Exploring the Effects of Institutional Research Level on Engineering PhD Recipients' Post-Graduation Plans

Abstract

This research study uses multilevel modeling to investigate the relationship between the academic affiliation and demographics of engineering PhD recipients and their post-graduation plans. Using signaling theory, this study, explores the question: controlling for graduate covariates, is there a statistically significant difference in the odds of a PhD recipient choosing to pursue postdoctoral training as a post-graduation plan, based on the research level of the academic institution awarding the degree? Results indicate those who earned a degree from a very high research activity institution, Asian recipients, and women were significantly more likely to purse postdoctoral training than employment. This nuanced understanding of post-graduation plans provides points of consideration for the future of the engineering professoriate and broader workforce.

Exploring the Effects of Institutional Research Level on Engineering PhD Recipients' Post-Graduation Plans

This research study uses multilevel modeling to investigate the relationship between the academic affiliation and demographics of engineering PhD recipients and their post-graduation plans. Scholarship concerning engineering career trajectories has lacked the depth necessary to understand post-graduation plans, as most research in this vein has focused on the student experience (Brunhaver et al., 2013, 2015; Harris et al., 2017; Ro, 2011; St. Clair et al., 2017; Su, 2012, 2013). Thus, this research aims to shed light on engineering career plans (postdoctoral training versus employment) among PhD recipients using the 2017 Survey of Earned Doctorates (SED) restricted-use files from the National Center for Science and Engineering Statistics (NCSES) within the National Science Foundation (NSF).

The outcome variable of post-graduation plans was hypothesized to correlate with the type of academic institution at which a PhD degree is earned. Particular attention also was given to the plans of those from historically underrepresented minority (URM) backgrounds (American Indian/Alaska Native, Black, Hispanic, and Native Hawaiian/Pacific Islander); women; and by first-generation status. The driving research question of this study is, controlling for graduate covariates, is there a statistically significant difference in the odds of a PhD recipient choosing to pursue postdoctoral training as a post-graduation plan, based on the research level of the academic institution awarding the degree? This study is sponsored by the NSF Alliances for Graduate Education and the Professoriate.

Literature Review

Understanding the career trajectories of engineering PhD recipients is an important topic of investigation, particularly to understand their post-graduation plans. Approximately 66% of

PhD recipients enter employment in industry, government, or academia upon graduation, while nearly 34% seek further training through a postdoctoral appointment (NCSES, 2019). According to the 2015 Survey of Graduate Students and Postdoctorates in Science and Engineering, the number of postdoctoral scholars in engineering grew between 2010 and 2015 from 6,969 to 7,656, respectively indicating growing popularity of postdoctoral appointments in engineering academia (NSF, 2017). In engineering, those who choose a postdoctoral position are most likely to pursue a career as a professor, as obtaining a postdoctoral appointment has become an important step in the career pathway of an engineering PhD recipient entering academia (Andalib et al., 2018; Nerad & Cerny, 1999; Stephan & Ma, 2005; Su, 2012; Webber & Yang, 2015).

Recent research has shown postdoctoral appointments often are pursued by those with a greater interest in academic research and are critical precursors to the professoriate because they are more likely to obtain tenure-track faculty positions within seven to nine years of graduation (Main & Wang, 2019a). Furthermore, postdoctoral scholars are 6.1% more likely to obtain a tenure-track professor line than those who seek a professorship directly from their doctoral studies (Webber & Yang, 2015). A recent longitudinal study of science, technology, engineering, and mathematics (STEM) career paths using the SED and Survey of Doctorate Recipients (SDR) indicated remaining longer in a postdoctoral appointment does not significantly improve the possibility of obtaining a tenure-track position; however, it makes the attainment of academic research jobs 2.5% more likely (Cheng, 2020).

The depressed employment rates for engineering doctoral recipients, and specifically the decline in available tenure-track positions in the professoriate (Davis, 2006; Silva et al., 2016; St. Clair et al., 2017; Waaijer et al., 2016), encourages many engineers to turn to the private sector despite their interest in academia (Recotillet, 2007). Others may not have the “taste for science,”

finding salary and downstream work more important than the difficult pursuit of an academic appointment (Roach & Sauermann, 2010). Consequently, a need exists to understand engineering PhD recipient post-graduation plans and the way in which those plans intersect with the research level of the academic institution awarding the degree.

The institution from which a STEM degree is obtained has been found to enhance career prestige and success. The U.S. Carnegie Classification of Higher Education Institutions (Indiana University Center for Postsecondary Research, 2018) has been a significant predictor in the difference between STEM doctoral recipients pursuing a career in research or teaching (Barry, 2013; Burris, 2004; Kim et al., 2019). Colleges and universities in the first quartile of research-intensive institutions produce more doctoral recipients who assume academic careers in research and development than institutions in the third and fourth quartiles (Barry, 2013). Doctoral recipients from the latter tend to follow academic teaching career pathways, and those who studied in programs outside the US were 1.2 times more likely to pursue a teaching career. Characteristics of doctoral programs that influence research-focused career outcomes include research reputation and stature, funding opportunities, advisor support, mentoring, and professional development training (Blume-Kohout & Adhikari, 2016; Main & Wang, 2019a; Upton & Tanenbaum, 2014).

While institutional type and prestige of a program or department impacts employability in academia, a candidate's demographic background also plays a role in career selection and attainment (Barry, 2013; Brunhaver et al., 2013; Celis & Kim 2018; Cognard-Black, 2004; Donnelly, 2011; Harris et al., 2017; Main & Yang, 2019b). Increasing the number of URMs and women who seek postdoctoral training is key to diversifying the professoriate, since future faculty are derived mostly from this career group (Allen-Ramdial & Campbell, 2014; Jaeger et

al., 2017; NSF, 2019; St. Clair et al., 2017; Wilson, 2020). Trends suggest diversification will continue to be slow as the percentage of URM postdoctoral scholars has hovered around 5% for the past decade (Wilson, 2020) and only 6% of engineering professors identify as racial/ethnic minorities, with 17% identifying as women (Roy, 2019).

Despite the career desires of URMs and women to enter a tenure-track faculty position, they are more likely to have received no academic job offers at the time of doctoral STEM graduation (Kinoshita et al., 2020). For URM engineers, a disconnect often exists between career intentions and career pathways once acquiring their PhD due to perceived lack of support from advisors and negative perceptions of academic culture that have long-standing impacts on early career outcomes of these groups (Hunter, 2015; Main & Yang, 2019b). Turk-Bicakci et al. (2014) found half of URM and women STEM PhD recipients are in academic careers, while the other half work in industry or government and these groups are the most likely to work outside a STEM career field. Compounding this attrition out of academia, studies have shown women STEM faculty are less likely to be employed at prestigious institutions in comparison to their male counterparts (Clauset et al., 2015; Shaw & Stanton, 2012). Clearly, the understanding of career trajectories among engineering PhD recipients is not only complicated, but also requires further investigation.

Theoretical Framework

Signaling theory (Kim et al., 2014) is used as the theoretical framework for this study. Theoretical frameworks build upon a foundation of established knowledge, offer logical explanations for the relationships observed, and reveal new understandings of a phenomenon (Anfara & Mertz, 2014), in this case the ways in which post-graduation plans may be shaped by the research intensity of the academic institution at which a PhD degree is earned by engineers.

Research intensity is defined by the Carnegie Classification of Institutions of Higher Education by the amount of total research expenditures and number of research/scholarship doctoral conferrals (Indiana University Center for Postsecondary Research, 2018). According to the theory, potential employers search for "signals" of quality in their candidates and attribute strong higher education credentials from selective and prestigious institutions as an indication of heightened future performance. Research-intensive institutions are more likely to provide doctoral students with a respected research reputation, stature in the field, and increased funding prospects. Additionally, these individuals often receive greater advisor support, mentoring, and professional development opportunities that prepare them to successfully compete for an academic position (Blume-Kohout & Adhikari, 2016; Main & Wang, 2019a; Upton & Tanenbaum, 2014). Subsequently, employment demand is higher for individuals who earned their doctoral degree from high research-intensive institutions.

Method

Research Design

This study investigated engineering PhD graduates' post-graduation plans (postdoctoral training versus employment) using the 2017 SED restricted-use files (NCSES, 2019). The study was grounded by signaling theory (Kim et al., 2014), as the outcome variable of post-graduation plans was hypothesized to correlate with the type of academic institution at which a PhD is earned (Barry, 2013; Burris, 2004; Kim et al., 2019). Graduates' demographic characteristics also were taken into consideration, as other studies have demonstrated their predictive power (Barry, 2013; Brunhaver et al., 2013; Celis & Kim 2018; Clauset et al., 2015; Cognard-Black, 2004; Donnelly, 2011; Harris et al., 2017; Shaw & Stanton, 2012). Thus, the researchers conducted a multilevel mixed-effects logistic regression to answer the following question:

Controlling for graduate covariates, is there a statistically significant difference in the odds of a PhD recipient choosing to pursue postdoctoral training as a post-graduation plan, based on the research level of the academic institution awarding the degree?

Data Source

The SED is a survey that compiles a wealth of personal and professional data from recent graduates of doctoral programs throughout the US (NCSES, 2019). The 2017 SED restricted-use files include a census of approximately 55,000 individuals from over 400 institutions who graduated with a doctoral degree between July 1, 2016, and June 30, 2017.

Data Transformations

Upon obtaining the 2017 SED restricted-use files from the NCSES (2019), the researchers transformed selected variables to build those required for the analysis. The dependent variable in the analysis was PDOCPLAN. We dichotomized the PDOCPLAN variable by combining the various post-graduation plans of PhD recipients into the broader category of postdoctoral training, which included individuals entering a postdoctoral fellowship (12.79%), a postdoctoral research assistantship (8.34%), a traineeship (0.69%), intern or clinical residency (0.19%), or other and unspecified training (1.21%), versus employment, which included employment (63.69%), military service (0.81%), or other and unspecified employment (0.58%). The new variable was named PDOCPLANBINARY.

Indicator codes were created for the universities' Carnegie classification (PHDCARN), which was the cluster-level variable in the equation. To address the research question, only three of the Carnegie classification categories were needed: R1, Doctoral Universities–Very high research activity (PHDCARNHIGHEST); R2, Doctoral Universities–High research activity (PHDCARNHIGH); and D/PU, Doctoral/Professional Universities–Moderate research activity

(PHDCARNMODERATE). D/PU was used as the reference category in the model. Race/ethnicity classifications were coded in a binary fashion; all non-group members (i.e., all other race/ethnicity categories) served as the reference categories in order for each variable to be either yes or no for the race/ethnicity indicators. For example, individuals who indicated they were American Indian or Alaska Native (AIAN) were compared against all non-AIAN individuals, all Native Hawaiian or other Pacific Islander (NHPI) were compared against all non-NHPI, and so on. The SEX variable also was binary, with men as the reference category. Finally, parent education variables (EDMOTHER and EDFATHER) were destringed and coded dichotomously as either less than a bachelor's degree or bachelor's degree or more. Those variables were then combined to create a binary FIRSTGEN variable, with "not first generation" as the reference category. All variables were grand mean centered prior to running the model to facilitate optimal interpretation of the model intercept. Variables with reference categories are listed in Table 1.

Table 1

Variables and Codes

Variable	Coding in STATA
PDOCPLANBINARY	
Employment	0
Postdoctoral Training	1
PHDCARNHIGHEST	
No	0
Yes	1
PHDCARNHIGH	
No	0
Yes	1
PHDCARNMODERATE	
No	0
Yes	1
AIAN	
No	0

Yes	1
ASIAN	
No	0
Yes	1
BLACK	
No	0
Yes	1
HISPANIC	
No	0
Yes	1
NHPI	
No	0
Yes	1
WHITE	
No	0
Yes	1
SEX	
Female	0
Male	1
FIRSTGEN	
No	0
Yes	1

Sample

After data transformations, frequencies were calculated for each variable in the model. The final data sample (n = 75340) as seen in Table 2 indicates 33.56% of respondents planned to pursue postdoctoral training while 66.44% sought employment. The majority of respondents, 85.85%, earned their PhD degree from an R1 institution (PHDCARNHIGHEST), 12.63% from an R2 institution (PHDCARNHIGH), and 1.52% from a D/PU institution (PHDCARNMODERATE). Relative to respondent demographics, 0.61% identified as American Indian or Alaska Native (AIAN), 49.15% as Asian, 2.72% as Black, 3.95% as Hispanic, 0.21% as Native Hawaiian or other Pacific Islander (NHPI), and 48.74% as White. Respondents can select more than one racial/ethnic category, so the total exceeds 100%. In terms of sex, 20.20%

of the sample identified as female and 79.80% as male. Last, 31.31% identified as first generation, with neither parent earning a bachelor's degree or higher.

Table 2

Sample Demographics

Variable	Percentage
Postdoctoral Training	33.56
Employment	66.44
Institutional Type	
R1 Doctoral Recipient	
R2 Doctoral Recipient	85.85
D/PU Doctoral Recipient	12.63
	1.52
Race/Ethnicity	
American Indian/Alaska Native	0.61
Asian	49.15
Black	2.72
Hispanic	3.95
Native Hawaiian or other Pacific Islander	0.21
White	48.74
Sex	
Female	20.20
Male	79.80
First Generation	31.31

Note. Sample sizes rounded to the nearest 10 to protect against participant identification. Data from National Science Foundation, National Center for Science and Engineering Statistics (2019), *Survey of earned doctorates: 2017* [Data set]. NCSES. https://ncses.nsf.gov/pubs/nsf19301/data

Data Analysis

Through the use of multilevel modeling, the SED dataset was used to examine the relationship between the PhD Carnegie institution classification from which an engineering graduate earned their PhD and the odds of choosing to pursue postdoctoral training, controlling for graduate-level covariates. Multilevel modeling is a regression-based analysis that takes into

account the hierarchical structure of the data by providing a framework that incorporates independent variables on each level of the model (Aguinis et al., 2013; Raudenbush & Bryk, 2002). In this case, the hierarchically structured data included nested data in which graduates were clustered within institutions. As the dependent variable was binary categorical, a multilevel binary logistic regression was used. Binary categorical coding of independent variables was chosen to aid in reporting group differences. Effects estimated through the models were interpreted as odds ratios, and 0.05 was used as the Type I error threshold for the test statistics (Raudenbush & Bryk, 2002).

Results

The researchers conducted a multilevel binary logistic regression (n = 75,340) using STATA, with random effects at the institution level. Results are located in Table 3. The overall model ($p < .001$) suggests it was a good fit for interpreting the data with the variables that were included. For graduates from R1 institutions, the odds of choosing postdoctoral training were 80% greater than for PhD recipients from D/PU institutions (OR = 1.80, $p < .001$). For PhD recipients who identified as Asian, the likelihood of obtaining postdoctoral training rather than employment was 17% greater than for non-Asian PhD recipients (OR = 1.17, $p = 0.010$). The PhD recipient's sex also was significant (OR = .867, $p < .001$), indicating the odds of men obtaining postdoctoral training rather than employment was 13% less than for women. The effect of first-generation status also was significant (OR = .963, $p = 0.033$), indicating the odds of seeking postdoctoral training rather than employment were 4% less for first-generation students, compared to students who were not. No other covariates in the model had statistically significant effects.

Table 3

Multilevel Model of Engineering PhD Recipients' Post-Graduation Plans

Covariates	Odds Ratio	Std. Err.	Z	P > |z|	[95% Conf.	Interval]
AMERIND	.85	.091	-1.49	.137	.692	1.052
ASIAN	1.17*	.073	2.59	.010	1.040	1.325
BLACK	1.01	.072	.19	.853	.881	1.165
HAWAIIAN	.94	.164	-.030	.764	.677	1.332
HISPANIC	1.06	.044	1.62	.105	.986	1.160
WHITE	1.13	.069	1.92	.055	.998	1.270
FIRSTGENERATION	.96*	.017	-.214	.033	.935	1.000
SEX	.87**	.017	-7.41	.000	.835	.900
PHDCARNHIGHER	1.29	.181	1.83	.067	.982	1.703
PHDCARNHIGHEST	1.80**	.242	4.35	.000	1.379	2.338
_CONS	.53	.019	-17.40	.000	.493	.569
PHDINST var(_cons)	.17	.024			.130	.223

Note. Data from National Science Foundation, National Center for Science and Engineering Statistics (2019). *Survey of earned doctorates: 2017* [Data set]. NCSES. https://ncses.nsf.gov/pubs/nsf19301/data

*$p < .05$.; **$p < .001$

Discussion

Using the 2017 SED restricted-use files and signaling theory (Kim et al., 2014), this study investigated the post-graduation plans (postdoctoral training versus employment) of engineering PhD recipients. The results of the multilevel mixed-effects logistic regression demonstrated Carnegie classification of the institution from which a recipient earned their PhD was significantly related to post-graduation plans. From the analysis, if a respondent earned their PhD from an R1 institution, the odds of choosing postdoctoral training were 80% greater than for graduates of a D/PU institution; thus, R1 institutions are more likely to graduate PhDs who seek postdoctoral training and other similar research opportunities. This result may be related to the stronger research offerings R1 graduates are exposed to at their institutions (Main & Wang, 2019a). Signaling theory would suggest (Kim et al., 2014) R2 and D/P institutions should focus

on heightening the research opportunities afforded to PhD recipients in order to enable engineering PhD graduates to be more competitive in the postdoctoral training market. These opportunities could occur through increased research opportunities, advisor support, mentoring, and research-related professional development offerings (Blume-Kohout & Adhikari, 2016; Main & Wang, 2019a; Upton & Tanenbaum, 2014).

This study also observed relationships between graduates' demographic characteristics and their post-graduation plans. Other research on engineering PhDs has demonstrated the important relationship of race/ethnicity and gender with early employment outcomes (Main & Yang, 2019b). The current study found Asian and women engineering PhD recipients were more likely to obtain postdoctoral training than to seek employment. In contrast with previous research, this finding suggests greater numbers of women are pursuing additional training to potentially support future acquisition of a tenure-track position, a promising notion for the diversification of the professoriate. Specifically, this study found that the odds of women obtaining postdoctoral training were 13% greater than for males. The work of Kinoshita et al. (2020) found women and URMs holding STEM PhDs were more likely to have no job offers at the time of graduation, one possible rationalization for why women may be pursuing postdoctoral training following graduation.

When considering race/ethnicity, past research has found Asian engineering PhDs were more likely to work in industry and less likely to work in non-tenure track academic positions (Main & Yang, 2019b). The current investigation, which utilized 2017 rather than the 2013 SED data, found PhD recipients identifying as Asian were 17% more likely to seek postdoctoral training than employment, a finding that reinforces the continuation of the overrepresentation of Asians in engineering academia. First-generation status also had a statistically significant

negative relationship with the odds of seeking postdoctoral training, 4% less likely. First-generation PhD recipients were more likely to plan to seek employment rather than postdoctoral training, which could be indicative of familial need and tendencies for prioritizing employment opportunities and the need for immediate and greater financial compensation.

Limitations

This research was limited by the self-report nature of the SED dataset; researchers were unable to verify an individual's response. Specifically, the intersection of intended and actual career plans was unknown. In addition, the reasons for the graduates' post-graduation plans were not available and potentially informative. For example, are women more likely to pursue additional training because of their desire for a tenure-track position, or is it due solely to the lack of job offers at the time of graduation? This research also was limited by selection bias, as individuals seeking a PhD in engineering from an R1 institution may differ substantially from those who apply to R2 or D/PU institutions, on variables outside those controlled for in this study. Additional bias may have been introduced by R1 institutions in the selection of candidates they accept and who ultimately complete their PhD programs, as R1s tend to hold a more selective admissions process, suggesting graduates may have different levels of preparation, research aptitude, future aspirations, or motivations than those from R2 and D/PU institutions.

Implications and Future Research

This investigation provides several important implications and directions for future research. Institutions of higher education must understand the impact of institutional research intensity on their PhD recipients' post-graduation career plans as they relate to employability. R2 and D/P institutions may find it prudent to expand the research experiences, advising, mentoring, and professional development programs offered within their programs to increase the likelihood

of being competitive for postdoctoral training opportunities. Additionally, it is important for institutions to consider the ways in which race/ethnicity, gender, and first-generation status intersect with post-graduation career plans in academia, government, and industry as respondents' race/ethnicity and gender were important predictors of engineering PhDs' post-graduation plans.

An area for future research lies in further exploration of the types of careers and training sought by engineering PhD recipients after obtaining their degree. Understanding market research on job availability in relation to the types of careers pursued by engineering PhD recipients can aid doctoral programs in appropriately preparing students for their next career stage. Additionally, more research is needed in understanding the motivations for pursuing postdoctoral training versus accepting a position in industry post-graduation, particularly as it relates to URMs, women, and first-generation students. Are these decisions based solely on a lack of offers (Kinoshita et al., 2020), depressed employment rates (Davis, 2006; Silva et al., 2016; St. Clair et al., 2017; Waaijer et al., 2016), or are they based on professoriate aspirations. Other recent longitudinal research using the SED and SDR has demonstrated postdoctoral appointments make academic research jobs 2.5% more likely (Cheng, 2020) but further study is needed on how race/ethnicity, gender, and first-generation factor into that likelihood. Another fruitful area of inquiry may be to investigate first-generation PhD recipients and their career pathways, as this area is less commonly studied and represents a distinct gap in the literature.

Conclusion

Results of this study indicate the Carnegie classification of the institution significantly impacts engineering PhD recipient post-graduation plans. Those who earn a degree from an R1 institution are more likely to pursue postdoctoral training than those from R2 and D/PU

institutions. Similarly, Asian and women engineering PhD recipients are significantly more likely to plan to pursue postdoctoral training. The increase of women suggests greater diversity in postdoctoral appointment plans and subsequent future hiring pools for engineering tenure-track positions, a promising finding for the diversification of the field. The increase of Asians pursing additional training, however, suggests their continued overrepresentation as both postdoctoral scholars and as those next in line to assume future engineering tenure-track faculty positions. Yet, first-generation PhD recipients are significantly less likely to seek postdoctoral training, opting instead to pursue employment post-graduation.

This nuanced understanding of post-graduation plans among engineering PhD recipients provides important points of consideration if the engineering workforce is to reflect the U.S. population at large. The metaphor of a leaking STEM pipeline is inadequate and potentially damaging, as it implies the number of underrepresented individuals entering the field must be increased rather than reckoning with the fact that institutional "signaling" (Kim et al., 2014) may need to be dismantled in order to truly achieve equitable outcomes. Promoting institutional change across all types of higher education institutions is crucial to ensure equitable access and success for all individuals aspiring to be engineers, and particularly for those planning to pursue the professoriate as a career.

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