2%). These data highlight stark differences in hiring practices between Harvard and HBCUs. Harvard is being used as a surrogate for other

prestigious US-based institutions. We quantified where faculty at a subset of 32 institutions received their doctoral degrees with annotations for the top 15 institutions (Supplemental Fig. S1).

Self-hiring and regional hiring of faculty is ubiquitous

At nearly every institution we examined, the most common doctoral degree was from the same institution (i.e., self-hires); however, we do not have data of where faculty performed post-doctoral work or additional training, if any, between their doctoral degree and faculty position. Some institutions have a higher self-hire rate than others, for example, >25% 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, respectively (Supplemental Fig. S1). At Brown, there are more faculty with Harvard doctoral degrees than Brown doctorates, and at Princeton, there are relatively few faculty with Princeton doctoral degrees. Princeton is only the 14th most common doctoral degree for faculty there (Supplemental Fig. S1). Certain elite institutions are nearly ubiquitous in the top 15 doctoral degrees for faculty at these institutions. These include Harvard, Columbia, U Penn, Stanford, Johns Hopkins, University of Michigan, UC Berkeley, Duke, and UNC. There is also apparent regional bias where institutions in the same region, city, or nearby cities are more heavily represented. For example, Tufts and Boston University are in the top 15 doctoral degrees for Harvard Faculty. Wayne State University, which is in Detroit, Michigan is the 6th most common doctoral degree for faculty at University of 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.

To better understand the institutional hiring of faculty, we examined the type of institutions that faculty received their doctoral degrees at (see Fig. 3). Massachusetts General Hospital (Harvard), Yale, and Stanford are private institutions included in the top NIH funding category along with public institutions like UCSF and U of Michigan. We also included HBCU and Foreign institution codes. The most common doctoral degree institution for private institutions with the largest NIH funding portfolios were from other private institutions with the largest NIH funding portfolios (Supplemental Fig. S2). The most common doctoral degree type at public institutions

with the largest NIH funding portfolios including University of Pittsburgh, University of Michigan, University of Wisconsin-Madison, UNC, U of Washington, and the UC system institutions were from other public institutions with the largest NIH funding portfolios. Similarly, the most common faculty degree type at public institutions with smaller NIH funding portfolios including Ohio State University and University of Alabama at Birmingham are from other public institutions with smaller NIH funding portfolios (Supplemental Fig. S2). For HBCU's including Florida A&M and Howard University, the most common doctoral degree institutions are from public institutions with smaller NIH funding portfolios and other HBCUs (Supplemental Fig. S2). No institutions except for other HBCUs have >2% of faculty with doctoral degrees from HBCUs except 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 elite institutions populate the faculty ranks of the bulk of other institutions along prestige hierarchies across fields and disciplines.[7,15] Our analyses extend these findings by focusing on the K99/R00 career development award. We demonstrate there are significant disadvantages associated with systematically marginalized groups, gender identity, type of R00 institution, and whether faculty candidates move from the K99 institution or stay at the same institution. 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. 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. The K99 award appears more tailored to PhD scientists as there are other NIH career development awards exclusively for physician-scientists such as the K08 award; however, the notion that physician-scientists stay at their K99 institution more is a possibility that should be explored. These data bring to light several factors that affect the scientific human experience. The first is that moving institutions throughout one's academic career can cause significant hardship on first generation scientists' and those in systematically marginalized groups' familial/friendships ties which play important roles in the happiness, support, and productivity in the lives of 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 Korea[34]; 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.[35] 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, we do not have data on the number of K99/R00 applications that were not funded from each institution. 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. What made these 302 K99 awardees from 2019 and earlier unable to convert their K99-R00 grants is cause for concern within our greater academic community. 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, none of the K99/R00 awardees in our dataset received K99 awards while 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 for those faculty to examine how faculty hiring practices differ between institutions and institution types, in particular, HBCUs. While self-hiring is generally thought of negatively in academia, in line with others, we also found that this is common, even among HBCUs.[36] 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 HBCUs. For example, we have data on 938 biomedical faculty members at Harvard but only 1 has a doctoral degree from an HBCU. We find that self-hiring rates are not consistent for every institution. For example, Princeton faculty have degrees primarily from other Ivy league and elite institutions but doctoral degrees from Princeton only represent the 14th most common for biomedical sciences. Despite this, the self-hiring rate between 10-20% generally follows for most other institutions. It follows that in line with the known and described systemic inequalities within the academic system we have highlighted in this article, that self-hiring within HBCUs likely occurs 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. We do not know how many un-funded K99 applications may have originated 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.

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 or not to pursue a faculty position and where that may be. These decisions are not made solely based on the offered start-up package or institutional clout, and each individual places different weight on each factor. In addition, the choice to award an individual with a K99/R00 and subsequent NIH awards lies mostly with grant

reviewers who are generally mid-career to senior 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 take into account the motivation behind these complex decisions, and an understanding of these motivating factors would be enlightening.

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.

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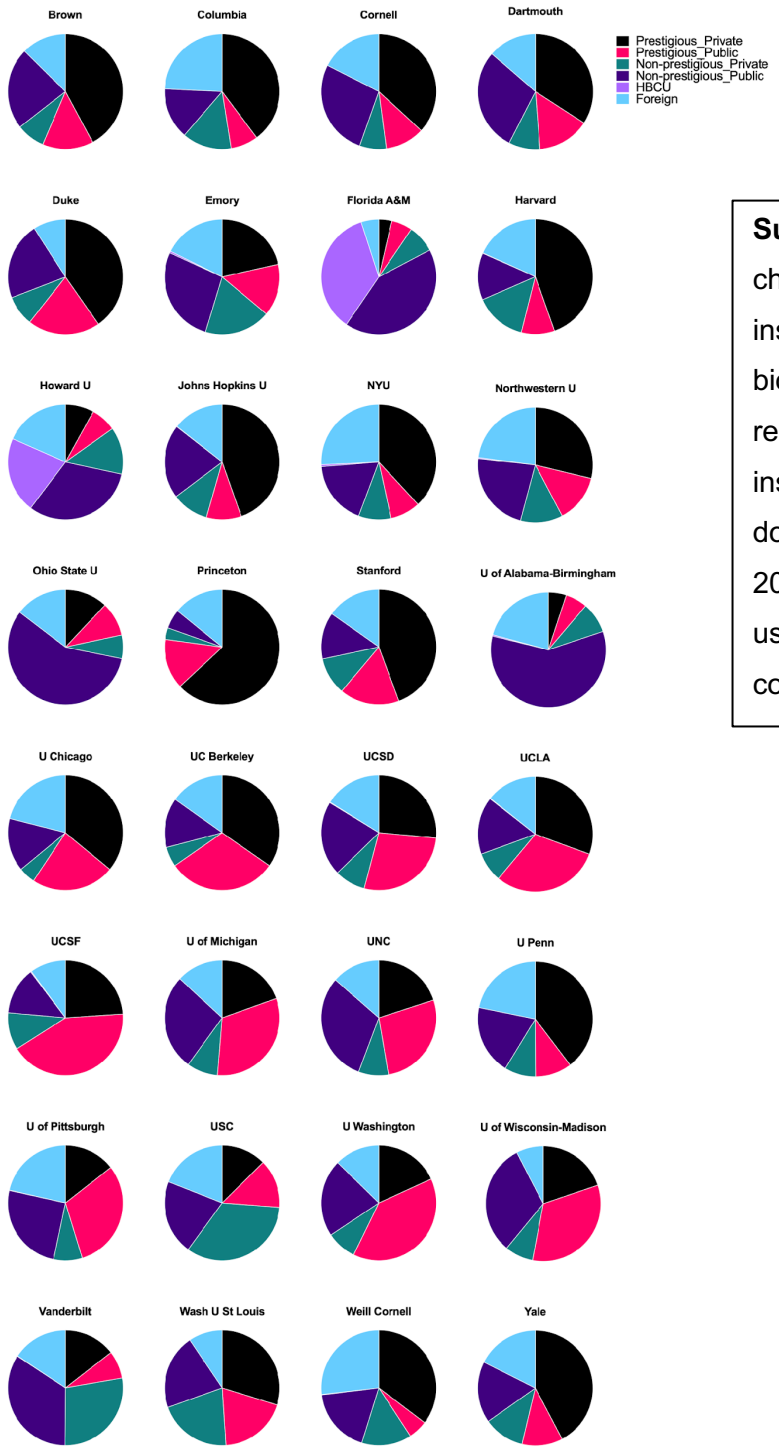
Supplemental Materials

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 used 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.