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ABSTRACT

This study shows that the demographic and institutional origins of new US trained science and engineering PhDs changed markedly between the late 1960s-1970s to the 1990s-early 2000s. In 1966, 71% of science and engineering PhD graduates were US-born males, 6% were US-born females, and 23% were foreign born. In 2000, 36% of the graduates were US-born males, 25% were US-born females, and 39% were foreign born. Between 1970 and 2000 most of the growth in PhDs was in less prestigious smaller doctorate programs. The undergraduate origins of bachelor's obtaining science and engineering PhDs changed only modestly among US colleges and universities while there was a huge growth in the number of foreign bachelor's graduates obtaining US PhDs.

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How have the demographics of PhD graduates changed from those in earlier decades? Have highly selective PhD producing universities maintained their share of science and engineering PhDs or have newer institutions and programs increased their proportion of doctorates? Do most science and engineering PhDs matriculate at the most prestigious colleges and universities or do recent PhD graduates come from a wider set of baccalaureate programs? Has there been a shift in the bachelor's origins of science and engineering PhDs from the larger most selective colleges and universities to the smaller but still most selective liberal arts colleges?

This paper uses data from the Survey of Earned Doctorates (SED) to examine these questions about the origins of new US-trained science and engineering PhDs in 2000 compared to earlier decades. The data document a significant shift in the demographic origins of new US-trained science and engineering PhDs from US born white males to women, minorities, and foreign-born persons They show that the proportion of PhDs from less selective doctoral programs and universities has increased noticeably. The data also show that the number of bachelor's graduates earning science and engineering PhDs from the most selective liberal arts colleges increased modestly relative to the number earning PhDs from the selective research universities. Still, both the number and proportion of bachelor's graduates obtaining science and engineering PhDs are bigger at the research universities

1. The New Demography of US trained science and engineering PhDs

PhD graduates from US universities in the early 2000s differ markedly from the graduates three or four decades earlier. In the 1960s and early 1970s the vast majority of PhDs graduating in the sciences and engineering from US universities were native born white males. In 2000, native born white males were a distinct minority of graduates. Figure 1 shows the decline in the native born male share of PhDs. In 1966, 71% of PhD graduates were US-born

males;[1] 6% were US-born females; and 22.5% were foreign born students. In 2000, 36% of PhD graduates were US-born males; 25.4% were US born females; and 38.9% were foreign-born. In addition, the graduates obtaining science and engineering PhDs in 2000 are older than earlier cohorts of PhDs. In 1966, the median age of a science and engineering PhD was 30. In 2000 the median age of a science and engineering PhD was 32. Measured by mean ages, the aging of new graduates was even greater: in 1966 the mean age of a PhD graduate was 31.5 years; in 2000 the mean age was 33.9.

The upward trend in the foreign-born share of US science and engineering PhDs did not occur smoothly. Figure 2 shows that the foreign proportion of US trained PhDs rose gradually from the 1960s through 1980 and then increased sharply to the mid 1990s, leveling off at about 40%. To see whether foreign born PhDs come largely from US baccalaureate backgrounds or receive their undergraduate training overseas, we tabulated the location of undergraduate degrees of foreign-born PhDs. These statistics show that the vast majority of foreign-born PhDs obtained foreign bachelor's degrees. The late 1980s-early 1990s jump in the foreign-born share of PhDs, in particular, came primarily from students educated overseas. Still, there was a substantial increase in the proportion of US science and engineering PhDs granted to foreign born students with US bachelor's education. From 1958 to 1968, 21.1% of US science and engineering PhDs went to foreign-born graduates of US colleges and universities. From 1991 to 2001 41.1% of US science and engineering PhDs went to foreign-born graduates of US colleges and universities. Foreign born PhDs with US baccalaureates were 6.3% of all PhDs in 1958-1968 and 9.4% of all PhDs in the 1991-2001. Foreign born PhDs with foreign baccalaureates increased from 14.8% of all PhDs in 1958-1968 to 31.7% of all PhDs in 1991-2001. Disaggregated by field, the data show

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1 The 71% figure in 1966 for males refers to "non-minority males", which we assume

that the foreign-born have become a majority of graduates in some disciplines, including branches of engineering, while increasing in all fields.

Among US citizens, there has also been a substantial upward trend in the proportion of PhDs granted to minorities – Asian and Pacific Islanders, blacks, and Hispanics. The US minority proportion of all PhDs has risen from less than 3% in 1966 to 9% in 2000. Figure 3 displays the increased proportion of science and engineering PhDs awarded US women and minorities over time. It records the share of US citizen PhDs that went to women from 1966 to 2000 and the share of US citizen PhDs that went to minorities from 1973 (when the surveys record detailed minority representation) to 2000. The figure shows steady increases in the female and minority shares of US citizen science and engineering PhDs beginning in the 1970s proceeding through 2000, with only the barest sign of leveling off by the end of the period. The female share of US citizen PhDs rose from below 10% in the late 1960s to over 40% by 2000. The share of U.S. citizen science and engineering PhDs going to Asian and Pacific Islanders rose from negligible in 1973 to 6.3% in 2000 – above their proportion of the US population. Black and other minorities (American Indian and non black Hispanics) increased their share of US citizen PhDs to approximately 2.7% in 2000, compared to negligible numbers in 1973, though these proportions are below their shares of the population.

The increased female and minority shares of US citizen science and engineering PhDs occurred in part because of increases in the number of degrees granted these traditionally underrepresented groups. The number of US females gaining PhDs increased from 748 in 1966 to 2,110 in 1973 to 6,614 in 2000. The number of US citizen minority PhDs increased from 450 in 1973 to 2,374 in 2000. But the increased female and minority shares of US citizen science

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were almost exclusively white.

and engineering PhDs also reflects a 37% drop in the number of US citizen white males gaining PhDs from 1973, when 12,518 white men earned science and engineering PhDs, through 2000, when 7829 white men earned science and engineering PhDs[2].

Interpretation

The demography of PhD production reflects the decisions of students, PhD granting institutions, and undergraduate institutions, influenced by government stipend and R and D policies and by the labor market for scientists/engineers and other high level occupations.

On the student side, the changed demographic composition of PhD graduates presumably reflects differential economic incentives to earn PhDs compared to other career alternatives. Foreign born students, particularly those with foreign bachelor's degrees can often earn much more from a US doctorate than from working in other careers in their native country, in part because the science and engineering doctorate opens the door to working in the US or working for US and other multinational firms. Since American students have diverse other US educational prospects, such as medical school, law school, business school, and can work as a scientist/engineer or college graduate without a PhD, they have less incentive to invest in a science and engineering PhD than otherwise comparable foreign-born bachelor's graduates. Equally important, increases in the number of young persons earning bachelor's degree overseas has increased the potential supply of bright students to science and engineering in the US as well as in the students' native countries.

By contrast, there is no clear explanation why women and minorities have chosen science and engineering PhDs in increasing numbers while fewer white men have gone on to earn

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[2] In 1973 2,972 men did not answer the ethnicity question. Given the low proportions who answered minority, we allocated all who did not answer to US citizen white men. In 2000, 259 men did not answer the ethnicity question. We allocated all who did not answer to US citizen white men.

science and engineering PhDs. US born women and minorities enter the same job market as white men, so these patterns cannot readily be attributed to markedly different market opportunities. One possible explanation is that opportunities outside science and engineering for women and minorities are sufficiently worse to make earning a PhD financially more attractive to them. Given flows of women and minorities into medical and law schools and observed earnings patterns, this cannot be much of the story, however. Another possibility is that the influx reflects an adjustment in the flow of women and minorities toward a previously unattainable "equilibrium" share of degrees. This explanation predicts that relatively more women and minorities will invest in PhD programs than will white males at the same earnings opportunities as those facing white men until the share of women and minorities among PhD scientists and engineers reaches approximate parity with their share of college graduates. At that point, the flows of women and minorities into science and engineering PhDs would presumably follow the same pattern as the flows of white male PhD graduates.

2. Who Produces PhDs?

The number of universities and programs has increased substantially. In 1970, 214 universities granted PhDs in science and engineering. In 2000, 339 universities/campuses granted PhDs in science and engineering. Some institutions produce 400-500 science and engineering PhDs per year: UC Berkeley, University of Illinois at Urbana, University of Wisconsin at Madison, University of Michigan, University of Minnesota, MIT, Stanford, for example. Others produce very few PhDs per year: Providence College, University of the Pacific, UC Santa Cruz, Ball State University.

Between 1960 and 2000, the US university sector "produced" an increasing number of

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Calculations that simply ignore these respondents give results similar to those in the figures.

PhDs in science and engineering. There were 6,520 science and engineering PhDs in 1960; 18,052 in 1970; 17,775 in 1980; 22,868 in 1990 and 25,951 in 2000. A priori, the increased number of PhDs could have come from increased PhD production at the larger leading universities; from proportional increases in degrees among all PhD granting universities; or from increases in the number of degrees from universities with smaller or less prestigious programs or with newly formed programs. Our analysis shows that the growth of science and engineering PhDs in the US was fueled by an expansion of degrees from smaller, lower quality institutions rather than from increased numbers of graduates from elite universities.

Table 1 present the data for this conclusion. It shows how the distribution of science and engineering PhDs changed over time along the specified dimensions. The columns "by number of doctoral degrees" give the distribution of degrees by the number of PhDs granted. They show that the proportion of PhDs granted by the ten largest PhD granting institutions fell from 24.1% in 1970 to 16.7% in 2000; that the proportion of the next largest fifteen PhD producers fell from 21.6% to 17.5%; while the proportion of the next 15 largest producers fell by 0.9 percentage points. As a summary of the overall concentration of science and engineering PhDs among large PhD producing universities, we calculated the Herfindahl-Hirschman index of concentration (HHI in table 1). This index is the sum of squares of the proportions of degrees given by each degree granting institution It is a standard measure of concentration in industrial organization, used for instance by the US Department of Justice.[2] Analysts of industrial organization consider markets in which the index is between 1000 and 1800 points to be moderately concentrated, and those in which the index exceeds 1800 points to be concentrated. From this perspective, the drop in the index for PhD granting universities from 123 to 78.7

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2 See www.usdoj.gov/atr/public/testimony/hhi.htm

implies that PhD-production went from moderately concentrated to highly competitive.

The columns labeled "Carnegie classification of institutions of higher education" in Table 1 use the Carnegie Foundation's well-established taxonomy of higher education institutions[3] to divide them into three groups: leading research universities; doctoral universities that grant at least 20 degrees in any field or 10 or more in three fields, but which did not fit the criterion for being a research university; and all other institutions. The data shows a drop in the proportion of degrees from the research universities, and corresponding increases in the proportion of degrees from doctoral universities and other institutions.

The next set of columns in Table 1, labeled "number of high quality programs" classifies universities by the number of PhD programs that attained high rankings in the National Research Council rankings for 1982. These columns show a decrease in the share of PhD production in universities with 10 or more and with 3 to 10 high quality programs, and a rise in the proportion of science and engineering PhDs from universities with no top program.

Finally, the last set of columns in table 1 record the proportion of PhDs coming from universities in the top ten of recipients of federal research and development money. The share of PhDs from these institutions fell sharply from 1985 to 2000 as PhD production expanded. The drop in the share of PhDs from these institutions was sufficiently large that the number of science and engineering PhDs from the top federal R and D recipients in 2000 was lower than the number from the top federal R and D recipients in 1985.

In sum, the increase in science and engineering PhDs in the US largely took the form of expansion of smaller and less prestigious programs. Between 1966 and 2000 over 2/3rds of the nearly 15,000 increase in the number of PhDs granted in the sciences and engineering occurred

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3 http://www.carnegiefoundation.org/Classification/CIHE2000/background.htm

among institutions below the top 40 PhD producers, while 83% of the growth occurred among universities with few high quality programs[3]. This pattern of expansion in smaller and lower quality institutions contrasts with pattern of growth in many other sectors of the economy where large enterprises dominate markets and where increases in production typically come from those large firms (automobiles, steel, software).

The simplest economic story for why the higher education sector expanded PhD production by developing new or small PhD programs rather than by major research universities increasing their doctorate programs is that the cost schedule for producing PhDs is very inelastic, due to capacity constraints set by faculty, plant, or other characteristics of existing programs. This contrasts with potential increasing returns to scale (at least up to much larger production) in many other sectors. Expansion of PhD production through lower quality doctorate programs may also, however, reflect the US system of financing higher education. In the public sector, legislatures may be willing to fund a new PhD program in their state universities, but not to support the education of students from their state at a program in some rival state. In the private sector, institutions may find it easier to raise funds to improve the quality of existing programs rather than to develop a "clone institution" at some other location.

3. Who Gets PhDs Where?

. Have the growing number of foreign-born and female PhDs obtained their degrees in the same doctoral institutions as US born men, or are they disproportionately represented in the smaller or less prestigious universities? To answer this question, we calculated the distribution

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3 In our data, there were 11,570 PhDs in 1966 and 25,951 PhDs in 2000, giving an increase of 14,381. The top 40 PhD producers granted 7643 PhDs in 1966 and 12,117 PhDs in 2000. The "high quality" institutions granted 5579 PhDs in 1966 and 8,289 PhDs in 2000. The Carnegie research institutions granted 10,852 PhDs in 1966 and 21,120 in 2000 so that 29% of the increased number of degrees came outside of that large group.

of PhDs among US-born men, foreign-born persons, and US born women at universities with 3 or more top rated PhD programs and at universities included in the top 40 PhD granting programs in term of degrees granted.[4] We then compared the representation of these groups at these universities to their representation among all PhDs in 1973 and 2000.

Table 2 summarizes the results of this analysis. The numbers under the labels "universities with 3 or more top programs" and "universities among top 40 PhD granters" gives the number of PhDs in the specified university categories. The percentages record the percentages earned by the groups in the relevant university category. Thus, the 62.35 for US men in the universities with three or more top programs in 1973 shows that US men made up 62.35% of all PhDs in universities with three or more top programs; while the 36.93 for US men in 2000 shows that US men made up 36.93% of all PhDs in that category in 2000. The columns labeled "relative representation" give the ratio of a group's share of degrees in the relevant category relative to its share of all PhDs in science and engineering. When these ratios are greater than one, the group is more represented in that university category than it is among all PhDs. An increase in a groups' relative representation ratio between 1973 and 2000 shows that the group obtained proportionately more PhDs in that category than in the past. Conversely, decreases in the relative representation ratios over time shows that the group lost representation in that group.

The table shows that the 1973-2000 decline in the number of US men obtaining science and engineering PhDs was associated with an increase in their proportion in universities with 3 or more high quality PhD programs and in large PhD producing universities. This means that the drop in male science and engineering PhDs occurred disproportionately at less prestigious

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4 The 40 largest PhD universities produce 50-60% of PhDs, according to table 1. Tabulating

smaller PhD granting institutions. For foreign born students the relative representation ratios in universities with 3 or more high quality PhD programs and in large PhD producing universities exceeded 1.00 in 1973 and remained above 1.0 in 2000, which implies that the huge increase in their shared of PhDs occurred with little fall in the quality of universities where they earned their PhDs.

The situation for women is quite different. As their share of science and engineering PhDs increased, the relative representation in high quality and large PhD granting universities fell. In 1973 women were slightly less likely to obtain a PhD at these universities than other demographic groups. In 2000 women were much less likely to obtain a PhD in the higher quality and larger universities than other demographic groups. There are several possible explanations for why the increase in female science and engineering PhDs occurred disproportionately at less prestigious smaller PhD granting institutions. One possibility is that women enrolled in smaller newer PhD programs because those programs specialized in biological science areas which were particularly attractive to women. Another possibility is that women were more geographically limited in their choice of PhD programs than men or the foreign-born because of family issues. It is also possible, however, that women had difficulty gaining admission to the most prestigious and larger programs. We have not examined these or other possible causes for the disproportionate growth of female science and engineering PhDs in the lower quality and smaller universities.

4. Baccalaureate Origins of PhDs

Some colleges and universities produce relatively large numbers of students who go on to PhDs. Among the science and engineering PhDs who graduated in 2000, 292 had an

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the data by other size groups gives similar results to those in table 2.

undergraduate degree from Berkeley, 266 were Cornell graduates, 252 were Michigan graduates, 225 were Illinois graduates. MIT (205) and Penn State (198) also produced over 200 bachelor's students who obtained science and engineering PhDs in 2000. These research universities combine large student bodies with high quality undergraduate science and engineering programs. Relative to the number of students who matriculate, however, some small liberal arts colleges have produced more future doctorates than the major research universities. Upwards of 3-5% of graduates of liberal arts colleges such as Oberlin, Swarthmore, Reed, obtain PhDs in science and engineering compared to 1% to 2% of bachelor's graduates at major research universities.

Has the baccalaureate origins of science and engineering PhD recipients changed over time as the number of PhDs, their demographic characteristics, and the composition of PhD granting institutions changed?

To answer this question, we examined NSF data on the US baccaluareate origin of PhDs along three dimensions.[5] First, we calculated the proportion of PhDs earned by graduates from institutions that produce relatively many PhDs. This highlights the importance of the large research institutions in the baccalaureate origins of science and engineering doctorates noted earlier. Second, we calculated the proportion of PhDs according to the Carnegie classification of colleges and universities. This distinguishes the major research universities from doctorate granting institution and primarily bachelor's granting institution.[6] It provides insight into the extent to which institutions outside the research nexus send students to PhD programs. Third,

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5http://caspar.nsf.gov/webcaspar

6 The Carnegie Commission on Higher Education has periodically (1970, 1976, 1987, and 1994) classified institutions of higher education by the range of programs and/or degrees offered, enrollment size, and amount of Federal funds received for research. We use the 1994 Carnegie Classification to study the baccalaureate origins of scientists and engineers who recently received their doctorate from U.S. institutions. The changes to the 1994 Classification were such that this analysis is not comparable to earlier Carnegie Classifications

we calculated the percentage of PhDs with origins in undergraduate programs by the selectivity of the bachelor's institution, as measured by Barron's Guide to the Selectivity of Colleges. This categorization differentiates between the most competitive (or selective) undergraduate institutions (45 colleges); highly competitive institutions (87 colleges); very competitive institutions (40), and all other institutions.[7]

Table 3 summarizes the results of our analysis for the period 1970-2000. The columns "US/Foreign Bachelor's Origins of Science and Engineering PhDs" show the numbers of PhDs granted to US bachelor's graduates as opposed to those with foreign bachelor's origins (and those for whom the bachelor's origin data is missing). It shows a huge increase in the number of science and engineering PhDs with foreign baccalaureates. By itself, the increased foreign baccalaureate share of PhDs reduces the proportion of PhDs with origins from all categories of US bachelor's granting institutions. In the remainder of the table, we concentrate on the distribution of PhDs from US undergraduate institutions only.

The columns labeled "percentage of US bachelor's origin PhDs by number of PhDs …" give the distribution of PhDs by bachelor institutions grouped by numbers of PhDs with those baccalaureate origins. In these calculations we credit each bachelor's institution with the number of PhDs graduates from its school in the specified year. For instance, in 2000, 159 persons with a Harvard bachelor's degree (from earlier years) gained a PhD, so we credit Harvard with 159 PhDs. The data show a modest drop in the proportion of PhDs granted to bachelor's from the largest undergraduate origin institutions between 1970 and 1975 but considerable stability thereafter. Because there are many more undergraduate institutions than

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7 The Barron's *Profiles of American Colleges* guide differentiates colleges by their admission criteria. The "most competitive" colleges are determined by SAT scores, percentage of freshmen scoring who ranked in the upper fifth and the upper two-fifths of their high school graduating classes percentage of applicants accepted for admission, and so on.

PhD granting universities, the baccalaureate origins of PhDs are less concentrated among larger institutions than are graduates by PhD-granting institution which we examined in table 1. The top 175 baccalaureate origin institutions have approximately the same percentage of doctorates as the top 40 doctoral institutions. The last column in this part of the table gives the Herfindahl-Hirschman index of the concentration of PhDs by their bachelor's origins. The index falls slightly between 1970 and 1975 and then holds steady at 43-45 m—a level of concentration far below the comparable statistic for PhD granting institutions in table 1.

The columns labeled "Percentage of US Bachelor's origin PhDs by Carnegie classification of institutions of higher education" also show considerable stability in the proportion of PhDs from the various categories. The same is true of data in the columns labeled "by Barron's competitiveness of institution". In 1970 2,519 graduates from the most selective schools earned science and engineering PhDs. In 2000, 2,832 graduates from these schools earned PhDs. This change roughly parallels the overall change in the number of US baccalaureate origin PhDs. Finally, the column labeled "federal R and D" shows stability in the share of PhDs from universities with large amounts of Federal R and D moneys.

Beneath the stability in bachelor's origins by categories of higher educational institutions are changes in position of particular colleges and universities as source institutions for PhD science and engineering graduates. These differences suggest an important role for college and university educational policies, including admission policies, in making some four year institutions major sources for PhD science and engineering doctorates. Among top source undergraduate institutions, Berkeley had 295 science and engineering PhDs in 1970 and 279 in 2000 -- a modest drop. Cornell had 191 science and engineering PhDs in 1970 and 262 in 2000 -- a marked increase. Harvard went from 223 science and engineering PhDs in 1970 to 159 in 2000. MIT went from 280 in 1970 to 203 in 2000. The biggest decline in a PhD producing

undergraduate institution was CUNY City College, which fell from the third largest bachelor's origin institution of science and engineering PhDs in 1970 with 245 doctoral graduates -- 10% more PhDs than Harvard -- to just 17 PhDs in 2000. At the other end of the spectrum, Texas A&M graduates earned 171 PhDs in 2000 compared to 83 PhDs in 1970, while UC San Diego undergraduates earned 152 PhDs in 2000, compared to just 1 PhD in 1970. Among smaller schools, Lehigh went from 59 PhDs in 1970 to 39 in 2000 while Harvey Mudd went from 11 PhDs in 1970 to 40 in 2000.

Variation among individual institutions notwithstanding, the principal conclusion from our analysis is that the bachelor's origins of PhDs from US undergraduate institutions barely changed over the period under study.[8] The increased share of foreign baccalaureates among science and engineering PhDs , not reallocation of PhD origins among those institutions, did however reduce the shares of PhDs originating from various categories of US institutions,.

5 The flow of Students from Baccalaureate Sources to PhD Granting Destination Universities

The following matrix describes the quantitative relation between the number of persons graduating from particular bachelor's institutions and the number obtaining PhDs from doctorate institutions:

(1) $[A_{ij}]t$

where A is an n by m matrix whose elements a_{ij} measure the number of persons with a bachelor's degree from baccalaureate institution i who obtain a PhD at institution j. The n rows represent

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8 Analysis of the undergraduate origins of PhDs by the National Science Foundation (NSF, 1996) highlighted the proportion of foreign bachelor's graduates obtaining science and engineering degrees and the concentration of PhDs from 25 major bachelor's granting institutions. Earlier analyses by the National Academy of Sciences examined the family background origins of PhDs (NAS, 1967).

bachelor's source institutions while the m columns represent PhD granting destination institutions. The t subscript refers to a given time period in which the PhDs are granted. For example, one row in the matrix would measure the number of bachelor's graduates from the University of Southern California who earned a science and engineering PhD; while one column would refer to the University of Nebraska PhD graduates; and the corresponding a_{ij} would show how many bachelors' from USC earned PhDs at Nebraska.

Using data from the Survey of Earned Doctorates and the NSF's WebCaspar data set, we estimated input-output flow matrices for two periods of time, 1970-74 and 1995-99. Each of the matrices shows the number of undergraduates from different institutions that obtained PhDs in the five-year window at specific doctorate granting universities. We used a five-year window because many cells have only limited numbers in particular.[9] As an example of the elements in the matrix, the 1995-1999 matrix showed that 17 University of Chicago bachelor's graduates earned a science or engineering PhD at MIT in that period; that 94 Harvard bachelor's graduates obtained a science/engineering PhD at Berkeley; that 10 Harvey Mudd graduates earned at University of California-San Diego, and so on.

Table 4 summarizes the linkages between particular types of undergraduate institutions and particular types of doctorate granting universities from the flow matrixes. It shows the percentage of all PhDs who did their undergraduate training at a specified category of bachelor's institutions and obtained their PhDs in science and engineering at universities in the specified categories in 1970-1974 and 1995-1999. Each line links different undergraduate origins to different PhD granting institutions. The 4.58 in the first line for 1970-74, for instance, shows

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[9] We thank Teresa Grimes at QRC and Keith Wilkinson at NSF for suggesting that the five year window would work and for creating matrices in useful forms in our initial tabulations.

that 4.58% of PhDs in science and engineering in that year were awarded to students from the ten largest BS origin institutions who obtained PhDs at the ten largest doctorate granting universities. The 3.36 in the next column gives the comparable statistic for 1995-1999. The next line gives the proportion of PhDs granted to persons from the top 25 bachelor's origin institutions and top 25 PhD producing universities. These two measures show the link between large undergraduate and large PhD programs. Line 3 gives the proportion of PhDs who did their undergraduate work at research universities and earned PhDs from research universities. Line 4 gives the proportion of PhDs who graduated from Barron's most highly selective undergraduate institutions and earned PhDs from universities with ten or more top rated PhD programs. Line 5 gives the proportion of PhDs who graduated from Barron's highly competitive undergraduate institutions and received PhDs from universities with

The table shows a modest drop in the proportion of PhDs awarded to persons coming from the specified pairings, which implies that some of the growth of PhD production occurred outside this group of institutions. But the reason for the drop is not any weakening of the link between the relevant undergraduate institutions and PhD granting institutions. Rather, it is the rising proportion of PhDs granted by less prestigious graduate schools that underlies the declines in the proportions in the table. Conditional on the number of PhDs produced, universities with ten or more top-rated PhD programs actually increased their share of students from the most selective and highly selective undergraduate institutions. In 1970-74 universities with ten or more top-rated PhD programs drew 51% of their PhDs who matriculated at US bachelor's institutions from the most selective and highly selective undergraduate institutions. In 1995-99, these universities drew 55% of their US bachelor's origin PhDs from the most and highly selective undergraduate programs.

Table 5 presents a more detailed look at the link between undergraduate institutions and

PhDs in science and engineering at four leading doctorate universities, Harvard and MIT, for private universities, and Berkeley and Michigan for public universities. The upper panel records the number of PhDs granted by each of the institutions, disaggregated by those who came from Barron's most selective, highly selective, and very selective institutions, from other US baccalaureate schools and from foreign schools. These data show a mixed pattern of change in the undergraduate origins of PhD science and engineering students. The number of science and engineering PhDs from the selective undergraduate schools falls at Harvard and MIT, but rises at Berkeley and Michigan.

The bottom panel of the table records the number of PhDs granted graduates from seven most selective undergraduate institutions. It shows that one important factor in the decline of PhDs from the most selective undergraduate schools at Harvard and MIT is a sharp fall in the number of their own bachelor's graduates staying on for PhDs. In 1970-74 224 of Harvard's 1575 PhDs went to former Harvard undergraduates. In 1995-99, only 133 Harvard bachelor's graduates obtained science and engineering PhDs at Harvard. At MIT the drop in the number of bachelor's graduates obtaining PhDs at the school is even greater, from 370 to 191. But the fall in "own-PhDs" is not limited to those institutions. Taking all PhD-granting institutions in the flow matrix, we find that the percentage of PhDs granted to persons with a baccalaureate from the same school fell from 14% to 10%, on average.

Destinations of Bachelor's Graduates

We examine next the distribution of bachelor's graduates among doctorate granting universities – the rows of the $[A_{ij}]$ matrix. For each of the bachelor's origin – PhD destination groupings in table 4, we calculated the conditional probability that graduates from a given type of bachelor's institution earned a PhDs at the specified types of universities. Table 6 summarizes our tabulations. Each statistic in the table gives the percentage of science and

engineering PhDs from the bachelor's source category who earned their PhD in the destination doctorate category. The probabilities that a bachelor's graduate earned their PhD in the specified destination category are lower in all cases in 1995-99 than in 1970-74. This shows that graduates from large bachelor's origin schools, from research institutions, and from selective bachelor's programs were less likely to obtain their PhD at major or high quality PhD universities over time. Graduates from the best bachelor's programs were more dispersed among PhD programs in 1995-99 than they were in 1970-74.

Finally, we have tabulated the number of science and engineering PhDs from the most selective four year institutions using the Barron's categorization, and divided the institutions into two groups: small liberal arts schools (such as Oberlin) and large research universities (such as Harvard). During the weak job market for bio-science PhDs in the 1990s (Freeman, et al, 2001), some academics and university administrators worried that undergraduates at leading research institutions were not pursuing bio-science careers because they observed first-hand the difficult economic conditions facing the post-docs and graduate students in science labs. By contrast, equally able and interested students at liberal arts colleges were reported to be pursuing bio-science careers because they did not have comparable first-hand information about economic prospects. The statistics in table 7 are designed to assess this claim. The table records the number of science and engineering PhDs, the number of foreign born science and engineering PhDs, and the number of bachelor's graduates five years earlier, at the two types of schools. In addition, it records the ratio of PhDs in the given year to the number of bachelor's graduates five years earlier – a measure of the propensity of bachelor's from these undergraduate institutions to obtain doctorate degrees in the future. The statistics show a modest increase in the number of science and engineering PhDs from the small liberal arts colleges relative to the larger research universities. The ratio of the number of PhDs from the liberal arts colleges to the number of

PhDs from the large research universities in the period rises from 0.21 in 1970 to 0.25 in 2000. Similarly, the difference between the ratios of PhDs to bachelor's graduates between research universities and the liberal colleges narrows over the period. Still, proportionately more bachelors' graduates from the research universities obtain PhDs in science and engineering than do bachelors' graduates from the liberal arts colleges, and the ratio of PhDs to bachelor's degrees remains higher for research institutions than for liberal arts colleges. While some liberal arts colleges that produce relatively many PhDs such as Reed and Oberlin are included in Barron's highly selected rather than most selective group, expanding the institutions under comparison is unlikely to overturn the general picture of relatively little change

Conclusion

This study has documented that in the 1970-2000 period, there were large changes in the demography of science and engineering PhDs from US universities, in the concentration of PhD production among universities, and in the bachelor's origins of science and engineering PhDs from the most selective undergraduate institutions.

1. The principal demographic development was the decline in the share of US-born white men among PhD recipients, and increasing shares for US women and minorities and the foreign born. In 1966 US-born white males earned 71% of science and engineering PhDs; in 2000, US born white males obtained 35% of science and engineering PhDs. Larger shares of science and engineering PhDs went to the foreign born, to US women, and to US minorities.

2. On the university PhD producing side, the proportion of science and engineering PhDs from traditional leading doctorate institutions declined. These universities tended to maintain the size of their PhD programs in the face of rising graduate enrollments, so that growth of PhDs occurred largely from less prestigious and smaller PhD programs -- different market response than those found in many other parts of the society.

3. On the undergraduate source side, the proportion of PhDs coming from various US source baccalaureate institutions has been relatively stable, with the major change being the reduced share of PhDs coming from US bachelor's institutions of all types due to the increase in foreign baccalaureate doctorates. In the most competitive undergraduate schools, there was a modest increase in share of PhDs from liberal arts colleges relative to universities.

The observed changes reflect the interrelated decisions of students, PhD granting institutions, and undergraduate institutions, influenced by government financing of education and stipend and R and D policies and by the labor market for scientists/engineers and other high level occupations. We have not examined the relative importance of these factors in accounting for the three developments summarized above nor examined the policy question of whether the observed changes were desirable from the perspective of the US and other societies, and if not, what policy levers might produce different patterns in the future.

Figure 1a: Changing Demographics of US Trained PHDs - 1966

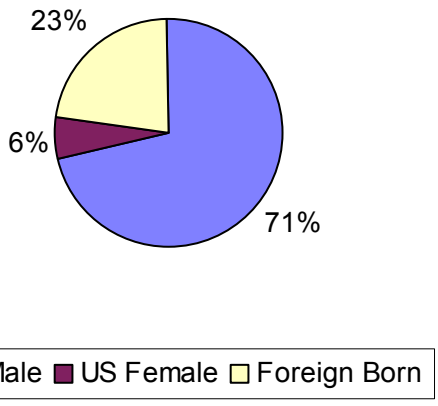
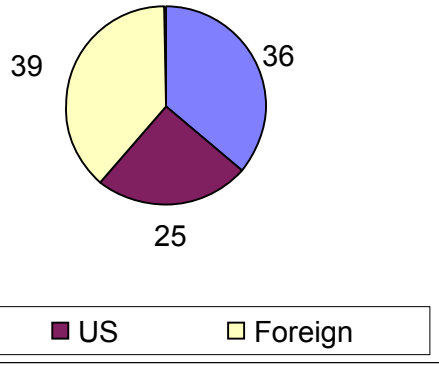


Figure 1b: Percentage Distribution of PhDs, by Demographic Characteristics, 2000



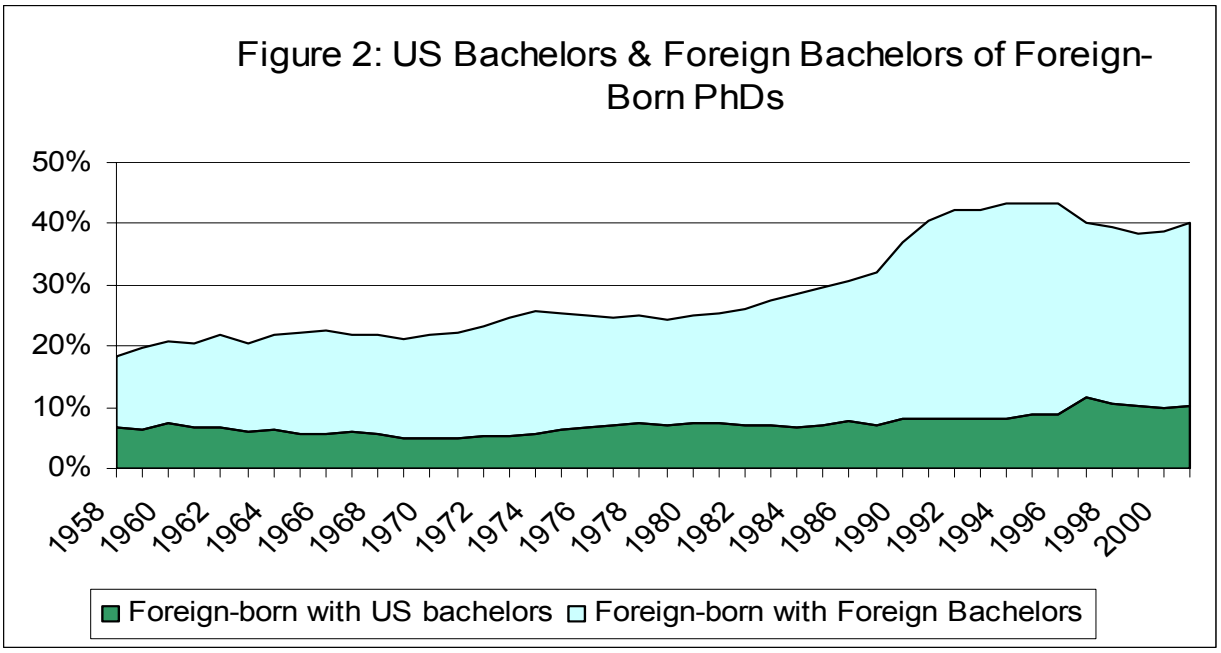


Figure 2: US Bachelors & Foreign Bachelors of Foreign-Born PhDs
50%
40%
30%
20%
10%
0%
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1990
1992
1994
1996
1998
2000
Foreign-born with US bachelors
Foreign-born with Foreign Bachelors

Figure 3: Women or Minorities Share of US Citizen PhDs

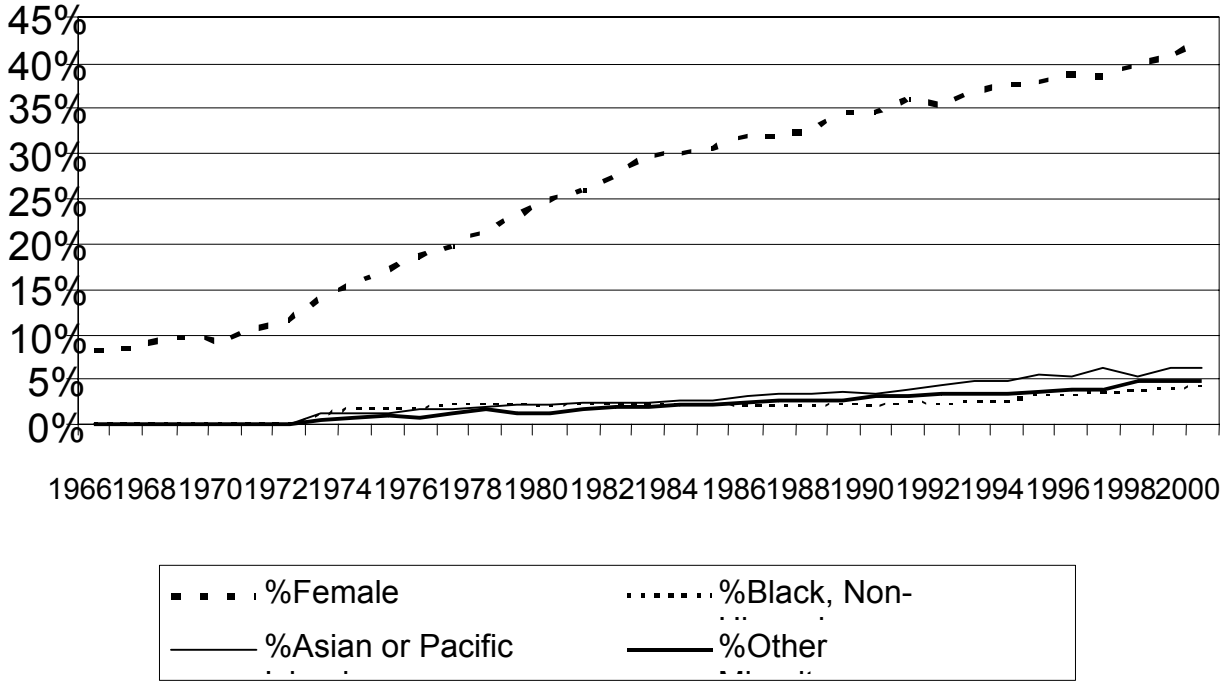


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Table 1: Measures of the Concentration of PhDs by Doctoral Institution

Year	Total # of S&E PhDs awarded	By Number of Doctoral Degrees				By Carnegie Classification		
		%Top 10 (by size)	% Top 11-25	% Top 26-40	HHI	research	doctoral	other
1970	18052	24.11	21.64	13.38	122.98	91.6	7.78	0.62
1975	18799	21.30	19.87	13.67	105.51	88.82	9.35	1.83
1980	17775	20.19	18.82	13.47	98.27	86.17	10.58	3.25
1985	18888	20.64	17.95	13.41	96.99	86.68	10.28	3.03
1990	22868	19.62	18.29	12.70	91.32	84.22	11.45	4.32
1995	26536	18.26	18.57	12.63	86.54	83.31	11.66	5.03
2000	25951	16.68	17.51	12.50	78.69	81.39	12.50	6.11

Year	By Number High Quality PhD programs				By Federal R&D data (percent of PhDs granted by institution over Total)			
	10+ Top Programs	3-10 Top programs	1-2 Top Programs	No Top Program	Year	% top10	% top 25	% top 40
1970	26.11	15.36	20.98	37.55	1970	20.17	37.52	51.25
1975	23.66	14.83	20.90	40.61	1975	19.01	37.99	49.50
1980	22.37	14.17	21.19	42.27	1980	16.88	35.06	45.88
1985	22.04	14.43	20.44	43.10	1985	18.60	34.52	47.59
1990	21.03	14.22	19.76	44.99	1990	17.66	33.83	45.26
1995	19.63	14.48	20.33	45.56	1995	15.60	32.99	45.42
2000	18.25	13.69	19.47	48.59	2000	13.09	30.92	42.35

Note: In classifying the institutions by federal financed R&D expenditure, I used the 1972 ranking for the year 1970 because 1970 has no data on federal R&D expenditure. The percentages are obtained using 1970's number of PhDs. We eliminated Woods Hole from the calculation of the percentage of top 26-40 institutions according to federal financed R&D expenditure, since from 1970 to 1995 Woods Hole Oceanographic Institute had no PhD recipients; we included the 41st institution in terms of federally funded R and D instead.

SOURCE:

National Science Foundation. Various Years. NSF Division of Science Resource Statistics. *Survey of Earned Doctorates*

Table 2 Numbers and Percentages of Doctorate Recipients in Specified PhD Granting Institutions,
by Demographic Characteristic of PhD Recipient, 1973-200

	year					
	1973		**2000**		**1973**	**2000**
Characteristics of PhD granting Institutions	Number	Percentage	Number	Percentage	Ratio of Percentage in group to percentage in total	Ratio of Percentage in group to percentage in total
With 3 or More Top Programs						
US-born Men	4694	62.35	3061	36.93	0.96	1.09
Foreign-Born	2049	27.22	3423	41.30	1.10	1.06
US-born Women	785	10.43	1790	21.59	0.99	0.85
All	7528	100.00	8289	100.00		
In Top 40 PhD producing university						
US-born Men	6817	63.11	4474	36.92	0.97	1.04
Foreign-Born	2881	26.67	4972	41.03	1.08	1.05
US-born Women	1104	10.22	2649	21.86	0.97	0.86
All	10802	100.00	12117	99.99		
Total PhDs in US						
US-born Men	12561	64.84	9225	35.55	1.00	1.00
Foreign-Born	4786	24.70	10087	38.87	1.00	1.00
US-born Women	2026	10.46	6584	25.37	1.00	1.00
All	19373	100.00	25951	100.00		

SOURCE: National Science Foundation. Various Years. NSF Division of Science Resource Statistics. *Survey of Earned Doctorates* Restricted Data. In 2000 55 persons had unknown sex among the US-born. This was 0.21% of the total

Table 3: Distribution of PhDs, By US Baccalaureate Origin Institution

	Number of S&E PhDs, by US Bachelor's and Foreign Bachelor's Origin				Percentage of US Bachelor's Origin PhDs by number of PhDs from Baccalaureate Institution				
Year	Total from all BA institutions	# of PhDs of US Bachelor's Origin	# phds with foreign BA	#phds with blank BA	% of PhDs fromTop 10 (by size)	% of PhDs from Top 25 (by size)	% of PhDs from Top 40 (by size)	% of PhDs from Top 175 (by Size)	HHI
1970	18052	14898	3062	92	15.13	27.86	36.65	72.84	52.69
1975	18799	14845	3657	297	13.42	25.13	32.69	68.51	44.83
1980	17775	14057	3225	493	13.3	24.24	32.42	68.97	44.24
1985	18888	13699	4486	703	12.42	23.78	31.72	67.58	41.81
1990	22868	14739	7080	1049	12.95	24.15	32	67.9	42.84
1995	26536	15868	9478	1190	12.85	24.43	33.29	66.91	43.64
2000	25951	15677	7826	2448	13.14	25.36	34.43	67.9	45.13

	Percentage of US Bachelor's Origin PhDs by Carnegie Classification of Institutions				Percentage of US Bachelor's Origin PhDs, by Barron's competitiveness of Institution			Percentage of US Bachelor's Origin PhDs, By Federal R&D spending at BA institution		
Year	Research	Doctoral	Other institutions classified by Carnegie	Not Classified	Most competitive	Highly competitive	Very competitive	Top 10 receivers of Federal R&D	Top 25 receivers of Federal R&D	Top 40 receivers of Federal R&D
1970	56.47	10.93	32.10	0.49	16.91	24.06	7.57	11.81	21.36	29.04
1975	54.07	10.5	34.86	0.58	15.06	24.28	8.11	11.54	22.18	28.22
1980	55.41	11.15	33.04	0.41	16.2	24.29	9.18	10.99	21.97	28.28
1985	55.29	10.83	33.44	0.45	16.13	23.35	10.15	11.18	21.13	28.59
1990	55.63	11.07	32.78	0.52	15.14	24.09	9.95	11.63	20.86	28.6
1995	55.42	11.07	32.98	0.54	16.53	23.27	9.8	11.27	21.7	29.38
2000	56.10	10.48	32.99	0.43	18.06	24.4	9.58	10.27	22.59	30.45

SOURCE: National Science Foundation. Various Years. NSF Division of Science Resource Statistics. *Survey of Earned Doctorates*

Table 4. The Percentage All US-Baccalaureate Origin PhDs by Undergraduate Origins and PhD Granting Institutions

Bachelor's Source Institutions	Doctorate Granting Destination Institutions	Percentage of US Bachelor's Origin PhDs	
		1970-74	1995-99
1. Top 10 by size BS Origin Institutions	Top 10 by size PhD Institutions	4.58	3.36
2. Top 25 by size Origin Institutions	Top 25 by size PhD Institutions	13.59	11.14
3. Bachelor's from Research Institutions	PhD Research Institution	44.83	43.18
4. Most Selective Bachelor's	University with 10+ Top PhD Programs	6.38	5.56
5. Highly Selective Bachelor's	University with 10+ Top Programs	6.79	5.38

Source: National Science Foundation. Various Years. NSF Division of Science Resource Statistics. Survey of Earned Doctorates.

Table 5: Numbers of the PhDs with Specified Bachelor's Origins at Leading Doctorate Universities

		Harvard		MIT		Berkeley		Michigan	
		1970-74	1995-99	1970-74	1995-99	1970-74	1995-99	1970-74	1995-99
All PhDs		1575	1591	1959	2379	2797	2785	2135	2319
By Barron's Selectivity									
	Most Selective	724	596	766	581	473	647	318	347
	Highly Selective	308	289	321	263	803	735	690	491
	Very Selective	49	71	70	78	87	126	61	98
	Other U.S.	255	180	312	191	527	538	690	558
	Foreign	232	399	480	499	754	670	368	775
	Blank response	7	56	10	767	153	69	8	50
By Specific Undergraduate Institutions									
	Harvard	224	133	55	55	80	94	44	16
	MIT	47	51	370	181	64	80	24	28
	Berkeley	55	54	40	65	462	292	28	38
	Michigan	30	23	27	19	38	40	367	185
	Stanford	26	41	22	36	41	56	12	20
	Cornell	52	45	36	33	36	41	29	40
	Princeton	42	52	34	31	25	55	17	19

Note: Blank response means no baccalaureate institution was reported.

Source: National Science Foundation. Various Years. NSF Division of Science Resource Statistics. Survey of Earned Doctorates

Table 6: Conditional Probabilities of Baccalaureates from Specified Undergraduate Institutions Programs Earning PhDs at Top PhD Institutions, 1970-74 and 1995-99

Bachelor's Source Institutions	Doctorate Granting Destination Institutions	Percentage of PhDs from Bachelor's source getting PhDs in destination doctorate granting institutions	
		1970-74	1995-99
1. Top 10 by size BS Origin Institutions	Top 10 by size PhD Institutions	4.58	3.36
2. Top 25 by size Origin Institutions	Top 25 by size PhD Institutions	13.59	11.14
3. Bachelor's from Research Institutions	PhD Research Institution	44.83	43.18
4. Most Selective Bachelor's	University with 10+ Top PhD Programs	6.38	5.56
5. Highly Selective Bachelor's	University with 10+ Top Programs	6.79	5.38

Source: National Science Foundation. Various Years. NSF Division of Science Resource Statistics. Survey of Earned Doctorates.

Table 7: The Number of Science and Engineering PhDs from bachelor's institutions on Barron's list of most selective schools and the number relative to bachelor's graduates, 1970-2000

20 small liberal art schools from Barron's most selective undergraduate institutions					25 research universities from Barron's most selective undergraduate institutions				
year	# S&E PhDs	# foreign-born S&E PhDs	# of bachelor degrees granted five years earlier	Ratio of S&E PhDs to bachelors granted five years earlier	year	# S&E PhDs	# foreign-born S&E PhDs	# of bachelor degrees granted five years earlier	Percentage Of S&E PhDs as of # bachelors Granted
1970	442	13	7627	5.80	1970	2077	142	22538	9.22
1975	422	24	8588	4.91	1975	1814	105	24895	7.29
1980	468	26	10375	4.51	1980	1808	141	29360	6.16
1985	440	32	11666	3.77	1985	1770	129	31781	5.57
1990	452	30	12494	3.61	1990	1779	178	33897	5.25
1995	495	38	12733	3.88	1995	2128	249	35410	6.01
2000	572	55	12920	4.43	2000	2260	341	35741	6.32

Source:

National Science Foundation. Various Years. NSF Division of Science Resource Statistics. Survey of Earned Doctorates.

Department of Education's National Center for Education Statistics. The Higher Education General Information Survey (HEGIS) and the Integrated Postsecondary Education Data System (IPEDS). Data available on WebCaspar: http://caspar.nsf.gov/cgi-bin/WebIC.exe?template=nsf/srs/webcasp/start.wi

Bachelor's graduates in the 1970 are for 1966, four years earlier.

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