THE PIPELINE FOR SCIENTIFIC AND TECHNICAL PERSONNEL: PAST LESSONS APPLIED TO FUTURE CHANGES OF INTEREST TO POLICY-MAKERS AND HUMAN RESOURCE SPECIALISTS

(NSF: Division of Policy Research and Analysis)

The National Science Foundation (NSF) has collected extensive data covering science and technology activities in the U.S. since the 1960's. Other agencies and professional associations have also collected data for decades that bear on resources used in science and technology activities (particularly human resources). Recorded changes in the levels of these activites over the last 25 years are a roadmap of changes in national priorities, either federally or collectively expressed.

This paper deals with the the "production" and employment of scientists and engineers. NSF data (and data from other sources) will be employed to describe past, present, and future developments in these activity areas. We have learned from past experience in ways that will contribute to planning for the future.

Currently, a growing national priority has been the quality and quantity of human resources engaged in science or technology, particularly entry level natural scientists[1] and engineers (NS&Es) newly graduated from U.S. colleges and universities.

This area of concern is certainly not new. In a world in which military and civilian economic competition depend importantly on the development of new technologies, NS&Es are important national resources that are frequently in the public eye. There have been numerous instances during the last 45 years in which high-ranking national figures have called for national action to increase the flow of college students into NS&E fields, either directly or indirectly. These calls for action were often in reaction to temporary shortages of specialists narrowly located within the broad domain of NS&E. The shortages, however, were swiftly eradicated without major focused policy initiatives[2] through market forces and minor adjustments by employers: recent graduates switching occupations, students switching majors, and relaxation of required credentials with expanded on-the-job training.

[1. The natural sciences are comprised of the physical sciences (chemistry, physics, geology, oceanography, atmospheric science, and astronomy), the life sciences (the agricultural sciences, the biological sciences, and the medical sciences, but not the health sciences), and the math sciences (mathematics, statistics and computer science).]

[2. We are differentiating between policy initiatives focused on single fields and federal programs of support broadly applied. It has been a national priority for decades to provide subsidies to education to yield a steady flow of talented students (cont.)

Despite this historical tendency towards alarmism, current concerns rest on firmer ground. Demographically, the U.S. and its major economic or military rivals have embarked on a path leading ultimately to zero or negative population growth. Post World War II birth rates began to drop in the early 1960's and declined to levels yielding eventual zero or negative population growth rates in the mid-1970's.[3] No matter how long into the future the current low birth rates persist, the birth rate has been depressed long enough so that if present NS&E use patterns persist, future shortages of NS&E's will be more than narrowly located in specialized subsectors of NS&E. Most probably, shortages will be experienced broadly within major field groupings of NS&E (and in other occupational areas as well).

Figure 1 indicates the demographic changes in the population of 22-year olds in the U.S. and their expected effects. The "4% of 22-year olds" population line indicates the size of the decline in population of 22-year olds that began in the early 1980's and will continue until 1996. The "B.S. Degrees" line indicates that future labor markets for NS&Es are facing an additional restriction, encountered in other professional occupations in the form of arbitrary, institutionally determined limits placed on the number of new graduate students (e.g. in medicine). During the last 30 years, only a maximum of 4.3% of the 22-year old population annually has acquired bachelors degrees in NS&E fields (excluding computer science --- a new field). A minimum of 3.7% have acquired these degrees. This suggests that increasing the proportion of students in traditional NS&E fields will be very difficult, e.g. that students may be preselecting fields of potential undergraduate major in ways that reflect their high school and junior high school experiences far more than concurrent market signals during their early years in college.

Barring major improvements in organizational effectiveness or support equipment for NS&Es, shortages of the "classic" economic type will develop in the late 1990's and beyond. Fungibility of human talent will prove much less effective in buffering short term dislocations than it has in the past because the supply of skilled entry level people will be shrinking across the board. In addition, large organizations will find themselves coping with internal stress brought on by pay compression. The result will be renewed efforts to bring higher percentages of minorities and

---

[2...into science and engineering degree programs. The NSF has provided base level support to students in NS&E programs and to science curriculum development, while other agencies and programs have at times provided substantial boosts in student subsidies, such as the National Defense Education Act fellowship program.]

[3. In the opinion of many demographers, this decline in the U.S. birth rate had its origins in the 19th century, and a steady decline was only briefly interrupted by the 1930's baby bust and the post World War II baby boom.]

women into NS&E fields, relaxed attitudes towards immigration of skilled foreign nationals, greater subsidies of higher education (per student), and higher real salaries for skilled workers at all levels. The roots of these forecasts are already in evidence for workers of young ages; wage rates for "fast" food establishments have risen substantially above the minimum wage level in most large SMSA's in the Washington D.C.- Boston urban corridor, the region with the largest decline in young people.

However, let us turn to a broad perspective before continuing with this train of thought, because this perspective yields evidence that there is sufficient aggregate indecisiveness in undergraduates choice of undergraduate major that national policy could influence the baccalaureate "yield" from a given age cohort of students.

THE NS&E PIPELINE

Data from the Department of Education and 3 longitudinal surveys of single age cohorts initiated during high school provide the quantitative basis for constructing the so-called NS&E pipeline. This pipeline describes the numbers of students of the same age cohort indicating interest (before college) or intentions (after initial college enrollment) to acquire progressively more advanced training in NS&E fields (See Figure 2). Using a composite of information, Figure 2 begins with the approximately 4 million U.S. high school sophomores in 1977, indicating that 730 thousand were interested in NS&E careers at this point in their lives.[4] While it is evident that major attrition in interest has already occurred by the high school sophomore year, it is still true that the remaining 18 percent would produce far more NS&Es than are needed if this entire group persisted through the baccalaureate level with their interest in NS&E fields. However, the number of interested females at this point is less than one-third the number of interested males, indicating that substantial sex-role stereotyping still exists.

Most recent data indicate that by their senior year in high school, 15 percent (or 590 thousand) were still interested in NS&E careers.[5] More than on-half of the attrition that occurred was due to the "dropout" from high school (about 1 out of 7) of students expressing interest in NS&E in their sophomore year.

[4. The stability of this percentage (18%) is not known because only the most recent of the 3 longitudinal surveys began with students this young.]

[5. This compares to 13 percent of high school seniors in the earlier "High School and Beyond" survey.]

The attrition from high school seniors to college freshman is quite large; "only" 340 thousand (8.5% of the age cohort) indicated an intention to major in some field within NS&E, according to the first "High School and Beyond" survey. This represents a 43 percent attrition from the high school senior year. Of this 43 percent, about one-third (14 percent) can be attributed to the loss of students who intended a year earlier to go to college, but did not enroll in college.

The attrition rate for all other fields combined was substantially less at 4 percent. In fact, because this rate is less than the 14 percent loss of students intending to enroll in college, it suggests that a re-evaluation of skills and interest by new college students plays an important role in accounting for the 43 percent attrition of potential NS&E majors.[6]

Field Switching During Undergraduate Years.
(These data are not reported in Figure 2.) Of these 340 thousand 1980 freshman with intentions to major in NS&E fields, 250 thousand were in 4-year colleges and universities and 90 thousand were in 2-year colleges. According to the first High School and Beyond survey, of the 250 thousand freshman in 1980, only 110 thousand were NS&E majors in their junior year (1982). Sixty thousand had switched to other major fields and 80 thousand had either dropped out of college or switched to 2-year colleges (with an unknown number remaining in NS&E fields). There were compensating flows, however. Fifty five thousand students intending to major in non NS&E fields in their freshman year had shifted to NS&E fields by their junior year. Another 55 thousand students shifted into NS&E majors at 4-year colleges[7] from either 2-year colleges (40%) or after temporarily dropping out of school (60%).

[6. The most recent "High School and Beyond" survey indicates a much lower rate of attrition for NS&E students --- only 30 percent --- but of more significance is the similarity in both surveys of the continuation rate of NS&E-interested high school seniors into college freshmen intending NS&E majors in 4-year colleges or universities. This figure was 42 percent for the first survey and 45 percent for the most recent survey. NS&E-interested high school seniors continuing on into NS&E majors in 2-year colleges rose from 15 percent to 25 percent. We used the earlier figures because we believe that the large increase reflects a temporary surge in interest in computer-related careers.]

[7. It is not known what fraction of students returning to the pipeline had at earlier survey points indicated their intention to enroll in college in an NS&E field. One-half of the students switching in from 2-year colleges had also been NS&E majors at those 2-year colleges.]

The above data indicate that students in 4-year institutions switching majors between NS&E fields and other fields are virtually offsetting flows, yielding a small net loss (5,000 to 10,000) to NS&E. Students shifting into and out of 4-year institutions (before completing baccalaureates) produced a net loss of NS&E majors of nearly 25 thousand, or 10 percent of the freshman class in the NS&E pipeline. The overall attrition rate is not large --- about 13 percent. However, 4-year college students remaining in college but moving out of intended NS&E majors represent 25 percent of the freshmen that indicated this intention, a fairly substantial loss.

A somewhat similar pattern of pipeline flows is observed during the transition from junior year in college to receipt of baccalaureate degree.[8] On the surface of things, there is very little attrition --- 218 thousand junior majors produced 206 thousand baccalaureates in NS&E --- about 5 percent. However, this masks much larger shifts among college students. Only 135 thousand junior majors continued on to completion in NS&E, 25 thousand finished in other fields, and 55 thousand did not finish (either converting to a part time status or leaving their 4-year institution before completing their bachelor's). On the other hand, 30 thousand students that received NS&E baccalaureates were not majoring in NS&E during their junior year and 40 thousand students that received NS&E baccalaureates were transfers from 2-year colleges or students returning to the college pipeline after dropping out temporarily.[9] Summarizing, field switching within 4-year institutions from the junior year to graduation produced a small net gain of 5,000 but dropouts exceeded returnees by 15,000.

Flows Beyond the Completion of Undergraduate Training

Some of the 206 thousand graduates in NS&E fields continued their education without interruption at the graduate level. However, others also will return for graduate studies at a later point in the course of their professional lives. Sixteen percent of the 1984 graduates were in graduate school in an NS&E field in 1986 (32,000). Figure 2 indicates the higher figure of 61,000 to include 5,000 NS&E graduate students in 1986 with bachelor's degrees in non NS&E fields and to allow for those BS graduates who will attend graduate school later (about 24,000).[10]

[8. We have used the actual number of BS degrees awarded to NS&E majors in 1984 as the figure applicable to the high school class of 1980. This is a simplification of reality --- but a reasonable portrayal of the eventual NS&E degree production from this age cohort.]

[9. How many of these "returnees" had previously departed the NS&E pipeline is not known.]

[10. Also, it is of some policy interest that 36,000 of the 206,000 graduates were in other graduate or professional degree programs in 1986.]

The time dimension of the NS&E pipeline has fragmented considerably by the time of conferral of master's degrees, which is treated as happening in 1986 in Figure 2. In reality, the 46 thousand master's degrees will be received over a broad period of time beginning in 1985. (Based on past data, the yield from enrollment in graduate school is expected to be about 75 percent at the master's level). Past data also indicate that nearly 10,000 U.S. citizens belonging to this age cohort will acquire PhD degrees. This event is indicated as occurring in 1992, 8 years after receipt of BS degree, because 8 years has been the long run median time from initiation of graduate studies to PhD degree in the NS&E fields. In real time, these doctorates will be received from 1987 to beyond the year 2000. Using a somewhat simplified construct (the ratio of PhD's in year "t" to BS's in year "t-8"), the percentage of BS degree holders receiving PhD's appears to have stabilized at 5% since the late 1970's.[11]

ACCURACY OF PIPELINE DATA

The pipeline concept provides two types of useful information. It describes past rates of continuation and --- if these rates are stable --- it allows predictions of future new graduates. The retrospective population and degree data used to describe the historical pipeline are accurate. It is extremely unlikely that these data differ by more than 5 percent from the true figures. The intermediate steps in the pipeline, referencing NS&E interest or the intention to major in NS&E fields, are based on relatively small although carefully constructed population samples (one person per 350). As an example of the sampling error, consider that the true value of the estimated 18% of high school sophomores interested in NS&E careers has a 95% chance of being within the interval (16.9% to 19.1%), and that the true value of the estimated 5% of these same high school sophomores who earn NS&E bachelor's has a 95% chance of being within the interval (4.4% to 5.6%).

The PhD terminus of the pipeline cannot be estimated accurately by means of the longitudinal survey samples, because the samples are too small. Even if the evident calculated rate of about 25 PhD's per 1000 H.S. sophomores were reproduced through this sample approach, a 95% confidence interval would range from 11 to 39 per thousand. Consequently, the PhD figure used in the pipeline figure was predicted as 5% of the 1986 bachelor's degrees in NS&E fields. This rate (5%) has been 90% accurate (or

---

[11. The "true" rate of continuance from the bachelor's to the doctorate degree is difficult to calculate from available data, is not calculable until many years after the majority of the BS degree recipients from a given age cohort have received their BS degrees, and, hence, is not very useful to policymakers. Consequently, we have adopted the convenient approach of pretending that the median time-to-PhD has a very small standard deviation (< 3 months) rather than a large one (> 3 years).]

better) in describing the measured BS to PhD rate since 1978, using the simplified pipeline concept.

The pipeline concept itself is a simplification of reality, as discussed earlier, but is the kind of simplification that is useful for forecasters, policymakers, and long term planning. Two major simplifications are that BS conferrals are made to 22-year olds and that PhD conferrals are made to 30-year olds. (The first is closer to actual experience than the second.) The key reason we employ such simplifications is to allow timely information to be provided to policymakers and human resource specialists. The remainder of this paper will provide some detail as to how this information is joined with other information and used for future planning.

MONITORING THE PIPELINE PARAMETERS FOR STABILITY

Linkages Through the Baccalaureate Degree

The value of the pipeline concept as a planning tool is improved if some of its key parameters are monitored on a periodic basis. at least several opportunities are available to undertake such monitoring. Perhaps the most crucial linkage is the rate of conferral of baccalaureate degrees in traditional NS&E fields (to a hypothetically age-homogeneous subgroup of the population of 22-year olds). In the introduction to this paper it was mentioned that this annual rate has been within the narrow band from 3.7% to 4.3% since the late 1950's (see Figures 1 & 3). This finding, first noted by Brode in the early 1970's[12], has been sustained since then with virtually no change in the conferral rate of 4% in the same fields of NS&E that were recognized in the early 1970's. This finding appears to indicate a truly stable relationship between population and BS-level training, reflective of a saturation of the population proportion both interested in the NS&E fields and able to earn undergraduate degrees in them.

Given the turbulence characterizing student decisions to continue in the education pipeline and in the NS&E branch of this pipeline, the low variance in the annual percentage of 22-year olds receiving traditional NS&E baccaluareates is remarkable. Figure 3 also indicates that there was a major jump in BS degree conferrals in the computer and information sciences during the 1980's. This jump does not appear to be be at the expense of majors drawn from traditional NS&E fields, but rather at the expense of majors in fields outside of NS&E. The key issues are whether new computer science degree holders would have completed college and if they would have picked another NS&E field if computer science had not been available. Because the evident low degree of field switching from traditional NS&E fields to

----

[12. W. Brode, "Manpower in Science and Engineering, Based on a Saturation Model", Science No. 16, 1971, pp. 206-213.]

computer science cannot be proven empirically, it is inferred from the relatively unchanged rate of conferral of BS degrees in traditional fields (evident in Figure 3) and from fragmentary evidence of the very unstandardized requirements for bachelor's degrees in the relatively new field of computer science. During the last 30 years, changes in the conferral rate in any other field in NS&E have been reflected in offsetting changes in the remaining NS&E fields. Figure 4 indicates this point broadly by showing the substitution back and forth along a rising trend line between engineering and traditional natural science fields during 1959 to 1986.

An alternative hypothesis is that the pool of potential new BS-level natural scientists and engineers has grown relative to the population from which this pool is realistically drawn. If true, this alternative hypothesis would be good news for policymakers worried about impending future shortages.

Data collected annually by the American Council on Education (ACE) since the late 1960's have sought to profile freshman field intentions. These data allow us to check 4 years beyond the most recent published degree data for possible deviations from historical rates of BS conferrals in NS&E fields.[13] Freshman intentions are more accurate reflections of sophomore intentions in the sense that the percentage of freshmen planning majors in a given cluster of NS&E disciplines best predicts the actual proportion of BS degrees in that cluster 3 years later. Hence, the most recent freshman intentions data from the fall of 1987 are expected to most accurately predict the NS&E proportion of all bachelor's degrees in 1990, which is 4 years beyond the most recent baccalaureate data (1986).

Figures 5, 6, and 7 indicate the past predictive success of freshman intentions data in 3 subfields of NS&E: computer science, engineering, and the remaining traditional natural science fields. In the computer sciences, intentions data have been collected only since 1977. The largest error was in 1977; the proportion of bachelor's degrees conferred in this field in 1980 (1.25%) was 25 percent higher than the proportion reported as intended (1.0%). Considering that it is likely that a significant percentage of degrees in this field were conferred in 1980 to students not sophomores in 1977, ie, given that this pipeline was hardly in equilibrium, this is not a serious survey error rate. The most recent error rate calculations (intentions in 1982 and 1983 versus degrees in 1985 and 1986) yield errors of 11 and 6 percent; actual proportions were 3.9% and 4.25% as compared to intentions of 4.4% and 4.5%. The direction of these prediction errors suggests a tendency to overpredict when the

---

[13. These "freshman intentions" data are collected by Alexander Astin and his colleagues at the Cooperative Institutional Research Program of the ACE at UCLA. See, for example, The American Freshman: Twenty Year Trends (January, 1987) for historical time series.]

actual proportion is peaking prior to a downturn. Notice that only 1.7% of freshman in 1987 reported intentions to major in computer science. This means that the number of BS degrees in 1990 will almost certainly be less than one-half the number conferred in 1986.

Figures 6 and 7 are similar to Figure 5. The intentions data are plotted 3 years after the year they were collected to indicate graphically the accuracy of these data in reporting proportions of bachelor's degrees in traditional fields of natural science and in engineering. In the engineering figure (6), intentions have been scaled down by one-third to better match the BS degree proportion line. This indicates that since 1971 (plotted as 1974 in Figure 6) the intentions of about one in three freshmen are not realized, probably due to the demanding degree requirements. Prior to 1971, the attrition was even higher than one-third. Notice that the intentions data overpredicted degrees during the peak of the boom in undergraduate engineering degree conferrals during 1983-1985, by 6%, 3%, and 6%. Notice also that the intentions data indicate a drop in the engineering proportion of bachelor's degrees from 7.8% in 1986 to 6.2% in 1990.

Figure 7 indicates trends in the traditional fields of the natural sciences. The intentions data have been only approximately accurate in this cluster of fields. Predictions of degree proportions in 1971, 1975, 1983, 1985, and 1986 were in error by 10% to 12%. However, the broad trends were successfully identified. The intentions data indicate that BS degrees in these fields will continue to drop from the 1986 proportion of 9.5% to some where in the range 7.7% to 8.9%.

Overall, these data indicate that BS degrees in the traditional NS&E fields will reach the range 3.8% to 4.0% of the population of 22-year olds in 1990 from 4.3% in 1986, and that BS degrees in computer science will drop to 0.4% or 0.5% in 1990 from 1.1% in 1986.[14]

Linkages from Baccalaureate to Doctorate Degree

This is the least stable section of the pipeline. The reason is fundamentally a matter of economics. Decisions to enroll in PhD programs (or master's programs) are principally driven by opportunities for advancement and improved employment prospects. During the 1960's, before the MBA degree and the law degree had blossomed in popularity as educational precursors to attractive career opportunities, only medical school was in serious competition with doctoral programs as career preparation at the

---

[14. The drops in proportions of freshmen intending to major in these fields during the last four years overstates the drop in the percentage of 22-year olds because the percentage of the 18-year olds enrolling as first-time full-time freshmen in colleges and universities has been rising in recent years .]

graduate student level with mass appeal.[15]

Also in the 1960's there was a voracious demand for PhD's. This was true for all disciplines, but particularly true for S&E fields (including the social and behavioral sciences, which were enjoying growing --- and ultimately mass --- appeal). The rapid growth of college and university enrollments fueled the lion's share of this demand, but the space program being run by the National Aeronautics and Space Administration was also an important source of demand for NS&E's at all degree levels. The key observation from this period is that this record demand was met with minimal disturbances to sectors needing new PhD's, at the cost to the nation of ensuring readily-available financial assistance for graduate students and record salaries for doctorate level S&E's. With reference to Figure 8, note that the rate of successful continuation of BS degree holders to PhD degrees in S&E hit a peak above 12 percent in 1970 and 1971. Considering that the typical rate of attrition from doctoral programs in S&E was above 50 percent (perhaps 5 out of 8 students), this means that a very large fraction of BS degree holders was enrolling in doctorate programs (perhaps 1 out of 3).

As quickly as this record rate of continuation was achieved, demographics changed both the underlying supply and demand conditions. On the demand side, the rate of enrollment growth in those colleges and universities with degree programs in NS&E slowed to a low level after the early 1970's. Meanwhile, annual BS graduates in S&E fields (the pool from which doctoral students are drawn) rose substantially in number. The rate of continuation adjusted quickly and substantially, from 12+% in 1971 to 6% in 1977. From 6%, it drifted down to 5% in 1981 and has remained at that level through 1986.

The historical evidence clearly supports the idea that this rate is not stable. But this does not mean that the rate can shoot back up to 12% as readily as it did in the 1960's, for three important reasons. First, for undergraduate NS&E graduates, there are now very competitive alternative career paths available in business and law in addition to medicine. Second, the war in Vietnam is believed to have enhanced the attractiveness of graduate education for males (who accounted for most of the potential NS&E doctoral students 15 to 20 years ago). Third, labor markets for new BS degree holders in NS&E fields have tightened recently and, abstracting from temporary fluctuations in demand, will continue to tighten well into the next decade.

Hence, current graduate students must consciously decide to forego attractive employment opportunities or alternative

---

[15. Considering the social change occurring during the 1960's, law and business may have been too "establishment" for many bright potential graduate students to seriously consider them. Such social impediments rapidly waned, and were probably gone by 1980.]

graduate professional studies to enroll in full time doctoral programs. In contrast, potential graduate students during the 1968 to 1975 period were typically not faced with this opportunity cost of remaining in the pipeline. Nonetheless, it can be reasonably expected that the continuation rate of U.S. citizens will rise again starting in the 1990's. Figure 8 has depicted future continuation rates as stable versus rising at the expected rate needed. Stability would occur if present relative salary structures for degrees and experience remained constant. A rising rate would follow from increased support of graduate students and rising real salaries for PhD-level scientists and engineers.

PAY RATES FOR SCIENTISTS AND ENGINEERS: PAST EXPERIENCE AND FUTURE CONSIDERATIONS

Introduction

Salary data are both very important indicators of relative changes in supply and demand, and very difficult to obtain in clean, consistent and usable form. There are a number of key dimensions that need to be controlled to produce clean longitudinal data series. These are: (1) field of highest degree, (2) highest degree earned, (3) field of occupation, (3) years of experience, (4) sector of employment, (5) professorial rank (if employed in an academic institution) or supervisory level (if employed in other sectors), and (6) total professional compensation for the year. Because these descriptors are not routinely available with published salary data, the quality of the data is to some extent compromised.

For example, the movement in aggregate salary data for full professors of physics over the last 7 years probably overstates the scarcity premium this group commands because this group's average age has risen, confounding the effect of seniority with scarcity. Rising group seniority is much less of a problem for assistant professors of physics, because there are natural limits on movements in their average age or experience. However, in periods when total college enrollments are experiencing low or no growth, reductions in the number of new faculty hires at the assistant professor level may necessitate an adjustment for the type of academic institution employing new assistant professors in order to avoid biases resulting from variations in starting salaries in different types of institutions.

Unfortunately, many desirable adjustments cannot be made due to data limitations.[16] For this reason it is necessary to employ inferences and deductions about salary movements whenever possible. Perhaps the single most useful inference can be made from our knowledge that labor markets are competitive, particularly for new degree holders. The consequence of this is

---

[16. The salary data for engineers and chemists are the best overall across all fields.]

that starting salaries across sectors cannot differ substantially unless there are substantial nonpecuniary rewards to consider as well. The academic sector has traditionally been the most troublesome in this regard. Published stated advantages of academic employment have included (1) more flexible hours, (2) free summers, (3) a high degree of personal discretion to choose research projects, (4) lifetime job security after tenure, and (5) high status. However, salary comparisons of academic NS&E's to those employed in other sectors seem to indicate that there is (and has been) approximate equivalence in the monthly salaries paid.

The following data are intended to indicate generally changes in real and relative salary levels over the last 20 years, using available data somewhat judiciously.

<u>New Degree Holders in Electrical Engineering as a Starting Point</u>
We have selected electrical and electronic engineering (ee) as a starting point because it is the specialized field with the best sample size and sectoral coverage, particularly for observing pay offers to new graduates at all degree levels. Figure 10 indicates the average annual real (ie inflation-adjusted) salary offers to new BSEE's in 1980 dollars. Several observations are noteworthy. First, real starting salaries are related positively to demand (proxied by the number of offers made) and negatively to supply (which could be represented by the annual number of new BSEE's, a number which rose from about 11,000 in in 1968 to 12,000 in 1971&72, dropped to 10,000 in 1975, 76, &77, then rose steadily thereafter, reaching 20,000 in 1986). It is evident from Figure 10 that real starting pay rose and fell (in broad trend terms) in response to increases and decreases in the number of offers. Even though the number of offers recovered in the late 1970's to levels higher than those experienced in the late 1960's, average real pay offers did not recover as much, because the supply of new BSEE's also shot up rapidly.

Second, Figure 11 indicates that the same pattern of average real salary offers to new graduates at the MS and PhD level, with the added observation that both downswings and upswings are relatively more pronounced, the higher the degree level. Using the trough year as the comparison year and 1968 or 1969 as the base year, real salary offers dropped 12% at the BS level (from 1.13 to 1.00), 14% at the MS level (from 1.16 to 1.00), and 24% at the PhD level (from 1.31 to 1.00). From the mid-1970's to 1986, real salary offers rose 8% at the BS level, 14% at the MS level, and 22% at the PhD level.

Several related factors account for this pattern. As the demand for BSEE's fell in the early to mid-1970's, some students having difficulty finding first jobs (crucial to later success) enrolled in graduate school as a way of productively warehousing themselves until the labor market improved. This step also allowed students elsewhere in even harder hit subfields to shift into ee (or other subfields less affected by the downturn). This strategy tended to exacerbate the effect of the poor job market for new MSEE degree holders several years later. At the PhD level, the demand for new teaching doctorates dropped because losses in engineering enrollments at the undergraduate level (in response to reduced demand for BSEE's) exceeded gains in enrollments at the master's level (in response to the warehousing process). Generally, there is a multiplier effect at the PhD level when enrollments drop at the undergraduate level.

Figure 12 is another view of these relative salary movements. From 1967 to 1980, there was a small erosion in the starting pay premiums paid to MSEE's versus BSEE's (from 20% to 13%), followed by a return to the 20% pay premium in 1986. The apparent starting pay premium for PhD's (versus BS's) dropped from 73% to 43% during 1967-1975, slowly recovering afterwards to 55% in 1985 and 63% in 1986. It should be noted, however, that an average time of 8 years has elapsed from BS to PhD, and that a BSEE with 8 years of experience earns considerably more than a new BSEE. (This point is discussed further below.)

Comparing Starting Pay in Electrical Engineering with Pay in Other Fields

A comparison of pay offers to new bachelor's level job seekers across fields provides some evidence of the boundaries defining natural clusters of undergraduate fields (Figure 13). The lowest line in Figure 13 is the ratio of starting pay offered to engineers in all subfields to offers made to ee's. Virtually no trend is visible in this ratio, nor is the ratio much different than 1.0. These data reassure us that engineering college training carries over from one specialized field to another as far as employers are concerned, and that students do engage in subfield switching in response to market signals.

The second lowest line is the ratio of starting pay offers in engineering versus fields in natural science. That this line is above 1.0 indicates that engineers command a premium in pay. A persistant positive premium indicates that the pay differential was the result of more difficult training (from the students' collective point of view), and was possibly also a reward for more valuable training (from the employer's point of view). If students did not consider engineering to be more difficult or less enjoyable, they would tend to switch from natural science to engineering majors until the pay premium disappeared.[17] The trend in the premium for engineering was approximately positive until 1975. The trend subsequently reversed, and the premium dropped from 17% in 1975 to 11% in 1985 (7% in 1986). BS degree data in Figure 4 indicate that degrees in natural science were

---

[17. By "more difficult", we do not mean "requiring a higher IQ" (although this may be true in some instances), but instead requiring more work measured in hours expended per semester, with associated fewer opportunities to sample other aspects of college life, including selecting courses electively.]

generally rising while degrees in engineering were roughly level until the mid-1970's. By 1977/1978, degrees in natural science were falling while degrees in engineering were rising. The direction and timing of these movements suggests that students responded to market signals within the NS&E aggregate of fields.

The top two lines in Figure 13 indicate that business, social science fields (ss), and humanities fields were less substitutable for either engineering or the natural sciences. The premium in pay for new BS-level engineers was considerably higher in comparison with these fields than in comparison with fields in natural science. Further, the starting pay premium for engineers grew enormously from 1972 until 1982, from 17% to 41% compared to business, and from 27% to 61% compared to ss and humanities. This period of time witnessed a leveling off of bachelor's degrees in all fields at the 925,000 level after years of rapid rise through 1973.

However, during 1972-1982, major changes were occurring in the composition of degrees. The number of social science and humanities degrees dropped from 240,000 to 140,000, and the number of education degrees dropped from 190,000 to 100,000, as the demographic decline now occurring in the college-age population rippled through the primary and secondary school population, destroying the labor market for school teachers. The decline in degrees in the social sciences and humanities failed to completely stem the erosion in starting pay, as measured by the yardstick of engineering starting pay.

During the same 1972-1982 period, degrees in business rose from 120,000 to 215,000 and degrees in computer science rose from 3,000 to 20,000, offsetting the decline in ss and humanities, and degrees in health fields rose from under 30,000 to over 60,000, partly absorbing the decline in education bachelor's. The rapid expansion in business degrees probably explains the decline in starting pay of business majors relative to engineering majors. The key point is that students who would have otherwise been ss and humanities majors (and education majors) could switch out of these fields as it became clear that there were only limited openings and poor starting pay, and move into business fields, computer fields (and health fields), where job opportunities and starting pay levels were better. But they were evidently unable to switch into traditional NS&E fields, where degrees rose less than 20 percent despite a growing pay differential with the other fields. A much smaller differential in starting pay persisted between business and "ss & humanities", in favor of business. This difference probably reflected the greater nonpecuniary value that the shrinking body of ss and humanities students derived from these fields. Students who derived greater enjoyment from ss & humanities fields (the shrinking fields) needed a positive differential in starting pay to give up these fields for business fields (the expanding fields).

The rapid acceleration in the premiums in starting pay enjoyed by new BS-level NS&E's versus other fields was driven by a booming market for engineers that lasted from 1975 to 1982. At that point, the combination of a softening labor market for engineers, a greatly reduced production of ss and humanities bachelor's, and an improving labor market for school teachers served to reduce the premium in starting pay for engineers from 61% in 1982 to 33% in 1986. After 1982, the number of humanities degrees leveled off, the decline in ss degrees (and education degrees) slowed, and the increase in business degrees (and health degrees) slowed.

Without presenting data, it can be asserted that starting pay for advanced degrees in these broad field groups followed similar patterns as those outlined for ee's. The market for academic PhD's in those fields experiencing declines in enrollment were virtually wiped-out (limited to replacement of retiring faculty) and, because many of these fields did not have large labor markets for nonacademic positions, the overall effect on starting pay was strongly negative.

The Effect of More Education versus More Experience on Pay Levels

The National Science Foundation is interested in ensuring an adequate flow of NS&E's at all degree levels, but is particularly concerned with the adequacy of PhD's. A crucial question in this respect is whether labor market "forces" are adequate by themselves to ensure the needed flow of new PhD's. Figure 12 (discussed earlier) indicated the large decline in the ratio of starting pay of PhD's to BS's in electrical engineering during 1967-1975, followed by a partial recovery during 1975-1986. This relative movement in starting pay was very likely witnessed in most other NS&E fields, because of the connectivity of pay rates across NS&E fields. This pattern of relative pay appears to have been in the desired directions: relative declines in PhD-level starting pay during a period of oversupply, and increases during period of growing scarcity.

While information about starting pay tends to be the most widely available to students and, consequently, may be an important determinant of decisions made by new baccalaureates to enter labor markets or continue their education at the graduate level, this information is by itself inadequate to ensure that the best financial decision is being made. The most even-handed approach is to compare pay levels of PhD's and BS's of the same age soon after the typical PhD holder earns that degree, to see if the salary premium is large enough to cover the opportunity cost of not working at peak earning levels during the period of graduate education[18].

[18. The typical PhD student does work and receive compensation in the form of fellowships, traineeships, and assistantships, but these provide income considerably below standard pay levels for full time employees with BS degrees.]

In order to make this comparison, "Batelle" salary data[19] were used to compare pay levels for nonsupervisory PhD's 9 to 11 years after their BS degrees were earned with pay levels for nonsupervisory BS's, also 9-11 years after their BS degrees were earned. This elapsed time was chosen to ensure an adequate sample size of PhD's (recall the median time to degree is 8 years). Also, salary data for employed BS degree holders with one year of experience (the Batelle equivalent of starting pay) were compared to salaries of BS and PhD NS&E's 9 to 11 years beyond the BS degree. These comparisons are displayed in Figures 14, 15, and 16 for engineers, chemists and physicists working in nonsupervisory R&D positions. The sample sizes in these three fields are adequate to allow this type of carefully controlled comparison. The comparisons yield two useful observations and one cautionary note.[20]

The bottom lines (versus the top lines) in Figures 14, 15, and 16 indicate that the true salary premium for PhD's has been much more stable and much lower than a comparison of PhD and BS starting pay would suggest. In engineering, new PhD's have enjoyed a salary premium of only 10 to 15 percent over their BS age counterparts. In physics, the PhD salary premium has been even lower, ranging from 1 to 9 percent, reflecting the tendency of BS-level physicists to work as engineers. In chemistry, the PhD salary premium has been somewhat higher, ranging from 12 to 21 percent. At the very least, these data suggest that increases in the pay of R&D scientists and engineers due to growing scarcity over the next ten years will force up the starting levels of PhD level scientists and engineers. They also raise the issue of the adequacy of the PhD salary premium.

[19. These data were collected by Batelle Memorial Institute annually during 1967 to 1986 under contract to the Department of Energy. In 1987, this contract was given to The Hay Group.]

[20. On the cautionary side, PhD-level salary data collected by the College Placement Council and by Batelle seem to cover different subgroups and may be seriously unrepresentative of salaries of all new PhDs in the various fields examined in this paper. CPC data indicated a drop in the ratio of PhD starting pay to BS starting pay for ee's until 1975, followed by a steady increase. In comparison, Batelle data indicate this ratio dropped until 1980 for engineers, chemists, and physicists. The reason for this discrepancy is a systematic difference in reported pay levels of new PhD-level engineers. Batelle reported 23% higher pay than the CPC in 1975; the difference gradually dropped in each subsequent year, reaching 7% in 1979 and a negligible 3% in 1980. Batelle data were intended to be representative of R&D laboratory employees, dominated by private corporations; CPC data are in effect drawn from a convenience sample of college and university placement directors reporting to the CPC.]

Unfortunately, we have not been able to locate Batelle data for the 1967-1974 period, which would reveal whether PhD salary premiums were higher in the late 1960's and then dropped to their low levels during the early 1970's. A search for these earlier data is in progress.

Before continuing with the issue of growing future scarcity, notice that middle lines in Figures 14, 15, and 16 indicate a growing pay compression between starting pay of BS NS&E's and pay levels associated with 9-11 years of experience at the BS level. As the scarcity of engineers grew in the late 1970's, the premium for 9-11 years of experience dropped from slightly under 50% in 1976 to slightly over 30% during 1980-82. As the labor market for engineers softened after 1982, the pay differential for experience widened once again, reaching 40% or higher in 1985 and beyond (see Figure 14). The same movement is evident in the ratio of starting pay of PhD's (ie, PhD's 9-11 years after their BS degree) to starting pay of BS's in engineering (the top line in Figure 14), indicating that BS-level starting pay is more volatile than PhD-level starting pay. Similar patterns of relative salary movement are evident for chemists and physicists (see Figures 15 and 16).

Even though the "real" premiums for PhD-level training did not change very much after 1975 (the bottom lines in Figures 14, 15, and 16), it is possible that potential doctoral students were focused more frequently on starting pay differentials, and thought they were declining. This may partly explain the decline in the continuation rate of U.S. citizens from BS to PhD during the late 1970's (see Figure 8).

Future Scarcities of NS&E PhD's

The major reason for studying the past is to monitor current and future developments that will change key relationships between new graduates and pay rates. It is almost always advantagous to know about impending future changes in advance. Policymakers can act on advance information to alter changes in advantagous ways. Employers can form better employment strategies and position training programs to augment skill areas that may be future trouble spots. Students can respond to opportunities for picking fields promising particularly renumerative first jobs and prepare for socially useful careers.

In this respect, it is widely known (or at least believed) that there will be a shortage of PhD's beginning at some point in the 1990's at current BS to PhD conversion rates. Given our knowledge that conversion rates depend on both real and relative (to BS level) salaries, the conclusion is that both real and relative PhD salaries will have to rise to induce a response in the form of higher percentages of BS degree holders in NS&E fields obtaining NS&E PhD's (see Figure 8 for the expected needed increase in conversion rate). PhD-level salary increases are expected during 1988-1996, but these are anticipated to result primarily from the need to maintain the current modest real salary premium over BS-level NS&E's (in order to maintain the production of PhD's at current levels), as real BS-level salaries begin to rise at a growing rate as a result of growing scarcities of BS-level NS&E's. The demand for PhD's is unlikely to rise substantially until a combination of rising college enrollments and unusually extensive replacement demand combine to drive them up in the late 1990's. At that point, both real and relative PhD-level salary growth is expected (see Figure 18).

We have already seen a small, but gradual upward rise in real starting pay for BS-level NS&E's since 1975 or 1976. With NS&E BS degrees peaking in 1985 and 1986, and poised for a 20 to 25% drop during 1986-1996, the pace of this rise will begin to accelerate. If PhD-level pay doesn't keep pace, the conversion rate will drop. Qualitatively, the links between pay and degree production are clear. Quantitatively, the strength of the linkages between real BS-level pay, real PhD-level pay and PhD production is difficult to establish with precision. We have made one effort to quantitatively link real PhD-level starting salary offers with PhD production.

<u>The Elasticity of Supply of NS&E PhD's</u> During 1973-1976, real starting pay offers to PhD's dropped, as did pay offers to new PhD's <u>relative to</u> new BS's according to CPC data). During 1976-1981 both recovered (see Figures 11 and 12). We examined the elasticity of supply[21] of NS&E PhD's in 5 NS&E fields for which data were available, finding that the best fit occurred with a lag of 3 years between changes in salary and changes in new PhD conferrals. The estimated elasticities are good enough to claim there is a statistically valid relationship between real salary changes and changes in the number of PhD's 3 years later. However, it should be noted that real increases and decreases in starting pay offers were reinforced by simultaneous changes in relative pay offers in the same direction. Also, there is considerable variation in estimated elasticities across the 5 fields, with engineering being the highest and physics being the lowest (not significantly different from 0).

The average elasticity of supply was 3.0 (including foreign students) and 1.0 (for U.S. citizens alone). As can be seen in Figure 17, U.S. citizens seem to have departed the PhD pipeline during 1976-1980 more rapidly than the average elasticity of 3 would predict, and to have returned more slowly since 1980 than the elasticity of 1 for U.S. citizens would suggest. In other words, the supply elasticity for U.S. citizens appears to have dropped considerably since the early 1970's. But these same data can be interpreted to indicate that foreign students are displacing U.S. students because foreign students are not responsive to small decreases in real starting salaries for

---

[21. The elasticity of supply is the % change in degree production divided by the % change in real starting salary. A value of 2.0 means that a 10% increase in salary will induce a 20% increase in annual PhD production.]

PhD's, and much more responsive to modest increases in real salaries (or that they are more responsive to the immigration opportunities represented by openings in graduate school than to salary signals).

What will occur if foreign student enrollments begin to lose responsiveness to positive salary signals, or if the growth in these enrollments begins to slow down for other reasons (e.g. if state governments begin to cap graduate enrollments of foreign students, as California has done)? In that case, increases in doctoral enrollments and new PhD's will become much more dependent on U.S. citizens. In exploring the future, it is useful to consider the effect of a leveling off of PhD conferrals to foreign citizens. We examined the scenario in which foreign PhD's in NS&E reach a ceiling of 5,000 per year, a few years hence, so that the very large increases in enrollment and degrees needed after the mid-1990's would have to come from U.S. students. In addition to the rise in real salaries needed to keep pace with BS-level salaries, relative PhD-level pay would also have to rise starting in the mid-1990's to produce the desired response. We specified the supply elasticity to be 2 and allowed for very little pay compression[22] in constructing the salary curve for 1996-2002 in Figure 18, which shows real pay for full-time (11 months) academic NS&E's performing substantial amounts of R&D.

The historical salary data in Figure 18 are based on detailed data available since 1975 from the National Association of State Universities and Land Grant Colleges (NASULGC). This is the only data series which provides good sample coverage of all NS&E subfields in the NS&E aggregate. These disaggregate data were combined using actual proportions of academic researchers in each NS&E field as weights, adjusted for the somewhat higher pay levels found in private universities (versus public institutions), and adjusted to include direct fringe benefits (obtained from the AAUP and the Department of Education). The historical series were extended backwards to 1966 using AAUP salary data, by taking advantage of the constant proportional relationship during 1975-1982 between salaries paid to faculty in AAUP Category I Institutions (ie, research universities) and the adjusted NASULGC salary series. These salary data show that real PhD-level pay began to rise after 1982, moving from $52,000 to $64,000 in 1987 (measured in 1984 dollars). One set of salary projections show that real pay will reach $75,000 in 1996 and approach $100,000 shortly beyond the year 2000.

These projections are based on the calculation that the U.S. will need to increase the current BS to PhD continuation rate of U.S. citizens in NS&E by two-thirds in the years following the year 2000, necessitating an increase in real salaries of about one-third. (See Figure 8.) However, this projection of new PhD's

---

[22. The lack of pay compression means that average salaries would rise as rapidly as starting salaries.]

needed is highly tentative for a number of reasons. Included among these reasons is the lack of adjustment for a reduction in the quantity of NS&E PhD's demanded as real salaries rise. In other words, the elasticity of demand has been treated as "0" (i.e., need has been treated as completely unresponsive to salary changes). In reality, there will undoubtedly be some moderation in the quantity demanded and some improvements in the utilization of NS&E PhD's as real salaries rise, even given the slow change over past years in the way PhD's are utilized. Unfortunately, not much is known about the determinants of PhD demand in sectors other than the academic sector. Clearly it would be worthwhile to remedy this shortcoming, considering the future scarcities we are confronting.

The Issue of Foreign Citizens in U.S. Doctoral Programs

This pessimistic scenario of rising PhD scarcities and rapidly rising salaries serves to highlight some of the key issues that will be faced in the U.S. over the next several decades. First, the cost of decreasing U.S. reliance on NS&E PhD's earned by foreign citizens appears to be high. Not only will the salary costs of PhD-level researchers and teachers rise substantially, but also the scarce talent lured into PhD-level NS&E career paths will not be available for other uses. This suggests that conscious decisions to limit the number of foreign citizens admitted to U.S. PhD programs should be carefully examined for all repurcussions before they are accepted. To the extent that increases in foreign student enrollments in doctoral programs decline or turn negative for reasons other than state or national policies, it may be in the national interest to actively encourage foreign students. One way to do this is to ensure that foreign students have equal access to graduate student support funds provided through federal agencies. Another approach is to grant permanent resident status or immigrant status to foreign students successfully completing PhD degrees at U.S. universities.

A second issue is the prevalence of subsidized education in the U.S.. Subsidies are particularly high at the graduate level and particularly high in state universities, because the tuition charges are consciously set far below the "true" cost of education, providing an annual subsidy on the order of $10,000. In a sense, this subsidy can be viewed as a hidden (untaxed) supplement to the income officially paid to graduate students who assist in teaching and research, a group that covers virtually all of the successful PhD students. On the other hand, the participation of foreign citizens in state-level education subsidies without any associated obligations to the state after graduation is a potential sore point with state legislators and taxpayers. This is particularly true if the doctoral field of study is presently adequately supplied with new PhD's, so that the foreign doctoral students are not perceived as filling state or national needs. However, even if the fields of study most heavily populated with foreign citizens are widely considered to be undersupplied by flows of U.S. citizen PhD's, the national character of labor markets for new PhD's and the exceptional mobility of PhD's seeking employment may combine to create the same state-level antipathy towards further increases in foreign enrollments in doctoral programs.

Another issue stems from informal assessments of the ability of graduate students from the U.S. versus those from abroad, especially from East Asian nations. In a number of key NS&E fields, graduate student deans and admissions officers frequently offer assurances at national meetings that they give every possible consideration to citizen applicants, with the result that in most cases the average quality of foreign students in a given U.S. doctoral program is higher than the quality of U.S. citizens. This readily translates into evidence that, for the aggregate of U.S. doctoral programs in a given field, the average quality of foreign students is higher U.S. students, because in no major NS&E field is there a systematic relationship between the quality of a department (as determined by the National Academy of Sciences) and the percentage of foreign students enrolled.

The associated issue is what to make of this information. Does it mean that foreign graduate students are unusually able, that U.S. PhD programs are not attracting a sufficient number of the best U.S. citizen baccalaureates, or (most discouraging of all) that these programs <u>are</u> drawing the best citizen baccalaureates, but that as a group these students are simply not as good as the foreign students?

If the answer is that doctoral studies are failing to appeal to a large (or growing) percentage of the best citizen baccalaureates, then a key issue is pay. The relatively modest salary premium for acquiring an NS&E PhD may be too low to attract a number of able potential graduate students. A number of these will select alternative career paths <u>outside of NS&E</u>, by choosing to acquire a "professional" degree in business or law, or by switching into management as rapidly as possible after gaining employment in private industry. For these baccalaureates, the effective premium for acquiring a PhD may actually be negative. Serious attention should be given to this interpretation. Earlier, evidence was offered that more than one-half of the NS&E baccalaureates immediately continuing their education choose fields outside of the NS&E aggregate (see footnote 10).

To the extent that the issue is inadequate pay (as just described), a continuation of current trends may actually exacerbate these trends. To the extent that the best U.S. citizen baccalaureates are choosing to avoid doctoral studies, more room will be available for qualified foreign students. A growing influx of foreign PhD's into U.S. labor markets will hold down the level of PhD salaries to the extent that foreign students are attracted to U.S. doctoral programs as a way of immigrating to the U.S.. A related point is that for this group the PhD salary premium is much higher, because it is based on BS-level pay in students' home nations versus PhD-level pay in the U.S..

There is a national policy that is relatively safe in terms of picking a middle course among all the possible interpretations of what to make of rising participation in doctoral programs by foreign citizens. That policy is to gradually begin to expand fellowship and research assistantship programs for doctoral students and to actively recruit women and minorities into the NS&E pipeline. In the long run, recruitment could have a large positive effect on the supply of NS&E's at all levels, because women and minorities continue to be seriously underrepresented at all levels, particularly at the PhD level. A variation of this policy that is worthy of consideration would be to make graduate student subsidies equally available to needy foreign applicants.

Considering that a key part of the financial calculus of deciding on graduate school or employment after earning a BS degree is the opportunity cost of lost earnings and the immediate out-of-pocket costs of tuition and living expenses, increased financial subsidy of doctoral students seems much more cost effective to the nation than the free market solution of allowing real and relative salaries of NS&E PhD's to rise. Subsidies are an immediate lure to enter graduate studies. By comparison, the inducement of rising salary is a distant lure, which would produce results with a considerable time lag and would probably require the payment of a large risk premium to compensate students for the possibility of falling real salaries before they have completed their degree.