

*patterns of production and demand for NS&Es compared to social and behavioral scientists. Furthermore, most published concerns of the impending growing scarcity of scientists and engineers are focussed on NS&Es.*

*Supply: B.S. degrees*

*Irrespective of the many factors that enter into the choice of careers, between four and five percent of the U.S. 22-year-old age population has obtained B.S. degrees in NS&E for almost three decades (Figure 1). Although the ratio has been slightly above 5% recently, college freshman career intentions survey data predict that the ratio of annual NS&E B.S. degrees awarded to the national 22-year-old population (the average age of B.S. graduates) will fall to below 5% in 1989 and 1990. Projections in this paper use a slightly optimistic value of 5%. This estimate does not greatly overstate the near future supply or downplay severity of forecasted shortfalls. If this participation rate remains constant as assumed, the factor controlling future supply of scientists and engineers is the size of the pool from which they are drawn (Figure 2). The decline in the number of people in the 22-year-old age group will continue until after the mid-1990s, at which time it will begin to rise. The anticipated decline in B.S. degrees has not yet been observed in actual counts, although the 1986 total was the same as in 1985. (Data for 1987 were unavailable from the Department of Education (DOE) when this paper was prepared.) NS&E B.S. degrees have been awarded annually to a relatively fixed fraction of the U.S. 22-year-old population (average age of B.S. recipients) for almost three decades (Figure 1), using NSF/Science Resources Studies Division (SRS) data on NS&E degrees and Bureau of the Census (BOC) data to estimate the number of 22-year-olds. This fraction has varied from a low of 3.7% in 1963 to a high of 5.2% in 1986. Although the highest fraction was reached in 1986, the ration is anticipated to fall back to 4.4% by 1991, based on an analysis of college freshman career intentions survey data collected annually by the American Council on Education. Most of the increase in the rate of degree conferral has been due to rapid growth in the new field of computer science. Excluding computer science from NS&E, the rate of degree conferral has varied from 3.7 to 4.2%. Projections in this paper assume that the average percentage of 22-year-olds earning B.S. degrees in all NS&E fields from 1990 to 2010 will rebound to 5.0% by 1996 and remain at that rate thereafter. This rate has been chosen to avoid overemphasizing the near-future expected dip in the rate of production, and has been held constant after 1996 to stress the importance of demographic factors, a key lesson of the last 30 years. k If this participation rate remains constant as assumed, the factor controlling future supply of scientists and engineers is the size of the pool from which they are drawn ( Figure 2).*

*According to the Bureau of the Census, the decline in the number of people in the 22-year-old age group will continue until after the mid-1990s. It will begin to rise after 1998. The anticipated decline in B.S. degrees has not yet been observed in NSF/SRS degree data, although the 1986 total was the same as in 1985. (Data for 1987 and 1988 were unavailable from the Department of Education when this paper was prepared. Engineering degree data for 1987 and 1988 were obtained from the American Society for Engineering Education.)*

---

*Most growth of computer science baccalaureates did not come from likely candidates for baccalaureates in other NS&E disciplines.*

---

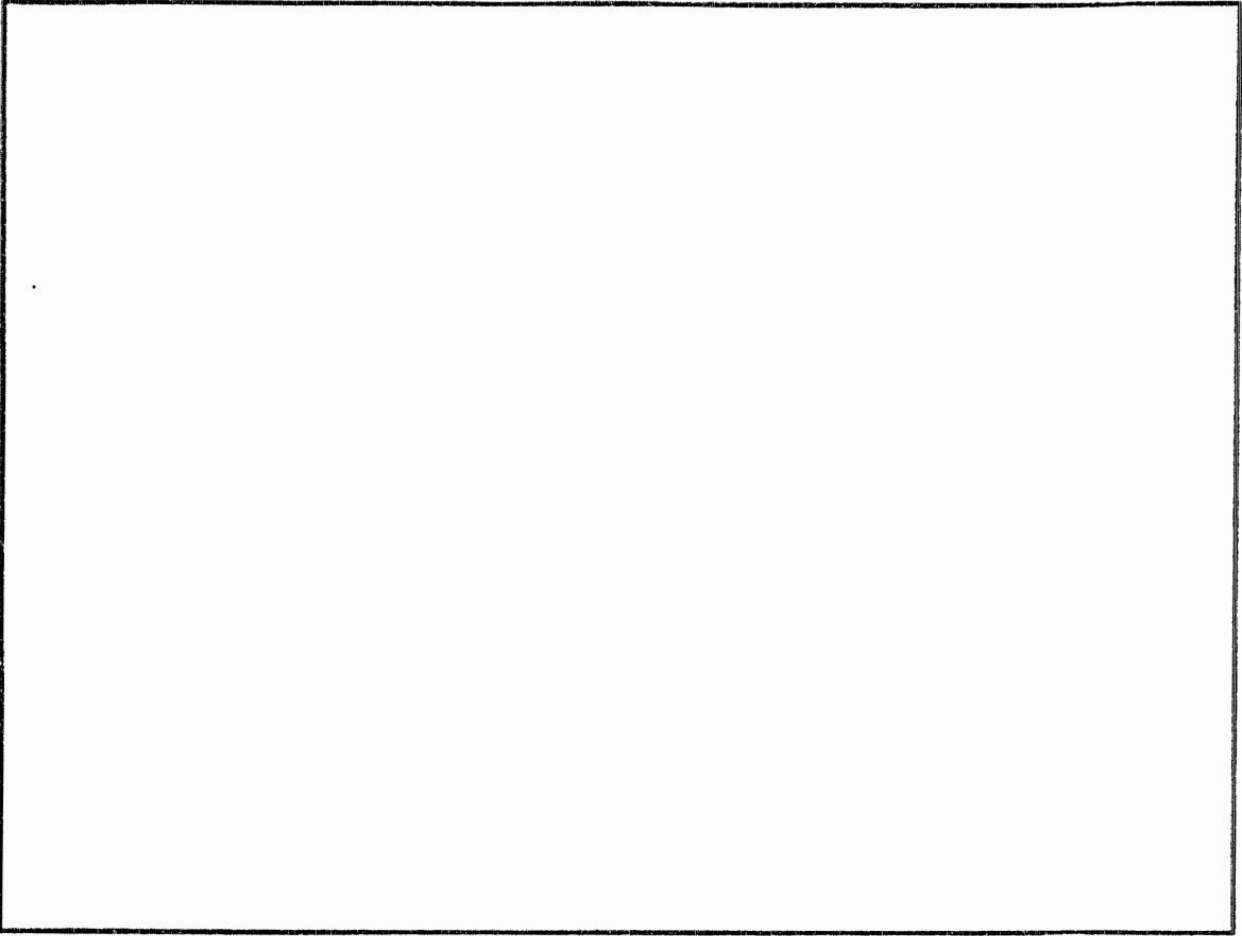
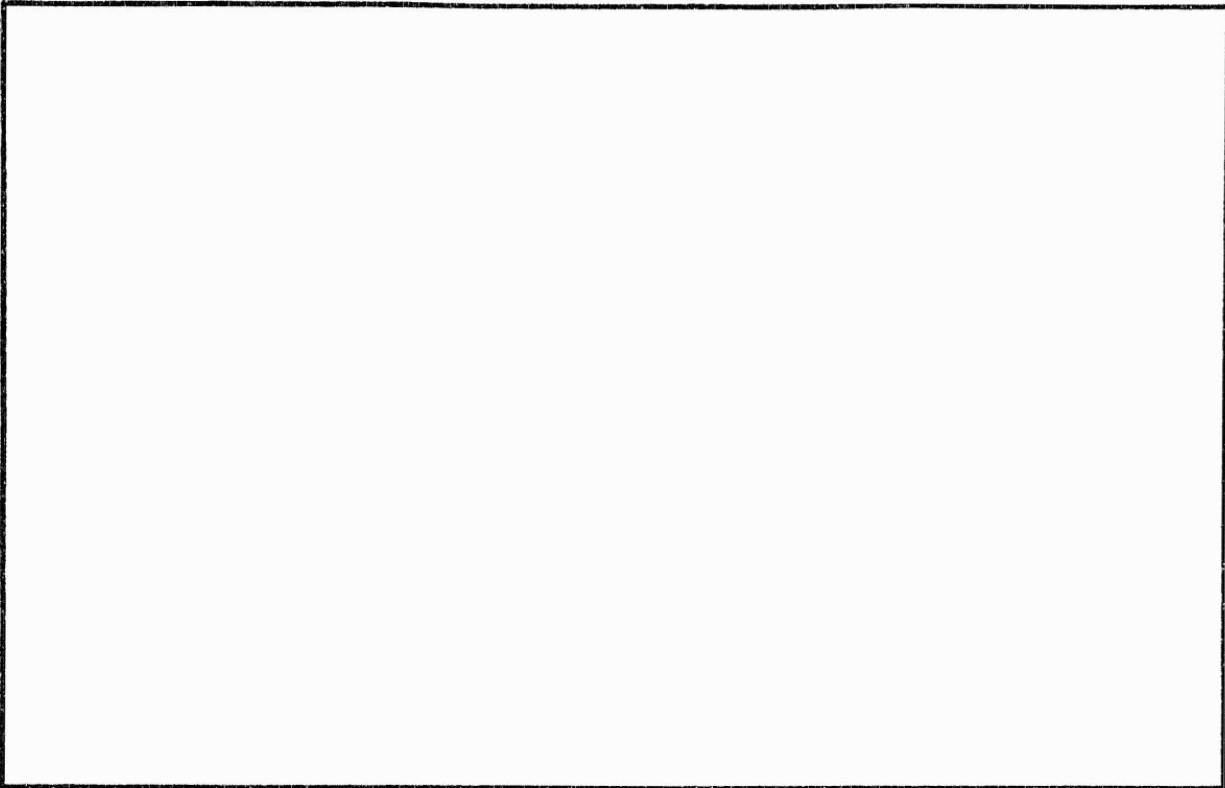


Figure 1 The recent rise in NS&E degrees was mostly due to computer science.

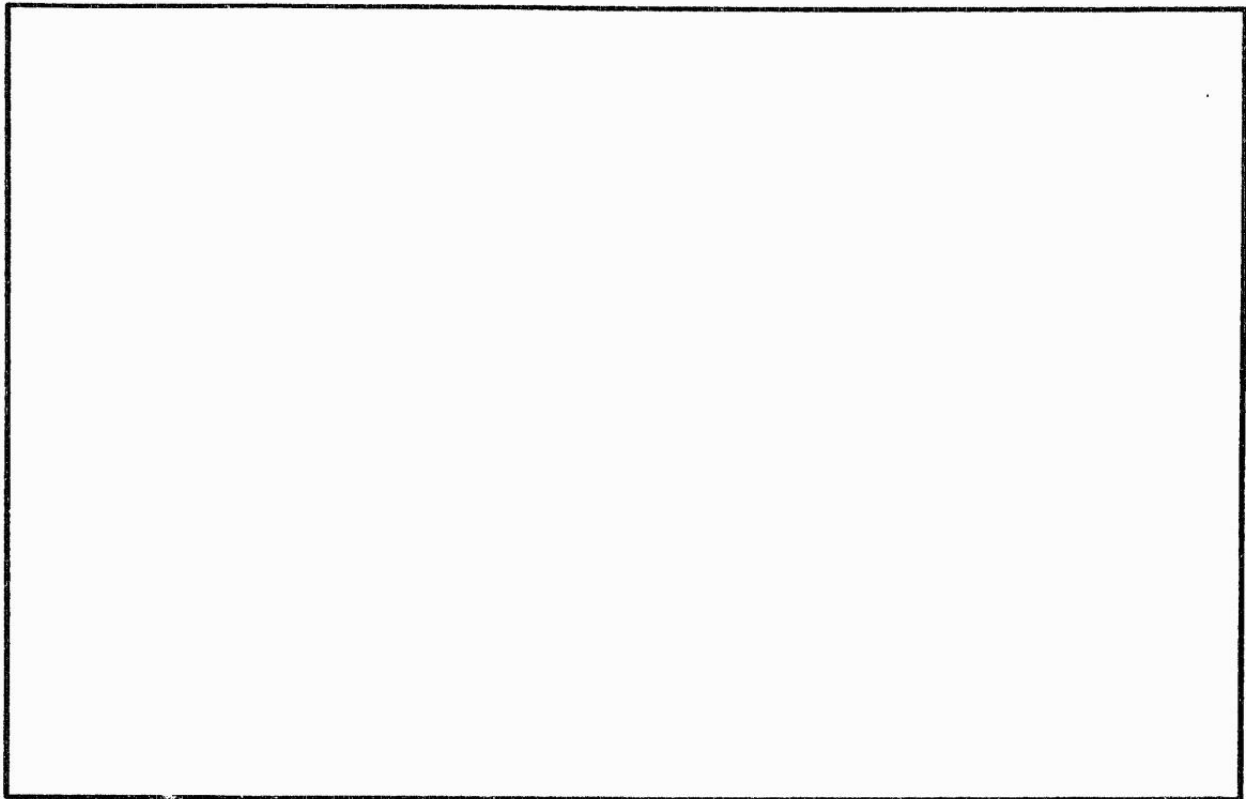
Over the past three decades, the number of baccalaureate degrees in natural science and engineering has increased steadily with population, but the growth of the individual components has shifted significantly. Separating NS&E into three major components (natural sciences *excluding computer science [hereafter "natural science"]*, computer sciences, and engineering) presents very different pictures of the trend in degree production components. ~~Natural science degrees, for example, peaked in the mid-1970s and have since been declining. Engineering degrees, on the other hand, have been increasing since the mid-1970's. The combined fields show a considerably modulated growth which has been consistently between 4 and 4.5 per cent of the 22-year-old population. The declared intentions of the current student body presages a decline in BS level NS&E degrees due to a reduction in the percentage of majors in NS&E fields, but the major decline is expected to be demographically driven. According to NSF/SRS degree data, natural science degrees peaked in 1976, and have declined steadily by 20 percent during 1976 to 1986. Engineering degrees, on the other hand, sustained a steady major rise to 100 percent during that decade, dropping by 10 percent in the following two years. The number of computer science degrees grew seven-fold during the 1976-86 decade. Degrees in all fields of NS&E show a considerably modulated growth of about 3 percent per year from 1976 to 1985.~~



**Figure 2** The dominant factor controlling NS&E B.S. degree supply is the size of the college-age population, which will decline until the late 1990s.

*American Council for Education freshman intention survey data have proven to be very good predictors of NS&E B.S. degrees three years hence. For a decade or more linear correlations between these two variables for the three subsectors of NS&E have explained about 90% of the variance in degree production ( $r^2 \geq 0.9$ ). These correlations and college enrollment data were used to extrapolate B.S. degree production for the years 1988 through 1991. These extrapolations presage a decline of 16 percent in NS&E B.S. degrees during 1986-1991 due to a reduction in the fraction of 18-year-olds declaring majors and ultimately matriculating in NS&E fields (expected to drop from 5.2% to 4.4% of 22-year-olds). The projections in this paper assume that this declining participation rate will recover to 5% by 1996 and continue steady thereafter as discussed above. A larger decline of 20% in the annual production of NS&E degrees is expected from 1986 to 1996, mirroring the reduction in the number of 22-year-olds estimated by Census. This drop is expected to recover partially during 1998 to 2003 according to census data. The number of computer science degrees appears to be very unstable relative to population or other economic indicators. Rapid increases through 1986 appear to be devolving into rapid decreases, based on freshman intentions data (Figure 3).*

*The computer science degree production rate has been unstable relative to population or other economic indicators. ~~Computer science degrees are less predictable.~~ From the early 1970s until the early 1980s, the number of individuals receiving computer science degrees was relatively small, and these students seemed to be coming from the same pool as other NS&Es, particularly those interested in mathematics. Recent data, and the substantial growth in these degrees from 1980 to 1986 suggest that they have been increasing at the expense of degrees in a number of non-NS&E fields. There is some evidence that this field is attracting students that previously were not candidates for B.S.*



**Figure 3** Choice of major fields by currently enrolled students portends a decline in NS&E degrees over the next few years.

degrees. The addition of computer science to other NS&E fields has made the NS&E aggregate a much less coherent set.

---

*Slow persistent growth in the rate of conferral of NS&E baccalaureates to women has been largely offset by a decline in conferral to men.*

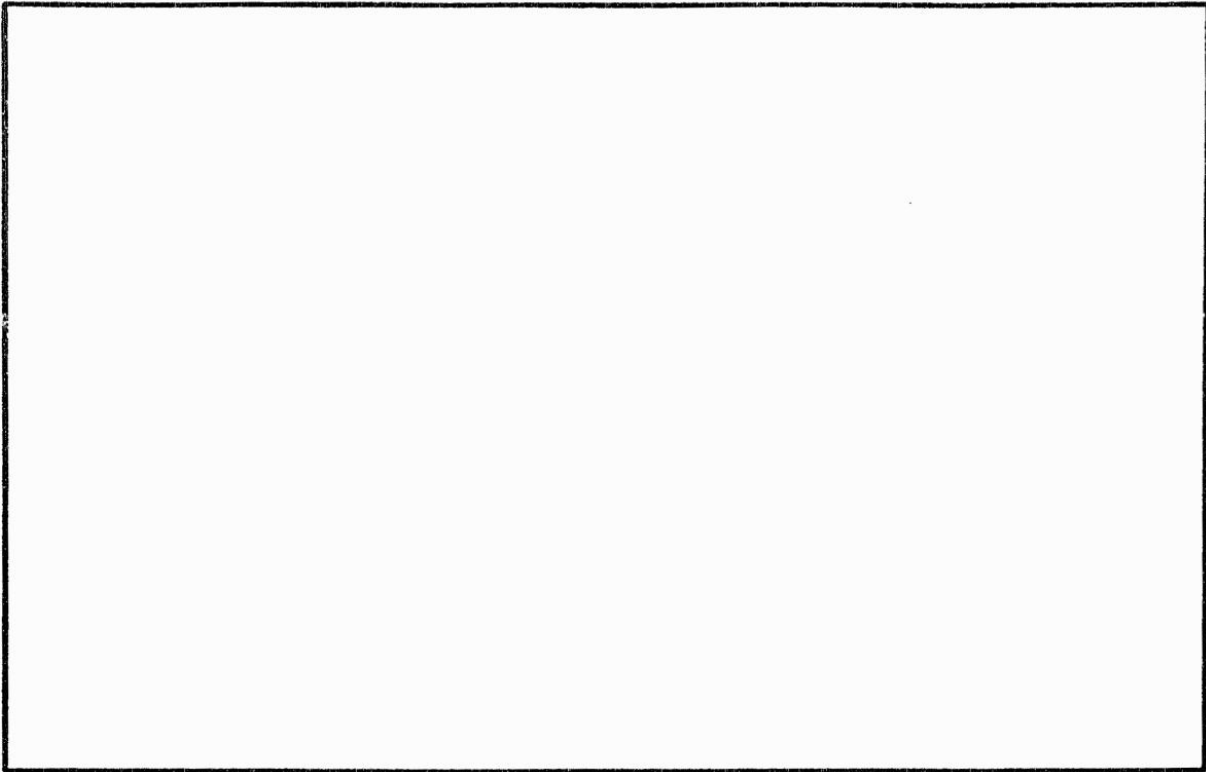
---

Two other points are noteworthy. There has been a slow but persistent rise in the rate of conferral of baccalaureate degrees to women in traditional NS&E fields, from less than 1 percent of female 22-year-olds in 1959 to 2.5 percent in 1986. This rise has been offset in large measure by a decline in the conferral rate to males, from 7 percent of male 22-year-olds in the early 1970s to 6 percent in recent years. Between 1972 and 1982 new female baccalaureates in NS&E fields grew steadily from 1.5 percent of female 22-year-olds to 2.5 percent in 1982, but in the first five years the growth was entirely in life science, while in the latter five years growth was entirely in the remaining NS&E fields. During 1982-86, female NS&E baccalaureates rose to 3.3 percent of female 22-year-olds, with the growth almost entirely in computer science. B.S. degrees in computer science, the new NS&E field, have risen very fast during the 1980s. The conferral rate in this field alone was only 0.3 percent in 1980, compared to over 1 percent in 1986. The 1986 conferral rate to women in this field alone was equivalent to the rate in all other NS&E fields combined in 1959 (0.8 percent).

The 5 percent conferral rate may be optimistic as a projection because underrepresented minorities have been (and are expected to continue) growing at a proportion of all 22-year-olds. The participation rate of the underrepresented minorities has been substantially below average during the last ten years. Currently, blacks account for 13 percent of 22-year-olds but only 4 percent of NS&E B.S. degrees, and Hispanics account for 7.5 percent of 22-year-olds, but only 2.5 percent of NS&E B.S. degrees (*data from NSF/SRS, DOE, BOC*). College age (18-24 years old) blacks and Hispanics are expected to increase their proportion of the total college age population from 20 percent currently to 25 percent in 1996, and 33 percent in 2010. In summary, without some positive action to overcome the observed tendencies in students' choices in courses of study, B.S. degree production in the fields of natural science and engineering will decline. *Based on observations of the past decade, it appears unlikely that the labor market for NS&E B.S. graduates will "solve" it is not reasonable to expect the labor market for undergraduate degree holders in NS&E fields to solve this emerging problem, for two major reasons. First, statistical correlations between annual production of NS&E B.S. graduates with starting salary data from the College Placement Council (CPC) shows that in the past there has been virtually no relationship between changes in the relative starting salaries (i.e., relative to other fields such as business, the social sciences and the health sciences) and degree production in the combined fields herein defined as NS&E. The subfields of engineering and computer science do show some response to relative salary changes, but increases in engineering graduates appear to be directly offset by declines in natural science graduates, rendering the combined NS&E category relatively unresponsive. Only in the computer science field is there strong evidence of market responses which are not offset by declines in other NS&E fields. for BS holders in NS&E fields and the annual production of aggregate NS&E BSs, so there is no sound reason to expect market signals to expand NS&E degree production in the future. Second, in the future, because of the decline in population of young adults, all occupations will be commanding increasing salaries, including unskilled and skilled labor and technician jobs as well as all professional disciplines.*

*The cumulative reduction in production of NS&E B.S. degrees below the average rate achieved in 1984-86 is labelled a "shortfall". The "shortfall" is not necessarily a "shortage" unless the demand for such skills exceeds the declining supply. Because of complexities in the utilization of NS&E training (e.g., many NS&E graduates use their skills productively in occupations not officially counted as scientists or engineers) and limitations of occupational census data (counting only those individuals officially categorized as scientists or engineers), quantitative projection of the demand for individuals with NS&E knowledge and training is highly uncertain, and was not attempted in this work. Instead, the 1984-86 production rate is taken as a proxy for future demand. This proxy is conservative because it limits future replacements and increases in demand to a fixed number of new graduates, even though many analysts believe that demand will grow in the future.*

~~—This analysis does not attempt to forecast future demands for B.S. degree earners.~~ The size of the problem caused by the lowered production depends on the need for such skills in the future in a healthy competitive economy. The shortfall is measured as the drop in estimated future production from the 1983 production level. If the NS&E participation rate remains at 5% of the 22-year-old population, the cumulative shortfall of B.S. degrees to the year 2006 would be about 675,000, with 275,000 being in engineering degrees (Figure 4). Even with an optimistic assumption that the demand for new degrees at the BS level will drop by 1,000 each year from 1989 to 2006 due to improved utilization and productivity of the NS&E workforce, the Nation would still face a cumulative shortfall of 440,000 during this period.



**Figure 4** By 2000, the U.S. will have a cumulative shortfall of 675,000 B.S. degrees, when compared to the 1983 production level.

*Supply: Ph.D. Degrees*

A shortage of baccalaureate degrees also suggests a corresponding scarcity of doctorates. However, the historical link between population and degree production has not been as strong at the Ph.D. level, in contrast to the 4 to 5 percent link between B.S. degrees in traditional fields of NS&E and 22-year-olds. Part of the reason is the wide age distribution of Ph.D. recipients (90 percent of whom are 25 to 37 years old) compared to B.S. recipients (90 percent of whom are 21 to 24 years old). The median age of all new NS&E Ph.D.s was 29 to 30 years old during the 1960s and 1970s, but it has drifted up over the last 5 years to about 31 years old in 1987.

---

*Ph.D. degree production forecasts must consider economic factors and immigration.*

---

Two major reasons for a weaker population-degree link to the Ph.D. degree production are the greater importance of specific economic considerations and immigrations of graduate students in determining the number of Ph.D. students. Both favorable expected job availability and improved salary prospects will increase the rate of enrollment in Ph.D. programs from a given number of B.S. degree holders. Ph.D. production in natural science and engineering approximately tripled between 1960 and 1972, dropped gradually in the late seventies, then slowly recovered, though not quite to the 1972 level. Most of this recovery, particularly recently, is due to a rise in Ph.D.s conferred to foreign citizens who are in the United States on a temporary basis. On the average, across all

---

---

***FUTURE SCARCITIES OF  
SCIENTISTS AND ENGINEERS:  
PROBLEMS AND SOLUTIONS***

---

---

---

---

**NATIONAL SCIENCE FOUNDATION**

**Directorate for Scientific, Technological  
and International Affairs**

**Division of Policy Research and Analysis**

---

---

**WORKING DRAFT  
November 13, 1989**

## INTRODUCTION

The Division of Policy Research and Analysis has examined an array of factors that are widely held to influence the production of bachelors and doctorates in the academic fields known as the natural sciences and engineering (NS&E). This paper develops quantitative relationships between these factors and degree production. The primary conclusions are:

1. Because of demographic trends, the United States faces a much reduced production of NS&E bachelors and Ph.D. graduates over the next two decades.
2. This situation is likely to create a scarcity of NS&E graduates for the NS&E labor force. The extent of the scarcity depends critically on the rate of increase in research and development activity.
3. Free market responses to bachelors and Ph.D. level scarcities from the supply side in the form of increased production are both likely to be limited and slow, forcing major adjustments by employers of NS&E's.
4. Evidence about characteristics of career choices among students suggests some policy approaches which could stimulate NS&E degree production in the next five to ten years.

The discussion in this paper is focused on natural scientists and engineers (NS&Es), rather than the larger population of scientists, which includes the sub-population of social and behavioral scientists. Natural scientists are those trained and working in the physical sciences, the environmental sciences, the mathematical sciences, the agricultural sciences, and the biological sciences. The choice of focus is based on observed differences in patterns of production and demand for NS&Es compared to social and behavioral scientists. Most published concerns of the impending growing scarcity of scientists and engineers are focused on NS&Es.

The analyses in this paper have used trend projections or past relationships between variables only if these are stable in the sense that they have held for years (in a few cases, decades). All such assumptions about the persistence of past trends and relationships have been identified, and the analyses should be interpreted as conditional on their continuation. In a broad sense, social values are assumed to undergo little change.

### Overview

The ratio of NS&E bachelors to 22-year-old citizens living in the U.S. has been relatively fixed over the last 30 years. An increase in the fraction of 22-year-olds earning bachelors degrees in NS&E fields could offset the reduction in the population of college age students and the attendant expected shortfall of 675,000 bachelors. It would also make a strong contribution to reducing the future scarcity of NS&E Ph.D.s, assuming the bachelors-to-Ph.D. continuation rate remains unaffected by the larger pool of new bachelors. What are the prospects for such an increase? Is the ratio of NS&E bachelors to 22-year-olds fixed for convincing behavioral reasons, or is its unchanging level over the past 30 years coincidence? Reviewing past changes in the field components of NS&E bachelors, and the relative propensities of men, women, blacks, Hispanics, Asians and whites to earn NS&E bachelors is one approach to addressing these questions as described in the next section.

In the past, the combination of increased federal support of graduate education and market forces produced substantial increases in the number of NS&E Ph.D.s during the hiring build-up of the 1960s. The twin build-up of demand and support of doctoral students in NS&E led to a doubling of the bachelors-to-Ph.D. continuation rate during the 1960s. In the reverse direction, the reduced demand and reduced fellowship/traineeship support of graduate students during the 1970s led to a substantial decrease in Ph.D. production despite the growing pool of qualified bachelors resulting from the baby boom undergraduate cohorts. How would market forces work in the future, given the unique demographic conditions expected during the next several decades? Can the U.S. rely on further increases in foreign citizen graduates of U.S. doctoral programs to meet expected growing future needs for doctorates? These questions are addressed in the Ph.D. section.

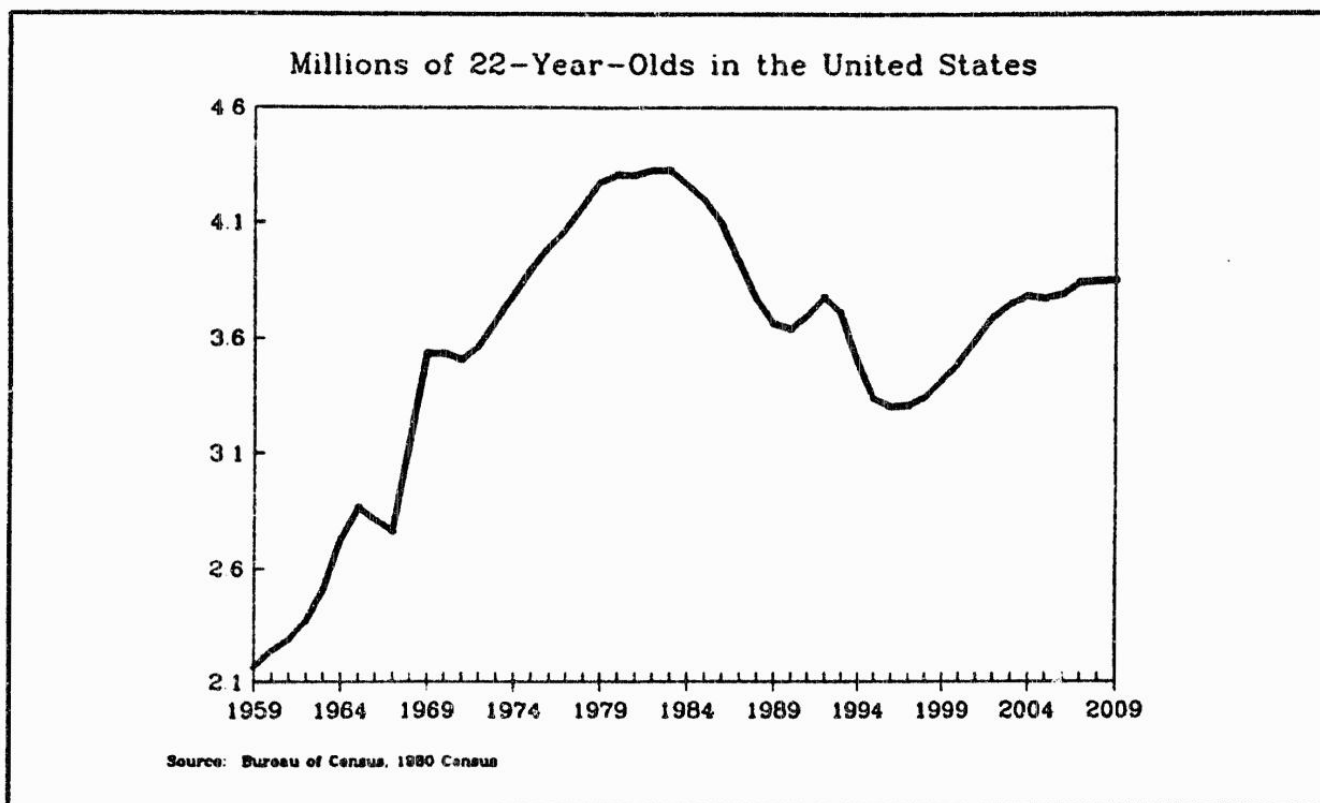


Following the Ph.D. discussion is a description of the entire NS&E educational pipeline, including an examination of reasons for students entering or leaving this career path. It is claimed that the propensity of different population groups to sample NS&E courses and select NS&E majors in college is strongly conditioned by educational experiences in high school (and earlier), and by the affordability of 4-year colleges and universities to the population of interested, eligible, potential NS&E majors. Understanding when and why students cease any further efforts to advance their knowledge of science and mathematics is important in determining whether better teaching, improved curricula, and more effective teaching materials could improve the flow of students to more advanced stages of learning, through the bachelors degree stage and beyond.

The final section examines systematically a variety of generic attraction and retention strategies at successively more advanced stages of education. The issue of proper timing of increased support is stressed, and the issue of affordability is considered.

### The Concept of Scarcity

**Factors Causing Scarcities** The purpose of this paper is to explore the impact of two future demographic events that will alter the supply and demand for natural scientists and engineers, and to determine options for public policy. The key event is a 25 percent reduction in the number of "college age" students during 1983-1996 after a doubling during 1961-1979, as measured by the number of 22-year-olds. Thus, one-half of the population gains made during 1961-1979 will be lost during 1983-1996. (Figure 1).



**Figure 1** The dominant factor controlling the NS&E bachelors output is the size of the college-age population, which is in the midst of a decline that will last until the late 1990's.

The second event is an anticipated doubling of replacement demand for Ph.D. level natural scientists and engineers during 1990-2006, as a consequence of the large number of Ph.D.s hired during the 1960s. The expected effect of these demographic changes is a growing scarcity of natural scientists and engineers (NS&Es) during the 1990s and first decade of the next century. Reduced production of NS&E bachelors during the next 5 years will contribute to the Ph.D. level scarcity in the first decade of the next century.

**Measurement of Scarcity** In this paper, the measurement of scarcity impact is limited to estimating the shortfall of bachelors degrees and the scarcity of doctorate degrees which are likely to occur in the absence of substantial changes in young people's career choices. The "textbook" way to measure scarcity is to describe the time paths of equilibrium quantity (of which the major component is degree production) and price (e.g., starting salaries).

At the bachelors level this is not attempted because many other considerations confound the measurement of changes in students choice of major in response to changing starting pay for associated occupations. The total value of a first college degree is not accurately captured by short run equilibrium prices (i.e., starting salaries) for new bachelors, because undergraduate students are still exploring career options and responding to a variety of factors that are not related to near term starting salary levels. A substantial number of students earning bachelors in NS&E fields are not planning NS&E careers (at least not at that level of training) but still derive substantial benefits from their NS&E training.

Rising real starting salaries are indicative of a growing scarcity of bachelors entrants to the NS&E labor force, and they will increase the fraction of recent graduates who plan to enter the NS&E labor force. However, the strength of this relationship cannot be estimated at an acceptable level of precision. Hence, a simpler method has been adopted: estimating the expected number of NS&E bachelors in future years and measuring the amount by which this falls short of a target level of bachelors production. This task is made relatively easy by the fact that for the last 30 years about 4% of the number of 22-year-olds have completed NS&E baccalaureates, excluding computer science baccalaureates.

At the Ph.D. level a possible future equilibrium path is presented after describing and specifying the basic factors that influence supply and demand. Undertaking advanced training in NS&E fields represents a major commitment of time and lost income. Generally, doctoral study is more specifically related to occupational choice (teaching and research) than is undergraduate study. Hence, relative scarcity seems to play a much stronger role in determining the number of new bachelors that enter doctoral programs. The number of U.S. citizen bachelors completing doctorates in NS&E fields rose from about 5 percent in the early 1960s to more than 10 percent in the late 1960s and early 1970s, only to drop back to 5-6 percent in the late 1970s, where it remains today.

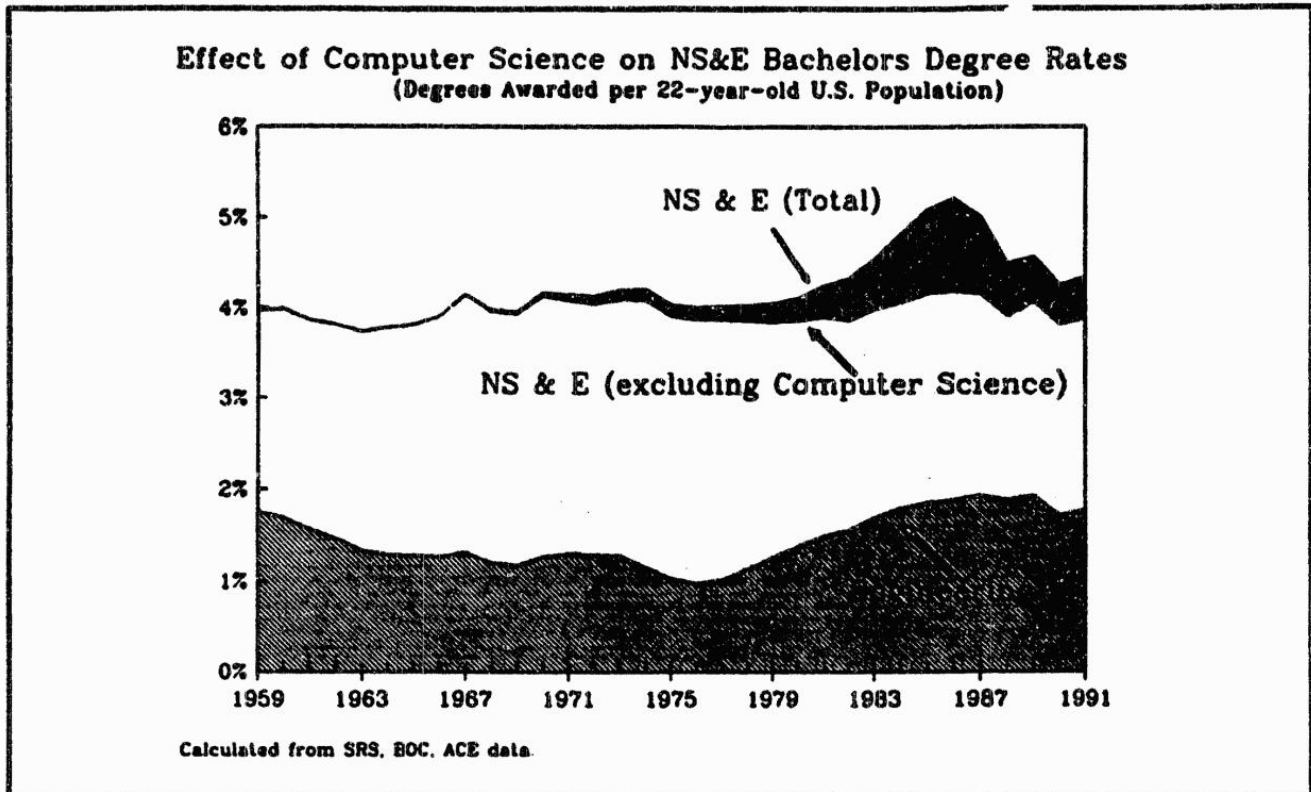
A factor complicating the analysis of bachelors to doctorate continuation rates is the rising importance of foreign graduate students. In 1988, 28 percent of NS&E Ph.D.s were conferred to foreign citizens studying in the U.S. on student visas. The future equilibrium path is influenced by the fraction of these foreign graduates who enter the U.S. labor force.

## BACHELORS DEGREES

### Participation

Although many factors enter into the process of choosing a career, many of which have changed substantially over the last 30 years, NS&E bachelors degrees have been awarded annually to a relatively fixed fraction of the U.S. 22-year-old population for almost three decades (Figure 2), using NSF/Science Resources Studies Division (SRS) data on NS&E degrees and Bureau of the Census (BOC) data to estimate the number of 22-year-olds. (The median aged NS&E undergraduate student is 22-years-old at graduation.) This fraction has varied from a low of 3.7% in 1963 to a high of 5.2% in 1986, and has been more tightly bounded between 3.7% and 4.2% excluding computer science, a field not separately recognized in the 1960s. The evident limit on the percentage of 22-year-olds earning bachelors in NS&E fields during the 1960s led Wallace Brode to speculate in 1971 that the production of these degrees had reached a saturation level, which he identified as 4% of 22-year-olds. (See: *Manpower in*

*Science and Engineering, Based on a Saturation Model*, *Science*, July 16, 1971.) In Brode's view, the nation had successfully geared itself to recruit all able interested primary/secondary school students into NS&E majors in college, and that this process of recruitment was the dominant determinant of supply, with feedback from fluctuating demand playing a much less important role.



**Figure 2** The recent rise in the fraction of 22-year olds earning NS&E degrees was mostly due to increases in computer science.

Empirical evidence through the mid-1980s confirms Brode's perspective but also suggests that change is possible. The introduction of the new field of computer science has clearly removed the 4% ceiling to bachelors production. Also, as is discussed below, female participation in undergraduate programs has increased substantially since 1971. On the other hand, male participation has dropped as a counterpart to increased female participation, and the 4% rule has held for the aggregate of traditional NS&E fields despite large changes in the distribution of bachelors among engineering, the physical sciences, mathematics, and the life sciences (described below). The small variation in the rate of degree conferral from 3.7% to 4.2% indicates that there has been stability of interest in traditional NS&E majors. It implies that NS&E majors have been drawn disproportionately from backgrounds where for three decades or more most high school graduates have entered 4-year colleges. The broadening of the college enrollment base that occurred in the 1960s and is occurring again in the 1980s does not seem to have had much impact on the fraction of 22-year-olds earning bachelors in traditional NS&E fields.

*Most growth of computer science baccalaureates did not come from likely candidates for baccalaureates in other NS&E disciplines.*

### Growing Participation by Women

Increasing degree conferrals to women seems to offer the most responsive path to increasing the overall ratio of NS&E bachelors to 22-year-olds. There has been a slow but persistent rise in the rate of conferral of baccalaureate degrees to women, from less than 1 percent of female 22-year-olds in 1959 to 3.2 percent in 1986. During 1972-1982 new female baccalaureates grew steadily from 1.5 percent to 2.4 percent of female 22-year-olds. This rise was offset in large measure by a decline in the conferral rate to males, from 7 percent to 6 percent of male 22-year-olds during the same period. In the first five years the growth in female bachelors was entirely in the life sciences, while in the latter five years it occurred entirely in the remaining NS&E fields. During 1982-86, female NS&E baccalaureates rose to 3.2 percent of female 22-year-olds, with the growth almost entirely in computer science. In 1980, the conferral rate to women in this field alone was only 0.3 percent, compared to 1 percent in 1986 (higher than the 0.8% rate in all NS&E fields combined in 1959). The increase in computer science bachelors awarded to males pushed the aggregate NS&E conferral rate to males from 6 percent in 1982 back to 7 percent in 1986.

### Minority Participation

A challenge to increasing future NS&E bachelors is the fact that two important population minority groups (blacks and Hispanics) have been (and are expected to continue) growing as a proportion of all 22-year-olds. Their participation in NS&E degree programs has been substantially below average during the last ten years. In 1985, blacks accounted for 13 percent of 22-year-olds but only 5 percent of NS&E bachelors, and Hispanics accounted for 8 percent of 22-year-olds, but only 3 percent of NS&E bachelors (data from NSF/SRS, Dept of Education, and Bureau of the Census). College age blacks and Hispanics are expected to increase their proportion of the total college age population from about 23 percent currently in 1989 to 28 percent or more in the year 2000, and 30 percent or more in 2010, according to the Bureau of the Census.

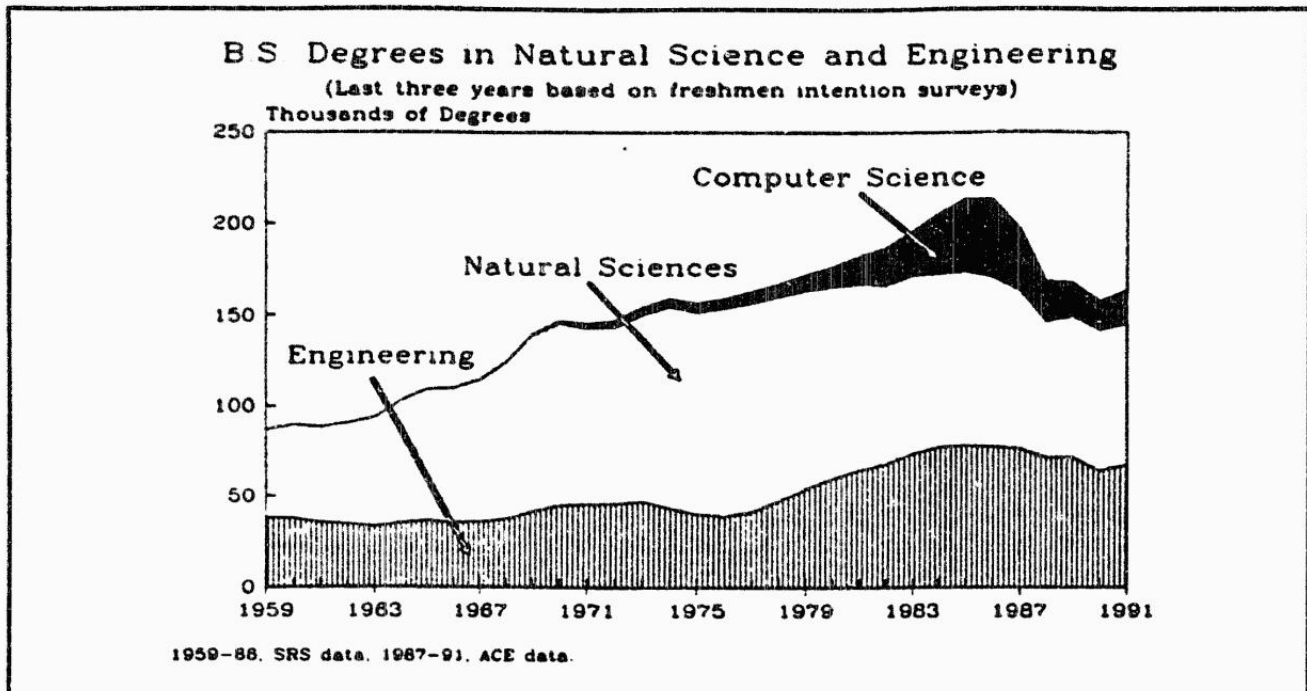
### Field Composition of NS&E Bachelors Degrees

The computer science bachelors production rate has been unstable relative to population or other economic indicators (Figure 2). From the early 1970s until the early 1980s, the number of individuals receiving computer science degrees was relatively small, and these students seemed to be coming from the same pool as other NS&Es, particularly those interested in mathematics. The substantial growth in these degrees from 1980 to 1986 suggest that they have been increasing at the expense of degrees in a number of non-NS&E fields. There is some evidence that this field is attracting students that previously were not candidates for NS&E bachelors degrees.

The number of baccalaureate degrees in the remaining fields of natural science and engineering has increased steadily with population over the past three decades, but the growth of the individual components has shifted significantly (Figure 3). Separating NS&E into three major components (natural sciences excluding computer science [hereafter "natural science"], computer sciences, and engineering) presents very different pictures of the trend in degree production components. According to NSF/SRS degree data, natural science degrees peaked in 1976, and have declined steadily by 20 percent during 1976 to 1986. Engineering degrees, on the other hand, sustained a steady major rise during that decade totalling 100 percent, dropping by 10 percent during 1986-88. In contrast, the number of computer science degrees grew seven-fold during the 1976-86 decade. Degrees in all fields of NS&E show a considerably modulated growth of about 3 percent per year from 1976 to 1985.

### Factors Causing Declines

The 25 percent decline in the number of 22-year-olds during 1983-1996 is the primary cause of the anticipated decline in NS&E bachelors. However, a projected decline in the proportion of college students selecting NS&E majors (discussed below) is an important secondary factor underlying the expected future shortfall. A reduction has not yet been observed in aggregate NSF/SRS bachelors data, although the 1986 total was the same as in 1985. (Data for 1987 and 1988 were still unavailable from the Department of Education at the time this manuscript was printed.) As noted above, engineering-degree data collected by the American Society for Engineering Education indicate a decline in engineering bachelors of almost 10% during 1986-1988. Also, chemistry degree data collected by the American Chemical Society show a decline from 9,300 to 8,300 bachelors from 1986 to 1988.



**Figure 3** Choice of major fields by currently enrolled students and fewer young undergraduates portends a decline in NS&E bachelors over the next few years.

Annual freshman intentions surveys, conducted annually by the American Council on Education (ACE), have been very good predictors of NS&E bachelors three years hence (see annual issues of *The American Freshman: National Norms*). Since the early 1970's the covariance between "intentions" and "bachelors earned 3 years later" in each of the three major subsectors of NS&E appearing in Figures 2 and 3 has explained about 90% of the variance in the ratio of bachelors to 22-year-olds ( $r^2 \geq 0.90$ ). Freshman intentions data for the period 1984-88 and college enrollment data were used to extrapolate bachelors production for the years 1987 through 1991. These extrapolations presage a decline of 16 percent in NS&E bachelors during 1986-1991 due to a reduction in the fraction of 18-year-olds declaring majors and ultimately matriculating in NS&E fields (expected to drop from 5.2% to 4.4% of 22-year-olds). A recently completed study by the Educational Testing Service (ETS) of SAT test-takers is in broad agreement with the ACE data. It found that the percentage of college-bound high school seniors intending to major in a "quantitative science" field (defined as all NS&E fields except the life sciences) dropped from a high of 19% in 1983 to 13% in 1988 (see *ETS Policy Notes*, June 1989). Most of this drop is due to reduced interest in computer science. At face value, this finding translates into a prediction that the percentage of 22-year-olds earning NS&E bachelors will drop to a value even lower than 4.4% in 1991, and less than 4.0% in 1992.

The projections in this paper assume that the declining participation rate will bottom-out at 4.4% in 1991, recover to 5% by 1998 and remain steady thereafter, as discussed above. During 1986-1998 a decline of 20% in the annual production of NS&E degrees is expected, mirroring the reduction in the number of 22-year-olds estimated by Census. This drop is expected to recover partially during 1998 to 2003, as the number of 22-year-olds increases according to Census data estimates.

***Slow persistent growth in the rate of conferral of NS&E baccalaureates to women has been largely offset by a decline in conferral to men.***

In summary, empirical evidence admits the possibility that the rate of NS&E degree conferrals to 22-year-olds could rise through further gains by female students. Projections in this paper assume that the average percentage of 22-year-olds earning bachelors in all NS&E fields will rebound after 1991 to

5.0% by 1998 and remain at that rate thereafter. This rate has been chosen to avoid overemphasizing the near-future expected dip in the rate of production, and has been held constant after 1998 to stress the importance of demographic factors, a key lesson of the last 30 years. If this participation rate remains constant as assumed, the factor controlling future supply of scientists and engineers is the size of the pool from which they are drawn (illustrated in Figure 2).

### Market Effects

Without some positive action to substantially reverse the decline in student preferences for choosing NS&E majors, bachelors degree production in the fields of natural science and engineering will decline. Based on observations from the past decade, it appears unlikely that the labor market for NS&E bachelors graduates will "solve" this emerging problem by steering more undergraduates into NS&E majors, for two major reasons. First, statistical correlations between annual production of NS&E bachelors with starting salary data from the College Placement Council (CPC) shows that in the past there has been virtually no relationship between changes in the relative starting salaries (i.e., relative to other fields such as business, the social sciences and the health sciences) and degree production in the combined fields herein defined as NS&E. The subfields of engineering and computer science do show some response to relative salary changes, but increases in engineering graduates appear to be directly offset by declines in natural science graduates, rendering the combined NS&E category relatively unresponsive. Only in the computer science field is there strong evidence of market responses which are not offset by declines in other NS&E fields. Second, in the future, because of the decline in population of young adults, all occupations will be commanding increasing salaries, including semi-skilled and skilled hourly wage labor and technician jobs as well as all professional disciplines.

### Bachelors Degree Shortfall

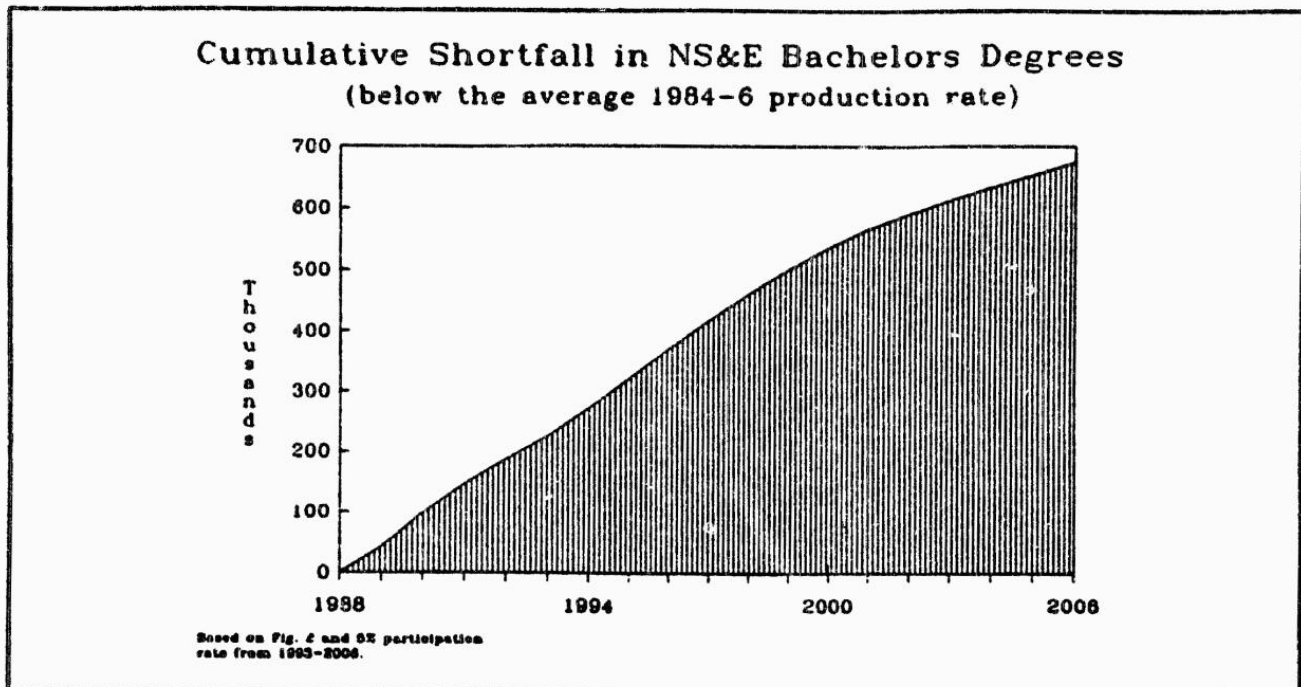
The cumulative reduction in production of NS&E bachelors degrees below the average annual number graduated during 1984-86 is labelled a "shortfall". This "shortfall" does not necessarily translate directly into a "shortage" unless the demand for such skills exceeds the declining supply. Because of complexities in the utilization of NS&E training (e.g., many NS&E graduates use their skills productively in occupations not officially counted as scientists or engineers) and limitations of occupational census data (counting only those individuals officially categorized as scientists or engineers), quantitative projection of the demand for individuals with NS&E knowledge and training is highly uncertain, and was not attempted in this work. Instead, the average production during 1984-86 was taken as a proxy for future demand. This proxy is conservative because it limits future replacements and increases in demand to a fixed number of new graduates, even though many analysts believe that demand will grow in the future.

The size of the problem caused by the lowered production depends on the need for such skills in the future in a healthy competitive economy. If the NS&E production rate drops to 4.4% of the 22-year-old population in 1991 and then returns steadily to 5% in 1998 and beyond, the cumulative shortfall of bachelors to the year 2006 would be about 675,000, with 275,000 being in engineering degrees (Figure 4). Even with an optimistic assumption that the demand for new degrees at the bachelors level will drop by 1,000 each year from 1989 to 2006 due to improved utilization and productivity of the NS&E workforce, the Nation would still face a cumulative shortfall of 440,000 during this period.

### PH.D. DEGREES

#### Supply

As noted in the introduction, possibly the most severe scarcity will occur at the Ph.D. level of training during 1994-2006. The expected shortfall of baccalaureate degrees during the next 5 to 10 years is part of the problem. However, there is no convincing evidence of a historically fixed link between bachelors and Ph.D. degree production despite the relative stability of the bachelors-to-Ph.D. continuation rate (at 5 percent) over the last ten years. In general, the two key factors in reducing the scarcity caused by demographics (fewer NS&E bachelors) and growing demand are economic prospects and immigration. An indicator of economic prospects is the rate at which new NS&E bachelors continue their education through the doctorate level.



**Figure 4** The U.S. will have a cumulative shortfall of 540,000 by 2000 and 675,000 by 2006, when compared to constant production at the 1984-86 average.

**U.S. Citizens** It is difficult to measure continuation rates from the bachelors to the doctorate with precision. There is such a wide age distribution of Ph.D. recipients (90 percent of whom are 25 to 37 years old) compared to bachelors recipients (90 percent of whom are 21 to 24 years old) that one cannot be certain how many NS&E Ph.D.s a given cohort of baccalaureates will produce until 15 to 20 years after the date of bachelors graduation. However, trends in the mean and median ages of new Ph.D.s, coupled with annual bachelors and doctorate graduation figures and bachelors to Ph.D. crossover tendencies, allow us to calculate approximate continuation rates. It is clear that these rose substantially during the 1960s and reached a peak considerably above 10 percent in 1971 and 1972. It is equally clear that continuation rates dropped substantially during 1972-77, to about 6 percent in 1977. During 1977-85, continuation rates in individual fields of NS&E appear to have dropped very slowly (to about 5.2 % in all fields of NS&E), and during 1985-88 to have leveled-off or recovered slightly, moving a weighted average NS&E continuation rate with fixed weights back to 5.5%. But because the mix of bachelors degrees has been shifting towards fields with lower-than-average continuation rates (eg, most engineering fields and computer science), the overall continuation rate has remained unchanged in the neighborhood of 5+ percent. From 1958 to the present, the lowest average elapsed time from bachelors to Ph.D. in all NS&E fields combined for all U.S. Citizen Ph.D.s (excluding those Ph.D.s that dropped out of school for more than 5 years) was 6.7 years old in 1968. This average gestation time from bachelors to Ph.D. has drifted up over the last 20 years to almost 8 years in 1987.

The major reason for the reduction in continuation rates is that Ph.D. level training is needed primarily only for upper level college teaching and for basic and applied research. These needs have not grown at a stable rate over the last 30 years. When needs cease growing (or shrink) job vacancies are reduced to replacement positions for retirees (or less). Doctorate training is so specialized that the economic value of acquiring it when there is a surplus of doctorates is low, and possibly negative for most doctoral candidates. Most doctoral students take into account the expected financial value of earning a Ph.D., although students motives for entering doctoral programs are not only to enhance future job status and earnings.

**Foreign Students** Although Ph.D.s trained in foreign universities have not been a significant source of new NS&E personnel (providing only 3 to 6 percent annually since 1975), foreign doctoral students (on temporary visas) studying in U.S. universities have been a significant source of supply of NS&E doctorates. In 1988, these foreign students accounted for more than 28 percent of NS&E Ph.D.s, and

---

---

***FUTURE SCARCITIES OF  
SCIENTISTS AND ENGINEERS:  
PROBLEMS AND SOLUTIONS***

---

---

---

**NATIONAL SCIENCE FOUNDATION**

**Directorate for Scientific, Technological  
and International Affairs**

**Division of Policy Research and Analysis**

---

**WORKING DRAFT  
April 13, 1990**



## INTRODUCTION

The Division of Policy Research and Analysis has examined an array of factors that are widely held to influence the production of bachelors and doctorates in the academic fields known as the natural sciences and engineering (NS&E). This paper develops quantitative relationships between these factors and degree production. The primary conclusions are:

1. Because of demographic trends, the United States faces a much reduced production of NS&E bachelors and Ph.D. graduates over the next two decades.
2. This situation is likely to create a scarcity of NS&E graduates for the NS&E labor force. The extent of the scarcity depends critically on the rate of increase in research and development activity.
3. Free market responses to bachelors and Ph.D. level scarcities from the supply side in the form of increased production are both likely to be limited and slow, forcing major adjustments by employers of NS&E's.
4. Evidence about characteristics of career choices among students suggests some policy approaches which could stimulate NS&E degree production in the next five to ten years.

The discussion in this paper is focused on natural scientists and engineers (NS&Es), rather than the larger population of scientists, which includes the sub-population of social and behavioral scientists. Natural scientists are those trained and working in the physical sciences, the environmental sciences, the mathematical sciences, the agricultural sciences, and the biological sciences. The choice of focus is based on observed differences in patterns of production and demand for NS&Es compared to social and behavioral scientists. Most published concerns of the impending growing scarcity of scientists and engineers are focused on NS&Es.

The analyses in this paper have used trend projections or past relationships between variables only if these are stable in the sense that they have held for years (in a few cases, decades). All such assumptions about the persistence of past trends and relationships have been identified, and the analyses should be interpreted as conditional on their continuation. In a broad sense, social values are assumed to undergo little change.

### Overview

The ratio of NS&E bachelors to 22-year-old citizens living in the U.S. has been relatively fixed over the last 30 years. An increase in the fraction of 22-year-olds earning bachelors degrees in NS&E fields could offset the reduction in the population of college age students and the attendant expected shortfall of 675,000 bachelors. It would also make a strong contribution to reducing the future scarcity of NS&E Ph.D.s, assuming the bachelors-to-Ph.D. continuation rate remains unaffected by the larger pool of new bachelors. What are the prospects for such an increase? Is the ratio of NS&E bachelors to 22-year-olds fixed for convincing behavioral reasons, or is its unchanging level over the past 30 years coincidence? Reviewing past changes in the field components of NS&E bachelors, and the relative propensities of men, women, blacks, Hispanics, Asians and whites to earn NS&E bachelors is one approach to addressing these questions as described in the next section.

In the past, the combination of increased federal support of graduate education and market forces produced substantial increases in the number of NS&E Ph.D.s during the hiring build-up of the 1960s. The twin build-up of demand and support of doctoral students in NS&E led to a doubling of the bachelors-to-Ph.D. continuation rate during the 1960s. In the reverse direction, the reduced

demand and reduced fellowship/traineeship support of graduate students during the 1970s led to a substantial decrease in Ph.D. production despite the growing pool of qualified bachelors resulting from the baby boom undergraduate cohorts. How would market forces work in the future, given the unique demographic conditions expected during the next several decades? Can the U.S. rely on further increases in foreign citizen graduates of U.S. doctoral programs to meet expected growing future needs for doctorates? These questions are addressed in the Ph.D. section.

Following the Ph.D. discussion is a description of the entire NS&E educational pipeline, including an examination of reasons for students entering or leaving this career path. It is claimed that the propensity of different population groups to sample NS&E courses and select NS&E majors in college is strongly conditioned by educational experiences in high school (and earlier), and by the affordability of 4-year colleges and universities to the population of interested, eligible, potential NS&E majors. Understanding when and why students cease any further efforts to advance their knowledge of science and mathematics is important in determining whether better teaching, improved curricula, and more effective teaching materials could improve the flow of students to more advanced stages of learning, through the bachelors degree stage and beyond.

The final section examines systematically a variety of generic attraction and retention strategies at successively more advanced stages of education. The issue of proper timing of increased support is stressed, and the issue of affordability is considered.

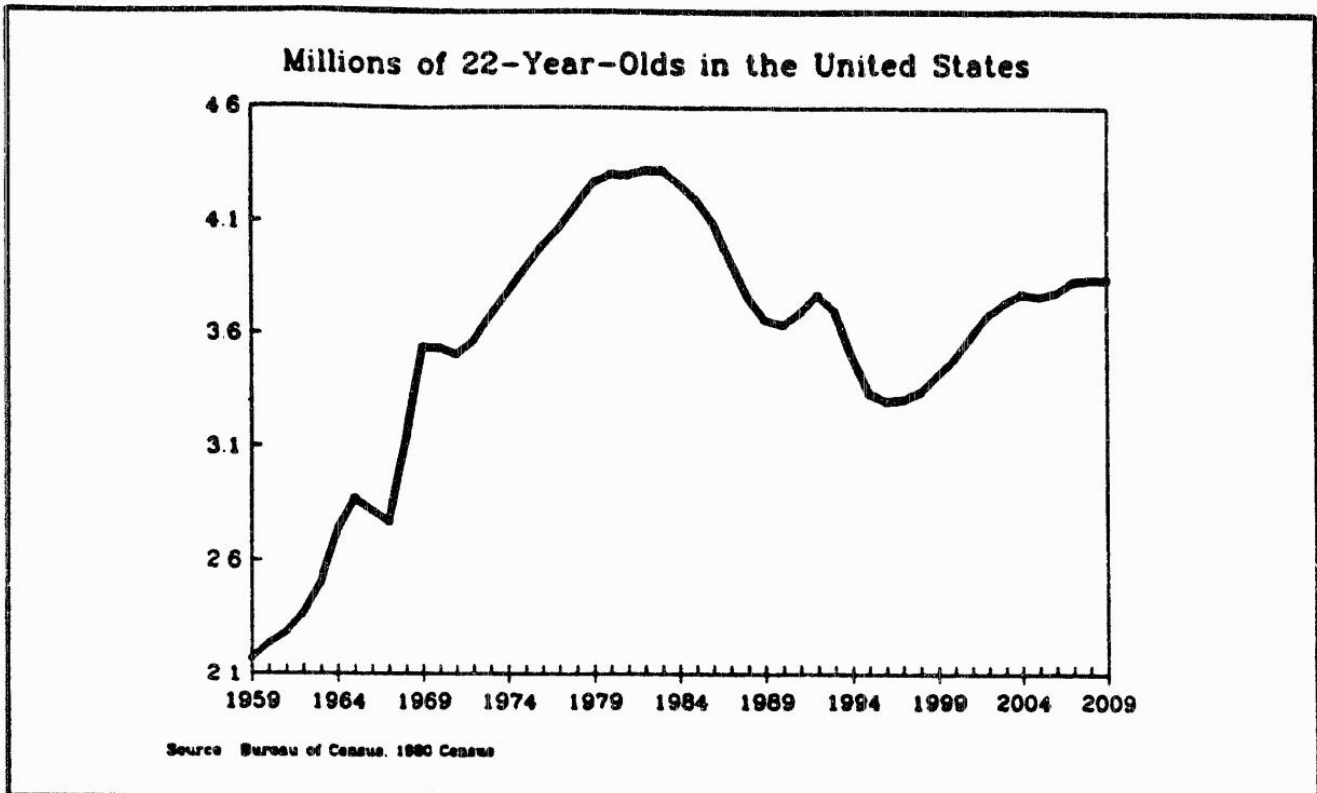
### **The Concept of Scarcity**

**Factors Causing Scarcities** The purpose of this paper is to explore the impact of two future demographic events that will alter the supply and demand for natural scientists and engineers, and to determine options for public policy. The key event is a 25 percent reduction in the number of "college age" students during 1983-1996 after a doubling during 1961-1979, as measured by the number of 22-year-olds. Thus, one-half of the population gains made during 1961-1979 will be lost during 1983-1996 (Figure 1).

The second event is an anticipated doubling of replacement demand for Ph.D. level natural scientists and engineers during 1990-2006, as a consequence of the large number of Ph.D.s hired during the 1960's. The expected effect of these demographic changes is a growing scarcity of natural scientists and engineers (NS&Es) during the 1990's and first decade of the next century. Reduced production of NS&E bachelors during the next 5 years will contribute to the Ph.D. level scarcity in the first decade of the next century.

**Measurement of Scarcity** In this paper, the measurement of scarcity impact is limited to estimating the shortfall of bachelors degrees and the scarcity of doctorate degrees which are likely to occur in the absence of substantial changes in young people's career choices. The "textbook" way to measure scarcity is to describe the time paths of equilibrium quantity (of which the major component is degree production) and price (e.g., starting salaries).

At the bachelors level this is not attempted because many other considerations confound the measurement of changes in students choice of major in response to changing starting pay for associated occupations. The total value of a first college degree is not accurately captured by short run equilibrium prices (i.e., starting salaries) for new bachelors, because undergraduate students are still exploring career options and responding to a variety of factors that are not related to near term starting salary levels. A substantial number of students earning bachelors in NS&E fields are not planning NS&E careers (at least not at that level of training) but still derive substantial benefits from their NS&E training.



**Figure 1** The dominant factor controlling the NS&E bachelors output is the size of the college-age population, which is in the midst of a decline that will last until the late 1990's.

Rising real starting salaries are indicative of a growing scarcity of bachelors entrants to the NS&E labor force, and they will increase the fraction of recent graduates who plan to enter the NS&E labor force. However, the strength of this relationship cannot be estimated at an acceptable level of precision. Hence, a simpler method has been adopted: estimating the expected number of NS&E bachelors in future years and measuring the amount by which this falls short of a target level of bachelors production. This task is made relatively easy by the fact that for the last 30 years about 4 percent of the number of 22-year-olds have completed NS&E baccalaureates, excluding computer science baccalaureates.

At the Ph.D. level a possible future equilibrium path is presented after describing and specifying the basic factors that influence supply and demand. Undertaking advanced training in NS&E fields represents a major commitment of time and lost income. Generally, doctoral study is more specifically related to occupational choice (teaching and research) than is undergraduate study. Hence, relative scarcity seems to play a much stronger role in determining the number of new bachelors that enter doctoral programs. The number of U.S. citizen bachelors completing doctorates in NS&E fields rose from about 5 percent in the early 1960's to more than 10 percent in the late 1960s and early 1970s, only to drop back to 5-6 percent in the late 1970s, where it remains today.

A factor complicating the analysis of bachelors to doctorate continuation rates is the rising importance of foreign graduate students. In 1988, 28 percent of NS&E Ph.D.s were conferred to foreign citizens studying in the U.S. on student visas. The future equilibrium path is influenced by the fraction of these foreign graduates who enter the U.S. labor force.

## BACHELORS DEGREES

### Participation

Although many factors enter into the process of choosing a career, many of which have changed substantially over the last 30 years, NS&E bachelors degrees have been awarded annually to a relatively fixed fraction of the U.S. 22-year-old population for almost three decades (Figure 2), using NSF/Science Resources Studies Division (SRS) data on NS&E degrees and Bureau of the Census (BOC) data to estimate the number of 22-year-olds. (The median aged NS&E undergraduate student is 22-years-old at graduation.) This fraction has varied from a low of 3.7% in 1963 to a high of 5.3% in 1987, and has been more tightly bounded between 3.7% and 4.3% excluding computer science, a field not separately recognized in the 1960s. The evident limit on the percentage of 22-year-olds earning bachelors in NS&E fields during the 1960s led Wallace Brode to speculate in 1971 that the production of these degrees had reached a saturation level, which he identified as 4% of 22-year-olds. (See: "Manpower in Science and Engineering, Based on a Saturation Model". *Science*, July 16, 1971.) In Brode's view, the nation had successfully geared itself to recruit all able interested primary/secondary school students into NS&E majors in college, and that this process of recruitment was the dominant determinant of supply, with feedback from fluctuating demand playing a much less important role.

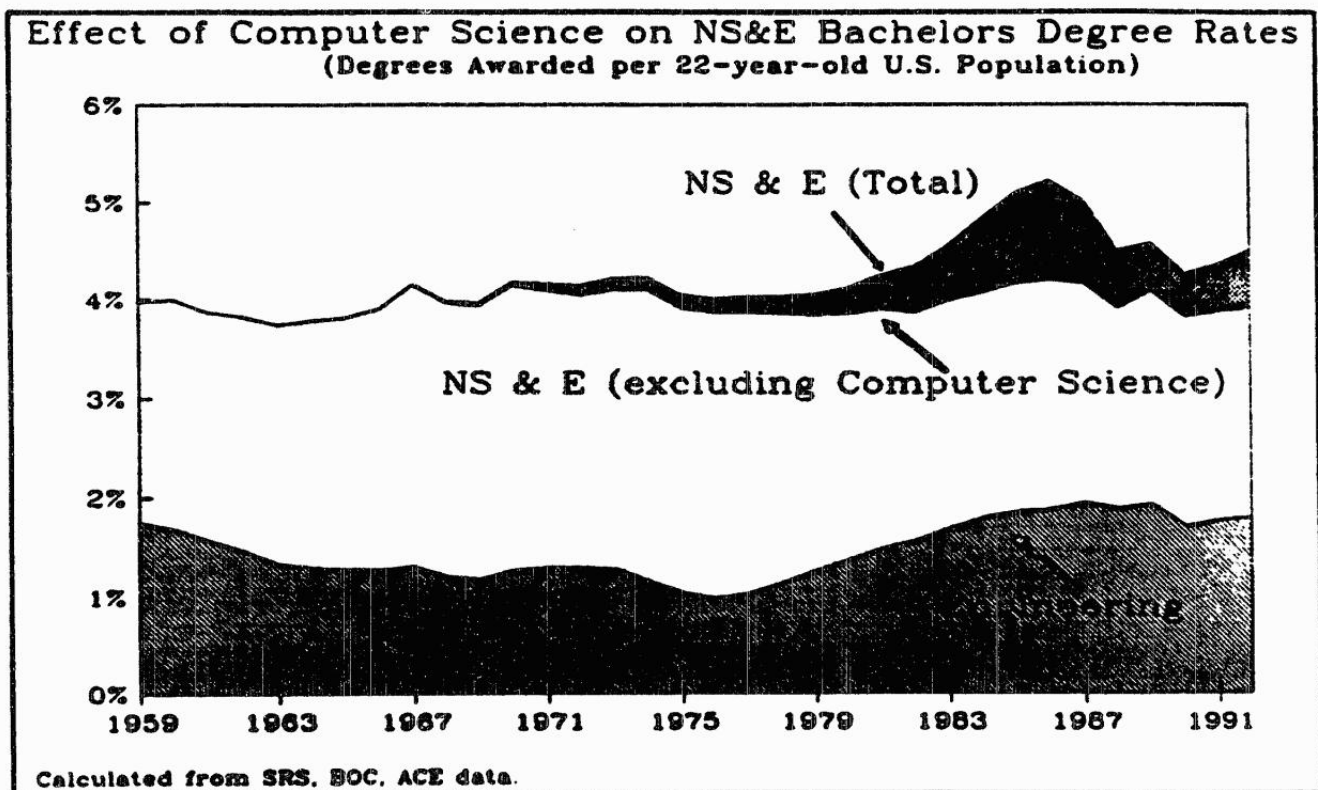


Figure 2 The recent rise in the fraction of 22-year olds earning NS&E degrees was mostly due to increases in computer science.

Empirical evidence through the late-1980s confirms Brode's perspective but also suggests that change is possible. The introduction of the new field of computer science has clearly removed the 4 percent ceiling to bachelors production. Also, as is discussed below, female participation in undergraduate programs has increased substantially since 1971. On the other hand, male participation has dropped as a counterpart to increased female participation, and the 4 percent rule has held for the aggregate

of traditional NS&E fields despite large changes in the distribution of bachelors among engineering, the physical sciences, mathematics, and the life sciences (described below). The small variation in the rate of degree conferral from 3.7 to 4.3 percent indicates that there has been stability of interest in traditional NS&E majors. It implies that NS&E majors have been drawn disproportionately from backgrounds where for three decades or more most high school graduates have entered 4-year colleges. The broadening of the college enrollment base that occurred in the 1960s and is occurring again in the 1980s does not seem to have had much impact on the fraction of 22-year-olds earning bachelors in traditional NS&E fields.

*Most growth of computer science baccalaureates did not come from likely candidates for baccalaureates in other NS&E disciplines.*

### **Growing Participation by Women**

Increasing degree conferrals to women seems to offer the most responsive path to increasing the overall ratio of NS&E bachelors to 22-year-olds. There has been a slow but persistent rise in the rate of conferral of baccalaureate degrees to women, from less than 1 percent of female 22-year-olds in 1959 to 3.2 percent in 1986, 1987, and 1988. During 1972-1982 new female baccalaureates grew steadily from 1.5 percent to 2.4 percent of female 22-year-olds. This rise was offset in large measure by a decline in the conferral rate to males, from 7 percent to 6 percent of male 22-year-olds during the same period. In the first five years the growth in female bachelors was entirely in the life sciences, while in the latter five years it occurred entirely in the remaining NS&E fields. During 1982-86, female NS&E baccalaureates rose to 3.2 percent of female 22-year-olds, with more than one-half of the growth in computer science. In 1982, the conferral rate to women in this field alone was only 0.3 percent, compared to 0.75 percent in 1986. During 1986-88 this rate abated to 0.6 percent. The increase in computer science bachelors awarded to males pushed the aggregate NS&E conferral rate to males from 6 percent during 1980-82 back to 7 percent during 1986-88.

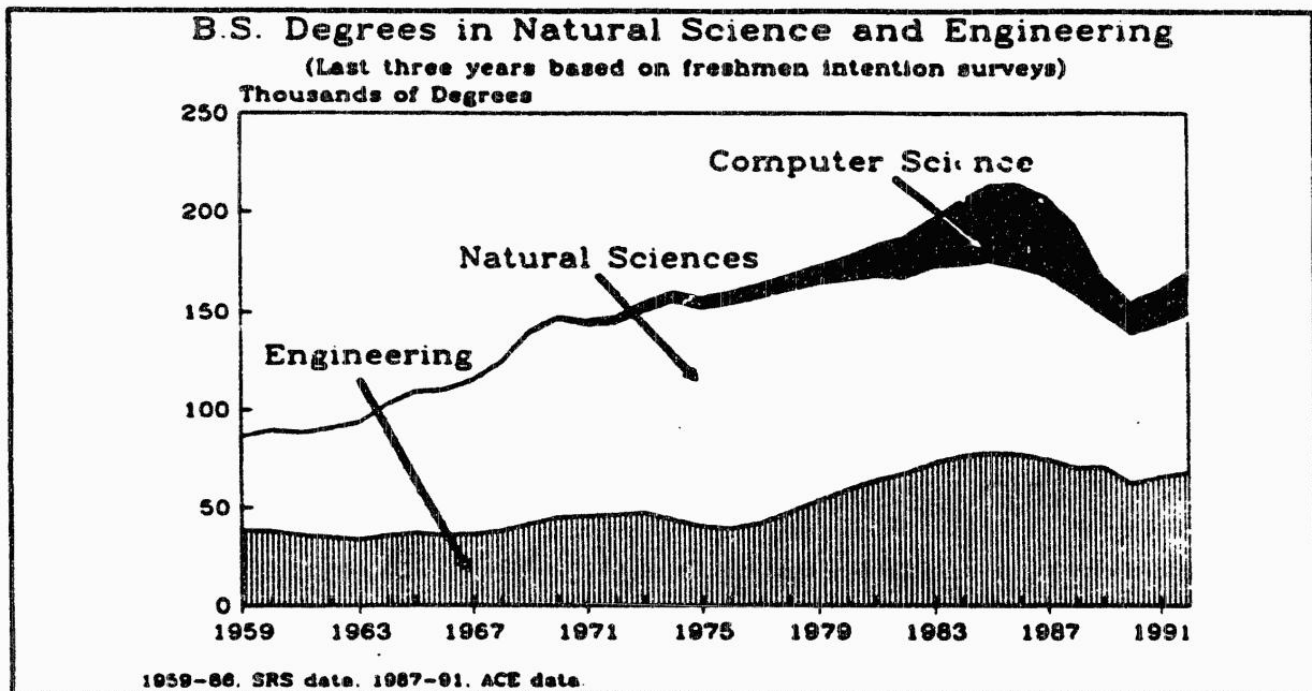
### **Minority Participation**

A challenge to increasing future NS&E bachelors is the fact that two important population minority groups (blacks and Hispanics) have been (and are expected to continue) growing as a proportion of all 22-year-olds. Their participation in NS&E degree programs has been substantially below average during the last ten years. In 1985, blacks accounted for 13 percent of 22-year-olds but only 5 percent of NS&E bachelors, and Hispanics accounted for 8 percent of 22-year-olds, but only 3 percent of NS&E bachelors (data from NSF/SRS, Dept of Education, and Bureau of the Census). College age blacks and Hispanics are expected to increase their proportion of the total college age population from about 23 percent currently in 1989 to 28 percent or more in the year 2000, and 30 percent or more in 2010, according to the Bureau of the Census.

### **Field Composition of NS&E Bachelors Degrees**

The computer science bachelors production rate has been unstable relative to population or other economic indicators (Figure 2). From the early 1970s until the early 1980s, the number of individuals receiving computer science degrees was relatively small, and these students seemed to be coming from the same pool as other NS&Es, particularly those interested in mathematics. The substantial growth in these degrees from 1980 to 1986 suggests that they have been increasing at the expense of degrees in a number of non-NS&E fields. There is some evidence that this field is attracting students that previously were not candidates for NS&E bachelors degrees. For example, they are awarded disproportionately by colleges with little or no research and development activity, few or no Ph.D. programs, and below average percentages of total bachelors in NS&E fields.

The number of baccalaureate degrees in the remaining fields of natural science and engineering has increased steadily with population over the past three decades, but the growth of the individual components has shifted significantly (Figure 3). Separating NS&E into three major components (natural sciences excluding computer science [hereafter "natural science"], computer sciences, and engineering) presents very different pictures of the trend in degree production components. According to NSF/SRS degree data, natural science degrees peaked in 1977, and have declined steadily by a cumulative 24 percent during 1977 to 1988. Engineering degrees, on the other hand, sustained a steady major rise during 1977-1985 totalling 100 percent, dropping by 10 percent during the next three years. In contrast, the number of computer science degrees grew nearly seven-fold during 1977-86 dropping thereafter by 20 percent. Degrees in all fields of NS&E show a considerably modulated growth of about 3 percent per year during 1977-85, and a minus 3 percent per year during 1985-88.



**Figure 3** Choice of major fields by currently enrolled students and fewer young undergraduates portends a decline in NS&E bachelors over the next few years.

### Factors Causing Declines

The 25 percent decline in the number of 22-year-olds during 1983-1996 is the primary cause of the anticipated decline in NS&E bachelors. However, a projected decline in the proportion of college students selecting NS&E majors (discussed below) is an important secondary factor underlying the expected future shortfall. During 1986-88, Bachelor's in NS&E fields have dropped by 21 thousand, equivalent to 10 percent of the 1986 total.

Annual freshman intentions surveys, conducted annually by the American Council on Education (ACE), have been very good predictors of NS&E bachelors awarded three years later, although the lag seems to have widened to four years later in the late 1980's (see annual issues of *The American Freshman: National Norms*). Since the early 1970's the covariance between "intentions" and "bachelors earned 3 years later" in each of the three major subsectors of NS&E appearing in Figures 2 and 3 has explained about 90% of the variance in the ratio of bachelors to 22-year-olds ( $r^2 \geq 0.90$ ). Freshman intentions data for the period 1985-89 and college enrollment data were used to extrapolate

bachelors production for the years 1989 through 1992. These extrapolations presage a decline of 12 percent in NS&E bachelors during 1988-1992 due to a reduction in the fraction of 18-year-olds declaring majors and ultimately matriculating in NS&E fields (expected to drop from 5.1% to 4.5% of 22-year-olds). A recently completed study by the Educational Testing Service (ETS) of SAT test-takers is in broad agreement with the ACE data. It found that the percentage of college-bound high school seniors intending to major in a "quantitative science" field (defined as all NS&E fields except the life sciences) dropped from a high of 19% in 1983 to 13% in 1988 (see *ETS Policy Notes*, June 1989). Most of this drop is due to reduced interest in computer science. At face value, this finding translates into a prediction that the percentage of 22-year-olds earning NS&E bachelors will drop to a value lower than 4.4% in 1991, and less than 4.0% in 1992.

The projections in this paper assume that the declining participation rate will bottom-out at 4.4% in 1991, recover to 5% by 1998 and remain steady thereafter, as discussed above. During 1988-1998 a decline of 15% in the annual production of NS&E degrees is expected, mirroring the reduction in the number of 22-year-olds estimated by Census. This drop is expected to recover partially during 1998 to 2003, as the number of 22-year-olds increases according to Census data estimates.

*Slow persistent growth in the rate of conferral of NS&E baccalaureates to women has been largely offset by a decline in conferral to men.*

In summary, empirical evidence admits the possibility that the rate of NS&E degree conferrals to 22-year-olds could rise through further gains by female students. Projections in this paper assume that the average percentage of 22-year-olds earning bachelors in all NS&E fields will rebound after 1991 to 5.0% by 1998 and remain at that rate thereafter. This rate has been chosen to avoid overemphasizing the near-future expected dip in the rate of production, and has been held constant after 1998 to stress the importance of demographic factors, a key lesson of the last 30 years. If this participation rate remains constant as assumed, the factor controlling future supply of scientists and engineers is the size of the pool from which they are drawn (illustrated in Figure 2).

### Market Effects

Without some positive action to substantially reverse the decline in student preferences for choosing NS&E majors, bachelors degree production in the fields of natural science and engineering will decline. Based on observations from the past decade, it appears unlikely that the labor market for NS&E bachelors graduates will "solve" this emerging problem by steering more undergraduates into NS&E majors, for two major reasons. First, statistical correlations between annual production of NS&E bachelors with starting salary data from the College Placement Council (CPC) shows that in the past there has been virtually no relationship between changes in the relative starting salaries (i.e., relative to other fields such as business, the social sciences and the health sciences) and degree production in the combined fields herein defined as NS&E. The subfields of engineering and computer science do show some response to relative salary changes, but increases in engineering graduates appear to be directly offset by declines in natural science graduates, rendering the combined NS&E category relatively unresponsive. Only in the computer science field is there strong evidence of market responses which are not offset by declines in other NS&E fields. Second, in the future, because of the decline in population of young adults, all occupations will be commanding increasing salaries, including semi-skilled and skilled hourly wage labor and technician jobs as well as all professional disciplines.

### Bachelors Degree Shortfall

The cumulative reduction in production of NS&E bachelors degrees below the average annual number graduated during 1984-86 is labelled a "shortfall". This "shortfall" does not necessarily

translate directly into a "shortage" unless the demand for such skills exceeds the declining supply. Because of complexities in the utilization of NS&E training (e.g., many NS&E graduates use their skills productively in occupations not officially counted as scientists or engineers) and limitations of occupational census data (counting only those individuals officially categorized as scientists or engineers), quantitative projection of the demand for individuals with NS&E knowledge and training is highly uncertain, and was not attempted in this work. Instead, the average production during 1984-86 was taken as a proxy for future demand. This proxy is conservative because it limits future replacements and increases in demand to a fixed number of new graduates, even though many analysts believe that demand will grow in the future.

The size of the problem caused by the lowered production depends on the need for such skills in the future in a healthy competitive economy. If the NS&E production rate drops to 4.4% of the 22-year-old population in 1991 and then returns steadily to 5% in 1998 and beyond, the cumulative shortfall of bachelors to the year 2006 would be about 675,000, or 275,000 in engineering degrees (Figure 4). Even with an optimistic assumption that the demand for new degrees at the bachelors level will drop by 1,000 each year from 1989 to 2006 due to improved utilization and productivity of the NS&E workforce, the Nation would still face a cumulative shortfall of 440,000 during this period.

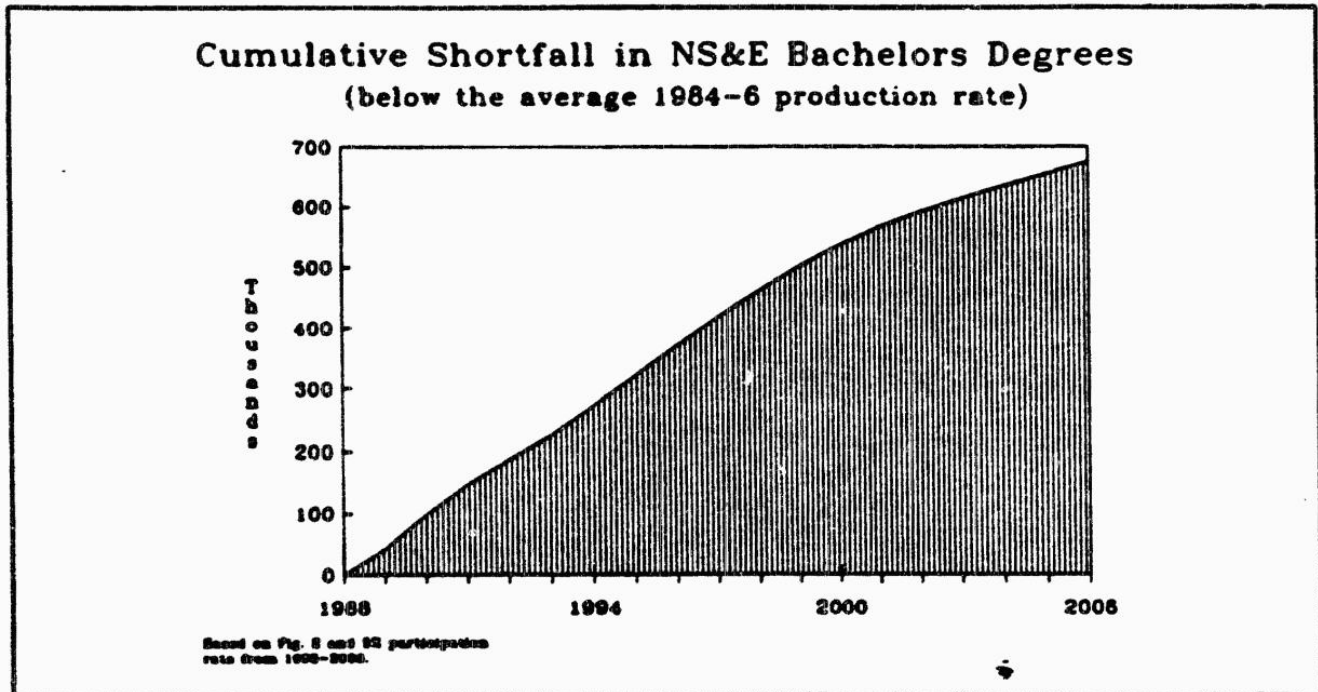


Figure 4 The U.S. will have a cumulative shortfall of 540,000 by 2000 and 675,000 by 2006, when compared to constant production at the 1984-86 average.

## PH.D. DEGREES

### Supply

As noted in the introduction, possibly the most severe scarcity will occur at the Ph.D. level of training during 1994-2006. The expected shortfall of baccalaureate degrees during the next 5 to 10 years is part of the problem. However, there is no convincing evidence of a historically fixed link between bachelors and Ph.D. degree production despite the relative stability of the bachelors-



---

---

***FUTURE SCARCITIES OF  
SCIENTISTS AND ENGINEERS:  
PROBLEMS AND SOLUTIONS***

---

---

---

**NATIONAL SCIENCE FOUNDATION**

**Directorate for Scientific, Technological  
and International Affairs**

**Division of Policy Research and Analysis**

---

**WORKING DRAFT  
Summer, 1990**

## INTRODUCTION

Due to declining birth rates two decades ago, the population of college-age people in the U.S. has been declining since the mid-eighties, and will continue to drop until the mid-nineties, when the number will be about 25 percent below the previous peak.

The fraction of Americans earning bachelors degrees in the group of fields herein labeled "natural science and engineering" (NS&E) has been very stable over the past three decades, after growing about 3 percent per year in the earlier part of the century. This fraction is called the "participation rate," and is defined as the ratio of bachelors degrees granted to the number of 22-year-olds in the population in any given year. Without some deliberate encouragement for people to pursue such careers, the participation rate for NS&E bachelors degrees is likely to remain stable or perhaps decline.

The declining number of college-age citizens combined with the nearly constant participation rate portends a virtually unavoidable decline in the production of NS&E bachelors degrees for the next several years.

It is not possible to confidently project the impact of this declining supply of trained personnel on the U.S. labor market, because the NS&E job market is not well defined, and the response of employers and college students to market changes is complex and slow. Furthermore, less than two-thirds of the 1987 NS&E B.S. graduates choose occupations formally classed as scientist or engineer, choosing to use their skills and knowledge in related jobs, such as management of scientific businesses, or to pursue professional careers in business, law, and medicine. However, since the NS&E share of all jobs has been growing over the entire history of the Nation, the downturn in supply of NS&E B.S. degrees may require some major reassessments and adjustments by NS&E employers.

Since NS&E Ph.D. candidates are drawn from the pool of NS&E bachelors degree graduates, a possible decline in production of Ph.D. degrees is also possible in the late 1990s. If National R&D activities continue to increase, this constraint on the supply of highly trained scientists and engineers will foster heightened competition among Ph.D. employers: industry, higher education, government, and other nonprofit research institutions. Concomitant with this decline in supply of Ph.D.s, replacement demand will be growing because of the simultaneous retirement of members of the Ph.D. hiring surge of the 1960s.

There are many classes of incentives which could increase the NS&E participation rate for U.S. citizens, all of which entail some cost. These incentives could be implemented by higher education institutions, employers, local, state, and Federal governments, and professional societies. Timing of these incentive programs is crucial; if initiated too late, they may lead to an unnecessary oversupply of people with NS&E training.

This paper focuses on natural scientists and engineers (NS&Es), rather than the larger population of scientists, which includes the sub-population of social and behavioral scientists. Natural scientists are those trained and working in the physical sciences, the environmental sciences, the mathematical sciences, the agricultural sciences, and the biological sciences. The choice of focus is based on observed differences in patterns of production and demand for NS&Es compared to social and behavioral scientists. Most published concerns of the impending growing scarcity of scientists and engineers are focused on NS&Es.

Analyses in this paper use trend projections or past relationships between stable variables. All such assumptions about the persistence of past trends and relationships are identified, and the analyses should be interpreted as conditional on their continuation. In a broad sense, social values are assumed to undergo little change.

## Overview

The ratio of NS&E bachelors degrees to 22-year-old citizens living in the U.S. has been relatively fixed over the last 30 years. An increase in the fraction of 22-year-olds earning bachelors degrees in NS&E fields could offset the reduction in the population of college age students and the attendant projected shortfall of 675,000 bachelors degrees. It would also make a strong contribution to reducing the future scarcity of NS&E Ph.D.s, assuming the bachelors-to-Ph.D. continuation rate remains unaffected by the larger pool of new bachelors. What are the prospects for such an increase? Is the ratio of NS&E bachelors to 22-year-olds fixed for convincing behavioral reasons, or is its unchanging level over the past 30 years coincidence? Reviewing past changes in the field components of NS&E bachelors, and the relative propensities of men, women, blacks, Hispanics, Asians and whites to earn NS&E bachelors is one approach to addressing these questions as described in the next section.

In the past, the combination of increased federal support of graduate education and market forces produced substantial increases in the number of NS&E Ph.D.s during the 1960s. The twin build-up of demand and support of doctoral students in NS&E led to a doubling of the bachelors-to-Ph.D. continuation rate during the 1960s. In the reverse direction, the reduced demand and reduced fellowship/traineeship support of graduate students during the 1970s led to a substantial decrease in Ph.D. production, despite the growing pool of qualified bachelors resulting from the baby boom undergraduate cohorts. How will market forces work in the future, given the unique demographic conditions expected during the next several decades? Can the U.S. rely on further increases in foreign citizen graduates of U.S. doctoral programs to meet expected growing future needs for doctorates? These questions are addressed in the Ph.D. section.

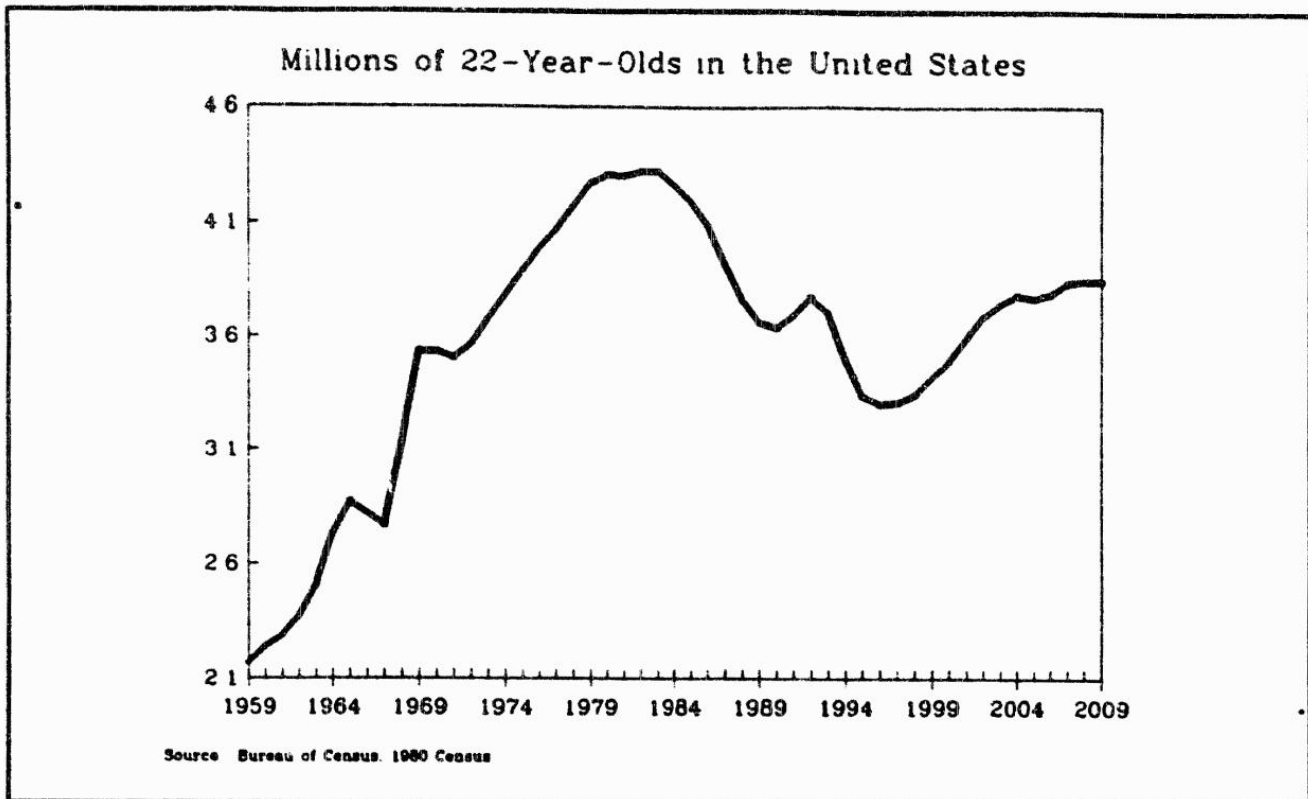
Following the Ph.D. discussion is a description of the entire NS&E educational pipeline, including an examination of reasons for students entering or leaving this career path. It is claimed that the propensity of different population groups to sample NS&E courses and select NS&E majors in college is strongly conditioned by educational experiences in high school (and earlier), and by the affordability of 4-year colleges and universities to the population of interested, eligible, potential NS&E majors. Understanding when and why students cease any further efforts to advance their knowledge of science and mathematics is important in determining whether better teaching, improved curricula, and more effective teaching materials could improve the flow of students to more advanced stages of learning, through the bachelors degree stage and beyond.

The final section examines systematically a variety of generic attraction and retention strategies at successively more advanced stages of education. The issue of proper timing of increased support is stressed, and the issue of affordability is considered.

## The Concept of Scarcity

**Factors Causing Scarcities** Two future demographic events will alter the supply and demand for natural scientists and engineers. The key event is a 25 percent reduction in the number of "college age" students during 1983-1996 after a doubling during 1961-1979, as measured by the number of 22-year-olds. Thus, one-half of the population gains made during 1961-1979 will be lost during 1983-1996 (Figure 1).

The second event is an anticipated doubling of replacement demand for Ph.D. level natural scientists and engineers during 1990-2006, as a consequence of the large number of Ph.D.s hired during the 1960s. The expected effect of these demographic changes is a growing scarcity of natural scientists and engineers (NS&Es) during the 1990s and first decade of the next century. Reduced production of NS&E bachelors during the next 5 years will contribute to the Ph.D. level scarcity in the first decade of the next century.



**Figure 1** The dominant factor controlling the NS&E bachelors output is the size of the college-age population, which is in the midst of a decline that will last until the late 1990's.

**Measurement of Scarcity** For this analysis, scarcity is measured simply as the cumulative difference between supply and demand at constant current salaries and in the absence of substantial changes in career choices. This cumulative difference is termed a shortfall, as described later.

In the classical economics definition, any commodity that can command a price has some measure of scarcity. Starting salaries for new college graduates reflect an agreement between employers' willingness to pay for certain skills and employees' willingness to work. Since the U.S. has a market economy, in theory, price adjustments will encourage a balancing of supply and demand for new scientists and engineers. College graduates in scarce fields will command increasingly higher salaries, until demand levels off as employers find ways to conduct business with fewer staff with those credentials. As starting salaries rise, more people will pursue those profitable professions, tempering the growth of salaries. Thus, supply and demand interact until some equilibrium is reached.

Labor markets do not respond instantaneously, and the market for college-trained individuals has a particularly sluggish response, since it takes a minimum of four years to obtain a bachelor's degree and about eight years more for a doctorate degree. As the following analysis shows, annual production of bachelor's degrees in the combined subset of disciplines identified as "natural scientists and engineers" has shown only weak response to market forces over the past thirty years (although considerable complementary shifting among the component disciplines has occurred).

Market analysis was not attempted for bachelors degrees because many other considerations confound the measurement of changes in students choice of major in response to changing starting pay for associated occupations. The total value of a first college degree is not accurately captured by short run equilibrium prices (i.e., starting salaries) for new bachelors, because undergraduate students are still exploring career options and responding to a variety of factors that are not related to near term starting salary levels. A substantial number of students earning bachelors in NS&E fields are not

planning NS&E careers (at least not at that level of training) but still derive substantial benefits from their NS&E training.

Rising real starting salaries are indicative of a growing scarcity of bachelors entrants to the NS&E labor force, and they will increase the fraction of recent graduates who plan to enter the NS&E labor force. However, the strength of this relationship cannot be estimated at an acceptable level of precision. Hence, a simpler method has been adopted: estimating the expected number of NS&E bachelors in future years and measuring the amount by which this falls short of a target level of bachelors production. This task is made relatively easy by the fact that for the last 30 years about 4 percent of the number of 22-year-olds have completed NS&E baccalaureates, excluding computer science baccalaureates.

At the Ph.D. level a possible future equilibrium path is presented after describing and specifying the basic factors that influence supply and demand. Undertaking advanced training in NS&E fields represents a major commitment of time and lost income. Generally, doctoral study is more specifically related to occupational choice (teaching and research) than is undergraduate study. Hence, relative scarcity seems to play a much stronger role in determining the number of new bachelors that enter doctoral programs. The number of U.S. citizen bachelors completing doctorates in NS&E fields rose from about 5 percent in the early 1960s to more than 10 percent in the late 1960s and early 1970s, only to drop back to 5-6 percent in the late 1970s, where it remains today.

A factor complicating the analysis of bachelors-to-doctorate continuation rates is the rising importance of foreign graduate students. In 1988, 28 percent of NS&E Ph.D.s were conferred to foreign citizens studying in the U.S. on student visas. The future equilibrium path is influenced by the fraction of these foreign graduates who enter the U.S. labor force.

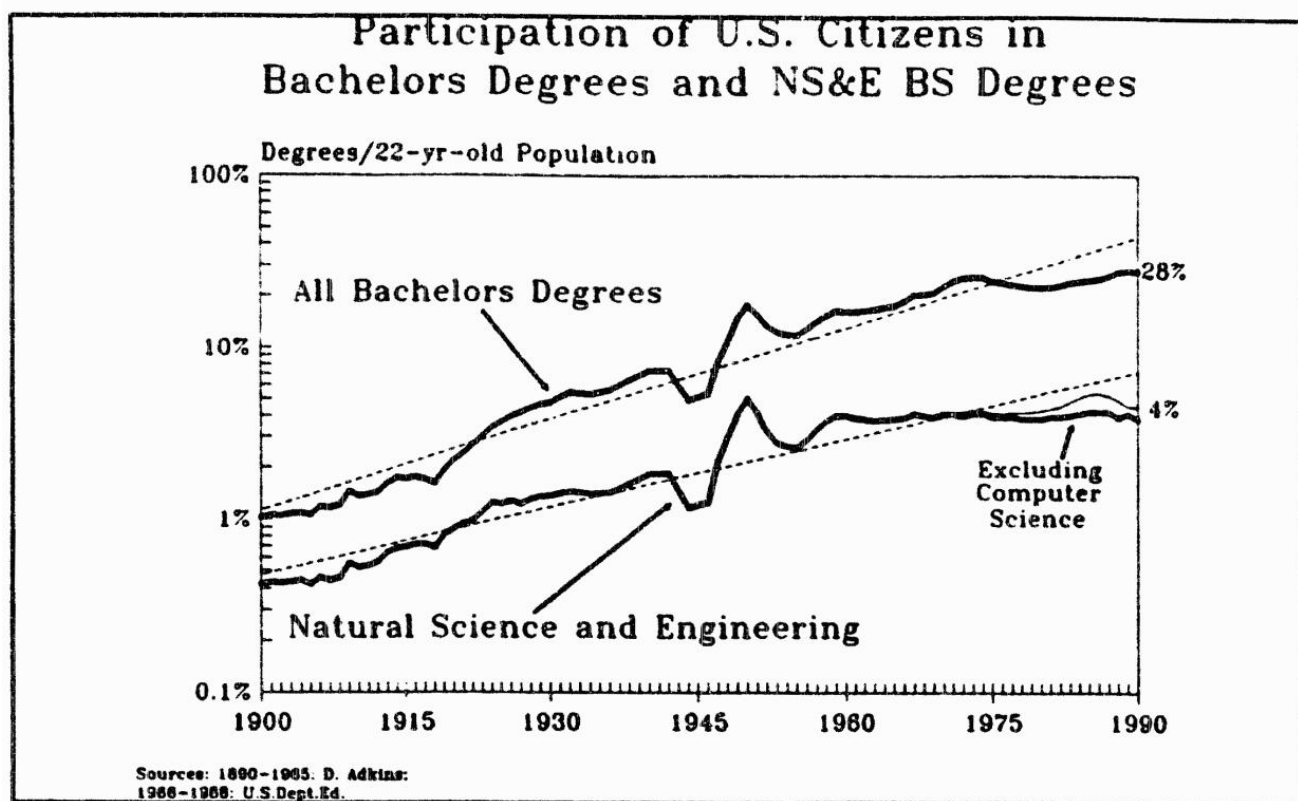
## BACHELORS DEGREES

The long-term growth in the rate of participation of U.S. citizens in undergraduate education is impressive indeed (Figure 2). Measured by total bachelors degrees earned relative to the population, the participation rate grew by an annual average of 4% throughout the century until about the early seventies, when it levelled off at 28% of the relevant age groups. The natural science and engineering participation rate has also increased steadily through the years, growing at an annual average of about 3% through the late 1950s. It then levelled off at about 4% of the relevant age cohort. The rise that began in the late 1970s (and has begun to fall again) is due to computer science.

### Participation

Although many factors enter into the process of choosing a career, several of which have changed substantially over the last 30 years, NS&E bachelors degrees have been awarded annually to a relatively fixed fraction of the U.S. 22-year-old population for almost three decades (Figure 2), using NSF/Science Resources Studies Division (SRS) data on NS&E degrees and Bureau of the Census (BOC) data to estimate the number of 22-year-olds. The median age for NS&E B.S. recipients was 22 years for the past few decades, but has recently been creeping toward 23 years. The 22-year-old cohort base has been retained to facilitate comparisons with earlier studies.

Following oscillations caused by World War II, this fraction (participation rate) has varied from a low of 3.7% in 1963 to a high of 5.3% in 1987, and has been more tightly bounded between 3.7% and 4.3% excluding computer science, a field not separately recognized in the 1960s. The evident limit on the percentage of 22-year-olds earning bachelors in NS&E fields during the 1960s led Wallace Brode to speculate in 1971 that the production of these degrees had reached a saturation level, which he identified as 4% of 22-year-olds. (See: *"Manpower in Science and Engineering, Based on a Saturation Model"*, *Science*, July 16, 1971.) In Brode's view, the nation had successfully geared itself to recruit all able interested primary/secondary school students into NS&E majors in college, and this process of recruitment was the dominant determinant of supply, with feedback from fluctuating demand playing a much less important role.

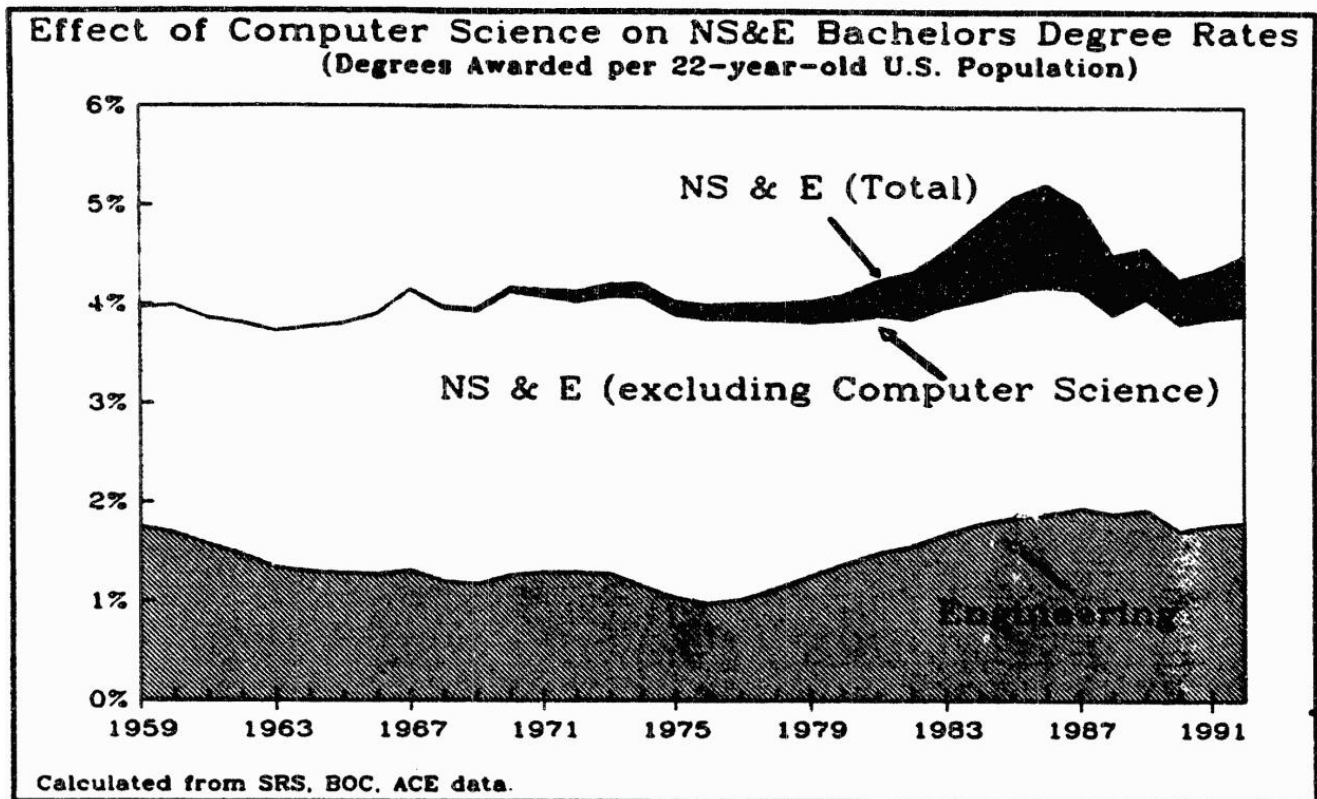


**Figure 2**

Empirical evidence through the late-1980s confirms Brode's perspective but also suggests that change is possible. The introduction of the new field of computer science has clearly removed the 4-percent ceiling to bachelors production. Also, as is discussed below, female participation in undergraduate programs has increased substantially since 1971. On the other hand, male participation has dropped as a counterpart to increased female participation, and the 4-percent rule has held for the aggregate of traditional NS&E fields despite large changes in the distribution of bachelors among engineering, the physical sciences, mathematics, and the life sciences (described below). The small variation in the rate of degree conferral from 3.7 to 4.3 percent indicates that there has been stability of interest in traditional NS&E majors. It implies that NS&E majors have been drawn disproportionately from social backgrounds where for three decades or more most high school graduates have entered 4-year colleges. The broadening of the college enrollment base that occurred in the 1960s and is occurring again in the 1980s does not seem to have had much impact on the fraction of 22-year-olds earning bachelors in traditional NS&E fields.

#### **Growing Participation by Women**

Increasing degree conferrals to women seems to offer the most responsive path to increasing the overall ratio of NS&E bachelors to 22-year-olds. There has been a slow but persistent rise in the rate of conferral of baccalaureate degrees to women, from less than 1 percent of female 22-year-olds in 1959 to 3.2 percent in 1986, 1987, and 1988. During 1972-1982 new female baccalaureates grew steadily from 1.5 percent to 2.4 percent of female 22-year-olds. This rise was offset in large measure by a decline in the conferral rate to males, from 7 percent to 6 percent of male 22-year-olds during the same period. In the first five years the growth in female bachelors was entirely in the life sciences, while in the latter five years it occurred entirely in the remaining NS&E fields. During 1982-86, female NS&E baccalaureates rose to 3.2 percent of female 22-year-olds, with more than one-half of the growth in computer science. In 1982, the conferral rate to women in this field alone was only 0.3 percent, compared to 0.75 percent in 1986. During 1986-88 this rate abated to



**Figure 3** The recent rise in the fraction of 22-year olds earning NS&E degrees was mostly due to increases in computer science.

0.6 percent. The increase in computer science bachelors awarded to males pushed the aggregate NS&E conferral rate to males from 6 percent during 1980-82 back to 7 percent during 1986-88.

#### Minority Participation

A challenge to increasing future NS&E bachelors is the fact that two important population minority groups (blacks and Hispanics) have been (and are expected to continue) growing as a proportion of all 22-year-olds. Their participation in NS&E degree programs has been substantially below average during the last ten years. In 1985, blacks accounted for 13 percent of 22-year-olds but only 5 percent of NS&E bachelors, and Hispanics accounted for 8 percent of 22-year-olds, but only 3 percent of NS&E bachelors (data from NSF/SRS, Dept of Education, and Bureau of the Census). College age blacks and Hispanics are expected to increase their proportion of the total college age population from about 23 percent currently in 1989 to 28 percent or more in the year 2000, and 30 percent or more in 2010, according to the Bureau of the Census (Figure 4).

#### Field Composition of NS&E Bachelors Degrees

The computer science bachelors production rate has been unstable relative to population or other economic indicators (Figure 5). From the early 1970s until the early 1980s, the number of individuals receiving computer science degrees was relatively small, and these students seemed to be coming from the same pool as other NS&Es, particularly those interested in mathematics. The substantial growth in these degrees from 1980 to 1986 suggests that they have been increasing at the expense of degrees in a number of non-NS&E fields. There is some evidence that this field is attracting students that previously were not candidates for NS&E bachelors degrees. For example, they are awarded disproportionately by colleges with little or no research and development activity, few or no Ph.D. programs, and below average percentages of total bachelors in NS&E fields.

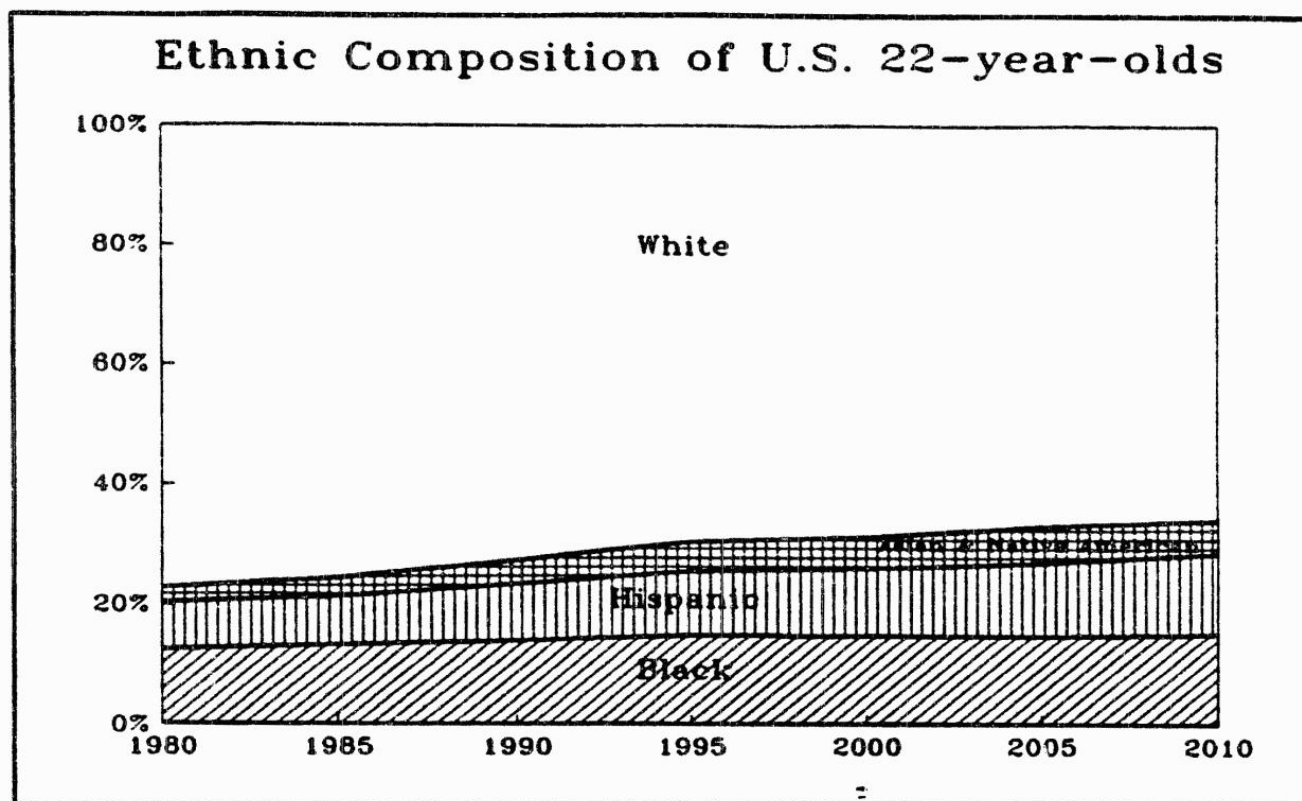


Figure 4 Minorities will be about 30% of the college-age population by 2010.

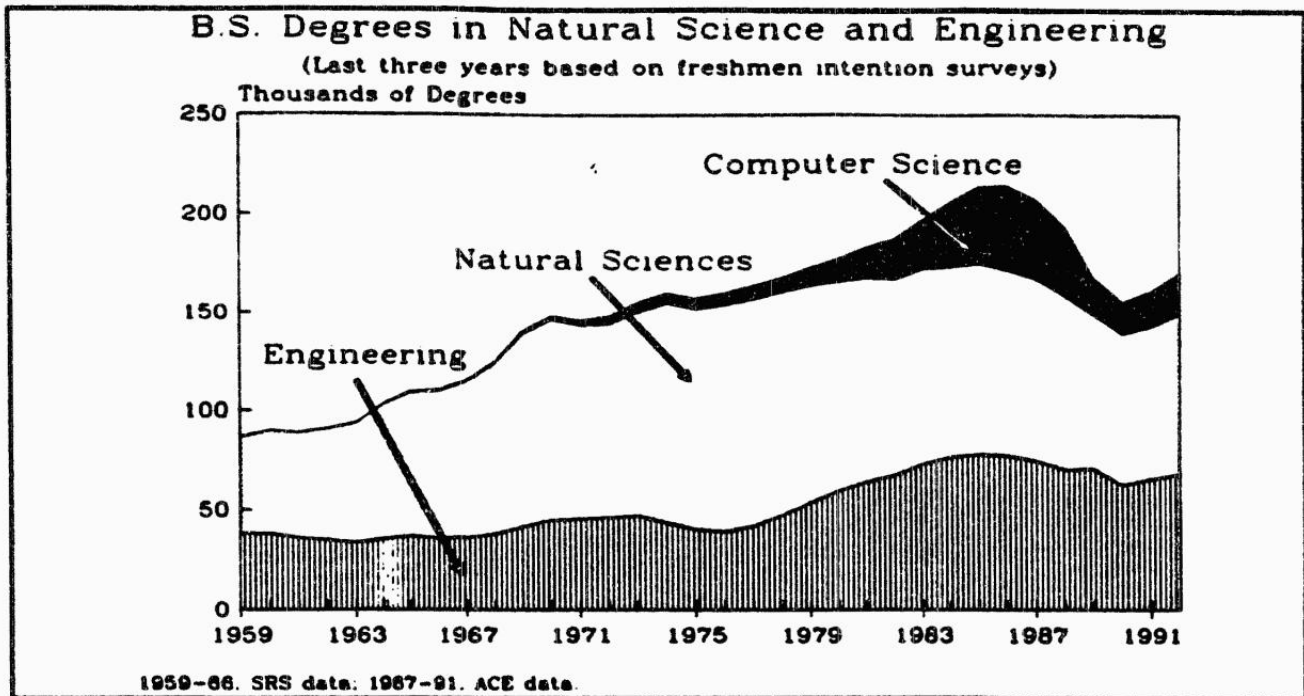
The number of baccalaureate degrees in the remaining fields of natural science and engineering has increased steadily with population over the past three decades, but the growth of the individual components has shifted significantly (Figure 5). Separating NS&E into three major components (natural sciences excluding computer science [hereafter "natural science"], computer sciences, and engineering) presents very different pictures of the trend in degree production components. According to NSF/SRS degree data, natural science degrees peaked in 1977, and have declined steadily by a cumulative 24 percent during 1977 to 1988. Engineering degrees, on the other hand, sustained a steady major rise during 1977-1985 totalling 100 percent, dropping by 10 percent during the next three years. In contrast, the number of computer science degrees grew nearly seven-fold during 1977-86 dropping thereafter by 20 percent. Degrees in all fields of NS&E show a considerably modulated growth of about 3 percent per year during 1977-85, and a minus 3 percent per year during 1985-88.

#### Factors Causing Declines

The 25 percent decline in the number of 22-year-olds during 1983-1996 is the primary cause of the anticipated decline in NS&E bachelors. However, a projected decline in the proportion of college students selecting NS&E majors (discussed below) is an important secondary factor underlying the expected future shortfall (Figure 6). During 1986-88, Bachelor's in NS&E fields have dropped by 21 thousand, equivalent to 10 percent of the 1986 total.

Annual freshman intentions surveys, conducted annually by the American Council on Education (ACE), have been very good predictors of NS&E bachelors awarded three years later, although the lag seems to have widened to four years later in the late 1980s (see annual issues of *The American Freshman: National Norms*). Since the early 1970s the covariance between "intentions" and "bachelors earned 3 years later" in each of the three major subsectors of NS&E appearing in Figures 3 and 5 has explained about 90% of the variance in the ratio of bachelors to 22-year-olds ( $r^2 \geq 0.90$ ).





**Figure 5** Choice of major fields by currently enrolled students and fewer young undergraduates portends a decline in NS&E bachelors over the next few years.

Freshman intentions data for the period 1985-89 and college enrollment data were used to extrapolate bachelors production for the years 1989 through 1992. These extrapolations presage a decline of 12 percent in NS&E bachelors during 1988-1992 due to a reduction in the fraction of 18-year-olds declaring majors and ultimately matriculating in NS&E fields (expected to drop from 5.1% to 4.5% of 22-year-olds), (Figure 6). A recently completed study by the Educational Testing Service (ETS) of SAT test-takers is in broad agreement with the ACE data. It found that the percentage of college-bound high school seniors intending to major in a "quantitative science" field (defined as all NS&E fields except the life sciences) dropped from a high of 19% in 1983 to 13% in 1988 (see *ETS Policy Notes*, June 1989). Most of this drop is due to reduced interest in computer science. At face value, this finding translates into a prediction that the percentage of 22-year-olds earning NS&E bachelors will drop to a value lower than 4.4% in 1991, and less than 4.0% in 1992.

The projections in this paper assume that the declining participation rate will bottom-out at 4.4% in 1991, recover to 5% by 1998 and remain steady thereafter, as discussed above. During 1988-1998 a decline of 15% in the annual production of NS&E degrees is expected, mirroring the reduction in the number of 22-year-olds estimated by Census. This drop is expected to recover partially during 1998 to 2003, as the number of 22-year-olds increases according to Census data estimates. In summary, empirical evidence admits the possibility that the rate of NS&E degree conferrals to 22-year-olds could rise through further gains by female students. Projections in this paper assume that the average percentage of 22-year-olds earning bachelors in all NS&E fields will rebound after 1991 to 5.0% by 1998 and remain at that rate thereafter. This rate has been chosen to avoid overemphasizing the near-future expected dip in the rate of production, and has been held constant after 1998 to stress the importance of demographic factors, a key lesson of the last 30 years. If this participation rate remains constant as assumed, the factor controlling future supply of scientists and engineers is the size of the pool from which they are drawn (illustrated in Figure 1).

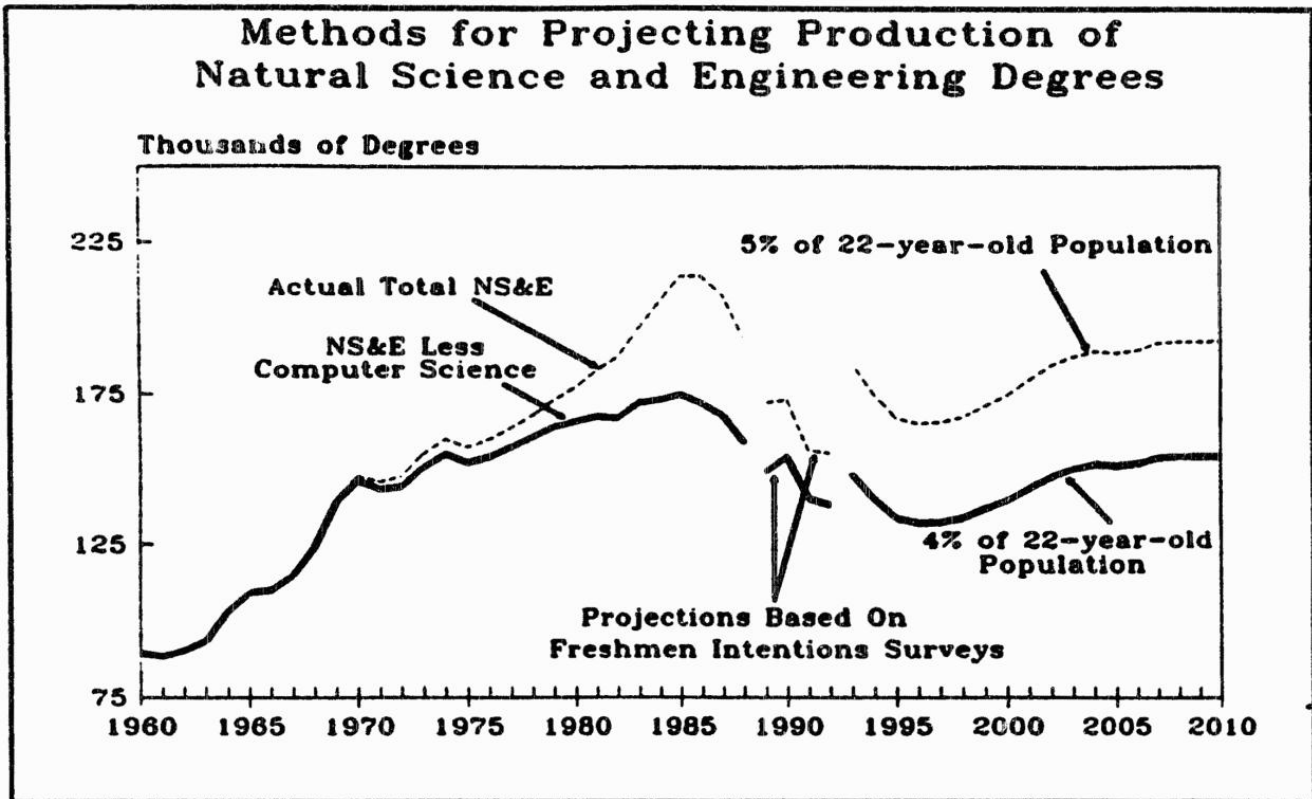


Figure 6

***Slow persistent growth in the rate of conferral of NS&E baccalaureates to women has been largely offset by a decline in conferral to men.***

### Market Effects

Without some positive action to substantially reverse the decline in student preferences for choosing NS&E majors, bachelors degree production in the fields of natural sciences and engineering will decline. Based on observations from the past decade, it appears unlikely that the labor market for NS&E bachelors graduates can, by itself, "solve" this emerging problem by steering an adequate number of undergraduates into NS&E majors.

In the past there has been virtually no relationship between changes in the relative NS&E starting salaries (i.e., relative to other fields such as business, the social sciences, and the health sciences) and degree production in the combined fields herein defined as NS&E. Although the combined NS&E category is relatively unresponsive to relative salary changes, individual NS&E fields do show a response to relative starting salaries. But when increases do occur in specific NS&E fields, they are generally offset by declines in other NS&E fields. Only in the computer science field is there strong evidence of market responses which are not offset by declines in other NS&E fields. The participation rate for NS&E degrees (excluding computer science) has remained fairly constant at 4 percent during a period in which a significant and increasing starting salary premium for NS&E bachelor degree holders has been present, although there has been a substantial shift away from agricultural and biological degrees towards engineering degrees.

The market for bachelor degree holders is complex. In fact, two to three separate or segmented markets can be identified from starting salary data (Figure 7). Starting salaries for the group comprising engineers, physical scientists, mathematical scientists, and environmental scientists are considerably higher than for the group comprising business majors, social and behavioral scientists, agricultural and biological scientists, and humanities majors. Education majors appear to have comprised a third group during the 1960s and 1970s, but differences in starting salaries for education bachelor degree holders and the second group indicated above have almost disappeared during the 1980s.

Market phenomena explain some but not all of the shifts in degree patterns observed during the past several decades and the data available for analysis are not rich enough to disentangle the many factors affecting career choices. For instance, the large increase in business bachelor degrees during the past two decades has occurred despite the fact that the premium for obtaining an NS&E degree relative to a business degree has increased during much of this period (Figure 8). However, the increase in business degrees may still be market driven. A lot of the increase in business bachelor degrees has been due to increases in women and minorities, groups whose viable alternatives may have been an education degree rather than an NS&E degree. In fact, as the number of business bachelors has increased relative to the number of education bachelors, the starting salary premium for selecting a business degree over an education degree has almost disappeared, suggesting that movement of individuals across these separate markets has converted it into a unified market.

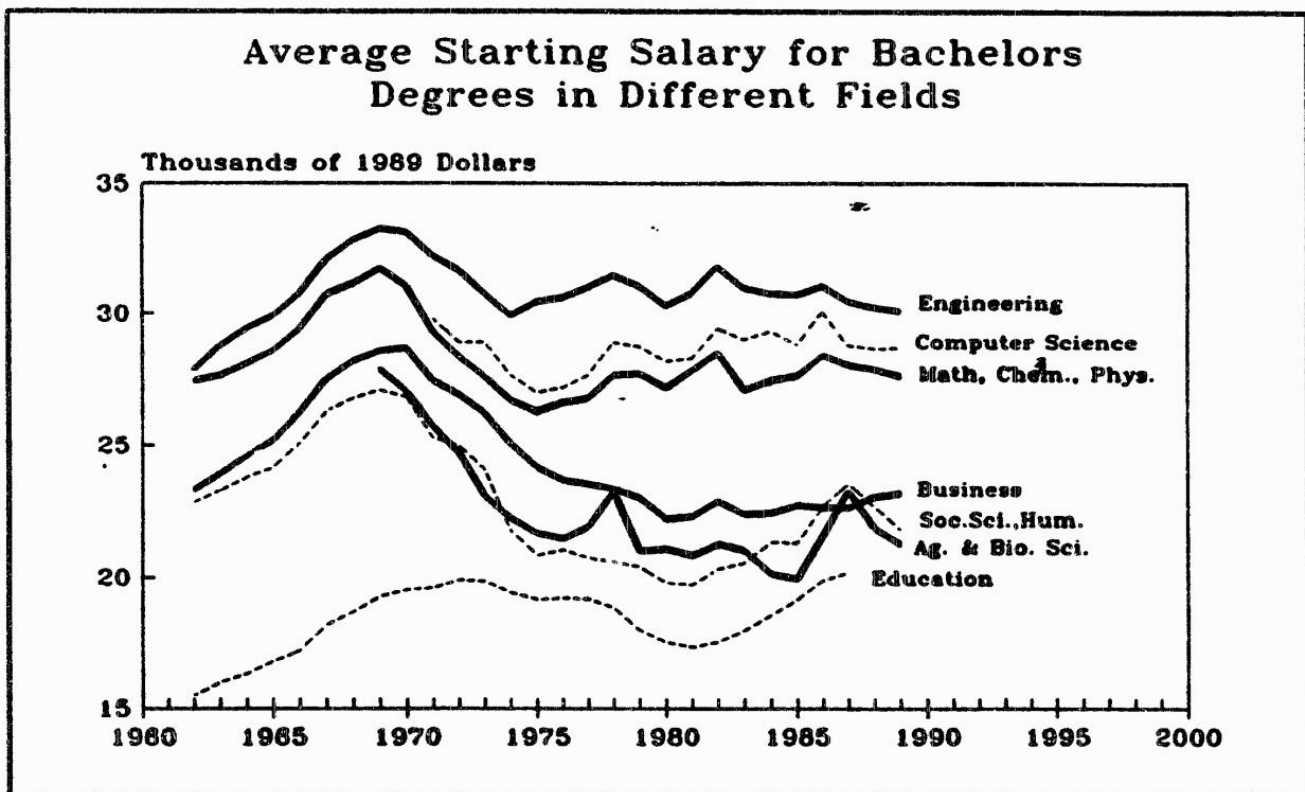


Figure 7

Starting salaries, however, are not the sole economic signals affecting degree choice. Lifetime income, or expected lifetime income, may not necessarily be closely correlated with starting salaries and may have a stronger influence on career choice. For example, the evident experience premium for middle aged business majors who graduated in the early 1960s is higher than the experience premium for engineering graduates from the same period. However, the historical promotion potential in a field may not be a good basis for forecasting its future promotion potential.

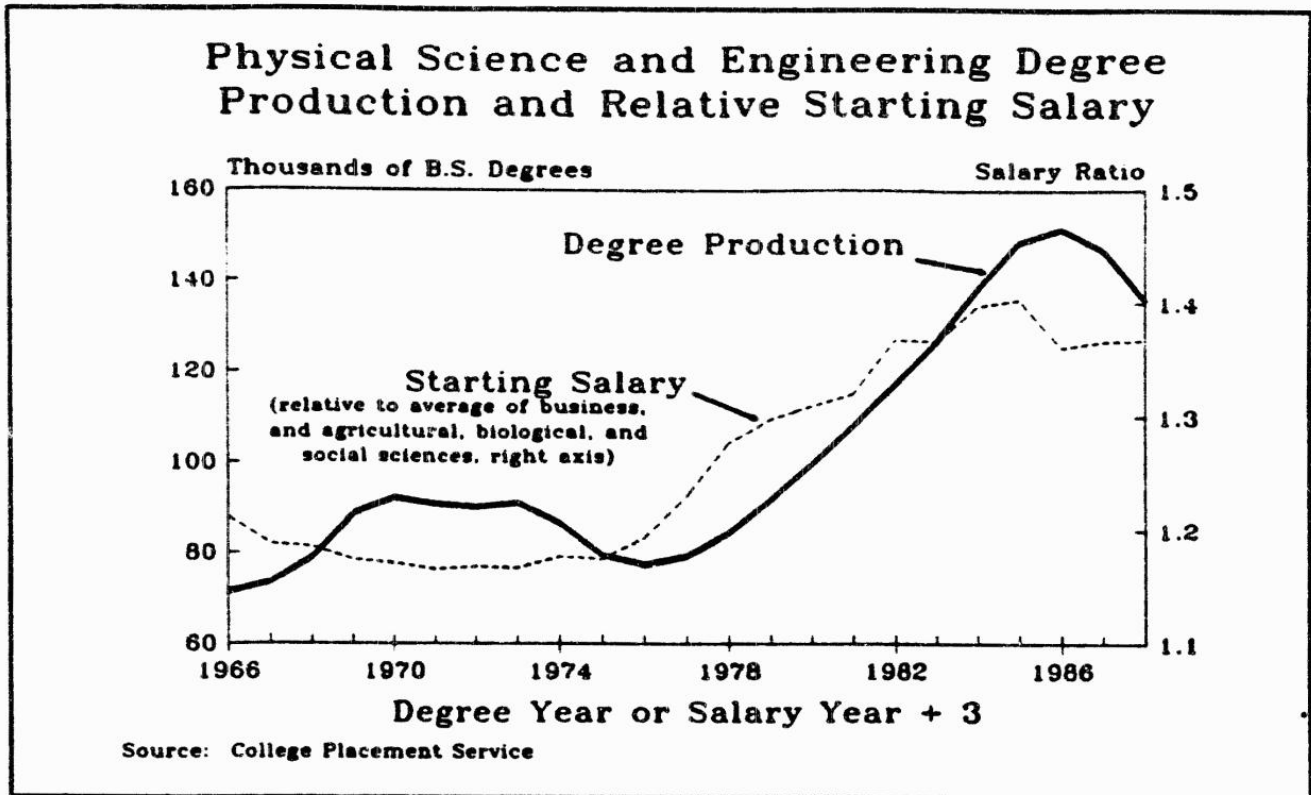


Figure 8

### Bachelors Degree Shortfall

The cumulative reduction in production of NS&E bachelors degrees below the average annual number graduated during 1984-86 is labelled a "shortfall". This "shortfall" does not necessarily translate directly into a "shortage" unless the demand for such skills exceeds the declining supply. Because of complexities in the utilization of NS&E training (e.g., many NS&E graduates use their skills productively in occupations not officially counted as scientists or engineers) and limitations of occupational census data (counting only those individuals officially categorized as scientists or engineers), quantitative projection of the demand for individuals with NS&E knowledge and training is highly uncertain, and was not attempted in this work. Instead, the average production during 1984-86 was taken as a proxy for future demand. This proxy is conservative because it limits future replacements and increases in demand to a fixed number of new graduates, even though many analysts believe that demand will grow in the future.

The size of the problem caused by the lowered production depends on the need for such skills in the future in a healthy competitive economy. If the NS&E production rate drops to 4.4% of the 22-year-old population in 1991 and then returns steadily to 5% in 1998 and beyond, the cumulative shortfall of bachelors to the year 2006 would be about 675,000 (Figure 9). Even with an optimistic assumption that the demand for new degrees at the bachelors level will drop by 1,000 each year from 1989 to 2006 due to improved utilization and productivity of the NS&E work force, the Nation would still face a cumulative shortfall of 440,000 during this period.

## PH.D. DEGREES

### Supply

As noted in the introduction, possibly the most severe scarcity will occur at the Ph.D. level of training during 1994-2006. The expected shortfall of baccalaureate degrees during the next 5 to 10 years is part of the problem. However, there is no convincing evidence of a historically fixed link between bachelors and Ph.D. degree production despite the relative stability of the bachelors-to-Ph.D. continuation rate (at 5 percent) over the last ten years. In general, the two key factors in reducing the scarcity caused by demographics (fewer NS&E bachelors) and growing demand are economic prospects and immigration. An indicator of economic prospects is the rate at which new NS&E bachelors continue their education through the doctorate level.

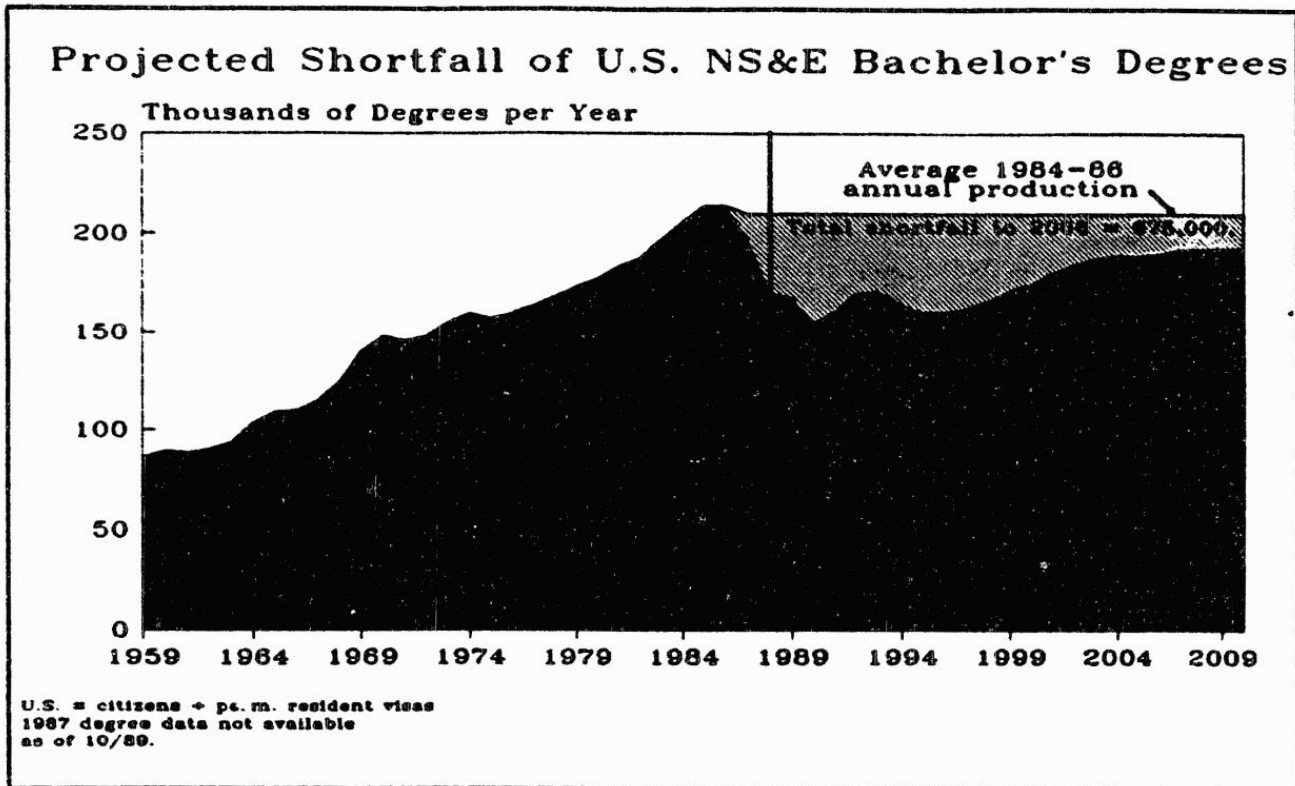


Figure 9 The U.S. will have a cumulative shortfall of 540,000 by 2000 and 675,000 by 2006, when compared to constant production at the 1984-86 average.

**U.S. Citizens** It is difficult to measure continuation rates from the bachelors to the doctorate with precision. There is such a wide age distribution of Ph.D. recipients (90 percent of whom are 25 to 37 years old) compared to bachelors recipients (90 percent of whom are 21 to 24 years old) that one cannot be certain how many NS&E Ph.D.s a given cohort of baccalaureates will produce until 15 to 20 years after the date of bachelors graduation. However, trends in the mean and median ages of new Ph.D.s, coupled with annual bachelors and doctorate graduation figures and bachelors to Ph.D. crossover tendencies, allow us to calculate approximate continuation rates. It is clear that these rose substantially during the 1960s and reached a peak considerably above 10 percent in 1971 and 1972. It is equally clear that continuation rates dropped substantially during 1972-77, to about 6 percent in 1977. During 1977-85, continuation rates in individual fields of NS&E appear to have dropped very slowly (to about 5.2 % in all fields of NS&E), and during 1985-88 to have leveled-off or recovered slightly, moving a weighted average NS&E continuation rate with fixed weights back to 5.5%. But because the mix of bachelors degrees has been shifting towards fields with lower-than-

---

**International Production of  
Scientists and Engineers**

---

**National Science Foundation**

**Directorate for Scientific, Technological,  
and International Affairs**

**Division of Policy Research and Analysis**

---

**July 23, 1990**

Recent findings about a probable decline in the production of natural scientists and engineers in the United States over the next two decades raises a number of issues. This paper will explore two important questions relevant to addressing these issues using available data of known trends.

- Are the other major producing countries facing a similar future?
- Will international migration of natural scientists and engineers mitigate or exacerbate the situation?

This paper examines the available data on the population trends and the production of natural scientists and engineers (NS&E's) among the major producing countries, including the U.S. These countries are defined as those which produce annually 20,000 or more bachelors degrees in science and engineering. There are 29 such countries, and they produce about 90 percent of the world's bachelors degrees in science and engineering. The paper also examines international migration patterns of natural scientists and engineers, both as students and as members of the labor force.

#### **Preliminary Findings:**

- Worldwide production of trained scientists and engineers has increased as population has grown, demand has grown, and educational opportunities have expanded;
- Several countries in addition to the United States will experience declines in the college age cohorts within the next twenty years, though at different times;
- If the relationship of college age cohorts to bachelors degrees in NS&E is of other countries is fairly stable (as it has been in the U.S.), a net decline in the number of NS&E bachelor's degrees worldwide is expected between 1985 and 2005;
- A similar pattern may occur relative to NS&E Masters and PhD degrees worldwide;
- U.S. experience with immigration of natural scientists and engineers suggests that, in the absence of changes in immigration policy, international migration should not be considered as a likely important influence on potential supply shortfalls among the various countries.

#### **A. SUMMARY OF A STUDY POINTING TO A U.S. SHORTEALL**

A recent study by the Division of Policy Research and Analysis in the National Science Foundation begins with the fact that the U.S. will experience a decline of twenty-five percent between 1983 and 1996 in the age group typical of college graduates. The median age of college graduates was about 22 years for many years; by 1989 it increased to about 23. A central finding of PRA study is the existence over the long-term of a fairly constant relationship between the number of 22-year-olds<sup>1</sup> and the annual number of bachelors degrees awarded in natural science and engineering. The relationship is most stable historically if the field of computer sciences is excluded from the set of fields examined. Although there is little evidence to suggest that this age/degree relationship holds true for other countries, it is used here as a point of departure for the analysis of this issue.

---

<sup>1</sup> "Personnel In Natural Science and Engineering", National Science Foundation, Directorate for Scientific, Technological and International Affairs, Division of Policy Research and Analysis. Working Draft, June, 1988, subsequently updated "Future Scarcities of Scientists and Engineers: Problems and Solutions", Working Draft, April 13, 1990, Washington, DC.

The relationship between 22-year olds and NS&E bachelors degrees (exclusive of computer science) awarded in the U.S. over the past 30 years is shown in Figure 1. When computer sciences are excluded, and the shift of graduation age to 23 is (roughly) reflected by shifting the right hand-side of the BS curve a year to the right, the similarity between the NS&E-less-computer-sciences bachelor's degree curve to the college-graduate age cohort is remarkable.

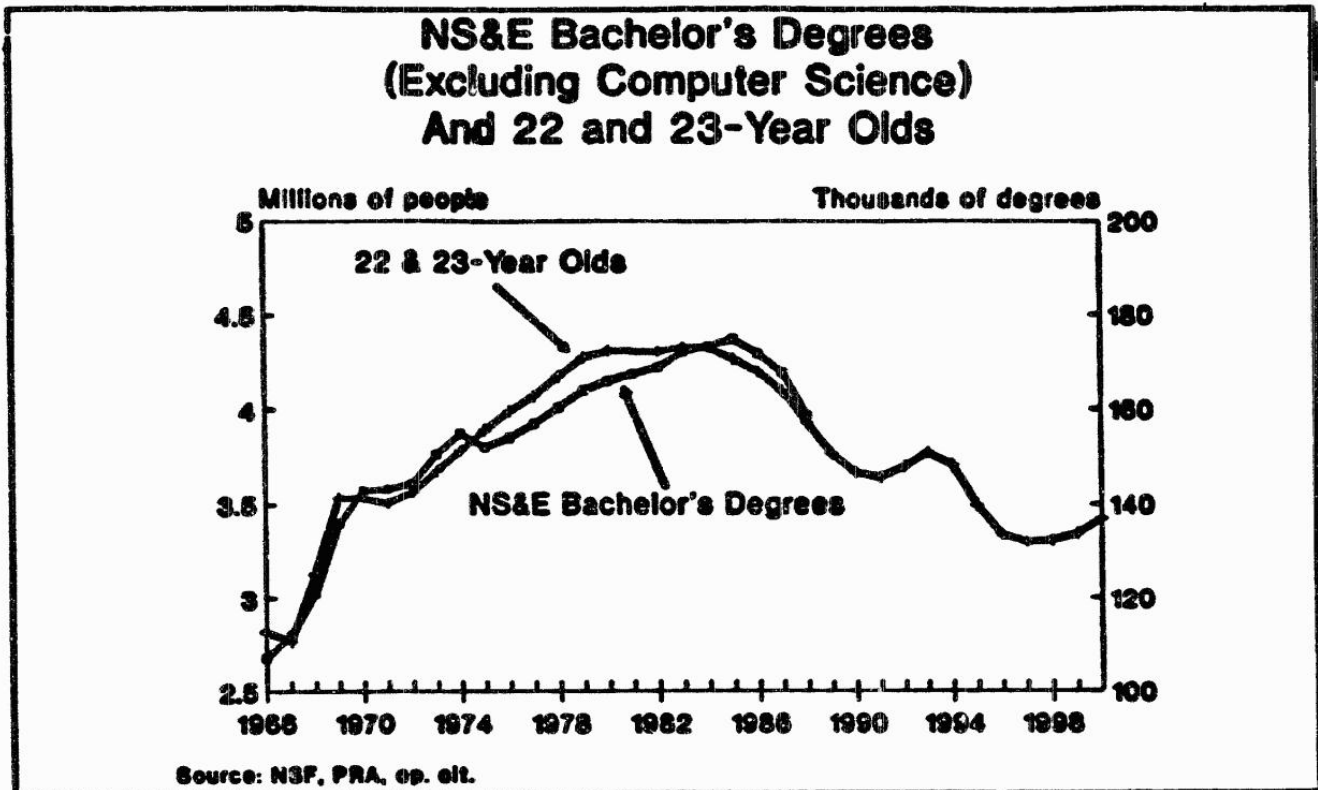


Figure 1

A recent survey of U.S. college freshmen intentions about their planned college major found that interest in NS&E fields in the last two years has been in decline. Combined with freshmen enrollment data, this finding suggests there will be fewer NS&E bachelor degree holders four years hence, 1993 and 1994. This short-term projection corresponds well with the projection based on demographic evidence alone. (Figure 2).

At the PhD level, expected departures of older science and engineering personnel in industry and academe will increase demand for replacement of NS&E PhD's between 1990-2006.

These combined considerations led to the earlier paper's conclusion that, without some sort of intervention to increase interest in NS&E fields in undergraduate education and the retention of students already in those majors, the United States was headed for a "shortfall" of trained scientists and engineers. Here, "shortfall" was defined differently for bachelor's degree holders than for PhDs.

For bachelor's degrees, the "shortfall" is defined as a cumulative reduction in production of NS&E bachelors degrees below some recent level (specifically, the average annual number granted during 1984-86) as estimated by those projected to be produced (absent interventions) in the next fifteen



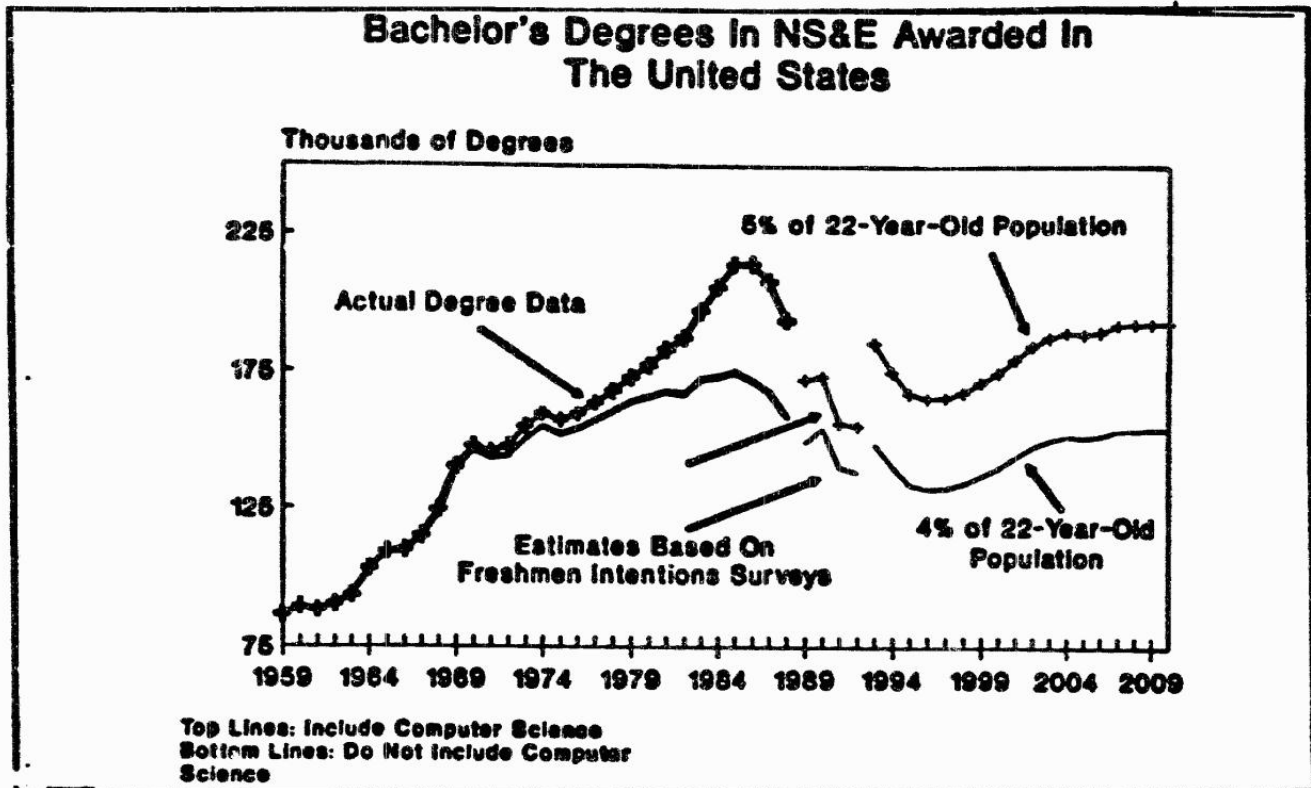


Figure 2

years. It was calculated to be about 675,000 by the year 2006. (This definition was used because, in the absence of a projection of demand for new NS&E bachelor degree holders, a constant level was assumed as a conservative estimate of how many will be demanded.)

For PhD NS&E personnel, estimates of demand were made, based on historical relationships between R&D dollars in various sectors of the economy as well as enrollments for the academic sector. The shortfall in that case was defined as the cumulative difference between this history-based projected demand and history-based projected degree production. In reality the supply and demand equilibrate somewhere in the middle - so the shortfall concept is a way of expressing the probability of future substitution of resources away from new scientists and engineers, as well as future relative salary increases. For PhDs, the expected shortfall is exacerbated by the expected retirements of large numbers of existing PhD's in universities and in industry.

These two shortfalls can be expressed as very rough yearly targets: the U.S. could probably fruitfully use about 30,000 extra NS&E bachelor's degrees a year for the next 15 years, and about 6,000 extra PhDs a year beginning in the late 90's.

## B. POTENTIAL FOR A WORLD-WIDE SHORTFALL OF NATURAL SCIENTISTS AND ENGINEERS

### Demographic Trends

Demographic changes in the United States--particularly the effects of the "baby bust"--are now being felt on American college campuses, where declining enrollments were noted for the freshman class matriculating in the fall of 1990<sup>2</sup>. Similar demographic patterns are expected over the next fifteen years in some other countries at differing times and in differing degrees outside the United States. Figure 3 shows population data from 29 industrialized and newly industrializing countries which are the major producers of NS&E degrees. For each country, the size of the cohort aged 20-24 is shown for each of 6 years, at five year intervals. The countries are grouped into three categories:

- 1) countries with increasing numbers of 20-24 year-olds, (Figure 4);
- 2) countries whose 20-24 year-old cohort declines after about 1990, (Figure 5);
- 3) those, like the United States, with a decline and then an increase, (Figure 6).<sup>3</sup>

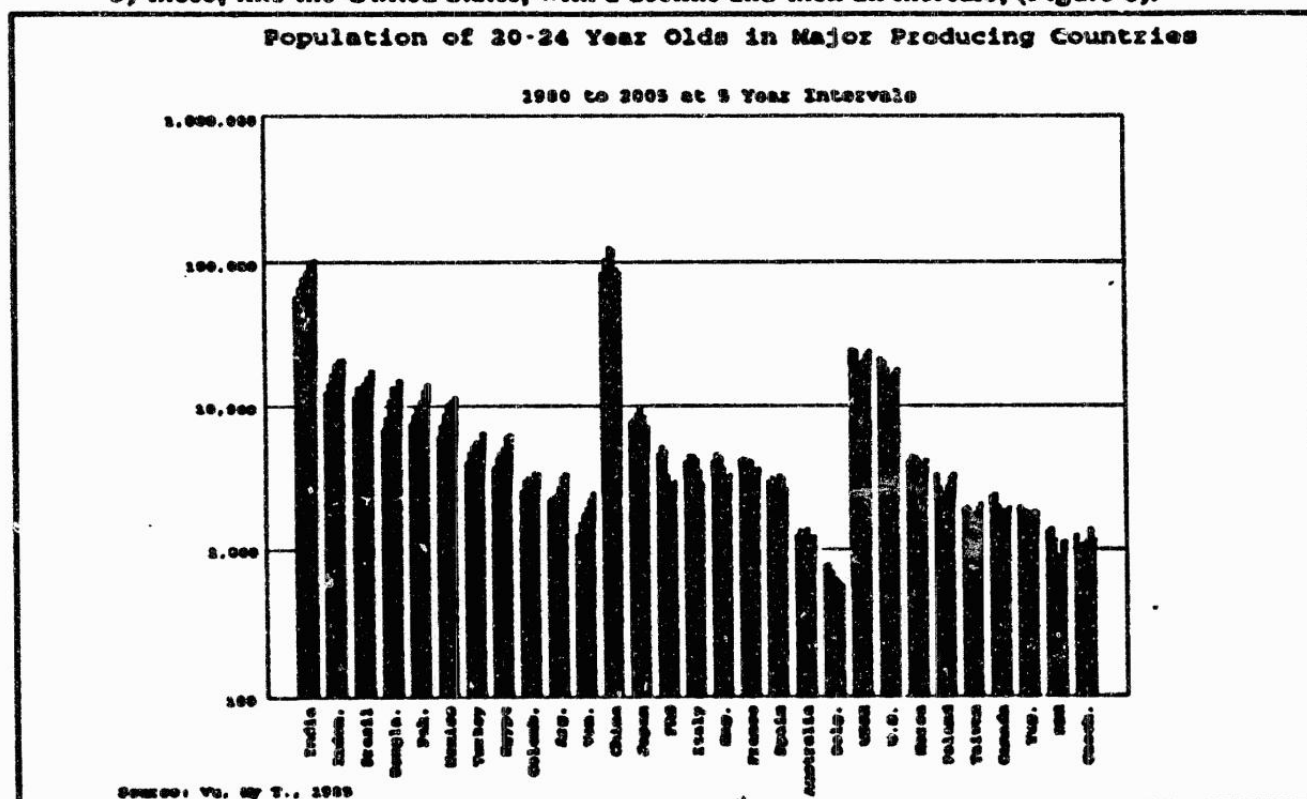


Figure 3

<sup>2</sup>Wall Street Journal, B1, June 18, 1990.

<sup>3</sup> Because India and China so dominate the scale in Chart 3, Charts 4, 5 & 6 show the same data but in index form, so that the relative rates of growth and decline can be compared. Chart 3 includes a cluster for all 29 countries combined, showing an overall increase.

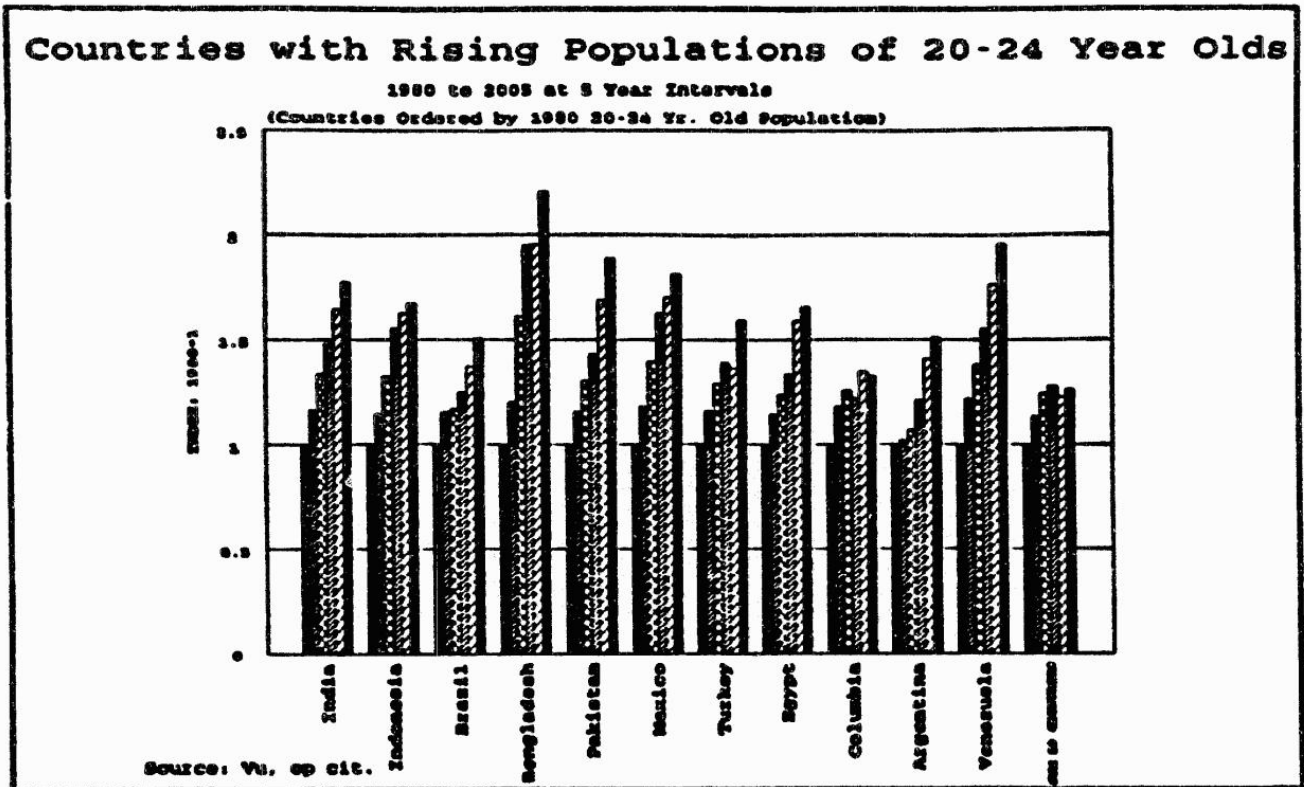


Figure 4

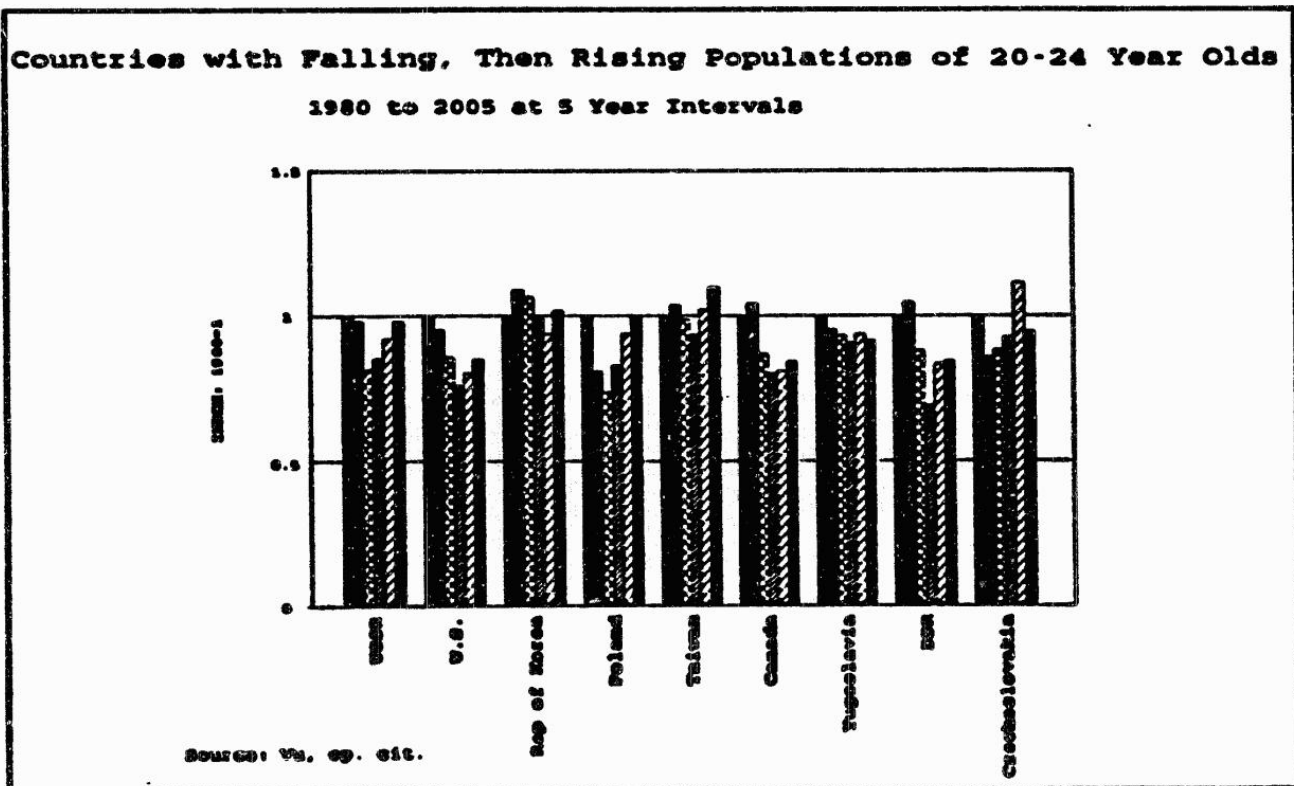


Figure 5

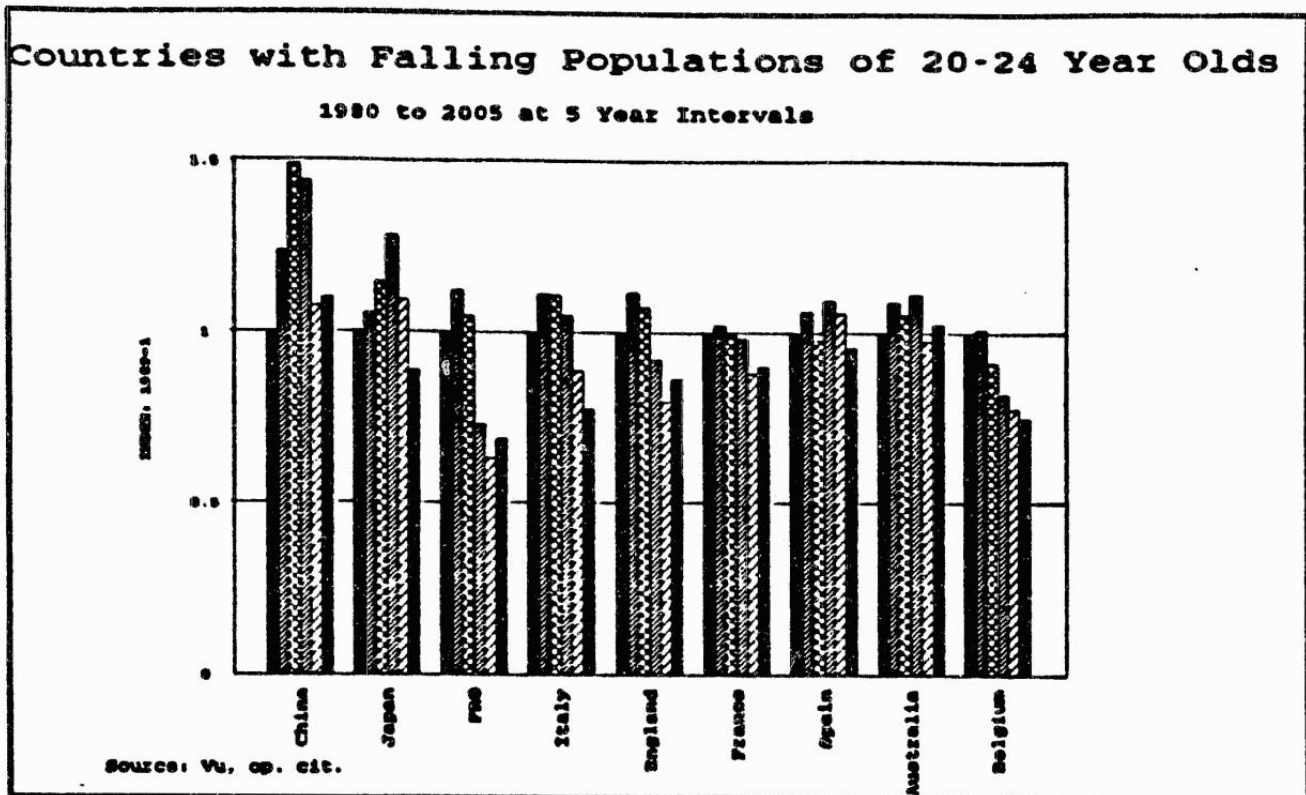


Figure 6

### NS&E Bachelor Degree

Figure 7 shows the number of bachelor's degrees in NS&E<sup>4</sup> for various recent years in a number of countries. A rough estimate for the total number of NS&E degrees produced in 1985 by the combined 29 countries shown in Figure 3 is 1,250,000. If a relationship like the one between college age cohorts and BS degree production in the United States exists in other countries, it is possible to roughly forecast the number of BS degrees in those countries on the basis of their future college-age population.

Using demographic data for 20-24 year-olds (divided by five to approximate the number of 22 year-olds) in each country listed above, a projected cumulative change in bachelor's degrees for each country (Table 1) was calculated by dividing recent BS degrees awarded by the current population of 22 year-olds in each country to determine a relatively recent ratio of BS degrees in NS&E fields to college graduate age cohorts. That ratio was applied to the forecasted population of 22 years-olds. The result is the number of NS&E BS degrees that would be produced in future years, if the current ratio to 22-year-olds persists.

<sup>4</sup>UNESCO data breaks degrees into three (among others) sets of fields which are summed and called NS&E: 1) biological sciences, physical sciences, environmental sciences, and math and computer sciences; 2) engineering; and 3) agricultural sciences.

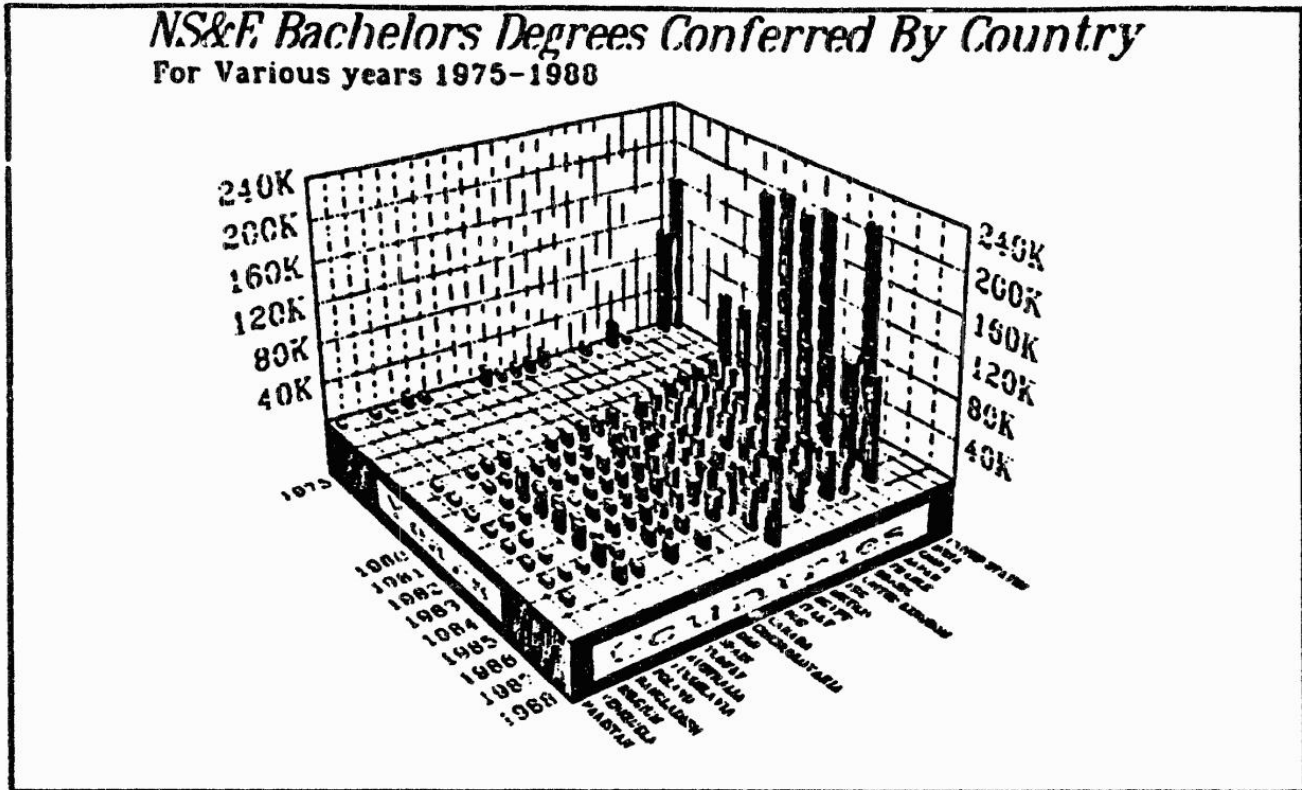


Figure 7

For each country, the total number of projected BS degrees was then subtracted from a recent yearly number of BS degrees. By adding together all of the cumulative changes in BS degree production from countries in the various demographic categories mentioned above, total change in the number of BS degrees produced by all of the countries shown was calculated. The cumulative change shown is negative for each of the three future time periods, 1995, 2000, and 2005, indicating that world-wide production of BS degrees in NS&E fields could cumulatively decline worldwide in the next fifteen years.<sup>5</sup>

A few countries, for which degree data were not easily available, were estimated using other pieces of information. The USSR, for instance, is a major source of NS&E degrees, but is not included in the UNESCO data. There is some information<sup>6</sup> about the ratio of degrees to 22-23 year olds in the USSR for earlier years, which was adapted to estimate roughly USSR's NS&E bachelor's degrees. It is widely thought that the USSR definition of 'engineer' is more inclusive than other countries', so the ratio was modified downwards accordingly. A few countries were estimated from their

<sup>5</sup>Note that excluding the US, the cumulative totals would be positive.

<sup>6</sup>The Science Race: Training and Utilization of Scientists and Engineers, US and USSR, Catherine P. Ailes and Francis W. Rushing, Crane Russak, New York, 1982.

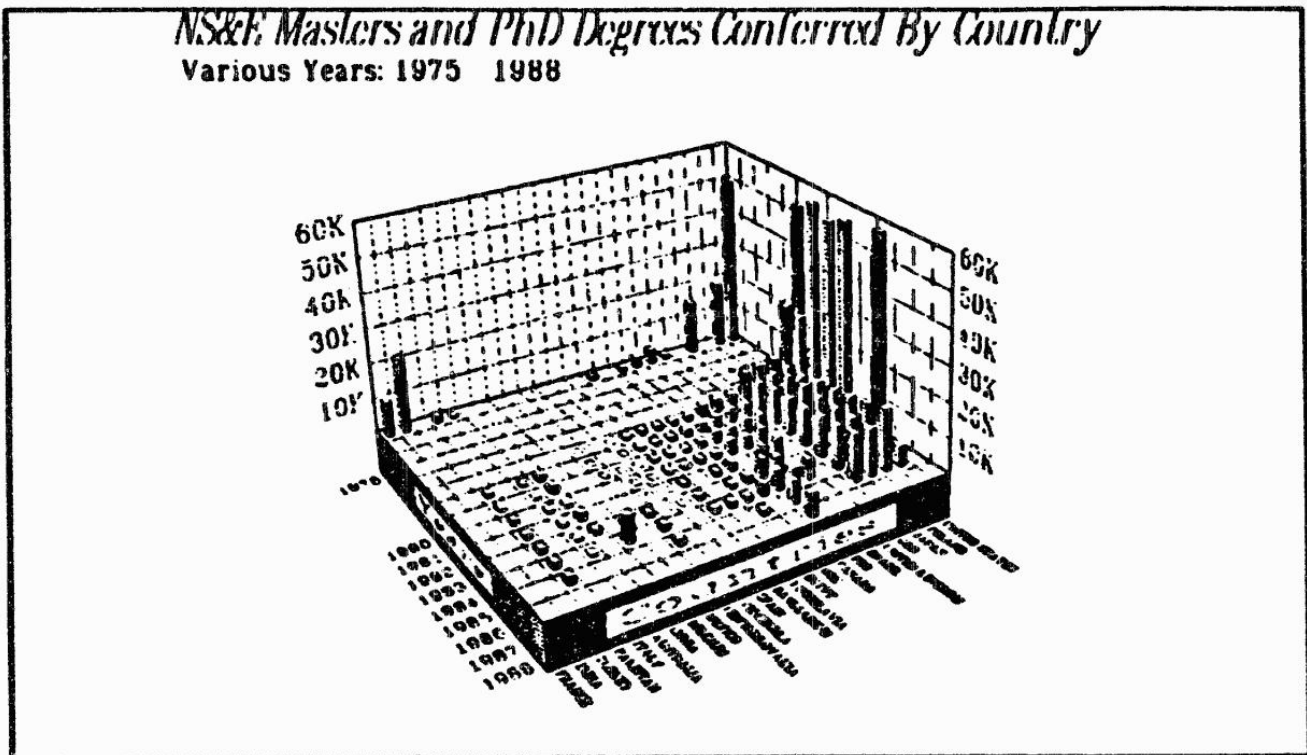
## POTENTIAL NS&amp;E BS DEGREES IN OTHER COUNTRIES

COUNTRY	# 22 YR OLDS 1990 (Mill.)	RECENT NS&E BS RATE (BSs/22 YR OLDS)	PROJECTED CUM. CHANGE OVER		
			RECENT BS PRODUCTION		
			1995	2000	2005
USA	37	52%	-233	-419	-552
<b>COUNTRIES WITH RISING # 22 YEAR OLDS</b>					
INDIA	16.7	-1%	212	456	783
INDONESIA	3.4	# 1%:	54	112	177
BRAZIL	2.8	13%	2	26	70
BANGLADESH	2.2	05%	24	49	78
PAKISTAN	2.0	02%	12	20	32
MEXICO	1.8	24%	48	110	186
TURKEY	1.0	13%	2	5	17
EGYPT	1.0	24%	20	35	69
COLUMBIA	0.6	# 13%:	3	7	12
ARGENTINA	0.5	# 13%:	5	14	27
VENEZUELA	0.4	18%	6	15	29
<b>TOTAL</b>			<b>388</b>	<b>869</b>	<b>1480</b>
<b>COUNTRIES WITH DECLINING # 22 YEAR OLDS (OR RISING THEN DECLINING)</b>					
CHINA	25.4	0.6%	92	33	-119
JAPAN	1.8	6.1%	74	110	65
FED.REP.GERMANY	1.0	4.0%	-53	-135	-222
ITALY	0.9	1.9%	-3	-15	-39
ENGLAND	0.9	5.2%	-29	-83	-144
FRANCE	0.8	5.0%	-13	-37	-104
SPAIN	0.6	2.3%	-13	-12	-19
AUSTRALIA	0.3	4.5%	-1	-3	-11
BELGIUM	0.1	4.5%	-6	-13	-21
<b>TOTAL</b>			<b>48</b>	<b>-157</b>	<b>-614</b>
<b>COUNTRIES WITH DECLINING THEN RISING # 22 YEAR OLDS</b>					
USSR	4.0	# 5%:	-300	-409	-441
(US)	3.7	52%	-233	-419	-552
KOREA	0.9	5.0%	-14	-40	-60
POLAND	0.3	3.7%	-28	-24	-10
TAIWAN	0.4	# 5%:	-11	-15	-12
CANADA	0.4	4.9%	-28	-51	-71
YUGOSLAVIA	0.4	2.5%	-2	-3	-4
CZECH.	0.2	8.1%	6	24	40
GERM.DEM.REP.	0.2	4.6%	-19	-34	-44
<b>TOTAL</b>			<b>-629</b>	<b>-971</b>	<b>-1154</b>
<b>GRAND TOTAL OF COUNTRIES SHOWN</b>			<b>-193</b>	<b>-259</b>	<b>-288</b>

Table 1

population using a degree/population ratio from a similar country: Taiwan estimates use Korea's ratio, Indonesia and Pakistan use India's, and Columbia and Argentina estimates are based on Brazil's ratio.<sup>7</sup>

Figure 8 shows data on NS&E Masters and PHD degrees conferred by country. Heroic assumptions would be required to project the production of these degrees. First, these advanced degrees in NS&E are not a very constant proportion of an age cohort in the U.S. (for which we have more complete data). Second, the data shown are incomplete and bear ratios to bachelors degrees that are not always credible. There is no obvious reason to expect a substantial increase in international production of NS&E graduate degrees soon.



**Figure 8**

### World-Wide Demand For NS&E Personnel

As economic systems of individual countries are integrated into a larger global technological system and economic growth continues, it is plausible to expect demand for NS&E personnel (whose particular training and skills seem necessary to continuing technical and economic advance) to rise. Indeed, limited available data suggest this to be the case. Figure 9 shows, the number of "economically active" scientists and engineers for all the countries for which more than one recent year was available

<sup>7</sup> Compared to the shortfall analysis done in PRA's earlier paper, the numbers shown in Table 1 are much rougher and more uncertain. They are based on very few years of degree data for most countries. The number of 22-year-olds is crudely estimated by dividing the 20-24 year-old cohort by five. The ratio of degrees to age cohort bounces around in some countries, and the degree data are clearly noisy. As an example, the BS shortfall for the US, using these data sets and methods, amounts to about 552 thousand by the year 2005, rather than the 675 thousand found in the earlier paper by the year 2006. This difference reflects different data and different data precision, rather than any different concept. More precise population data for the foreign countries combined with more years of degree data would permit better examination of relationships between degrees and population. The estimates here are an initial foray.

---

---

*INTERNATIONAL PRODUCTION OF SCIENTISTS  
AND ENGINEERS*

---

---

---

*NATIONAL SCIENCE FOUNDATION*

*Directorate for Scientific, Technological  
and International Affairs*

*Division of Policy Research and Analysis*

---

*WORKING DRAFT  
Fall, 1990*



Recent findings about a probable decline in the production of natural scientists and engineers in the United States over the next two decades raises a number of issues. This paper will explore two important questions relevant to addressing these issues using available data of known trends.

- Are the other major producing countries facing a similar future?
- Will international migration of natural scientists and engineers mitigate or exacerbate the situation?

This paper examines the available data on the population trends and the production of natural scientists and engineers (NS&E's) among the major producing countries, including the U.S. These countries are defined as those which produce annually 20,000 or more bachelors degrees in science and engineering. There are 29 such countries, and they produce about 90 percent of the world's bachelors degrees in science and engineering. The paper also examines international migration patterns of natural scientists and engineers, both as students and as members of the labor force.

#### Preliminary Findings:

- Worldwide production of trained scientists and engineers has increased as population has grown, demand has grown, and educational opportunities have expanded;
- Several countries in addition to the United States will experience declines in the college age cohorts within the next twenty years, though at different times;
- If the relationship of college age cohorts to bachelors degrees in NS&E is of other countries is fairly stable (as it has been in the U.S.), a net decline in the number of NS&E bachelor's degrees worldwide is expected between 1985 and 2005;
- A similar pattern may occur relative to NS&E Masters and PhD degrees worldwide;
- Though under past U.S. immigration rules, international migration was unlikely to offset potential supply shortfalls in a major way, recent (October 1990) liberalization of the U.S. immigration rules could mitigate the U.S. shortfalls to a large extent. But increased competition for NS&E's may reduce their desire to come to the U.S.

#### A. SUMMARY OF A STUDY POINTING TO A U.S. SHORTFALL

A recent study by the Division of Policy Research and Analysis in the National Science Foundation begins with the fact that the U.S. will experience a decline of twenty-five percent between 1983 and 1996 in the age group typical of college graduates. The median age of college graduates was about 22 years for many years; by 1989 it increased to about 23. A central finding of PRA study is the existence over the long-term of a fairly constant relationship between the number of 22-year-olds<sup>1</sup> and the annual number of bachelors degrees awarded in natural science and engineering. The relationship is most stable historically if the field of computer sciences is excluded from the set of fields examined. Although there is little evidence to suggest that this

---

<sup>1</sup> "Personnel In Natural Science and Engineering", National Science Foundation, Directorate for Scientific, Technological and International Affairs, Division of Policy Research and Analysis, Working Draft, June, 1988, subsequently updated "Future Scarcities of Scientists and Engineers: Problems and Solutions", Working Draft, Summer 1990, Washington, DC.

The relationship between 22-year olds and NS&E bachelors degrees (exclusive of computer science) awarded in the U.S. over the past 30 years is shown in Figure 1. When computer sciences are excluded, and the shift of graduation age to 23 is (roughly) reflected by shifting the right hand-side of the BS curve a year to the right, the similarity between the NS&E-less-computer-sciences bachelor's degree curve to the college-graduate age cohort is remarkable.

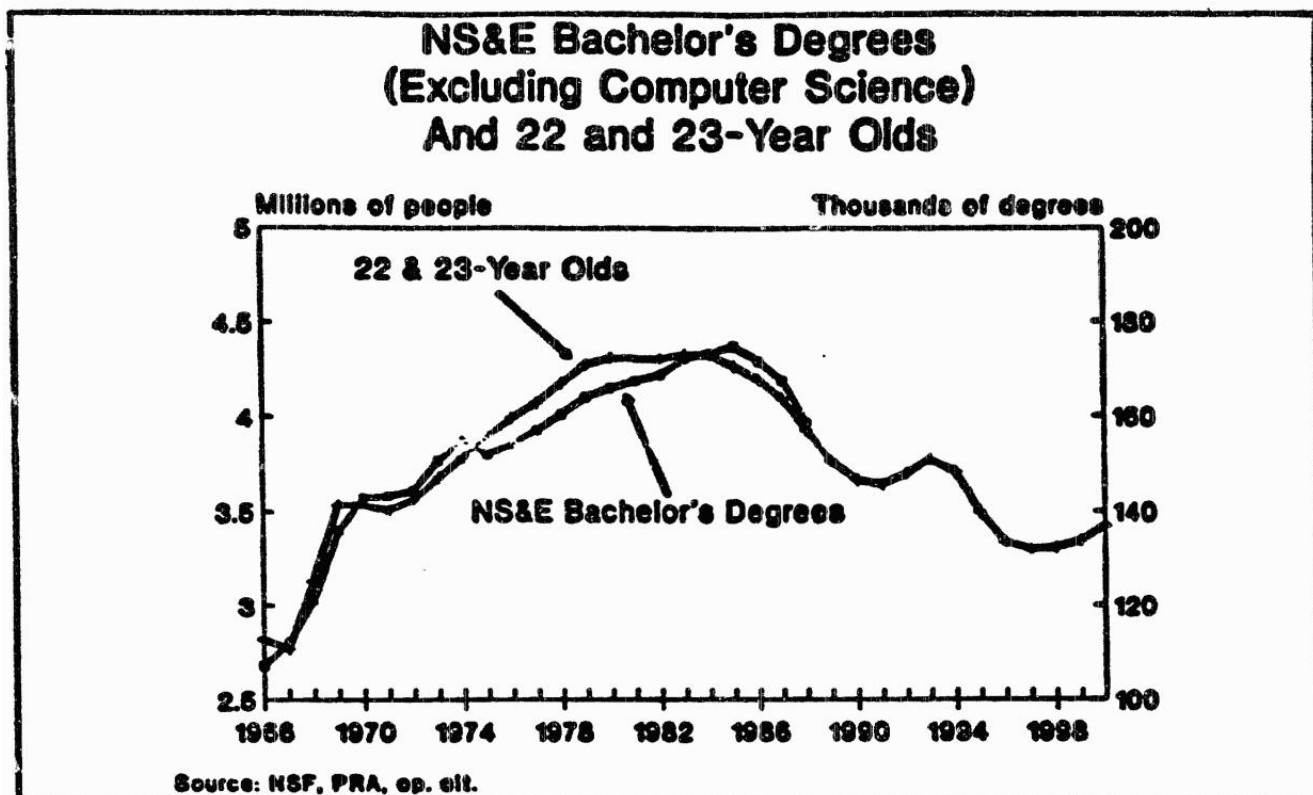


Figure 1

A recent survey of U.S. college freshmen intentions about their planned college major found that interest in NS&E fields in the last two years has been in decline. Combined with freshmen enrollment data, this finding suggests there will be fewer NS&E bachelor degree holders four years hence, 1993 and 1994. This short-term projection corresponds well with the projection based on demographic evidence alone. (Figure 2).

At the PhD level, expected departures of older science and engineering personnel in industry and academe will increase demand for replacement of NS&E PhD's between 1990-2006. These combined considerations led to the earlier paper's conclusion that, without some sort of intervention to increase interest in NS&E fields in undergraduate education and the retention of students already in those majors, the United States was headed for a "shortfall" of trained scientists and engineers. Here, "shortfall" was defined differently for bachelor's degree holders than for PhDs.

For bachelor's degrees, the "shortfall" is defined as a cumulative reduction in production of NS&E bachelors degrees below some recent level (specifically, the average annual number granted during 1984-86) as estimated by those projected to be produced (absent interventions) in the next fifteen