The Early Career Outcomes of Engineering PhDs in the United States

J. B. Main[1]
Purdue University
West Lafayette, IN, USA

Y. Wang
Purdue University
West Lafayette, IN, USA

Conference Key Areas: Diversity in Engineering Education; Talent Management; Impacts of Demographics in Tertiary Education

Keywords: Engineering PhDs; Career Pathways; Industry; Faculty; Employment Outcomes

ABSTRACT

Examining the career paths of engineering PhDs in the United States has important implications for strengthening the engineering workforce. This study models the early career outcomes of engineering doctorates by sex, race/ethnicity, citizenship, and other observable characteristics, as well as identifies factors that influence these pathways using regression analyses on nationally representative data from the National Science Foundation Survey of Doctorate Recipients. Research findings show that early employment outcomes vary by PhD demographic factors, including sex and race/ethnicity. The logistic regression results show that primary source of funding, such as fellowships/grants and research assistantships, are associated with employment in tenure track faculty positions. Additionally, the employment outcomes of previous PhD cohorts from the same program and the relative ranking of the engineering program also contribute to early career outcomes.

[1] Corresponding Author
J. B. Main
jmain@purdue.edu

1 INTRODUCTION

Although initiatives and programs designed to broaden participation in academic institutions have generated many positive changes, the proportions of women, African American/Black, Hispanic/Latino, and Native Americans have not seen commensurate increases in engineering fields in the U.S. [1]. There is a strong connection between the demographic composition of faculty and the level of diversity and persistence among undergraduate and graduate students, such that it is critical to identify who pursues faculty careers and why they pursue this career path to further develop strategies to broaden participation in the engineering professoriate [2-4]. It is equally important to identify who pursues careers in industry, government, and other areas to better explain career decision making and how PhDs view different career paths, as well as to develop strategies to help prepare PhDs for the realities of the multitude of careers available beyond the professoriate. This study examines the early career outcomes of engineering doctorates by sex and race/ethnicity, and identifies the factors that influence attainment of the first post-PhD employment sector using logistic regression analyses. We leverage data from the National Science Foundation Survey of Doctorate Recipients, which is representative of all engineering PhDs in the U.S., to address the following research questions:

1. What are the employment patterns of early career engineering PhDs, and are there differences by sex and race/ethnicity?
2. Which factors at the individual and departmental levels influence the first post-PhD employment sector of engineering PhDs?

Research findings provide important context and information for various applications, such as policy formation, development of strategies and interventions to promote a competitive engineering workforce, increasing information flow and partnerships between academia and industry, and providing students with critical information on the multitude of career paths available to doctorates. Doctoral students, particularly women and underrepresented minorities (African American, Hispanic/Latino, and Native American), will be able to more accurately assess their early career prospects, which have implications for persistence and broadening participation in the engineering workforce. This study has the potential to inform the approaches and strategies to prepare doctoral engineering students for a rapidly changing, global work environment.

2 LITERATURE REVIEW

The major employer sectors for engineering PhDs in the U.S. include academia (tenure track, non-tenure track), industry (private or business sector), and non-academic public sectors, such as government and non-profit organizations [5]. Although doctoral programs are traditionally designed to train scholars for academic research, the majority of engineering PhDs find employment in non-academic sectors, especially in industry [6-8].

The individual-level factors that affect career choice among new engineering doctorates include individual characteristics/background, experiences during PhD program, and field of study [5-9]. In general, PhDs with higher levels of interest in basic research, desire for peer recognition, and preference for autonomy in choosing research topics are more likely to pursue basic research in academia, whereas PhDs with greater preference for applied research aimed at technological development, professional experience, and monetary returns are more likely to pursue careers outside of academia [5-7]. Individual preference for types of careers changes over time, and experience during PhD training also influences subsequent career choice [9]. The field of study, including the engineering discipline, also has an impact on PhDs' career choice [8].

Labour market conditions also play a role in new doctorates' career choices. For example, there is evidence that institutions are training more engineering PhDs than can be employed as tenure-track faculty [9, 10]. Subsequently, a number of PhD graduates need to find employment outside of academia [11] or to find temporary positions within academia, such as non-tenure track faculty or research positions [12-14]. While the number of PhD students aspiring to work as faculty members tend to exceed the number of available tenure-track faculty positions [10], there is also increasing evidence that declining job security and lack of opportunities to establish a research program may be diminishing the attractiveness of academic positions to engineering PhDs [9, 11].

3 DATA AND METHODS

3.1 Data

Our sample is comprised of engineering PhDs who responded to the 1993-2013 waves of the National Science Foundation Survey of Doctorate Recipients (SDR). The SDR is conducted approximately biennially on a nationally representative sample of PhDs in engineering (and science and health), who received a PhD degree from a U.S. academic institution. The SDR provides demographic, educational, and employment history information for each respondent. We match our sample of SDR respondents to data from the National Science Foundation Survey of Earned Doctorates (SED). The SED is a census of recipients of research doctorates from accredited U.S. institutions, which provides demographic information, educational history, and post-graduation plans of recent doctorates. We also include data from the National Research Council's ranking of the PhD program, which we categorized into three groupings: top-ranked, mid-ranked, and not ranked. Our resulting merged data therefore includes both educational and employment histories for engineering PhDs, as well as measures for relative engineering doctoral program ranking.

Our sample includes PhDs from Aerospace, Civil, Chemical, Electrical/Computer, Mechanical, and Other Engineering. Due to a change in the specific fields of study reported in the SDR in 2001, the "Other Engineering" category includes Industrial,

Materials and Metallurgical, as well as other engineering fields not specified in the SDR. Table 1 presents the summary statistics of demographic characteristics and employment information for respondents who completed the SDR 1-2 years after their PhD completion (n = 6,192) during the 1993 through 2013 survey waves.

Consistent with reports regarding the underrepresentation of women in the engineering workforce, only 21% of the sample is comprised of women. Black and Hispanic engineering PhDs each comprise less than 6% of the engineering workforce. In terms of employment, during the period of 1-2 years after PhD completion, the largest proportion of engineering PhDs work in industry (57%), followed by non-tenure-track positions (19%), tenure-track positions (11%), and then government positions (8%).

Table 1: Description of the 1993-2013 Survey of Doctorate Recipients Sample

Variable	Initial career 1-2 years since PhD n (%)
Sex	
Female	1,309 (21.1)
Male	4,883 (78.9)
Race/Ethnicity	
Asian	2,557 (41.3)
Black	327 (5.3)
Hispanic	334 (5.4)
White	2,887 (46.6)
Other Ethnicity	87 (1.4)
Citizenship	
U.S. citizen	3,449 (55.7)
Perm. resident	1,056 (17.1)
Temp. resident	1,686 (27.2)
Disability	
No	5,470 (88.3)
Yes	722 (11.7)
Marital status	
Married	4,298 (69.4)
Not Married	1,894 (30.6)
Children under age 6	
0	4,305 (69.5)
1	1,292 (20.9)
2 or more	595 (9.6)
Work status/Employer sector	
Government	466 (7.5)
Industry	3,551 (57.3)
Non-profit	176 (2.8)
Non-tenure track	1,169 (18.9)
Tenure track	671 (10.8)
Unemployed	112 (1.8)
Not in labour force	47 (0.8)
Total	6,192 (100)

3.2 Methods

To examine the early career outcomes of engineering PhDs, we use descriptive statistics and logistic regression models.

Employment patterns. In addition to the descriptive statistics provided in Table 1, we generated Figure 1 to illustrate the employment patterns of early career engineering PhDs by sex, race/ethnicity, and employment sector.

Initial job placement by employment sector. Leveraging information from both the SED and the SDR, we use logistic regressions to identify individual- and departmental-level factors that influence engineering PhD initial job placement by employment sector (1-2 years after the PhD). Our analyses are based on the sample of engineering PhDs who responded to the SDR between 1993 and 2013 and were in the workforce during the survey reference week. We focus on the following employment sectors: tenure track, non-tenure track academic, industry, and government because these sectors are the most prevalent areas of employment based on the descriptive statistics (Table 1).

For each of the employment sector, we estimate the following model:

$$Ln\left(\frac{p_i}{1-p_i}\right)=X_i\beta+u_i, \qquad (1)$$

where p_i is the probability that individual *i* is initially employed in the given employment sector, X_i is a set of covariates for individual *i*, which includes sex, race/ethnicity, U.S. citizenship, disability status, marital status, number of dependents under 6 years old in the household, age at PhD completion, and primary financial support during the doctoral education, and u_i is the error term. For race/ethnicity, the model includes Asian, underrepresented minorities (URM), and White as the reference category. We also include in the model parents' education, time to PhD degree, PhD degree year, and engineering discipline, although the coefficients for these variables are not shown in the resulting table. Primary financial support includes fellowship/grant, research assistantship, teaching assistantship, and self-funded as the reference category. In terms of departmental characteristics, the model includes the categorized National Research Council ranking for the PhD department (top-ranked, mid-ranked, or not ranked), as well as the job placement/employment sector of the 5 previous cohorts graduating from the same engineering program as individual *i*.

4 RESULTS

Figure 1 provides a visual summary of the percentage of PhDs employed in different sectors (government, industry, non-profit, non-tenure track, tenure track, and unemployed) by sex and race/ethnicity. As also shown in Table 1, the majority of engineering PhDs work in industry. However, the percentage varies by demographic characteristics. Among Asian female and male engineering PhDs, those working in

industry constitute the highest relative percentage, but those working in tenure-track faculty positions or are unemployed constitute relatively lower percentages. Relative to Asian women, Hispanic and Black women have higher percentages of engineering PhDs in tenure track faculty positions. This trend is consistent among men as well.

Our logistic regression results are presented in Table 2. The attainment of tenure track, non-tenure track, industry, and government positions are shown in separate columns. In terms of tenure track faculty positions, women are 4.5 percentage points more likely than men to start out in these positions 1-2 years after PhD completion. However, consistent with Fig. 1, Asian engineering PhDs are 6 percentage points less likely, and URM engineering PhDs 4 percentage points more likely, than White engineering PhDs to be in tenure-track faculty positions. The primary type of financial support during doctoral education matters—PhDs with fellowships/grants are 5 percentage points more likely, and those with teaching assistantships 8 percentage points more likely, than PhDs who are self-funded to obtain tenure track positions. Departmental characteristics also play a role in the likelihood of obtaining a tenure track position. PhDs who graduate from top ranked institutions are 2.1 percentage points more likely than those from mid-ranked institutions to be an early career tenure-track faculty member. Departmental norms regarding job placement also appear to contribute to career outcomes, as departments with higher proportions of previous

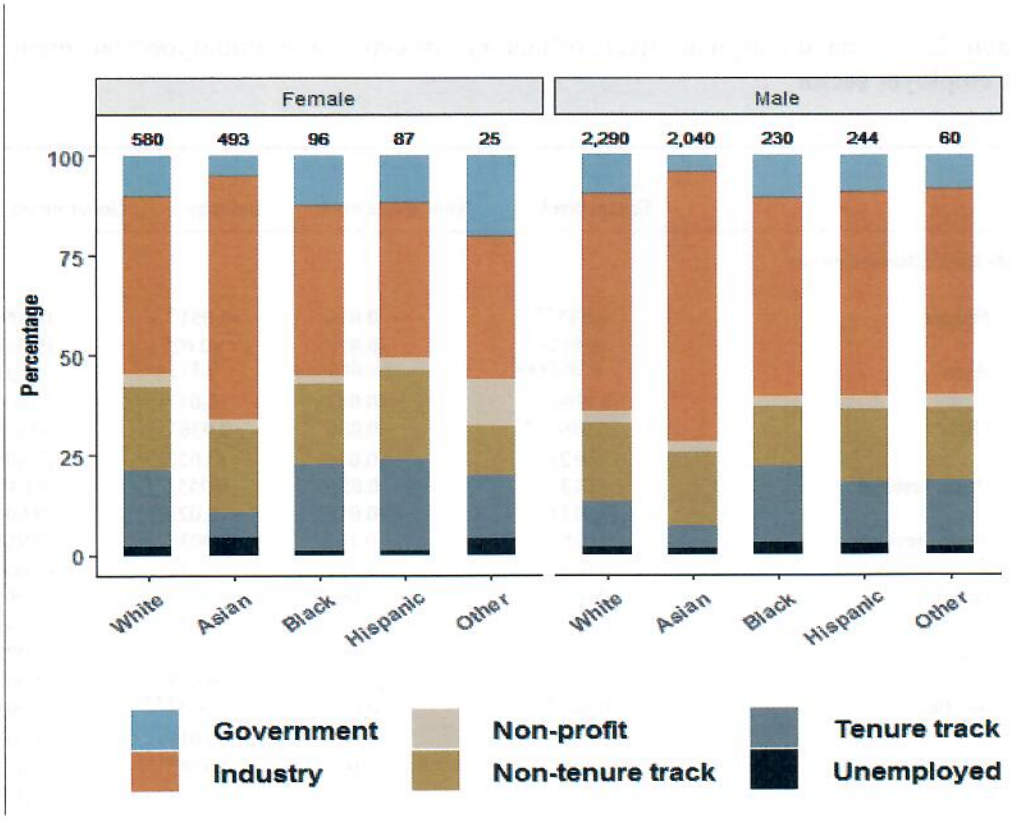

Fig. 1. Initial employment sector 1-2 years after the PhD by sex and race/ethnicity.

graduates obtaining academic positions are more likely to continue this pattern.

Consistent with our descriptive Figure 1, Asian engineering PhDs are more likely to work in industry, but less likely to work in non-tenure track academic positions, compared to their counterparts. URM engineering PhDs are also less likely to work in non-tenure track academic positions and in industry than White engineering PhDs. The primary financial support appears to only be significant for tenure track faculty positions, except that engineering PhDs who were self-funded are more likely to work in government sector compared to PhDs who were funded through research or teaching assistantships, by 1.3 and 2.4 percentage points, respectively.

In terms of department-level characteristics, PhDs graduating from programs that are not ranked are 4.5 percentage points more likely than those graduating from mid-ranked programs to obtain a non-tenure track academic position. Meanwhile, engineering PhDs who graduated from top-ranked programs, as measured by the NRC rankings, are less likely than PhDs graduating from mid-ranked programs to work in the industry and government sectors. The employment outcomes of previous PhD cohorts also appear to play a role. PhDs who earned their degrees from programs where a higher proportion of previous cohorts obtained jobs in government are also more likely to work in the government sector.

Table 2: Estimated marginal effects of factors associated with initial job placement by employer sector

	Tenure track	Non-tenure track	Industry	Government
Individual Characteristics				
Female	0.045**	−0.016	−0.051*	0.009
	(0.017)	(0.019)	(0.027)	(0.011)
Asian	−0.061***	−0.046***	0.113***	−0.001
	(0.009)	(0.012)	(0.017)	(0.007)
URM	0.039***	−0.036**	−0.036*	0.009
	(0.012)	(0.014)	(0.022)	(0.008)
Perm. resident	−0.013	0.053***	0.055***	−0.045***
	(0.011)	(0.018)	(0.021)	(0.006)
Temp. resident	−0.018*	0.102***	−0.003	−0.054***
	(0.01)	(0.017)	(0.019)	(0.006)
Disability	0.012	0.008	−0.03	0.005
	(0.011)	(0.016)	(0.021)	(0.008)
Child<6	0.017*	0.011	−0.025	−0.002
	(0.01)	(0.014)	(0.018)	(0.007)
Married	0.02**	−0.06***	0.055***	−0.004
	(0.01)	(0.015)	(0.019)	(0.008)
Child<6*Female	−0.006	0.009	−0.079*	0.017
	(0.019)	(0.031)	(0.043)	(0.019)
Married*Female	0.003	0.053*	−0.059	0.001
	(0.019)	(0.031)	(0.037)	(0.014)

31-40	−0.003	0.045***	−0.07***	0.014**
	(0.008)	(0.011)	(0.015)	(0.006)
40 or older	0.022	0.04*	−0.085***	−0.002
	(0.015)	(0.023)	(0.027)	(0.009)
PhD Financial Support				
Fellowship/Grant	0.048***	0.017	−0.031	−0.009
	(0.017)	(0.02)	(0.025)	(0.008)
Research Assistantship	0.009	0.009	0.022	−0.013*
	(0.011)	(0.014)	(0.019)	(0.008)
Teaching Assistantship	0.077***	0.002	−0.019	−0.024***
	(0.023)	(0.022)	(0.03)	(0.009)
Institutional Characteristics				
PhD Program NRC Ranking				
Not Ranked	−0.018	0.045**	−0.041	−0.01
	(0.012)	(0.02)	(0.025)	(0.008)
Top Ranked	0.021**	0.016	−0.028*	−0.015**
	(0.009)	(0.012)	(0.016)	(0.006)
Percent of Previous 5 Cohorts in				
Post-doc	0.017	0.052	−0.068	−0.022
	(0.034)	(0.045)	(0.064)	(0.024)
Academia	0.108***	0.028	−0.177**	−0.023
	(0.041)	(0.057)	(0.08)	(0.03)
Industry	0.008	−0.147***	0.229***	−0.056*
	(0.039)	(0.053)	(0.072)	(0.029)
Government	−0.04	0.0004	−0.32***	0.129***
	(0.062)	(0.076)	(0.107)	(0.03)
Observations	6,145	6,145	6,145	6,145

Estimated marginal effects of factors associated with initial job placement in tenure-track, non-tenure track, and industry, respectively. Parents' education, discipline, and degree year are included in the model, but not shown in the table. *p<0.1; **p<0.05; ***p<0.01.

5 DISCUSSION AND CONCLUSION

With the United States' call for a larger and more diverse engineering workforce, identifying the role of doctoral education in preparing engineering students for a multitude of careers is more important than ever. Our descriptive analysis showed that the first employment sector that engineering PhDs enter varies by sex and race/ethnicity. We also identified which individual- and departmental-level factors contribute to the different early career outcomes using logistic regression analyses. We found that demographic characteristics, primary financial support, program ranking, and the employment outcomes of previous cohorts matter.

These findings provide important context for developing strategies to increase diversity across the different employment sectors in the United States. Doctoral programs can use these findings to better inform their students about the different career outcomes of engineering PhDs. The findings also provide information for current and prospective doctoral students to develop post-graduation career plans given their own interests and the likely career outcomes of previous cohorts of engineering PhDs. While our study focuses on engineering PhDs in the U.S., our

findings provide important comparative information for PhD programs in other countries. Prospective students from other countries considering attending an engineering program in the U.S. can also use these findings in their academic and career decision making. For example, we found that PhDs who are temporary residents are more likely than U.S. citizens to work in non-tenure track faculty positions, but less likely to work in tenure-track or government positions.

Future research will examine how early career employment outcomes contribute to the long-term career pathways of engineering PhDs in the U.S. 5 years and 15 years from degree completion. We will also investigate whether non-tenure track academic positions, such as postdoctoral research positions, lead to tenure track faculty positions. We plan to complement our quantitative analyses with interviews with engineering PhDs to provide more information regarding their doctoral education preparation and career transitions and paths.

6 ACKNOWLEDGEMENTS

This material is based upon work supported by the USA National Science Foundation under Grant Number 1653378. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors thank the SPHERE research group for helpful feedback, and the National Science Foundation for their support.

REFERENCES

[1] Lichtenstein, G., Chen, H.L., Smith, K.A., and Maldonado, T.A. (2014). Retention and persistence of women and minorities along the engineering pathway in the United States. In Johri, A. & Olds, B. (eds.) *Cambridge Handbook of Engineering Education Research*. Cambridge University Press, New York, NY.

[2] Lovitts, B. (2001). *Leaving the Ivory Tower The Causes and Consequences of Departure from Doctoral Study.* Lanham, MD: Rowman & Littlefield Publishers, Inc.

[3] Bettinger, E.P. and B.T. Long. 2005. Do faculty serve as role models? The impact of instructor gender on female students. *The American Economic Review*, 95(2): 152-157.

[4] Main, J. B. (2018). Kanter's Theory of Proportions: Organizational demography and PhD completion in science and engineering departments. *Research in Higher Education*, 59(8): 1059-1073. DOI: 10.1007/s11162-018-9499-x

[5] Stephan, P. E. (1996). The economics of science. *Journal of Economic Literature*, 34(3), 1199-1235.

[6] Agarwal, R. and Ohyama, A. (2013). Industry or academia, basic or applied? Career choices and earnings trajectories of scientists. *Management Science*, *59*(4), 950-970.

[7] Roach, M. and Sauermann, H. (2010). A taste for science? PhD scientists' academic orientation and self-selection into research careers in industry. *Research Policy*, *39*(3), 422-434.

[8] Zolas, N., Goldschlag, N., Jarmin, R., Stephan, P., Owen-Smith, J., Rosen, R. F., ... and Lane, J. I. (2015). Wrapping it up in a person: Examining employment and earnings outcomes for Ph.D. recipients. *Science*, *350*(6266), 1367-1371.

[9] Sauermann, H. and Roach, M. (2012). Science PhD career preferences: levels, changes, and advisor encouragement. *PloS one*, *7*(5), e36307.

[10] Fox, M. F. and Stephan, P. E. (2001). Careers of young scientists: Preferences, prospects and realities by gender and field. *Social studies of Science*, *31*(1), 109-122.

[11] Bloch, C., Graversen, E. K., and Pedersen, H. S. (2015). Researcher mobility and sector career choices among doctorate holders. *Research Evaluation*, *24*(2), 171-180.

[12] Recotillet, I. (2007). PhD graduates with post-doctoral qualification in the private sector: Does it pay off? *Labour*, 21(3):473–502.

[13] Kahn, S. and Ginther, D. K. (2017). The impact of postdoctoral training on early careers in biomedicine. *Nature Biotechnology*, 35(1):90–94.

[14] Main, J.B. and Wang, Y. (2019). Is postdoctoral training linked to faculty careers and higher salaries in engineering fields? *ASEE Annual Conference & Exposition*, Tampa, FL.