Changing Trends in Federal Funding U.S. Doctoral Degree Programs and Women's Representation among Engineering Doctorate Recipients

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Abstract

Federal funds played an important role in the expansion of engineering graduate programs between 1977 and 2015. Simultaneously, U.S. immigration policies enabled international students to enter for studies, while Title IX opened the doors of engineering schools to women. This article blends institutional data from the National Science Foundation's survey of federally financed research and development with Department of Education data on doctoral degrees to explore the role of women and temporary residents in this expansion of engineering higher education. This paper shows that temporary resident women were an important component of women's increased presence among recent cohorts, as temporary residents of both genders became a larger part of engineering PhD recipients. The analyses also show that mid-tier institutions appeared to provide the best point of entrée for non-citizen engineering students.

Introduction and Background

THE TWENTIETH CENTURY signaled a shift in U.S. investment in higher education, transforming the post-secondary system from an elite luxury to an accessible goal for more of the U.S. population. This expanded access, and consequently larger high-skilled human capital pool, thus enabled the rapid pace of technological advancement for the United States (Goldin and Katz 1999). Indeed, the U.S. education system has been characterized by on-going evolution, change, and expansion, offering new opportunities to new populations in new fields over its history. In this way, the complex relationship between federal educational funding, expanded access, and available human capital becomes the key driver in innovation, invention, and employment opportunity which serve as the hallmarks of the U.S. economy (Kelly et al. 1998; Optimal Solutions Group 2011).

When considering the role of technological superiority in supporting a robust economy, fields such as engineering are particularly important. A number of efforts in the last half of the twentieth century led to expansion and growth of engineering education. In 1958 Congress passed the National Defense Education Act (NDEA) as part of the response to the Soviet Union's

Sputnik launch. This Act provided loans to college students, graduate fellowships, and funded improvements in elementary and secondary science and mathematics education (Public Law (P.L.) 85-864). Seven years later, Title III of the Higher Education Act of 1965 authorized $55 million to strengthen "developing institutions," which offered or prepared students for "engineering, mathematics, physical or biological sciences, or other technological fields…" (P.L. 89-329, Title III: 1229). Among many other programs, these examples highlight the relationship between federal funding and expanded access to science and engineering education to support U.S. economic growth and technological advancement (Kelly et al. 1998).

On the human resources side of the equation post-World War II baby boomers were coming of age in the 1960s, which further spurred the growth of colleges and universities. To encourage young men to pursue engineering and natural science fields, the Military Selective Service Act of 1967 (the "Draft Act") provided grounds for military service deferment for men "whose civilian activity is found to be necessary to the maintenance of the national health, safety, or interest" which included educational pursuits "deemed essential to the national interest …" Thus, young men could defer military service and avoid deployment by pursuing science and engineering studies - an option that was especially attractive in the Vietnam War era (P.L. 69-96).

The twentieth century also saw expanded access to higher education. For women in engineering, Title IX of the U.S. Education Amendments of 1972 was critical in opening the doors of previously-closed engineering schools.[1] The impact of Title IX on women's participation in engineering is unmistakable: whereas women earned less than 1% of engineering bachelor's degrees prior to 1972, by 1977 they earned 4%, with continued growth through to 2000, when women accounted for one-fifth of all engineering bachelor's recipients (Frehill et al. 2009).

Finally, global transformations and changes in U.S. immigration policy enabled the increased participation of temporary residents in U.S. engineering doctoral degree programs as an important component of growth of these programs in the latter decades of the 20th century. PhDs awarded to

[1] Under Title IX, "No person in the United States shall, on the basis of sex, be excluded from participation in […] any education program or activity receiving Federal financial assistance." (U.S.C A§ 1681, Title IX, 34 C.F.R. 106.1)

temporary residents increased from 847 in 1977 to 5,786 in 2015. Between 1990 and 1994, and then from 2000 onwards, temporary residents accounted for more engineering PhDs awarded by U.S. universities than did U.S. citizens or permanent residents (NSF 2017).

The role of women and temporary residents in U.S. engineering human capital, and the intersection of these two demographic characteristics as an instance of multiple marginalities, has been a little-explored issue. In the past several years, there has been increased attention by groups such as the U.S. National Academies and the Association for Women in Science (AWIS), among others, to the persistent "double-bind" experienced by women of color in science, technology, engineering, and mathematics (STEM). (Williams et al 2014) Taking a term from a 1976 report, these new studies have sought to describe how multiple marginalities continue to affect the working lives of women in the STEM fields. (Malcom *et al*. 1976) However, the high-profile National Academies reports of 2007, 2010, and 2013 are completely silent on the potential impact of citizenship status on the careers of women in STEM. While Williams *et al*. (2014) include reference to birth origin and STEM field when describing individual research respondents, the implications of status as a temporary resident is not explored.

Additionally, in the past four decades a growing body of literature has focused on the production of STEM human resources and similarities and differences of career outcomes across demographic groups (*e.g*., see Corbett and Hill 2015, Kanny, Sax and Riggers-Piehl 2014, Hill, Corbett and St. Rose 2010 and Frehill, DiFabio, and Hill 2008 for reviews). Quite often, especially since 2008, researchers often do not disaggregate "STEM," which obscures important differences between careers in these fields. Similar to other STEM fields, bachelor's (BS) and master's (MS) degreed engineers engage in different work than do PhD engineers. However, unlike some other STEM fields—most notably, the life sciences—MS and BS credentials have traditionally enabled engineers to secure relatively well-paying employment, posing recruitment challenges for U.S. doctoral degree programs different than those in the life sciences.[2] Engineering programs,

[2] At the bachelor's degree level, engineers with bachelor's degrees routinely earn some of the highest starting salaries when compared to their newly-graduated peers in fields like biology, business, and teaching. (Brandi et al 2010, Frehill 2011, and Langdon et al.

therefore, are often tightly connected with employers and attenuated to BS and MS needs.[3]

The engineering research workforce represents a distinct labor market. While the doctoral degree is a necessary credential for entry, as in other fields, the points of discontinuity between BS/MS-level education and doctoral education pose unique challenges for student recruitment to engineering doctoral programs. Well-paying jobs and family formation serve as economic disincentives for employed engineers to pursue doctoral degrees. Yet PhD students are a critical research workforce at universities, therefore, expansion of academic research-intensive engineering programs must solve this recruitment dilemma.

The role of federal funding in the engineering education enterprise is important to consider in this regard. Faculty secure research grants from external funders, particularly federal sources, while universities provide critical research infrastructure critical. Students support the bulk of the funded research work in exchange for tuition remission and stipends. The connection between research dollars and graduate education was quite notable in the 1990s, for example, when the National Institutes of Health doubled its research funding over a four-year period. During that period graduate education in life sciences expanded rapidly but once the doubling period ended, the large number of doctoral recipients who subsequently entered the PhD workforce found a severely limited labor market. (FASEB 2015; Frehill 2016)

This paper examines the convergence of the macro-level trends described here—namely the demographic changes in the composition of engineering doctoral degree programs, the proliferation and expansion of

2011) Advocates of increasing minority participation in doctoral engineering programs often cite the high salaries earned by new engineers as posing a special challenge for recruiting students to graduate school. Further, in fields like biology, physics, and chemistry the master's degree was sometimes considered a "consolation prize" for individuals who were not able to make-the-grade in research, but for engineering the master's is considered a valuable credential, enabling engineers to maintain currency in rapidly-changing technological environments. (Frehill 2003)

[3] Indeed, when providing guidance about PhD programs at Society of Women Engineers' conferences, the author was routinely informed by participants that when they asked the employer representatives in the career fair area about graduate school, such representatives suggested that a master's degree was "great" but that a PhD would mean the individual would be "over-qualified" and, therefore, unemployable.

these programs, and the policy framework that facilitated these changes. What has been the role of previously underrepresented groups—particularly women and international students--in the growth of the U.S. graduate engineering enterprise in recent decades? This paper will show that changes in federal funding of higher education have played a role in the general growth of engineering doctorate degrees.

In order to assess the role of demographic and funding trends the proliferation and expansion of engineering doctoral programs, and the policy framework that enabled change, the following research questions are posed:

- To what extent is there a relationship between demographic changes in engineering doctoral enrollment and the federal policy and funding changes supporting these programs?
- To what extent have changes in federal funding of post-secondary education supported increased access for U.S. women and international students in engineering PhD programs at U.S. colleges and universities?

Data and Methods

Data Sources

Three main data sources were used for this paper, all of which were accessed via the NSF WebCASPAR database system (NSF 2017). These included the Integrated Postsecondary Education Data System (IPEDS) "completions by race"[4] degree data. IPEDS data are compiled by the U.S. Department of Education from annual data submitted by colleges and universities, which are required to report as a condition of receiving federal financial aid. Second, we pulled annual data about federally financed higher education research and development (R&D) expenditures for engineering via WebCASPAR. Within the context of institutions with doctoral degree programs in engineering, which are highly dependent upon federal financing, these IPEDS and federal funding data are population data. Finally, via the same WebCASPAR system, we used data from the Survey of Earned Doctorates (SED). Administered annually to all recipients of research doctoral degrees from U.S. colleges and universities, the SED has a response

[4] This is a technical term used in the field.

rate in excess of 95 percent for each year since its first administration in 1957.

Variables

Consistent with the institutional approach of the paper, the selected datasets provided the opportunity to look at system-level and institutional level findings. The IPEDS and Federal R&D data were available at the institutional level; institutional level data were not available with the SED data. These latter data, therefore, provide additional descriptive information about the overall U.S. production of engineering PhDs. Federally Financed Higher Education R&D Expenditures in engineering were all adjusted to current (2016) dollars).

Gender is one of two key analytical variables, with results about individuals reported for women and men, consistently reported across the various datasets. Citizenship status was the second key categorical variable. IPEDS and SED provide disaggregation of degree data for two groups: U.S. citizens and permanent residents (hereafter denoted U.S.)[5] versus temporary residents (denoted "Temp. Resid." in graphs). Federal higher education R&D expenditures for engineering provide a measure of the university-based research infrastructure support for the field. These data were obtained using the NSF WebCASPAR database system for the period 1973-2015 at the institutional level.

Engineering is considered a "major field group" in NSF data publications. For additional demographic analyses, we disaggregated by specialty area for the four largest engineering fields: chemical engineering, civil engineering, electrical engineering, and mechanical engineering. As will be shown, these fields have different demographic profiles in terms of gender and citizenship status.

Women, especially temporary resident women, continue to represent relatively small numbers of students in engineering PhD programs, especially at the institutional level on which this paper focuses. This means that any given year could show a much different snapshot than the next year in the sequence. As such, we use three-year periods to even out these potential year-on-year biases. We selected the earliest and latest such periods

[5] For clarity, we often use the term "U.S." as a descriptor rather than the more cumbersome "U.S. citizens and permanent residents."

that were available in the data we used (i.e., 1977-1979 and 2013-2015) and three intervening periods: 1990-1992, 2000-2002, and 2010-2012[6]. These periods, therefore, provide snapshots of the 38-year timeframe covered by these data.

The number of doctoral degrees conferred in each of these five periods were used as a means of stratifying U.S. institutions conferring doctoral degrees. In this way, we control for the relative size of graduate engineering programs. Very large programs were defined as those that produced more than 133 PhDs in a year; large programs were those that awarded 67-133 PhDs per year); and all others that awarded one or more PhDs in a year.

Analyses

I use simple descriptive analyses to show trends for the four groups of interest: U.S. women; temporary resident women; U.S. men; and temporary resident men. Within the institutional-level data file, we also compute correlations between federally financed higher education R&D expenditures for engineering within each of the five periods under consideration with the overall number of doctoral degrees in engineering and the percentage of doctoral degrees conferred to women and temporary residents.

Post-hoc tests of the differences between correlations within each set across the five time-period snapshots were also performed. Using the Fisher r-to-z transformation (Lowry 2017), pairwise comparisons were performed, with results highlighted or noted at the bottom of each table. It should be noted, as well, that the IPEDS and financial data are population data, rather than the results of samples.

[6] IPEDS data for degrees were not available in 1978, 1980, 1982, 1983, 1984, 1986, and 1988. This means that with respect to degrees, the 1977-1979 period is an average of two (rather than three) values. Engineering R&D expenditure data were available for all years, so the 1977-1979 period included all three years. While the Survey of Earned Doctorates (SED) may have been a useful alternative source of data about doctoral degrees, these data have substantial missing data on one of our key variables-citizenship status-and are not publicly available for 2007 and later, rendering these data useless for our institutional level analyses. SED data were used only for our discipline-specific analyses due to limitations associated with availability of the IPEDS data.

Results

Figure 1, shows the overall federal R&D funding trend between 1973 and 2015 for institution groupings based on the 2013-2015 doctoral degree production. Average annual federally financed R&D increased for the very large and large institutions, while all other institutions (i.e., those that produced fewer than 67 PhDs per year in 2013-2015) experienced relatively modest growth in average federally financed R&D. In the most recent three-year period, there has been a slight decline for "All other" and a more pronounced decline for Very Large engineering PhD programs in average federally financed R&D expenditures. Finally, average federally financed R&D expenditures appear to be converging for the 11 Very Large and the 22 Large institutions.

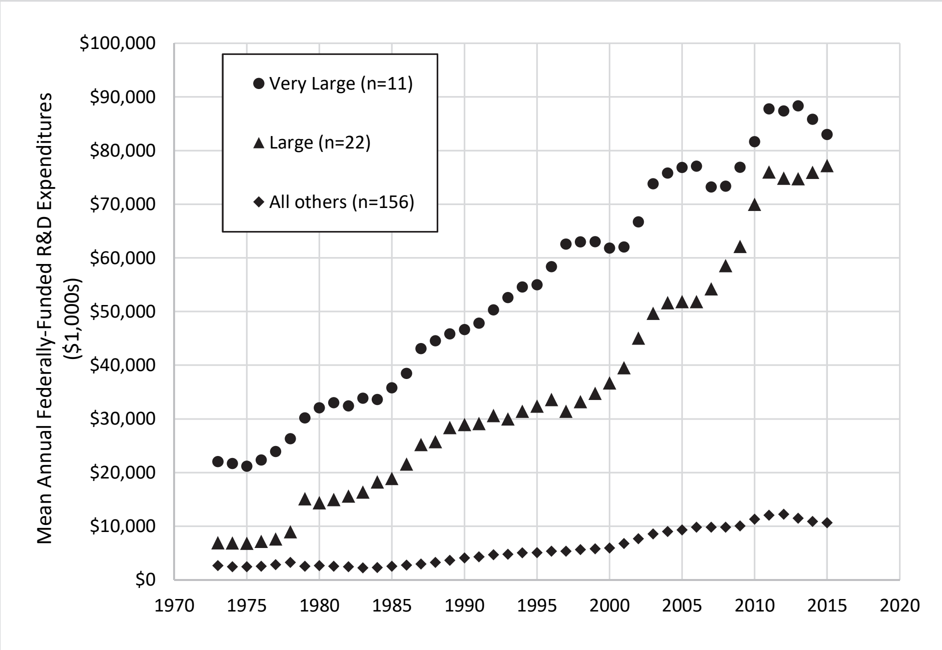

Figure 1: Annual Mean Federally Funded R&D Expenditures (in Constant 2016 $thousands) in Engineering per Institution within PhD-Cohort Size Group (Based on 2015 Doctoral Degree Conferrals in Engineering)

At the institutional level, a similar increase in temporary resident participation was evident. Figure 2 shows the number of U.S. institutions that issued at least one engineering PhD to a temporary resident student. This figure shows the same increase in temporary resident engineering PhDs over the study period, with nearly all U.S. engineering doctoral degree programs conferring at least one PhD to a temporary resident starting in the early 1990s, as indicated by the nearly overlapping lines in Figure 2.

Figure 3 is based on all institutions that reported engineering doctoral degree awards in the study period via the IPEDS data system, disaggregated by both citizenship status and gender. Temporary resident men, especially, have been a significant – but variable-sized - population within U.S. graduate engineering populations, earning a majority of U.S. engineering doctoral awards in a brief period in the early 1990s and then again in the post-2000 period. In 2015, temporary residents accounted for 56% of all engineering doctoral degrees (temporary resident women accounted for 12%), with U.S. women accounting for an additional 11% of the doctoral degrees awarded in 2015. As shown in Figure 1, the upward trend in temporary resident women's participation in U.S. doctoral engineering programs generally parallels that of U.S. women. In the most recent period from 2010-2015, however, the increase in the number of degrees for U.S. women was 28.5% as compared to the 38.8% for temporary resident women. In contrast, the number of engineering doctoral degrees awarded to both U.S. and temporary resident men increased by about 33% in 2015 as compared to the number awarded in 2010.

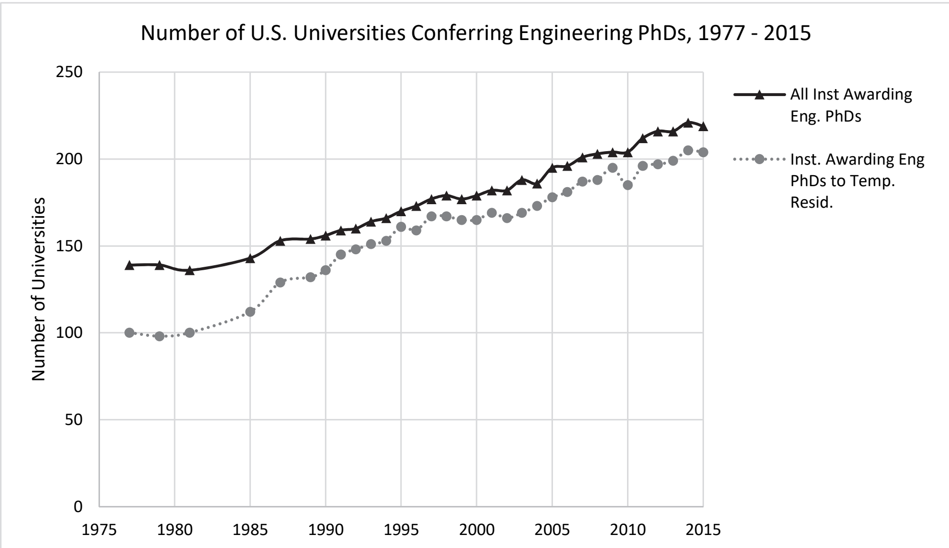

Figure 2: Trend in Engineering Doctoral Programs at U.S. Universities
Source: Author's analysis of NSF's IPEDS degree data accessed via the WebCASPAR database system.

Next we examine the descriptive statistics and correlations between demographics of engineering PhD recipients and federal R&D funding of U.S. universities. Table 1 reports the median funding level for institutions as well as degree awards by institutional group and time period. The five three-year periods were selected to show snapshots over time. As discussed, above, three-year averages are used as a standard way to account for the volatility in the small numbers of graduates when disaggregated by demographic characteristics in order to avoid the potential problem of false positive conclusions associated with change (i.e., due to year-on-year variations that are more "noise" than real effect). The first period is the earliest time at which IPEDS data for engineering disaggregated by gender and citizenship status were available, representing a time 5-7 years after Title IX. The final period represents the most recent three-year period prior to the most recent administration during which there has been a marked downturn in international graduate students at U.S. universities. (Okahana and Zhou 2019)

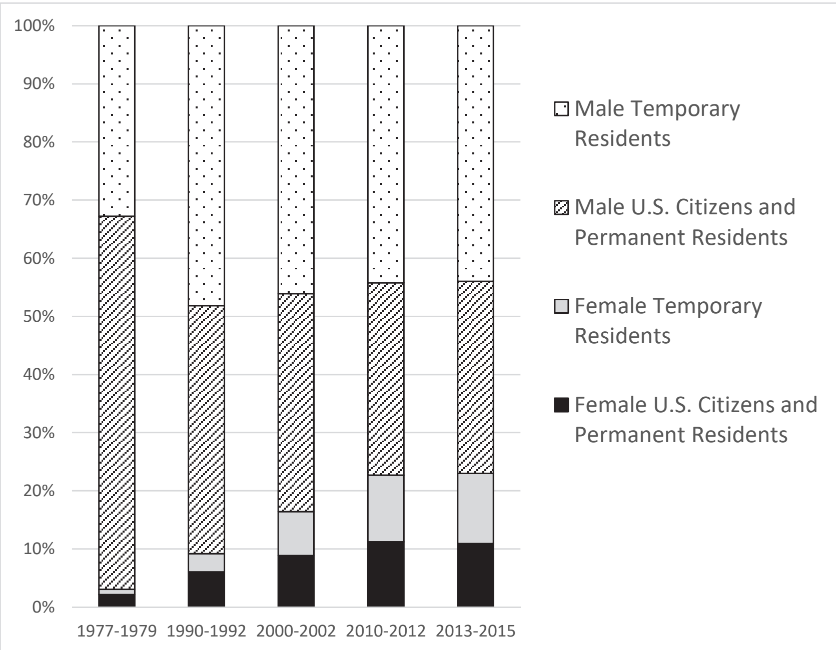

Figure3: Trend in Doctoral Degree Awards in Engineering from U.S. Colleges and Universities, 1977-2015 by Gender and Birth Origin Source: IPEDS data accessed via NSF WebCASPAR database system. Note: 1978 data were not available, therefore, the 1977-1979 period represent a two-year average, while all other periods are three-year averages

There was only one very large institution in the earliest period (1977-1979) but the number in this category (as well as the other two size categories) continued to grow through 2013-2015. The 17 very large institutions had median federal R&D expenditures in engineering of $65.5 million per year and produced about 213 PhDs each year in the most recent period, 2013-2015. In contrast, the 26 large institutions had a median $40.9 million of expenditures of federal R&D funds and graduated fewer than half as many engineering PhDs in the same period. Finally, there were 179 institutions who graduated an average of 22-23 engineering PhDs each year between 2013 and 2015, with a median of $6.9 million each year in federal-funded R&D expenditures.

Table 1. Median Funding (in millions of 2016 dollars), Average PhDs in Engineering, Percent Women and Percent Temporary Residents among Engineering PhDs, by Institutional Group and Time Period

	No. of Instit.	Median Annual Eng R&D	Annual Average PhDs	Ave. % Women	Ave. % Temp. Res.
Very Large (more than 133 PhDs/year)					
1977-1979	1	$101.6	143.5	4.2%	24.0%
1990-1992	7	$57.0	173.2	8.6%	49.1%
2000-2002	7	$86.9	169.4	16.8%	47.7%
2010-2012	12	$88.1	209.4	21.6%	55.8%
2013-2015	17	$65.5	212.7	21.8%	56.6%
Large (67-133 PhDs/year)					
1977-1979	4	$34.6	107.8	2.0%	37.1%
1990-1992	14	$25.0	89.7	8.4%	51.0%
2000-2002	16	$37.3	90.2	15.5%	56.5%
2010-2012	21	$48.2	97.0	22.6%	52.7%
2013-2015	26	$40.9	91.1	23.0%	51.1%
All Others (with 1 or more PhDs)					
1977-1979	140	$3.3	14.1	6.3%	37.1%
1990-1992	144	$3.6	19.2	10.4%	53.1%
2000-2002	166	$6.7	16.6	18.7%	55.8%
2010-2012	186	$8.1	20.6	25.1%	55.1%
2013-2015	179	$6.9	22.5	25.6%	57.2%

Table 2 examines the correlations between engineering PhD recipient demographics and federal funding levels (adjusted for inflation to constant 2016 dollars) in each of the four most recent time periods. The correlation between funding and the total number of PhDs has declined since the 1990-1992 period but remains relatively robust. There are no statistically significant correlations between the relative percentage of temporary residents and engineering R&D funding. The largest change in correlation coefficients, however, is evidenced between the percentage of women PhD recipients and engineering R&D funding; this correlation coefficient was only statistically significant in 1990-1992, with very weak or negligible associations in all other years.

Table 2: Correlations between Federal Engineering R&D Funding and PhD Recipients' Demographics and Federal Funding for Each Time Period

	Total PhDs	% Women	% Temp. Resid.
1977-1979	.809**	.035	.039
1990-1992	.501**	.177*	-.071
2000-2002	.589**	.031	-.031
2010-2012	.393**	.043	.031
2013-2015	.402**	-.005	-.038

* Indicates two-tailed significance at $p < 0.05$; ** indicates two-tailed significance at $p < 0.01$. Shading within the Total PhD column indicates the results of post-hoc tests (using the Fisher r-to-z transformation) of the differences between correlations within the column. For Total PhDs, 0.809 is larger than all others (p=0.00); 0.589 and 0.501 are equal (p=0.24) as are 0.393 and 0.402 (p=0.91); and 0.589 > both 0.402 (p=0.01) and 0.393 (p=0.01). None of the correlations in the last two columns are statistically significantly different using the Fisher r-to-z transformation. The largest difference in the % Women column produced a z=1.77 with p=0.07; while that in the % Temp. Resid. Column produced a z = 0.96 with p=0.34.

Table 3 controls for institutional type in these correlations, reporting results for the 17 institutions that were in the "very large" group in 2013-2015 (left three columns of Table 3) and the 26 institutions that were in the "large" group (right three columns of Table 3). For the very large institutions, there is a far stronger relationship between engineering R&D funding and PhD production, as evidenced by the larger correlation coefficients—all of which were statistically significant at least $p < 0.05$—in the first column of the table. However, there was a far weaker – and sometimes negative – correlation between PhD production and engineering

R&D funding for those institutions that produced between 67 and 133 PhDs per year in engineering in the 2013-2015 period. Indeed, only the 0.428 correlation in the 1977-1979 period for these 26 institutions was statistically significant.

The post-hoc tests for the correlations reported in Table 2 indicate that the correlations in the first column, those associated with the correlation between Total PhDs and federally-funded R&D expenditures, were in three groupings with the 0.809 for the 1977-1979 period significantly greater than all others; followed by the two correlations for the middle two periods; and then the two for the most recent two periods. None of the correlations in the last two columns are statistically significantly different for the five time periods shown.

Table 3. Correlations of Engineering PhD Demographics with Federal R&D Funding, by Year and Institution Classification for Top PhD Producing Institution Groups in 2013-2015

	Very Large (2013-2015) (n = 17 institutions)			Large (2013-2015) (n = 26 institutions)		
	Total Eng. PhDs	% Female	% Temp. Resid.	Total Eng. PhDs	% Female	% Temp. Resid.
1977-1979	.844**	-.213	-.251	.428*	-.122	.061
1990-1992	.870**	.414	-.129	-.044	.508**	-.176
2000-2002	.922**	.065	-.666*	.096	.242	-.228
2010-2012	.665*	.252	-.219	-.102	.556**	-.008
2013-2015	.761**	.184	-.326	.042	.245	-.136

* Indicates two-tailed significance at p < 0.05; ** indicates two-tailed significance at p < 0.01. Shading within columns indicate the results of post-hoc tests (using the Fisher r-to-z transformation) of the differences between correlations within the column. For Very Large institutions, Total Eng. PhDs, only 0.922 > 0.665 (z=2.12; p=0.03), no others were significant (comparing 0.922 to 0.761 had a z=1.60, p=0.11); none of the % Female or % Temp. Resid. correlations were significantly different (largest gap had z=0.99, p=0.32 in the former, and z=1.78, p=0.08 in the latter). None of the correlations within each column for the Large institutions were statistically significant when using the Fisher r-to-z transformation post-hoc test.

For both the very large and large institutions, the correlation between R&D funding and the percentage of temporary resident PhD recipients was always negative, quite volatile, and rarely statistically significant. For example, there was a strong negative correlation (-0.666) in the 2000-2002 period for the very large engineering PhD schools. The percentage of female PhDs was positively correlated with R&D funding in all but the first period for both types of schools but tended to be a stronger correlation for the large compared to the very large schools in each of the five time periods. The correlation between the percentage of women among PhD recipients and R&D funding was only significant – and of moderate size – for the 1990-1992 and 2010-2012 periods for the 26 large PhD producing engineering schools.

Next we examine the descriptive statistics and correlations between the demographics of engineering PhD recipients and federal R&D funding awarded to U.S. universities. Table 1 reports median funding level for institutions, divided by relative engineering PhD degree production. The five three-year periods were selected to show snapshots over time. As discussed, above, three-year averages are a standard way to avoid the problem of a potential false positive on change (i.e., due to year-on-year variation that are more noise than effect). The first and last periods are defined by data availability, while the other three periods were meant to provide milestone marks between the late 1970s and the present. Also shown in Table 1 are data on degree awards by institutional type.

There was only one very large institution in the earliest period shown, 1977-1979, but the number grew to 17 by the most recent period. These institutions had median federal R&D expenditures for engineering of $70.9 million per year and produced about 213 PhDs per year, on average, between 2013 and 2015. In 1977-1979 there were just four large engineering schools; this number had grown more than six-fold by the 2013-2015 period. These large institutions produced an average of just less than half as many PhDs annually (approximately 91) than did the very large institutions and received about $45.1 million in R&D funds for engineering each year in 2013-2015.

Conclusion

The twentieth century was marked with revolution and transformation, on many levels and for many domains- perhaps none more so than the educational system, which supports an educated, skilled population. While this particular paper did not explore causal links between funding, policy, and demographic changes in engineering programs- several compelling correlations emerged, providing the basis for further research into the complex relationship between federal post-secondary education funding, changing demographics (including gender, ethnicity, and nativity), and human capital. This paper found that immigration policy changes with the rise of temporary resident students included women in engineering. These temporary resident women were an important component of the increased presence of women among U.S. engineers in recent cohorts of PhD recipients, as temporary residents of both genders came to represent a larger share of engineering PhD recipients from U.S. universities.

Expansion of engineering in higher education, at the time when the Federal government was making investments in facilities and faculty quality, meant that there was an expansion in doctoral degrees awarded in engineering, as might be expected. As in other fields, the engineering doctoral degree provides a research-oriented toolkit for engineers, enabling movement from highly applied, technical work in industrial and government settings into research positions in those same sectors, in addition to entrée into academic careers.

The unexpected finding of a lack of a correlation between federal funding and increasing temporary resident PhD recipients suggested that mid-tier doctorate institutions appeared to provide the best point of entrée for non-citizen engineering students. Perhaps mid-tier institutions rely on increasing enrollment of temporary resident students as a growth strategy to supplement lower federal funding levels? Or maybe international students pay a larger percentage of tuition, or work as teaching assistants (rather than as research assistants supported by external funds) in exchange for tuition remission? Such questions suggest directions for future research. The weak (or non-existent) relationships between the percentage of women and R&D funding

The role of specific programmatic interventions in the demographic composition of engineering PhDs is another area for future study. Just as other researchers have examined the impact of the doubling of NIH funding on production of PhDs in the biomedical sciences (Blume-Kohout 2012, Diaz et al 2012, and Frehill 2016), similar analyses of the trends described in this article could be completed. NSF-funded programs such as the Alliance for Minority Participation "Bridge to the Doctorate" supplements, the Alliance for Graduate Education and the Professoriate, and the NSF Advance: Institutional Transformation[7] program may have affected the pools of graduate students and production of PhDs starting in the early part of the 21st century. Such analyses, however, require careful analyses to avoid over-stating program effects, given the larger social context in which they were embedded.

Overall, this paper concludes that there is some relationship between federal funding of post-secondary education and macro-level demographic changes. We also conclude that these changes are associated with increases in female representation in engineering PhD degree production. A limitation of this paper is the lack of further discussion of the actual effect, strength, and significance of this relationship. We plan to address these aspects through further research. This paper represented an exploratory look into the complicated and complex dynamics of federal funding, human capital, and changing demographics in PhD degree production. These initial findings have supported the formation of an initial research agenda to further pursue more detailed analyses of these variables and how these relationships can be better understood and leveraged to support continued and increase representation of women in the U.S. engineering enterprise.

Conflict of Interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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[7] The Advance program is focused on faculty composition rather than the gender composition of graduate degree cohorts.

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Bio

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