Board 97: Is Postdoctoral Training Linked to Faculty Careers and Higher Salaries among Engineering Ph.D.s?

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Is postdoctoral training linked to faculty careers and higher salaries in engineering fields?

Abstract

The number of engineering PhDs obtaining postdoctoral research scholar employment has increased over the last 20 years. This study examines the factors associated with obtaining postdoc positions, and the early career outcomes associated with postdoc training. Descriptive and regression analyses, and propensity score matching are conducted using a nationally representative sample of engineering PhDs from the 1993-2013 National Science Foundation Survey of Doctorate Recipients matched with the 1985-2013 Survey of Earned Doctorates. Findings show that engineering PhDs with greater research experience, research ability, or who graduated from doctoral programs with more prevalent postdoc employment among previous PhD cohorts, tend to be more likely to obtain postdoc positions. Compared to PhDs who obtain non-academic positions, postdoc training is associated with greater likelihood of attaining tenure track faculty positions and remaining in academia 7-9 years after PhD graduation. In terms of early career salary, postdoc training may delay salary growth among engineering PhDs who are eventually employed in the private sector, but not among those who are eventually employed in the academic sector. Research findings provide critical information regarding the outlook for postdoctoral employment and its role in the long-term career paths of engineering PhDs.

Introduction

It is common for PhDs in many Science, Technology, Engineering, and Mathematics (STEM) fields to pursue postdoctoral research scholar positions (postdocs) as their first jobs after PhD completion [1], [2]. In some STEM disciplines, postdoctoral employment is a prerequisite step toward tenure track faculty positions. The National Science Foundation defines postdoc training as "a temporary and defined period of mentored advanced training to enhance the professional skills and research independence" [3]. According to the National Science Foundation Survey of Earned Doctorates (SED), between 1985 and 2013, around 22% of engineering PhDs indicated postdocs as their plan upon obtaining the degree. In engineering, the number of postdocs more than doubled from 2000 to 2010, making engineering the field of study with the fastest growth in postdoc employment during this time period [4], [5].

Postdoc training provides PhDs opportunities to further develop their skills in academic research and professional networking, as well as to continue to build their publication record. Therefore, postdoc training can provide important preparation for a tenure track faculty position or a career in academic research [1], [6]–[8]. The effect of postdoc training on subsequent career outcomes, such as likelihood of an academic research career and research productivity, can vary across disciplines within STEM fields [8]–[11]. In engineering, only a small fraction of postdocs eventually obtain tenure track faculty positions, whereas many obtain non-tenure track academic or non-academic positions [11]. In order to gain meaningful insights into the role of postdocs in engineering fields and to inform engineering institutions and doctoral students about the long-term employment outlook of postdocs, we investigate the patterns in engineering postdoc employment over time, the factors related to engineering PhDs obtaining postdoc positions, and the role of these positions in engineering postdocs' long-term career trajectories.

Using a nationally representative sample of engineering PhDs from the National Science Foundation's Survey of Doctorate Recipients (SDR) matched with the SED, this study uses descriptive, regression analyses, and propensity score matching to address the following research questions:

1. Which individual- and institutional-level factors are associated with participation in postdoctoral training among engineering PhDs?
2. Does postdoctoral training increase the likelihood of attainment of tenure track faculty positions?
3. How does postdoctoral training relate to early-career salary?

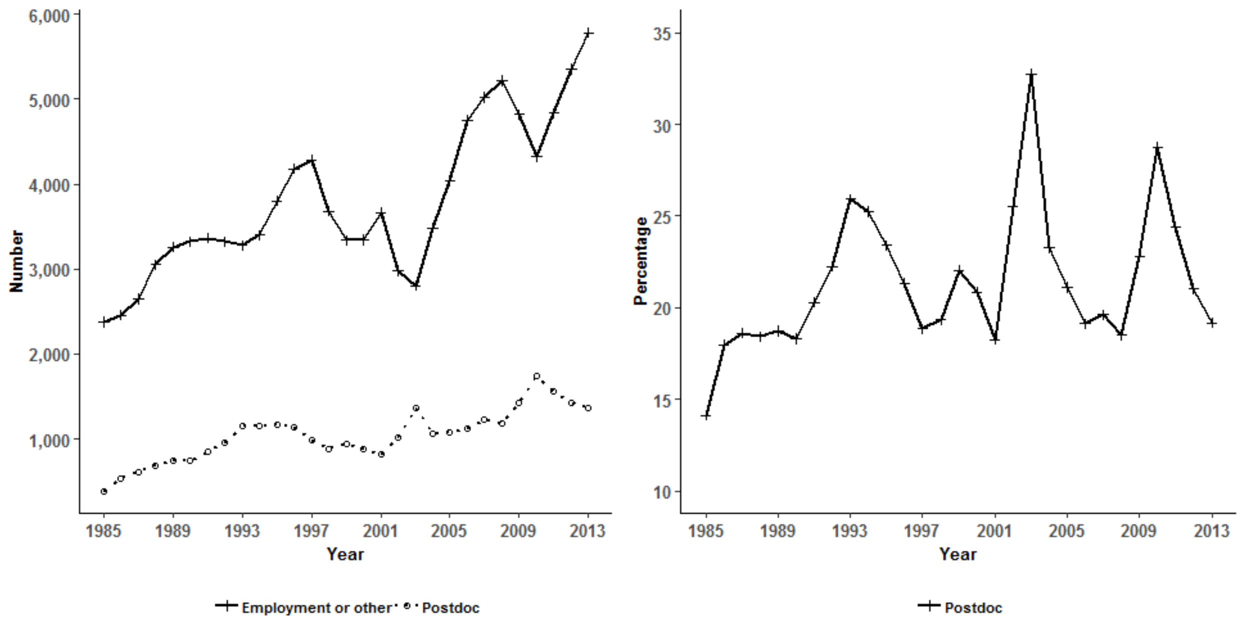
We find that postdoc training in engineering fields has been increasing slowly in recent years, and the primary reason that PhDs obtain postdoc positions is to achieve additional training either within or outside of their field of study. Engineering PhDs with greater research experience and research ability tend to be more likely to attain postdoc positions. Additionally, postdoc employment is also more prevalent among PhDs who graduate from programs where postdoc employment is normalized—that is, relatively more PhDs previous cohorts obtained postdocs. In terms of job placement after the postdoc period, PhDs who worked as postdocs are less likely than those who worked non-tenure track faculty to obtain tenure track faculty positions 7-9 years after PhD graduation. However, PhDs with postdoc training are more likely to obtain tenure track faculty positions than PhDs who instead pursued non-academic positions in industry, government, and other sectors. We also investigated the relationship between postdoc training and early career salary, and found that postdoc training may delay salary growth among engineering PhDs who are eventually employed in the private sector, but not among those who are eventually employed in the academic sector.

Our study provides important insights regarding the role of postdoctoral training in the long-term career paths of engineering PhDs. These findings can inform academic institutions, PhD programs, and policymakers regarding the role of postdoctoral training for academic career preparation. The findings could also be applied toward designing effective postdoc training programs that resonate with labor market demands, as well as the needs of engineering PhDs' career development. In addition, our findings regarding the career prospects and salary outlook of engineering postdocs may help prospective engineering doctorates to decide whether to participate in postdoc training based on their career goals, and to understand how this decision might affect their long-term career paths.

Background

Patterns of postdoc training in engineering fields

From 1985 to 2013, the number of engineering PhDs who reported postdoc training as their post-PhD plan in the SED increased from 391 to 1,370 [12]. Meanwhile, the total number of engineering PhDs graduated in these respective years increased from 2,769 to 7,150. As shown in Figure 1, along with the growth in the number of engineering PhDs over time, the number of engineering PhDs who planned for a postdoc upon graduation has also been increasing. The proportion of engineering PhDs who took postdoc positions was particularly high in years following economic downturns, with peaks in the years of 1993, 2003, and 2010. Previous studies have attributed the increase in the number of postdocs (in engineering and other fields) to the expansion of doctoral degree programs [4], [5] and the increasingly competitive academic job market, particularly for tenure track faculty positions [2], [13].



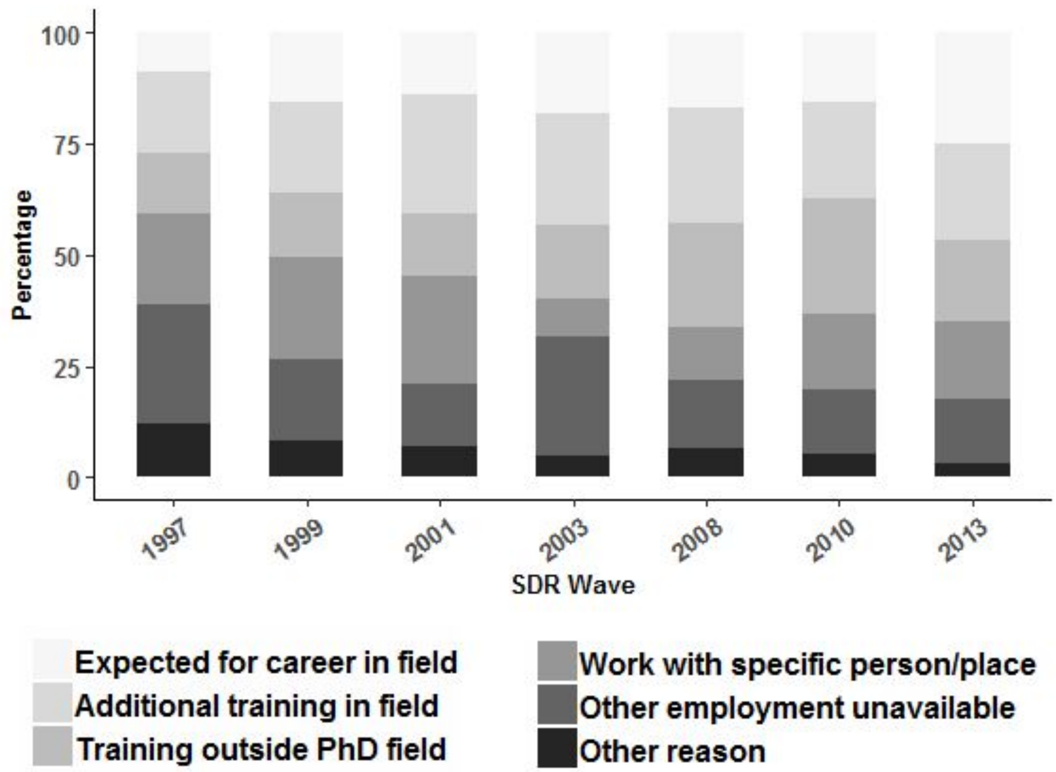
(a) Number by Postdoctoral Plan (b) Percent of Postdoc

Source: National Science Foundation Survey of Earned Doctorates

Figure 1. Postdoctoral plans of new engineering PhDs

Reasons for postdoc training

As an important or even necessary step towards tenure track faculty positions in many STEM fields, researchers have associated postdoc training with interest in academic research careers [1], [2], [6]. In particular, surveys of postdocs in the U.S. and Mexico have shown that postdoc training is considered to enhance their research profile [2], [14] and to increase their chance of attaining a tenure track faculty position [8]. On the other hand, some studies have indicated that postdoc positions are taken when no other employment options are available [10]. To better identify the motivation for postdoc training specifically in engineering fields, we obtained information from the NSF SDR survey question, "What was your primary reason for taking this postdoc?" among engineering PhDs who indicated their primary job to be a postdoc at the time of the survey. We plot the reported primary reasons in Figure 2. Over time, an increasing fraction of engineering PhDs in the SDR considered postdocs to be expected or necessary for their career path. On the other hand, around 20% of engineering PhDs indicated they took a postdoc due to other employment being unavailable. The most frequently indicated reason for taking a postdoc is for additional training or collaboration opportunities in the field. An increasing fraction of respondents also indicated receiving training outside of their PhD field as the primary reason for postdoc training.



Source: National Science Foundation Survey of Doctorate Recipients

Figure 2. Primary reasons for obtaining postdocs among engineering PhDs

Characteristics of postdoc participants

Previous studies have indicated the choice of postdoc training to be associated with an array of demographic and individual characteristics. Across fields of study, male PhDs on average are more likely to take postdoc positions than female PhDs [2], [9], [15]. Studies have attributed the underrepresentation of women in the postdoc workforce to the constraint of family obligations [15], [16]. A large proportion of the postdoc population in the U.S. is composed of international doctorate holders, perhaps partially due to their limited employment options compared to U.S. citizens [2]. Previous studies have found family obligations, including marital status and presence of dependents (young children in the family), to limit PhDs' likelihood of working as a postdoc due to the relatively low financial returns. This association is particularly strong among women [16]–[18]. Age at the time of PhD attainment tends to have a negative correlation with postdoc training, which has been attributed to shorter expected career span and/or family obligations for older PhDs [2], [9], [10]. Moreover, Lin and Chiu found that longer expected time of PhD degree completion is associated with higher likelihood of postdoc employment, possibly due to relatively fewer job options being available [10].

Career outcomes of STEM postdocs

Previous studies have found different effects of postdoc training across fields of study [9]–[11], partially due to the differences in the importance of postdoc training to the career trajectories [19], and the varying average lengths of the postdoc period [11]. It is estimated that among all postdocs in health, engineering, and science fields, only 15-20% eventually obtain tenure track faculty positions [20], while others find employment in non-tenure track positions or employer sectors outside of academia [11], [19]. Using data from Taiwan, Lin and Chiu [10] found that postdoc training is associated with higher likelihood of maintaining an academic research career for engineering PhDs. Using data from Frances, Hanchane and Recotillet [9] found postdoc experience to be correlated with likelihood of a research career in science, but not in engineering fields. Andalib et al.'s [11] analysis of the NSF SDR data shows that compared to other STEM fields, engineering postdocs are particularly likely to leave the postdoc role before obtaining a tenure track position, and instead obtain employment outside of academia. In terms of the effect on career outcomes, previous studies found evidence that postdoc training enhances research productivity and increases research output [14], [15]. However, postdoc experience does not significantly influence STEM PhDs' earnings up to 15 years after PhD graduation [15], [19], [21].

The importance of analyzing the effect of postdoc experiences that vary by field of study has been stressed by Horta [14] and Kahn and Ginther [19], for example, in part because the differences across fields of study reflect their distinct traditions and identities, especially at advanced levels of academic training [22]. Since the differences in postdoc experience across fields of study exist even within the STEM fields, it is important to depict the patterns of postdoc training and its impact for engineering PhDs. Findings are informative both to doctoral students in engineering in terms of making career decisions and to institutions in terms of offering effective postdoc training.

Data

Our data on doctoral training information and postdoctoral plans of engineering PhDs are from the 1985-2013 National Science Foundation SED, an annual census of all individuals who received a research doctorate from an accredited U.S. institution in a given academic year. The SED "collects information on the doctoral recipient's educational history, demographic characteristics, and post-graduation plans" [12]. According to the SED, a postdoc is defined as "a temporary position primarily for gaining additional education and training in research, usually awarded in academe, industry, government, or a non-profit organization." We determine whether an individual received postdoctoral training based on the response to the questions "What best describes your postgraduate plans (within the next year)?" and "What best describes the nature of your further training or study?" Specifically, we include in our sample engineering PhDs who selected "postdoc or other training" in response to the first question, and "postdoctoral fellowship" or "postdoctoral research associateship" to the second question as indicating their plan to participate in postdoc training. Our sample of engineering PhDs from the SED contains 140,381 individuals, out of which 31,368 indicated postdoc training as their postgraduate plan. Table 1 provides descriptive statistics of the engineering PhDs in the SED. Among all years between 1985 and 2013, around 22% planned for postdoc training upon completion of the PhD degree.

Table 1: Description of the 1985 - 2013 NSF SED respondents in engineering disciplines

	N	%
Sex		
Male	117,030	83.6%
Female	22,985	16.4%
Race/Ethnicity		
White	64,024	45.6%
Asian	61,765	44.0%
Black	3,140	2.2%
Hispanic	4,636	3.3%
Other Race	6,816	4.9%
Citizenship		
U.S. citizen or perm. resident	76,678	54.6%
Temp. resident	63,703	45.4%
Major		
Aerospace Engineering	5,312	3.8%
Agricultural & Bio Engineering	10,720	7.6%
Chemical Engineering	16,332	11.6%
Civil Engineering	12,088	8.6%
Computer & Electrical Engineering	38,698	27.6%
Industrial & Manufacturing Engineering	4,487	3.2%
Materials Science Engineering	11,006	7.8%
Mechanical Engineering	20,494	14.6%
Other Disciplines	21,244	15.1%
Financial support		
Savings/Earnings	11,771	8.4%
Fellowship/Grant	19,613	14%
Research Assistantship	72,854	51.9%
Teaching Assistantship	11,698	8.3%
Other Support	24,445	17.4%
NRC ranking		
Top ranked	22,653	16.1%
Mid ranked	105,021	74.8%
Not ranked	12,707	9.1%
Marital status at time of PhD		
Married	82,500	58.8%
Not married	57,881	41.2%
Children under age 6 at time of PhD		
0	126,200	89.9%
1 or more	14,181	10.1%
Post-PhD		
Postdoc plan		
Employment or other	109,013	77.7%
Postdoc	31,368	22.3%
Total	140,381	100%

We complement the educational and demographic information from the NSF SED with the doctoral program research quality rankings from the National Research Council (NRC). The NRC provides two rankings for each program's research activity (i.e., 5th and 95th percentiles of the program's ranks received from raters who rated all the programs in a given field). We average the rankings at the two percentiles to obtain a single rank, and categorize the rank into three groups—top-ranked programs (top 10 percentiles), mid-ranked programs (11th - 100th percentiles), and not ranked programs—for each engineering discipline.[1]

To assess the role of postdoc training in engineering PhDs' long-term career trajectory, we gather employment outcome information from the 1993-2013 National Science Foundation Survey of Doctorate Recipients. The SDR is conducted every two to three years and provides demographic, education, and career history information of a sample of U.S.-trained doctoral scientists and engineers. In many cases, survey respondents completed the SDR survey across multiple time points from when they received their PhD until they reached the age of 75. Therefore, for a subset of the survey respondents, we have information regarding their career history and trajectories. We link the data from the NSF SDR with the NSF SED using unique identifiers to merge the career history information from the SDR with information regarding the PhD's doctoral education program and experiences information from the SED. The resulting sample includes 5,104 engineering PhDs. Table 2 presents the summary statistics for this sample.

[1] We also constructed the NRC ranking variable using alternative cutoffs of the ranking percentiles. For example, we categorized programs in the top 25 percentiles as top-ranked, and the results are robust to these alternative definitions.

Table 2: Description of the 1993 - 2013 NSF SDR respondents in engineering disciplines

	N	%
Sex		
Male	4,484	87.9%
Female	620	12.1%
Race/Ethnicity		
White	2,788	54.6%
Asian	1,568	30.7%
URM	748	14.7%
Citizenship		
U.S. citizen or perm. resident	3,719	72.9%
Temp. resident	1,385	27.1%
Major		
Aerospace Engineering	201	3.9%
Agricultural & Bio Engineering	283	5.5%
Chemical Engineering	682	13.4%
Civil Engineering	446	8.7%
Computer & Electrical Engineering	1,390	27.2%
Industrial & Manufacturing Engineering	181	3.5%
Materials Science Engineering	376	7.4%
Mechanical Engineering	721	14.1%
Other Disciplines	824	16.1%
Financial support		
Savings/Earnings	676	13.2%
Fellowship/Grant	588	11.5%
Research Assistantship	2,304	45.1%
Teaching Assistantship	395	7.7%
Other Support	1,141	22.4%
NRC ranking		
Top ranked	999	19.6%
Mid ranked	3,721	72.9%
Not ranked	384	7.5%
Marital status at time of PhD		
Married	3,009	59%
Not married	2,095	41%
Children under age 6 at time of PhD		
0	4,935	96.7%
1 or more	169	3.3%
Post-PhD		
Postdoc plan		
Employment or other	4,176	81.8%
Postdoc	928	18.2%
Total	5,104	100%

Methods

A. Individual and institutional factors associated with participation in postdocs

Research question 1: Which individual- and institutional-level factors are associated with participation in engineering postdoc training?

To examine the relationship between individual and institutional factors and engineering PhDs' attainment of postdoc training, we estimate a binary choice model with the dependent variable indicating whether or not an engineering PhD plans to take a postdoc position. Specifically, we estimate the following logistics regression:

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

where p_i is the probability that individual i will take a postdoc position, and X_i is a set of covariates for individual i which we discuss in more detail below. And u_i is the logistic error term.

Individual-level characteristics

In addition to demographic factors, which include sex, race/ethnicity, and U.S. citizenship, we also control for age at the time of receiving the doctoral degree, as previous studies indicate that age may play a role in the set of career options available to PhDs [2], [10]. We include marital status and the number of dependents under age 6 to account for the potential influence of young dependents in PhD career trajectories. We also interact these variables with sex to account for the potential differences in career trajectories between men and women, following previous studies (e.g., [15], [18]). Given previous studies that suggest a PhD's parental education level influences the PhD's academic achievement and subsequent performance in academia [17], [23], as well as career choice [24], we include two categorical variables that measure the education level of the paternal and maternal parent/guardian of the engineering PhD.

We account for several covariates related to experiences during doctoral study which may influence initial career choice. Time to degree and the source of doctorate funding are closely related to the PhD's activities during the doctoral program (for example, research, teaching, fellowship, or other), which may influence the PhD's interest in and opportunities for different career paths [10], [21]. We measure time to doctoral degree as the number of years between the year of entry into the engineering doctoral program and the year of degree completion. We use information on the primary source of funding for doctoral training as a proxy for doctoral research experience gained during doctoral study [8]. Since the timing when a doctoral degree is received in relation to the job market cycle affects the likelihood of taking a postdoc position [10], [21], we include a categorical variable that indicates the academic term of doctorate receipt (independent of how many years it takes an individual to complete the degree).

Academic program characteristics

Social interactions within and research quality of the doctoral program can play an influential role in a graduate's job opportunities. Austin [25] considered doctoral education as a socialization process for students to develop critical understanding of a career in academia and prepare for the academic workplace. Thus, this suggests that the outcomes of previous cohorts of PhDs may influence an individual's career outcomes because they may normalize that career trajectory. Additionally, Roach and Sauermann [26] found via a survey that student perception of departmental norms regarding career choices, in particular between academia and other sectors, influence recent doctorates' career choices. To measure the social influence and culture of PhDs' doctoral programs, we use information on the initial job placements of recent PhD graduates from the same program reported in the SED. For each engineering PhD in our sample, we calculate the average fraction of previous graduates in the same doctoral program over the past five years who planned for a postdoc upon graduation. We also calculate the fraction of job placements in each of the following employer sectors: academia, industry, and government. We use this measure of departmental norms in terms of initial job placement to examine its relationship with the likelihood of a PhD's employment in a postdoc. Our measure also spans beyond academic and industry sectors, which gives a more complete picture of the relationship between previous cohorts' job placements and recent graduates' career outcomes.

To account for the effect of program research quality on job opportunities, we follow Sauermann and Roach's approach [8] and use the doctoral programs' research activity rankings by the NRC. We use research quality of the doctoral program as a proxy for student research ability [8], since institution and program rankings are highly correlated with student ability [27]. In one model specification, we interact doctoral program NRC ranking and primary financial support to identify whether the relationship between research experience and postdoc training depends on research ability.

B. Postdoc training and early career path

Research question 2: Does postdoctoral training increase the likelihood of attainment of tenure track faculty positions?

To estimate the effect of postdoc training on subsequent employer sector, we first address the comparability between postdocs and non-postdocs. The choice of postdoc training is not randomly determined; rather, it depends on individual and contextual factors such as those we investigate in research question 1. As such, to make meaningful comparisons between the career outcomes of postdocs and non-postdocs, we first need to make sure the two groups are comparable in terms of the factors that are associated with the choice of postdoc training. Our strategy is to match the two groups on the propensity score $p(X_i)$, which is the probability to obtain postdoc training conditional on the factors discussed in the previous section (i.e., X_i in Equation [1]) to ensure the two groups are comparable, and thereafter, compare the outcome variables between the matched groups. Similar to OLS regression, our matching procedure also requires the conditional independence assumption to interpret the coefficients casually. That is, under the conditional independence assumption that conditional on the observed covariates, X_i, the potential outcomes (i.e., earlier career path) are independent of the treatment (i.e., postdoc training), then they are also independent of the treatment assignment conditional on the propensity score $p(X_i)$ [28].

The approach of propensity score matching on treatment is widely adopted in empirical studies that evaluate programs on academic and career outcomes [29], [30]. We first estimate Equation (1) for all engineering PhDs who did not obtain a tenure track position immediately after PhD completion and calculate each individual's predicted conditional probability of postdoc training. We then select a subsample of non-postdocs with propensity score of postdoc training similar to those who actually took postdoc positions as the comparison group. Our primary outcome variable of interest is the likelihood of obtaining a tenure track position 7-9 years after PhD completion. Our first comparison group to postdoc participants contains all engineering PhDs who neither took a postdoc position nor obtained a tenure track position immediately after PhD completion, but have similar propensity of postdoc training compared to those who did take postdoc positions. The "effect" of postdoc training is calculated as the difference in the average probability of attaining a tenure track position between the two groups. We also disaggregate the first comparison group by initial employer sector, i.e., we compare the likelihood of obtaining tenure track faculty positions between postdocs and those who initially worked in non-tenure track positions, industry, or government.

C. Postdoc experience and early career salary

Research question 3: How does postdoctoral training relate to early-career salary?

Since postdoc participants are expected to strengthen their research skills, accumulate publications, and broaden professional networks through information exchange and collaboration during postdoc training [1], [2], postdoc training may positively contribute to participants' long-term labor market returns, especially among those who continue to work in the academic sector. We examine the relationship between postdoc training and early career salary for engineering PhDs who eventually work in tenure track faculty positions. We estimate the predicted tenure track faculty salary up to 12 years in the position, separated by postdoc experience, using the matched sample of engineering postdocs discussed in the previous section. In doing so, we first estimate the model

$$Y_{it} = Z_i\beta + \gamma * \ postdoc_i + \delta * Years\ in\ Position_{it} + \theta * Years\ in\ Position_{it}^2 + \varphi * postdoc_i \times Years\ in\ Position_{it} + \tau_t + u_{it} \quad (2),$$

where Y_{it} is the annual salary in 2013 dollars of individual i in a tenure track faculty position at year *t*, $Years\ in\ Position_{it}$ is the number of years individual *i* has worked in a tenure track faculty position as of year *t,* τ_t is a time fixed effect, and u_{it} is the error term. We control for engineering discipline, sex, race/ethnicity, and citizenship in Z_i. We then take the estimates from Equation (2) to predict tenure track faculty salary between postdocs and non-postdocs over time by varying only postdoc status and the number of years in the position, holding all control variables constant at the mean.

To understand the potential opportunity cost associated with postdoc training, especially for PhDs who do not end up working in the academic sector, we examine the relationship between postdoc training and early career salary of engineering PhDs up to 15 years after PhD degree completion in a separate set of analyses. We replace $Years\ in\ Position_{it}$ in Equation (2) with the number of years since PhD, and perform the salary prediction for all employer sectors combined, and industry, non-tenure track, and tenure track positions separately. This allows us to calculate the average loss in salary due to postdoc training (in other words, the "cost" of postdoc training), and estimate how many years it takes for an average individual to make up for the loss in salary.

Table 3: Marginal effects of factors related to postdoc employment

	(1)	(2)
Individual factors		
Female	0.001	0.001
	(0.004)	(0.004)
Temp. resident	0.099***	0.098***
	(0.003)	(0.003)
Asian	−0.025***	−0.025***
	(0.003)	(0.003)
Black	−0.032***	−0.032***
	(0.007)	(0.007)
Hispanic	−0.001	−0.002
	(0.006)	(0.006)
Other Race	−0.075***	−0.076***
	(0.005)	(0.005)
Disability	0.011	0.011
	(0.01)	(0.01)
Age at Degree	0.017***	0.017***
	(0.002)	(0.002)
Time to Degree	−0.006***	−0.006***
	(0.001)	(0.001)
Fellowship/Grant	0.153***	0.147***
	(0.007)	(0.008)
Other Support	0.04***	0.042***
	(0.006)	(0.007)
Research Assistantship	0.121***	0.121***
	(0.005)	(0.006)
Teaching Assistantship	0.052***	0.051***
	(0.007)	(0.008)
Married	0.001	0.001
	(0.003)	(0.003)
Child<6	0.0004	0.0003
	(0.004)	(0.004)
Married*Female	−0.007	−0.007
	(0.006)	(0.006)
Child<6*Female	−0.002	−0.002
	(0.01)	(0.01)
Institutional factors		
Prev. Postdoc	0.358***	0.359***
	(0.008)	(0.008)
Prev. Academia	−0.054***	−0.054***
	(0.009)	(0.009)
Prev. Industry	−0.088***	−0.087***
	(0.009)	(0.009)
Not ranked	−0.012***	−0.033**
	(0.004)	(0.014)
Top ranked	0.016***	0.033**
	(0.003)	(0.016)
*Financial support*NRC rank*		
Fellowship/Grant*Not ranked		0.047**
		(0.02)
Other Support*Not ranked		−0.017
		(0.017)
Research Assistantship*Not ranked		0.031*
		(0.017)
Teaching Assistantship*Not ranked		0.026
		(0.021)
Fellowship/Grant*Top ranked		−0.006
		(0.016)
Other Support*Top ranked		−0.009
		(0.016)
Research Assistantship*Top ranked		−0.021
		(0.014)
Teaching Assistantship*Top ranked		−0.018
		(0.019)
Observations	140,381	140,381

*, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Graduation term, degree year, engineering discipline, and parents' education are included in the models but not shown in the table.

Results

A. Factors associated with postdoc training

Table 3 presents the results of the logistic regressions that examine the factors associated with postdoc training. Consistent with previous studies, we do not find a difference in the likelihood of obtaining postdoc positions between male and female engineering PhDs [2], [31]. However, temporary residents in the U.S. are 10 percentage points more likely to take postdoc positions compared to U.S. citizens, perhaps due to the citizenship restrictions and limited availability of visa sponsorship in other employment sectors [2], [31]. Asian and Hispanic engineering PhDs are both around 3 percentage points less likely to work as postdocs compared to their counterparts. In contrast to previous studies which cover an array of fields of study [2], [9], for engineering PhDs, we find a positive correlation between age and likelihood of taking postdoc positions—on average, an additional year in the age of the PhD is associated with a 2 percentage point greater likelihood of taking a postdoc position. Time to PhD degree appears to have negative correlation with the likelihood of postdoc, although the effect is not quantitatively meaningful (less than 1 percentage point), and marital status and presence of dependents do not appear to correlate with postdoc training.

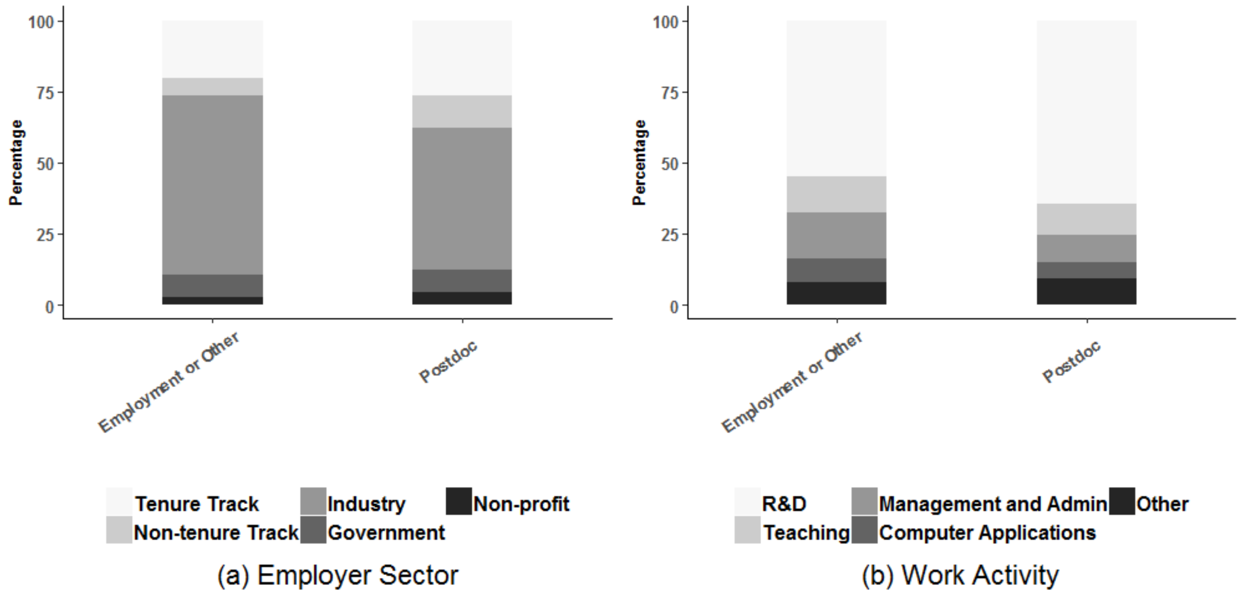
In terms of primary financial support during doctoral studies, engineering PhDs primarily supported by personal funds are the least likely to take postdoc positions, whereas those with greater research experience are more likely to become postdocs. In particular, engineering PhDs supported by fellowship/grant or research assistantship are, respectively, 15 and 12 percentage points more likely to take postdoc positions compared to those supported by personal funds. Financial support by teaching assistantship is also associated with higher likelihood of postdoc training compared to support by personal funds, though at a lower magnitude compared to research experience. Overall, the attainment of postdoc positions by engineering PhDs is associated with greater experience in academic activities during PhD training, suggesting that the choice of postdoc training likely reflects an interest in a career in academia.

Departmental norms in terms of job placement are strong predictors of the likelihood for an engineering PhD to become a postdoc. Programs with a proportion of previous graduates who worked as postdocs that is one standard deviation above the mean proportion are 36 percentage points more likely to have new graduates take postdoc positions. Similarly, programs with greater proportions of previous graduates placed in government agencies are more likely to place students into postdoc positions, whereas programs with more graduates placed in industry and the academic sector (including tenure track faculty positions) are less likely to produce graduates who take postdoc positions.

In terms of PhD program research activity NRC ranking, compared to graduates from mid-ranked programs, those from higher ranked programs, which suggests overall higher research ability, are more likely to take postdoc positions. On the other hand, graduates from programs without an NRC ranking, which suggests relatively lower research ability, are less likely to take postdoc positions. Turning to the interaction terms in Column (2), compared to engineering PhDs supported by personal funds at mid-ranked programs, those supported by fellowship/grant or research assistantship at unranked programs are more likely to become postdocs. Overall, we find strong evidence that postdoc training is associated with research experience during the PhD program, research ability, and program employment norms. That is, among engineering PhDs, postdocs are more likely to be taken by graduates with relatively better preparation and greater qualifications for an academic career, suggested by greater research experience and higher research ability, respectively. In addition to logit models, we have also estimated a linear probability model and a probit model with the same set of covariates and outcome variable, and the coefficient estimates are qualitatively the same as the estimates from the logit model.

B. Postdoc training and early career path

To examine the relationship between postdoc training and early career path, we first present descriptive evidence of the association between postdoc training and subsequent career outcomes. Figure 3 presents the distribution of engineering PhDs' employer sector and primary work activity 7-9 years after PhD graduation, separated by postdoctoral plan. Compared to engineering PhDs who directly obtained permanent employment or other options (e.g., joining the military), postdocs are more likely to work in the academic sector (i.e., tenure track or non-tenure track positions), and are more likely to perform research and development activities.



Sources: NSF SED and NSF SDR

Figure 3. Employer sector and primary work activity 7-9 years after PhD completion

Table 4 presents the estimated effect of postdoc training on the likelihood of attaining a tenure track faculty position 7-9 years after PhD graduation based on the samples of postdocs and non-postdocs matched on the propensity for postdoc training. Compared to all non-postdoc engineering PhDs who did not start their career as a tenure track faculty member (Column 1), postdocs are about 10% more likely to attain tenure track faculty positions. This effect, however, varies depending on the comparison group (Column 2 – Column 4). Compared to engineering PhDs who started their postdoctoral career in non-tenure track faculty positions, postdocs are 6% less likely to move to tenure track positions. On the other hand, postdocs are around 12% more likely than those who started in industry and 11% more likely than those who started in government positions to eventually obtain tenure track positions.

Table 4: Effect of postdoc training on the likelihood of attaining tenure track faculty position 7-9 years after PhD graduation by initial employer sector

	Initial Employer Sector			
	All but tenure track	Non-tenure track	Industry	Government
	0.096***	−0.057**	0.125***	0.113***
	(0.021)	(0.027)	(0.021)	(0.022)
Observations	728	540	702	469

Estimated average treatment effect on the treated of postdoc employment on the likelihood of attaining tenure track faculty position 7-9 years after PhD graduation, with comparison to different groups based on initial employer sector: all sectors excluding tenure track positions, non-tenure track academic positions, industry, and government. *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Since the effect of postdoc training on early career paths appears to be qualitatively different across initial employer sectors, particularly between non-tenure track faculty positions and other sectors, we further compare the career paths of these two types of non-tenure track positions in academia—postdoc and non-tenure track faculty positions. According to the 2003-2013 SDR, the types of non-tenure track position in our sample is mainly composed of research faculty (24% out of all non-tenure track academic positions in the comparison group) and teaching faculty (22%). In terms of primary work activity, the majority of the non-tenure track faculty primarily work in research and development (56%), while others are primarily engaged in teaching (11%) and management and administration (16%). As such, it is possible that the duties entailed in non-tenure track faculty positions are more closely related to tenure track faculty positions compared to postdoc positions.

We also compare the employment outcomes of engineering PhDs whose initial job placement is postdoc versus non-tenure track faculty position. In Table 5 we present the difference in the likelihood of being employed in tenure track faculty, non-tenure track faculty, and industry positions, comparing engineering PhDs who received postdoc training against those who obtained non-tenure track faculty positions immediately after receiving the PhD (instead of a postdoc). Consistent with our finding from Table 4, postdocs are about 6 percentage points less likely than the PhDs in the non-tenure track comparison group to eventually obtain tenure track faculty positions. However, compared to the non-tenure track faculty group, postdocs are more likely to eventually work in industry.

Table 5: Postdoc training vs. non-tenure track faculty position by employer sector 7-9 years after PhD graduation

	Likelihood of tenure track	Likelihood of non-tenure track	Likelihood of Industry
	−0.056**	−0.070***	0.086**
	(0.027)	(0.024)	(0.032)
Observations	540	543	543

Estimated average treatment effect on the treated of postdoc employment on the likelihood of employment in different employer sectors 7-9 years after PhD graduation: tenure track positions, non-tenure track academic positions, and industry, with the comparison group being non-tenure track academic positions. *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

C. Postdoc training and early career salary

Figure 4 presents the predicted salary of 1,083 individuals in tenure track faculty positions by postdoc experience based on estimates from Equation (2). Although on average the salary of PhDs who worked as postdocs is slightly higher than that of non-postdocs in tenure track positions throughout the years we observe, the difference is not statistically significant. As such, we do not find evidence that postdocs and the additional training involved in engineering leads to higher labor market returns among those in tenure track faculty positions, considering up to 12 years in the position.

Figure 5 presents the predicted salary of engineering PhDs over the number of years since PhD completion, separated by postdoc experience, over all employer sectors and separately. Among the 5,104 engineering PhDs in all employer sectors who worked full time after graduation, the median salary of former postdocs within three years after PhD completion is $71,025, while for non-postdocs it is $92,755. The salary gap between former postdocs and non-postdocs is narrowed over time. At 12-15 years after PhD completion, the median salaries for postdocs and non-postdocs are $124,025 and $129,950, respectively. As shown in Figure 5(a), the salary difference is not statistically significant after nine years since PhD completion.

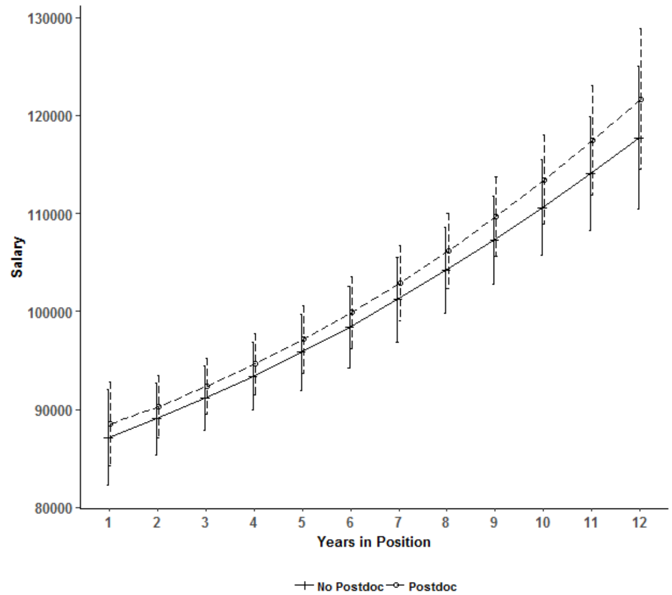


Figure 4. Predicted salary in 2013 dollars of engineering PhDs in tenure track faculty position with 95% confidence bands

Separating by employer sector, we do not find significant salary difference between postdocs and non-postdocs employed in tenure track positions (1,083 individuals), even though the average salary of postdocs later employed in tenure track faculty positions goes from below the mean salary of non-postdocs in such positions to above that. For the 3,043 engineering postdocs eventually employed in industry positions, on average, it takes around nine years to make up the initial salary difference associated with postdoc work. For the 368 who eventually work in non-tenure track positions, however, there is some evidence that the salary of former postdocs surpasses non-postdocs after 11 years since PhD completion.

Discussion

In this study, we examine the role of postdoc training in the career trajectories of engineering PhDs. We find that postdoc training is associated with greater research experience

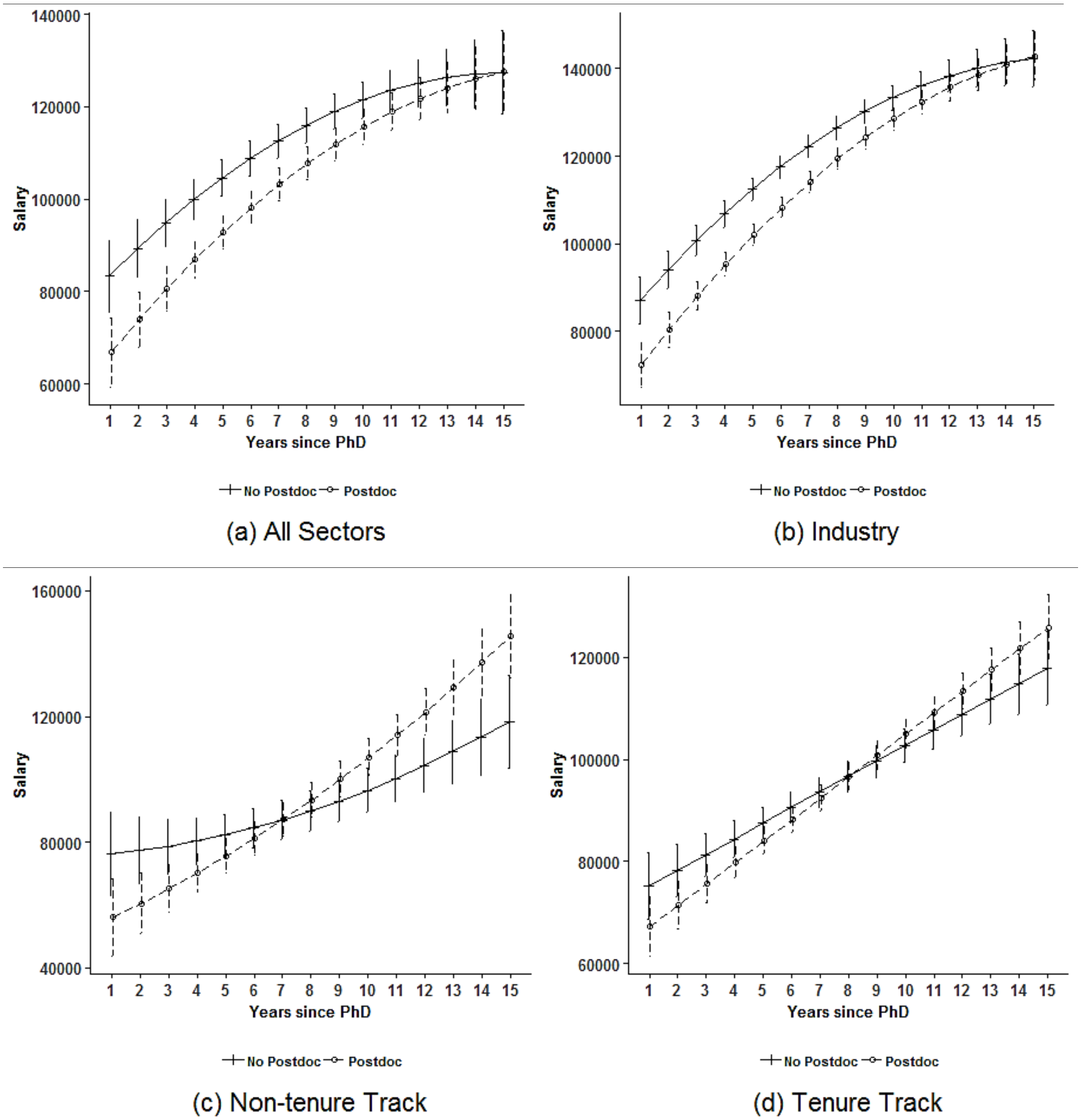


Figure 5. Predicted salary in 2013 dollars of engineering PhDs over number of years post-PhD with 95% confidence bands

during doctoral training, higher research ability, and the norms of job placement among previous PhD cohorts in the doctoral program. These findings suggest that among engineering PhDs, postdoc positions are more likely to be pursued by those who are relatively more qualified or interested in academic research. Indeed, postdoc participants are more likely to be employed in academic positions, and perform research and development activities 7-9 years after PhD completion. Nonetheless, a small yet consistent fraction of engineering PhDs choose postdoc positions due to lack of alternative job opportunities, which suggests that not all postdoc participants are necessarily headed for academic positions.

Postdoc experience is associated with higher likelihood of obtaining a tenure track faculty position among all engineering PhDs who did not obtain tenure track positions immediately after PhD completion. This suggests that postdoc training is used as preparation for a career in academic research. Overall, engineering PhDs with initial jobs in the academic sector (postdoc or non-tenure track faculty) are more likely to remain in academia, moving either to tenure track faculty positions or to non-tenure track positions. We find evidence that at least during early career (7-9 years after graduation), non-tenure track faculty are more likely to move to tenure track positions than are postdocs. This may be due to the nature of work activities and duties among non-tenure track faculty, which may be more closely aligned with the work activities of tenure track faculty compared to postdocs. The majority of the non-tenure track faculty in our sample primarily work in research and development, and assume the titles of research faculty or teaching faculty, which likely facilitates easier transition to tenure track faculty roles, as the latter often requires extensive research and teaching.

In terms of the relationship between postdoc training and early career salary, for tenure track faculty we do not find the projected average salary to be statistically different between those who were formerly postdocs and those who did not obtain postdocs. The opportunity cost of postdoc training in terms of salary also appears to vary across employment sectors, with the stakes particularly high for those eventually employed in industry. For PhDs who remain in academia, time as a postdoc may improve early career earnings. Therefore, from the perspective of financial returns to doctoral training, it is important for engineering PhDs to consider the long-term career prospects in different sectors. For engineering PhDs with career interests in non-academic employer sectors, awareness of the potential delay in salary growth associated with the low payment during postdoc training might be helpful in making career decisions. This again calls for PhD programs and institutions to provide more information and professional development opportunities to inform students with different career interests about various potential career paths.

Overall, our findings suggest that for engineering PhDs, postdoc training is associated with higher likelihood of attaining a career in academia compared to initial employment in other employer sectors, and does not negatively affect salary in academia. For engineering PhDs who aspire to pursue a career in academia, postdoc training is likely to facilitate such pursuit, especially for those who already have high research competency. For engineering PhDs with career interests in other employer sectors, it would be helpful to provide professional development opportunities to carefully plan career paths in the longer term with some consideration of the opportunity costs associated with postdoc training.

While our study contributes to the understanding of the role of postdoc training in the career trajectory of engineering PhDs, our empirical analyses have several limitations. First, we rely on the postdoctoral plan reported in the SED to determine whether an engineering PhD takes a postdoc position, and it is possible that a respondent's postdoctoral employment status may have changed after filling out the survey. Meanwhile, the first postdoctoral employment information in the SDR is available around two years after PhD completion, and by this time many postdoc appointments have ended, and thus we are not able to acquire postdoc employment information from the SDR. Nonetheless, given that the information in the SED is collected shortly before PhD completion, postdoctoral plans based on the SED is reasonably reliable. While the NSF SED and SDR provide many relevant observable factors, there are many individual-level factors related to career choice, motivation, and career outcomes that are unavailable, such as engineering PhDs' research productivity, motivation, and career interests and intentions. We are therefore not able to parse out the effect of such unobservable factors from the effect of postdoc training. Even though we use propensity score matching to construct a group of non-postdocs who are comparable to postdocs, our outcomes of interest—likelihood to obtain tenure track faculty positions and early career salary—still may not be independent of the postdoc experience conditional on our covariates. Thus, we treat our findings as descriptive rather than causal. Nevertheless, we have included a set of observable covariates that address individual and institutional factors that are correlated with the choice of postdoc training to provide a foundation for the ongoing dialogue about the long-term career trajectories of PhDs and how best to prepare them for the multitude of career paths.

Conclusion

We illustrated the patterns in postdoc training in engineering disciplines over the past two decades, and examined the factors associated with engineering PhDs' choice of postdoc training and early career outcomes of former engineering postdocs and non-postdocs. Our major findings include that greater research experience and research ability, as well as departmental norms in terms of job placement, are associated with higher likelihood of participating in postdoc training. Second, postdoc training is associated with increased likelihood of retention in the academic sector, including obtaining tenure track faculty positions. Moreover, the relationship between postdoc training and early career salary varies on subsequent career paths.

Our findings provide critical information regarding the outlook for postdoctoral training and its role in the long-term career paths of engineering PhDs. These findings can inform academic institutions, PhD programs, and stakeholders regarding the effectiveness of postdoc programs and the suitability of postdoc training for PhD graduates with different research profiles and career interests. Findings also provide prospective engineering doctorates with information relevant to their decision-making regarding first post-PhD employment. In particular, the decision for postdoc training should ideally involve their long-term career goals, particularly in terms of how strongly they aspire to remain in the academic sector after postdoc training, in light of the dependency of the effect of postdoc training on long-term career paths.

To achieve a deeper understanding of the choices for postdoc training and its role in engineering PhDs' career paths, there are several areas for future research. First, given the higher likelihood for former non-tenure track faculty to obtain tenure track faculty positions compared to postdocs, an investigation into the differences in the motivations of and the selection criteria for non-tenure track faculty positions versus postdoc positions would help unpack the mechanisms associated with the differences in their long-term career outcomes. In addition, information on the entire job search process for engineering PhDs, including the application and interview process for postdoc and other positions, would help extend the current study. Surveys or interviews designed to acquire information on the pathway and decisions related to the choice of postdoc positions would allow researchers to address the selection issues related to postdoc training, and therefore potentially establish causal links to subsequent career outcomes. Moreover, an increasing proportion of engineering postdocs indicated that the primary reason for taking the postdoc position is to receive training outside of their field of study. Since institutions invest a considerable amount of resources in training an engineering PhD, retaining graduates in the engineering workforce is important for the sustainability of the field. An interesting extension of our study is to investigate the fields of postdoc training in more detail and how their postdoc training contributes to these "new" fields of study.

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