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ABSTRACT

A search of literature was conducted to address whether and how the Federal Government should do more to encourage U.S. students to complete degrees, especially graduate degrees, in science and engineering. Science was defined to include all of natural science, including mathematics and computer science, but to exclude social and behavioral sciences. The study found that the number of U.S. citizens earning doctorates in science and engineering in 1987 was 9,724. This number is not enough to replace scientists and engineers who die or retire, but the number is greatly augmented by foreign residents who receive doctorates and remain in the United States. The level of science and engineering doctorate awards to U.S. citizens has been constant since 1976. Until now, the number of degrees awarded has usually been sufficient to meet employment needs, with the labor market expanding and contracting and student enrollments following suit, after a lag. However, although shortages are not widespread at present, there are general persistent shortages of personnel in computer science and engineering, and sometimes in mathematics and environmental and physical sciences. Federal intervention in the science and engineering job market can be made through graduate fellowships and traineeships, research assistanceships, forgivable loans, precollege programs, tax incentives, undergraduate assistance, and employee educational assistance, but such intervention has both pros and cons. (59 references) (KC)

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# 3. TRENDS IN SCIENCE AND ENGINEERING EDUCATION AND THE U.S. LABOR MARKET

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National Research Council

U.S. DEPARTMENT OF EDUCATION
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# 3. TRENDS IN SCIENCE AND ENGINEERING EDUCATION AND THE U.S. LABOR MARKET

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## Introduction

This paper addresses the questions whether, and how, the federal government should do more to encourage U.S. students to complete degrees, especially graduate degrees, in science and engineering. It does not present new research, but attempts to summarize what is known on this issue. Science is defined to include all of natural science, including mathematics and computer science, but excluding social and behavioral sciences.

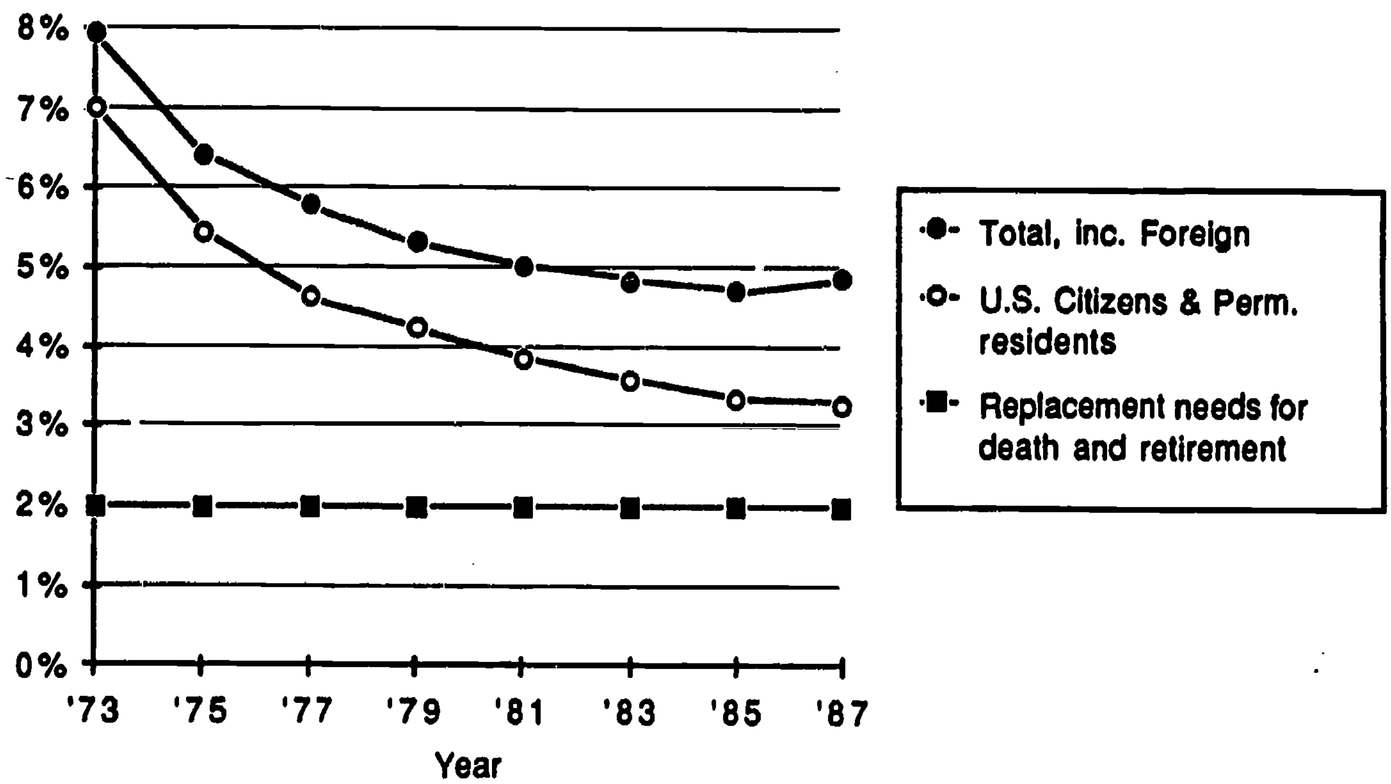
## Trends in Science and Engineering Education

### Trends in Graduate Student Enrollments

The number of U.S. citizens and permanent residents earning doctorates in science and engineering was 9,724 in 1987. This is only 3.3 percent of the total employed doctorate scientists and engineers in 1987. (See Figure 1) Given that losses due to death and retirement average around 2 percent, the current rate at which U.S. citizens are earning doctorates in science and engineering would not permit growth in doctorate science engineering employment equal to the rate of growth of total science and engineering employment experienced in the recent past or projected for the future [U.S. Department of Labor, 1988]. Ph.D. growth of less than two percent (after replacement of losses due to

Figure 1

New Doctorates as a Percentage of Total Employment of Doctoral Scientists and Engineers, 1973-1987




Source: National Research Council, Survey of Doctorate Recipients and Survey of Earned Doctorates

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death and retirement) would also be less than half the growth rate of science and engineering Ph.D. employment since 1973, and less than half the growth rate of real basic and applied research expenditures in the U.S. over the past decade [National Science Board, 1987].

The level of science and engineering doctorate awards to U.S. citizens and permanent residents has been constant in the range of 9,300 to 9,900 degrees since 1976. Prior to that the history of awards was erratic: awards increased steadily after World War II to achieve 9,500 in 1968, then they shot up rapidly to 12,500 in 1971 and fell rapidly to about the present level in 1976. Because of foreign student enrollments, total awards have always exceeded awards to U.S. students.

Prior to 1976 a rapid growth of doctorate employment in science and engineering was accommodated by rapid growth in degree awards to U.S. citizens and permanent residents. Since 1976 the number of these awards has been flat but employment has continued to grow, increasing by nearly 50 percent over a decade. This growth in employment in the face of constant degree awards was possible because (1) there was increased employment of foreign national degree recipients with temporary visas, and (2) the current level of degree awards was enough to accommodate substantial growth a decade ago -- because the same level of degree awards then exceeded replacement needs for retirements by a larger margin than at present. Since 1983 the employment of doctorates in science and engineering jobs has increased, but at a slower rate than it did from 1973 to 1983.

Figure 1 illustrates the constraint imposed by constant degree awards in the face of rising total employment. Since replacement needs due to death and retirement average about 2 percent of the doctoral work force, awards to U.S. citizens and permanent residents totaling 3.3 percent are insufficient to allow the doctorate population to grow at the same rate as total employment of scientists and engineers. However, we come closer to having enough to meet the needs of growth and replacement if all doctorate recipients, including foreign students on temporary visas, are available to join the U.S. work force.

Federal Graduate Student Support

Federal support for graduate education grew dramatically during the late 1960s but then fell sharply during the early 1970s. Since the mid-1970s federal support of graduate students in science and engineering has increased moderately. Though this paper defines science to include only the natural sciences, it is relevant to note that during the period since 1975 federal support of social and behavioral science has been cut in half. Thus, modest growth for the natural sciences and engineering have been accomplished in part by reallocation of funds.

Another important trend has been the decline in the relative importance of fellowships and traineeships relative to graduate research assistantships as a support mechanism. When federal fellowship support peaked in 1968 this was the dominant federal mechanism [National Board on Graduate Education, 1974, p. 33]. Since that time there has been a shift towards the use of research grants to faculty. These can employ graduate students as research assistants. This approach assures students are supported in fields where there is federal research interest, and it involves them in research projects. One important difference is that federal fellowships are almost always restricted to persons who are qualified to take employment in the U.S. after graduation, (U.S. citizens and permanent residents) while research assistantships can be and frequently are used to support foreign students on temporary visas.

Foreign students make a great contribution to the U.S. Although information on this is incomplete, it appears that about half of foreign doctorate recipients on temporary visas stay here to work after graduation, clearly increasing the average quality of the workforce [Greenwood and McDowell, 1986; National Research Council, 1988a]. Graduate faculty express some preference for U.S. graduate students, but admit large numbers of foreign students because they feel they need to maintain high quality [Barber and Morgan, 1987]. However, for federal policy makers trying to increase U.S. student involvement in graduate science and engineering education it must be acknowledged that the current support mechanism -- i.e., the graduate research assistantship -- has an important limitation. Even though federal policy makers may have values which differ from graduate faculty regarding the appropriate mix of U.S. vs. foreign students, federal policy makers have little or no control over the mix as long as most students are supported by research assistantships, and research assistants are selected by the faculty.

The lack of federal influence on the mix of students is more obvious when one recognizes that federally supported students make up fewer than 25 percent of all full-time science and engineering graduate students in doctorate granting departments [National Science Board, 1987, p. 205]. As long as others provide the support for most graduate students, a federal preference for U.S. citizens will likely have little effect on the total mix of students -- even if all federal support were subject to U.S. citizenship requirements.

## The Labor Market for Scientists and Engineers

Economists have been describing and modelling the labor market for scientists and engineers for three decades [Arrow and Capron, 1959; Hansen, 1961; Folk, 1970; Freeman, 1971; Cain, Freeman and Hansen, 1974; Freeman and Breneman, 1974; Shamia, 1986; Syverson, 1988]. They have established that there is a functioning market; but also, because of the long time needed to educate scientists and engineers, supply responds to changes in demand with a lag. Much of the research literature has discussed the issue of shortages. The consensus view of "shortages" seems to agree with Arrow and Capron, that shortages are a normal part of the process of movement toward equilibrium in a dynamic setting. In this view, shortages are part of the normal operation of the labor market. While this literature documents the influence of government subsidies (e.g., fellowships) for increasing supply, it also suggests a market that is largely self-regulating, i.e., shortages bring forth increases in supply while surpluses bring forth reductions in supply.

Recent studies by the National Research Council and others emphasize the fact that an increase in degree awards is only one of the adjustments to shortages; in the short run there are several other adjustments that frequently occur in the market [National Research

Council, 1986, 1988b; Collins, 1988]. The shortage that signals the need to increase degree awards is usually indicated by a rise in the wage received by scientists and engineers, and sometimes by unfilled job openings as well. These also affect employers' behavior. They may hire fewer scientists and engineers because they cannot find the skills they need, because marginal projects are deemed unprofitable or, if they have a fixed budget, simply because the budget will hire fewer. Other adjustments occur before an increase in degree awards can be fully accomplished. Among the adjustments that have been observed in recent years have been: (1) hiring of persons with different educational backgrounds, (2) less use of scientists and engineers in non-science/ engineering jobs, and (3) increased use of foreign scientists and engineers [Finn, 1989]. However, to say that labor markets adjust does not mean that the adjustments are without costs, or that society will be getting an optimal number of scientists and engineers.

## Is There a Case for Federal Intervention?

Though academic economists have rather consistently taken the view that the market for scientists and engineers functions reasonably well, public administrators and lawmakers have, almost as consistently, worried about the adequacy of our supply of scientific manpower. They have instructed government agencies to monitor this market, and they have given a mandate to assure adequate supply not only to the National Science Foundation, but also to such mission agencies as the National Institutes of Health and the Departments of Defense and Energy.



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Congress has frequently asked for special studies of science and engineering manpower needs. The National Academy of Sciences, with the National Academy of Engineering and the Institute of Medicine, has also recommended that, as a part of the budgeting process, assessments be made of the science and engineering manpower implications of changes in federal spending patterns [National Academy of Sciences, 1988]. Indeed, the request for this paper contains a statement that "One of America's traditional strengths has been the inventive genius of its scientists." The understanding that scientists and engineers play a special role in the U.S. economy is perhaps the reason public officials have been more concerned about assuring an adequate supply of scientists and engineers than have the academic economists.

In the next two sections I review arguments that can be used to justify these concerns. These arguments fall into two general categories. One is that, although the market can be said to work, the delays and the costs to society of various adjustment mechanisms may be too costly to tolerate. Market failure is a general name for the second line of reasoning -- imperfections in the labor market for scientists and engineers may keep the correct adjustments from ever happening.

### Science and Engineering Education as a "Public" Good

Many of the benefits of a science or engineering education accrue to the individuals involved (e.g., salary), but some take the character of a public good. The argument here is the same as the argument for public subsidy of R&D because scientists and engineers are major components of R&D expense. Simply put, patents and other mechanisms are inadequate to see that all of the benefits of R&D accrue to those who conduct it. Therefore, the private rate of return on investment in R&D is below the social rate of return [Mansfield, et al., 1977, National Research Council, 1986c]. Because of this gap between the private and social rate of return, society underinvests in R&D unless government intervenes to subsidize R&D or otherwise increase it beyond the level justified by the private rate of return.

Direct subsidy of privately funded R&D does occur (e.g., a federal R&D tax credit), but not enough to eliminate the substantial gap between the private and the social rate of return. Another way to increase R&D may be to increase the supply of scientists and engineers. There are scattered reports of firms that don't perform some research because of a lack of qualified engineers or scientists [Wall Street Journal, 1988]. However, the larger effect must come through salaries. Because B.S. engineers earn relatively high salaries, even higher salaries for doctorates are needed to induce engineers to forego earnings and attend graduate school. These very high doctorate salaries must have the effect of decreasing the amount of R&D performed, an unfortunate event given the high social rate of return on R&D spending.

Current estimates indicate that the social rate of return to academic research is at least 28 percent [Mansfield, 1988]. A tax credit can have little impact on this. However, federal support of graduate students can cause more research to occur from a given level of federal R&D funds. This happens directly from graduate student involvement in research, and indirectly because smaller Ph.D. salaries are needed to attract graduate students when higher levels of graduate student support are available [Shamia, 1988].

Other Market Imperfections

Government cannot cure all market imperfections. Indeed, since Adam Smith, it has been recognized that government has often been the cause of market imperfections. In the case of science and engineering education and labor market imperfections the most often cited problem is that while most science and engineering specialties earn top salaries, public institutions tend to eschew the use of these market signals in setting tuition levels, stipends and wages. Thus we see,

- A single uniform teacher salary schedule in most school districts, with the result that teachers who have math, computer and physical science skills are underpaid relative to their market wage more often than other teachers in the same districts [Murnane and Olsen, 1988].
- Pay caps in the federal government mean that the highest paid specialties (science and engineering) are often paid below market wages [National Research Council, 1988c]. Federal laboratories offer below market starting salaries in some high wage fields, e.g., engineering, in spite of "special rates" [National Research Council, 1983, p. 18].
- Salary compression at universities. Some colleges and universities use uniform salary policies, just like pre-college schools, and most of those lacking uniform salary policies compress market salary differences so that they are not as

great in the public and non-profit sectors as in the private sector where the market is allowed to work more freely.

- Uniform tuition policies. These tend to benefit those admitted to science and engineering departments (where costs are above average) but they also mean that the colleges and universities are often unable or unwilling to expand enrollments in high cost departments.
- Uniform stipends for graduate students and postdoctoral students. While there is some variation in stipends in some programs and universities, many programs offer stipends that do not vary by discipline [National Research Council, 1988d; Nelson, 1988].

This recitation of market imperfections is not intended to suggest that such imperfections are universal or that we have documented widespread impacts. For example, a recent study concludes that the uniform wage policy in our public elementary and secondary schools causes high turnover of science teachers [Murnane and Olsen, 1988]. However, our understanding of the educational process is such that we can not clearly establish whether this high turnover, in turn, causes a decrease in student learning or interest, though it seems plausible that it would.

## Federal Use of Scientists and Engineers

The federal government and its contractors have an atypical labor force in that it includes a high proportion of scientists and engineers. Intervention to increase the supply of scientists and engineers will tend to increase the quality and/or lower the cost of these personnel to the federal government and its contractors. The case for federal support is most obvious in sub-disciplines like aerospace/aeronautical engineering where 76 percent of employed persons with graduate degrees are employed in work supported by the federal government. However, 35 percent of natural scientists and 36 percent of engineers with graduate degrees were so employed in 1984 [Finn, 1988].

Problems with Reliance on Foreign Labor

Foreign nationals are not employed by the federal government, and by law can not be given access to certain technologies classified as sensitive from a national security perspective. Jobs performed by scientists and engineers with graduate degrees are among the most important and sensitive to our military and technological competitiveness. Currently, because of the shortage of U.S. citizens, U.S. employers depend on foreign nationals for a very substantial part of the new entrants to the work force. For engineering and computer science Ph.D.'s, 37 percent of recent new entrants to the workforce have been foreign nationals, and their representation among new engineering faculty is even higher [Finn and Clark, 1988; National Research Council, 1988a]. In the mathematical and physical sciences about 18 percent of new entrants to the doctorate work force were foreign nationals [Finn and Clark, 1988]. Those who question the wisdom of the U.S. economy's increasing reliance on foreign scientists and engineers also note that much of the immigration comes from countries which are rapidly



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increasing in technological sophistication and manufacturing exports. Already some immigrants with experience in U.S. industry are emigrating, and there is concern that increasing reliance on immigrants may leave the U.S. vulnerable if these scientists and engineers should choose to work outside the U.S. in the future.

## Shortages of Scientists and Engineers

Though shortages are not widespread at present, significant shortages have persisted in some fields for some time. The evidence cited below may be viewed as the empirical manifestation of the market imperfections cited above.

One source of information on shortages of scientists and engineers during the 1980s is a survey of employers conducted by NSF nearly every year since 1980 [National Science Foundation, Division of Science Resources Studies]. The NSF employer survey indicated severe shortages of most engineering and some science occupations at the beginning of the decade. By the mid-1980s the survey reported a substantial decline in the proportion of employers reporting shortages, but there were a few fields where more than 10 percent of firms reported shortages (e.g., electrical and nuclear engineering). The general picture given by these surveys is that shortages have persisted in only two fields (electrical engineering and computer science), but there have been significant, albeit temporary, shortages in other fields. Only a few fields have been relatively free of reports of shortages (e.g., biology) but even in these there is evidence that there have been and continue to be shortages in some of the specialties related to biotechnology [U.S. Congress, Office of Technology Assessment, 1988b, p. 135].

A similar survey was conducted for employers of engineers by the National Research Council [National Research Council, 1985, pp. 63-67]. It found that half or more of employers found it "difficult" or "very difficult" to hire quality recent graduates in the fields of computer, electrical, electronic, and mechanical engineering, and that at least 25 percent of employers reported this for every field except civil engineering where 15 percent of employers reported shortages [National Research Council, 1985b, pp. 66-67].

Data on the federal workforce provides a similar picture of shortage conditions. The Office of Personnel Management identifies job categories in the federal government that are difficult to fill, and this information is used to set "special rates" for selected fields. Fields which have been so identified during the 1980s include virtually all fields of engineering and many fields of science. At present, the list of special rates includes a wide variety of occupations in select (usually high cost) locations. However, engineers dominate the list of occupations for which such "special rates" have been authorized worldwide or nationwide. Within this group, nuclear, electrical, computer and electronic engineers qualify for the highest rates [U.S. Office of Personnel Management, 1989].

Similar data is collected from universities in a survey conducted by the American Council on Education. Their latest survey asked a sample of 357 institutions of higher education whether they were



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experiencing shortages in specific disciplines. For this survey shortage is defined to exist when the university is currently unable to find qualified applicants for vacant faculty positions. Two-thirds or more of the doctoral institutions reported shortages in three disciplines: engineering, computer science and business. Other disciplines where more than 20 percent of institutions reported shortages were physical science (22 percent) and mathematics (30 percent). In contrast, fewer than 10 percent of the doctoral institutions reported shortages in arts and humanities, foreign languages, social sciences, education, and vocational-technical fields [El-Khawas, 1988].

There have also been a series of surveys of engineering faculty vacancies. Since 1980 the survey reported a vacancy rate in the range of 7 to 10 percent for funded engineering faculty positions [Atelsek and Gomberg, 1981; Doigan, 1984, 1989]. This has been widely interpreted as a sign of a rather severe shortage of engineering faculty. However, it is difficult to interpret because we don't know what the "natural" vacancy rate is, i.e., the rate that would still prevail if the supply of engineering teachers were fully adequate.

Taken as a whole these direct measures of shortage find no general, persistent shortage of all categories of scientists and engineers but do find that there have been frequent shortages in computer science and engineering, and occasional shortages in other categories, most frequently in mathematics, environmental and physical sciences.



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## Adjustments to Shortage

In this section I cite empirical evidence for several adjustments which have resulted from employers actions to avert shortages of scientists and engineers.

## Salaries

A recent OTA report concluded that, "...although salaries are not increasing -- a sign of steady supply -- at all degree levels scientists and engineers enjoy the highest average starting salaries relative to other fields" [U.S. Congress, 1988a]. This general assessment can be corroborated by data from other sources [Korb, 1987; National Science Board, 1987]. We might disagree about salaries not increasing; there is evidence of at least a modest increase in science and engineering salaries relative to the earnings of all workers in private industry [National Research Council, 1988b, p. 48]. However, it is the level of salaries which is noteworthy, not their degree of change in recent years.

Some observers (focusing on the relative stability of science and engineering salaries) have interpreted this salary picture as indicating a lack of general "shortage." This is consistent with one use of the term "shortage." However, it does not necessarily mean that there is not a need for more scientists and engineers to be educated. The problem seems to be knowing what to make of the high salaries paid to engineers and most scientists. Do these high salaries indicate we should train more people in science and engineering disciplines? And if engineers have the highest paying jobs, why do fewer than 10 percent of college freshmen say they want to major in engineering? Clearly, we have to deal with the fact that the science and engineering disciplines are difficult courses of study. Successful engineering students are among the most able in their age cohort with high ability in science and math as well as strong verbal skills [National Research Council, 1985, p. 75]. Indeed, science and engineering disciplines in general, and especially the highest paying fields (engineering, math, computer and physical science) attract students with very high ability, especially quantitative ability [Hartnett, 1985]. No doubt some of the salary differential enjoyed by these graduates is a reflection of this ability.

Until recently I knew of no research which could be used to test whether the earnings of science and engineering graduates was superior to the earnings of other graduates after controlling for ability. However, an important study was recently completed using the 1986 follow-up study of the high school class of 1972 [James, et al., 1988]. This study controlled for ability using the students' SAT scores and also controlled for other background variables. It examined earnings in 1986, about 9 to 10 years after a typical student in the class of 1972 would have completed the bachelor's degree. It found that engineering graduates earned the highest salaries and that science and math majors earned above average salaries. Significantly, it also controlled for math courses taken in college so that these returns to the majors were over and above the return to taking math courses which science and engineering majors take in substantial numbers. To the extent that salaries indicate productivity it provides evidence that math courses and that science and math majors provide additional productivity compared with the education of other college students. The study also found a high positive return to the business major. Business and engineering were the highest paying undergraduate majors after controlling for ability, math courses taken and other factors. However, it found that business majors earned a differential only when they obtained management jobs. Engineering majors, in contrast, earned substantially the same large differential even when employed in non-engineering jobs. This is significant because the high school class of 1972 selected their majors during the early 1970s, a time when there was a relatively weak labor market for engineers and physical scientists. The finding that engineering majors do well even when they take non-engineering jobs is important because it means that the payoff from this investment is not dependent on the state of the somewhat cyclical engineering labor market.

Other studies confirm the finding that engineering graduates earn high salaries even when they take non-engineering jobs. One is a follow-up study of 1983-84 bachelors graduates conducted by the U.S. Department of Education [Korb, 1987]. The same was generally true of mathematics, computer science, and physical science majors except for the approximately 9 percent in these majors who took jobs as teachers. (This is probably due to the fact that most elementary and secondary schools have uniform pay policies, i.e., do not adjust pay to the market opportunity costs of different majors).

I conclude that the high salaries earned by most scientists and engineers do indeed indicate what seems to be a productivity differential apart from the ability of the students who currently major in those fields. There is fairly strong evidence to support the view that the productivity of the U.S. economy would be enhanced if more students who would otherwise major in other fields switched into science or engineering or took more mathematics courses in undergraduate school. One possible exception to this statement is biological science. At the B.S. level Korb found that 45 percent worked full-time after graduation and only the 13 percent of these working as biological scientists or health professionals earned salaries comparable to those of other science majors [Korb, 1987, p. 10]. Most took jobs that do not typically require a college degree and earned substantially less. This is confirmed by NSF surveys of recent science graduates which typically show that B.S. and M.S. life scientists earn substantially less than other B.S. and M.S. graduates in the sciences, and also that many take jobs outside of science or engineering [National Science Foundation, 1986].

Unemployment and Underemployment Rates

Unemployment rate for scientists and engineers have fallen to half the level of the mid-1970s [National Research Council, 1986, p. 73]. The rate for scientists and engineers are substantially below the unemployment rate for the labor force as a whole, and below the unemployment rate for all college educated workers. In 1986 the unemployment rate for scientists was under 2 percent and the unemployment rate for engineers was only 1.3 percent [National Science Foundation, 1987a, pp. 169-170].

NSF also computes an underutilization rate, which counts as underutilized not only the unemployed but also those who are working part-time when they would prefer full-time jobs and those who are working outside science and engineering when they would prefer to work in science or engineering. In 1985 the underutilization rate for doctoral scientists and engineers was about 2 percent, with the following fields well below 2 percent: physics, mathematical sciences, computer sciences and engineering [National Science Foundation, 1987, pp. 173-177].

## Immigration

Entry of non-U.S. citizens into the U.S. labor market for scientists and engineers has been an important mechanism for averting shortage of advanced degree holders. At the doctorate level, engineering is the field that is most dependent on foreign nationals. They have supplied 37 percent of new entrants to the U.S. labor market for Ph.D. engineers and computer scientists in recent years. Mathematics is similar to engineering in this regard, but mathematics and physical sciences combined depend on foreign nationals for about 18 percent of new entrants to the Ph.D. market [Finn and Clark, 1988]. Mathematics and engineering both award 50 percent or more of new doctorates to foreign nationals [National Research Council, 1989]. While U.S. citizens still predominate in the sciences, foreign students are a high and growing proportion of graduate students in most fields. Nearly all of the fields with especially high foreign enrollments are fields where U.S. enrollments have declined since the peak enrollments of the 1968-72 period. Thus, the willingness of top-notch foreign students to study in the U.S. is filling a number of gaps. They provide students when U.S. students seem not to be motivated to complete graduate study. They have allowed many academic departments to maintain or even raise their already high standards of excellence. Finally, because half or more of the foreign graduate awardees enter the U.S. workforce, they also make very valuable inputs into the labor market. A committee of the National Research Council examined this phenomenon in engineering and was convinced that it is in the U.S. interest to have these foreign students stay in the U.S. to work. However, the same committee also recognized possible problems with increased reliance on foreign students and recommended that increased numbers of U.S. students be encouraged to earn doctorates in engineering [National Research Council, 1988a].

Employment Growth Faster than Degree Growth

Over the entire period since 1972 it is estimated that engineering job openings due to growth (i.e., excluding replacement needs) have exceeded the total number of degree awards in engineering [National Research Council, 1988b]. With science it is more difficult to compare employment growth with degree growth because the correspondence between degree field and employment field is normally much less. However, to some extent it appears that there is so much substitution among fields like mathematics, engineering, physics and computer science that it is necessary to lump all natural science and engineering fields together to ask whether employment growth is outstripping the output of the educational pipeline. The National Science Foundation has done this, focusing on the fact that smaller cohorts are now passing through the educational "pipeline" [National Science Foundation, 1987b]. That NSF report shows that if the proportion of 18-22 year olds who earn degrees in science and engineering fields does not increase substantially, then the slow growth of projected college enrollments means that B.S. awards in science and engineering fields will decline substantially over the next decade. In contrast the Labor Department has projected that total employment will grow 13 percent in a low growth scenario and 19 percent in a moderate scenario from 1986 to 2000, while during the same period employment of scientists and engineers is expected to grow 28 percent in a low growth scenario and 49 percent in a moderate growth scenario [U.S. Department of Labor, 1988]. This is a remarkable contrast: a decline in B.S. degree awards while at the same time we have a 49 percent increase in employment! The disparity sounds too great to believe at first glance and deserves careful attention.

Some would say that the BLS projections have been wrong in the past, and, given the inherent difficulty in making forecasts of employment by occupation we should not rely on them in the future. To these criticisms defenders of the BLS forecasts can point out that the 19 percent employment growth projected from 1986-2000 is really partly based on reliable population projections and fairly reliable projections of labor force participation rates. The fact that the employment of scientists and engineers is expected to increase much faster than the total is just a reflection of the increasingly technological nature of



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our economy. BLS's highest rates within science and engineering are for electrical engineers, computer specialists, and systems analysts; thus it is merely assuming a continuation of recent trends. Further, an analysis of past BLS forecasts for engineers found no systematic bias for the mid-case scenarios to be high or low in past projections [Dauffenbach, 1986]. Thus, we must judge the BLS forecast to be very plausible.

The NSF scenario that indicates declining degree awards in science and engineering fields, can be criticized as being a manifestation of demographic determinism. However, this criticism would be valid only if applied to a deterministic version of the analysis, one which says that shortages are inevitable. The best use of the analysis is to point out that the United States risks shortages of scientists and engineers during the 1990s unless we find a way to increase the proportion of college graduates who earn degrees in science and engineering, or increase the mathematics and science knowledge of graduates in other majors. The growth in employment projected by the BLS could be frustrated if this does not happen, or, at the least, employers of scientists and engineers would have to make adjustments to a threatened shortage such as increasing the proportion of science and engineering hires that come from occupational mobility, hiring new graduates in non-science and engineering fields, or increasing the hiring of foreign nationals [Collins, 1988].

It can be argued that our economy can cope with these problems during the 1990s just as it has during the 1980s. Indeed, a recent inquiry by the National Research Council failed to find severe quality problems in the engineering labor force that occurred from the adjustments to shortage that occurred during the 1980s [National Research Council, 1988b]. However, the National Research Council studies concluding that we coped with the shortfall of U.S. citizen engineers during the 1980s have also indicated that there is a need to train more U.S. students in science and engineering fields. They have recommended that, while the influx of foreign scientists and engineers has been beneficial, we should nevertheless increase the supply of U.S. citizens going into these fields. Separate studies of physics and mathematics have also called for increased degree awards [National Research Council, 1984, 1986b].

The NSF analysis suggests there may be a need for federal government action to increase the number of U.S. citizens enrolling in science and engineering at virtually all levels. While college enrollments may hold up in spite of the declining number of 18-22 year olds, all plausible projections of college enrollments suggest that they will grow very little if at all during the next 5-10 years because of the reduced number of 18-22 year olds, the demographic trough following the peak of the baby boom [Gerald, et al., 1988, Ahlburg et al., 1981]. Thus, if the number of science and engineering graduates is to grow roughly in proportion to the needs of the economy between now and the end of the 1990s, then the proportion of 18-22 year olds earning bachelors degrees in science and engineering fields will have to increase to historically high levels [NSF, 1987b, p. 5]. Increasing female participation in science and engineering was responsible for attaining the historically high proportions of 18-22 year olds earning science and engineering degrees in 1984. Since the rise in female participation seems to have stalled, further increases are questionable unless increased efforts are made to prepare more young students for science and engineering careers. Proportional growth of Ph.D.'s in science and engineering fields would not require breaking into new territory -- only a return to higher ratios of doctorates to the relevant population group (25 to 34 year olds) that were experienced during past periods of strong federal support for science and engineering graduate students.

## Conclusion

No one understands student choice and behavior well enough to say with precision that U.S. graduate enrollments in science and engineering will not increase by a substantial margin without additional intervention. In fact, science and engineering degree awards in 1987 edged up slightly from the remarkably stable level held for the previous decade. However, there are reasons to suspect that we will experience less market response than we have in the past. One is the recent (1986) tax law change which makes taxable many graduate school stipends which had been previously been tax free (e.g., fellowships and graduate research assistantships). Another is the presence of large numbers of foreign doctorate recipients. To the extent they stay in the U.S. in greater numbers than at present they will help to moderate salary increases that would otherwise signal more young U.S. citizens to enter graduate school.

I conclude that we need to equip and encourage more U.S. students to enter graduate school, especially in engineering, mathematics and the physical sciences. The mention of specific disciplines is done with some hesitation. There is not a convincing case that the federal government can or should attempt to "fine tune" the labor market by adjusting supply to projected future demand in specific fields. However, there is a case for general support of science and engineering to increase supply. This case is strongest for the fields of engineering, mathematical, computer and physical sciences because there is evidence that market imperfections are causing greater problems in these fields.

## Policy Options

This section outlines major policy options available to the federal government if it chooses to take further action to increase the supply of U.S. scientists and engineers. This is necessarily an incomplete overview. Just to catalogue current federal training programs would take much more space than is available here if we wanted to view them with the detail needed to understand important differences. Further, it should be recognized that my statement of the advantages and disadvantages of these options is of necessity often based on my own judgments as there is an inadequate research base for judging the effects of different policies to increase the supply of scientists and engineers.



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Graduate Fellowships and Traineeships

A well established approach for increasing the supply of doctorates is to increase federally funded fellowships. One of the "key findings" of a recent Office of Technology Assessment study is that,

> "Federal funding has a direct positive effect on Ph.D. production. Fellowships and traineeships in particular have been a straightforward way to increase Ph.D. production in science and engineering" [U.S. Congress, 1988a, p. 68].

Pros

This is a proven approach with well established mechanisms. Administrative costs are reasonable. Fellowships tend to attract the best students and to draw attention to the fields where they are located (e.g., science and engineering generally in the case of NSF fellowships; specific disciplines or technologies in the case of fellowships from mission agencies such as DOE, DoD, NASA and NIH.) There is ample evidence that fellowship students finish faster, and have greater early career success than non-fellowship students [Harmon, 1977; Coggeshall and Brown, 1984; Snyder, 1988]. Of course, fellowship students are usually superior students to begin with, but there is some evidence that federal fellowship winners achieve somewhat higher success than other comparable students who are not recipients [Snyder, 1988]. Another advantage of this form of support from the point of view of national policy makers is that the criteria



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for awards can be specified by law (e.g., restrict to U.S. citizens, assure geographical balance within U.S.).

Cons

Apart from cost there are few drawbacks from national fellowship programs. Critics might argue that their reputed effectiveness in increasing degree awards is based on rather weak empirical evidence -- the correlation of fellowship growth and enrollment growth does not necessarily indicate that the fellowships caused the enrollment growth. Another reason to be wary of a large build up of fellowships is the fear of program inertia -- fellowship programs might encourage movement into science even after the supply is adequate. However, this kind of criticism seems most appropriate for a massive program or an attempt to fine tune supply to meet demand. A typical current proposal, the engineering deans' recommendation for a doubling of engineering fellowships [Engineering Deans' Council, 1988] would really be a marginal change since fewer than 2 percent of engineering graduate students have been supported by federal fellowships in recent years [National Research Council, 1988a, p. 94].

Traineeships differ from fellowships primarily in that the government makes awards to specific academic departments which in turn make awards to individual graduate students. Traineeships do not usually carry the prestige of nationally competitive fellowships. However, winners of competitive fellowships tend to attend graduate schools which already attract the nation's best students. If

Congress wants to disperse talent among a greater number of graduate schools, then traineeships offer an advantage over portable fellowships. The department of Health and Human Services uses this mechanism extensively. Other federal agencies (e.g., NSF) used this mechanism extensively in the past and are now considering its use again, in light of a perceived need for increased graduate student support. About 20 percent of federally supported graduate students were supported by traineeships in 1985 [Finn, 1988].

Research Assistantships

Federal research grants made to universities support graduate students (and a few undergraduates) as research assistants. This mechanism has increased greatly in relative importance since the early 1970s and now supports about 80 percent of the graduate students now receiving federal funding [National Science Board, 1987].

Pros or Cons?

Nearly all of the distinguishing characteristics of this mechanism may have effects that might be argued as pros by some and cons by others. For example, graduate assistants are selected by the professors who employ them. Thus, student support is tied to research. This has positive and negative effects. On the positive side we might cite the assurance that the student is involved in research. However, this system ties student support to research



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priorities, which do not always change in line with student support needs.

Research grants are a very indirect way of aiding students, and the number of students aided can be less than expected. Consider engineering where there was a recognized Ph.D. shortage at the beginning of this decade. Because of special efforts from NSF, DoD and other federal agencies the amount of federal funding for engineering R&D in universities increased 13.3 percent in real terms from 1979-1985. However, much of this funding was used up to finance increasing salaries for engineering faculty (up 20.8 percent over the same period). The number of federally supported graduate students increased by a much smaller proportion than funding (only 5.2 percent) over the same period. Engineering was not atypical in this respect [Finn, 1988b, p. 7].

Also debate arises from the fact that research grants place the selection of federal student aid recipients in the hands of the university. While there are undeniable merits to this approach it reduces the ability of national authorities to influence selection. Furthermore, the federal government's interest in the mix of students may differ from the mix of students generated by the sum of many local graduate student aid decisions. For example, in recent years foreign nationals earning Ph.D. degrees in engineering, mathematics and computer sciences have been virtually assured that they could be granted immigrant (i.e., permanent resident) status if they wished because the number of U.S. citizens graduated was small both in relation to total employment and in relation to the total number receiving doctorates.

In spite of weaknesses in reliance on research assistantships for graduate student support, the R&D program of the federal government is a major source of direct graduate student support. Further, the level and distribution of R&D spending shapes the job market for scientists and engineers and can indirectly affect future supply. Increased stability, possibly through the mechanism of multi-year budgeting can improve the effect of R&D funding on supply [National Research Council, 1986, p. 41].

## Forgivable Loans

Loans are not widely used as a means for financing graduate education in science and engineering. In 1987 most Ph.D. recipients had no debt at graduation, and those who did reported a median debt level of only $7,112 [National Research Council, 1989]. However, loans have been an important part of the graduate student aid package in the past. One example is the Ford Foundation forgivable loan program in Engineering. This program helped more than 900 persons earn Ph.D.'s in engineering. A study undertaken after it was terminated in 1966 indicated that it was effective in increasing the supply of Ph.D.'s for faculty positions, in part by facilitating the graduate education process of those already inclined toward teaching, rather than diverting to teaching those people whose original goals were non-academic [National Research Council, 1970, p. 22].



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## Pre-College Programs

Only a tiny portion of those getting bachelors degrees in science and engineering go on for doctorates. The supply of Ph.D. engineers would more than double if the proportion of B.S. degree recipients in engineering who go on to a Ph.D. were to return to the proportion experienced 20 years ago. This illustrates that the shortage of doctorates experienced at present is not simply the result of too few students in science or engineering at lower levels. Nevertheless, increasing the science and mathematics achievement of precollege youths is an important policy option because (a) it will make our graduate school problem easier, and (b) because there are great benefits to society from increasing the proportion of bachelors recipients who take mathematics courses and/or major in science and engineering.

Federal intervention at the pre-college level tends to have a limited effect because many important concerns (e.g., course requirements and teacher salaries) are within the domain traditionally controlled by state and local authorities. The kinds of actions traditionally engaged in by the federal government have included curriculum development and research and summer institute programs for high school teachers and top high school students, dissemination activities, and student enrichment programs e.g., the 4-H program of the U.S. Department of Agriculture supported by federal agencies [U.S. Congress, Office of Technology Assessment, 1988c, pp. 109-131].

Undergraduate Education

The federal Government spends about $10 billion on undergraduate student aid, but with few exceptions this vast sum is distributed without any expression of preference towards the undergraduate student major. One of the exceptions to this generalization is the Minority Access to Research Careers (MARC) program of the National Institutes of Health. An evaluation by the National Research Council showed this to be effective in increasing minority participation in science [Garrison and Brown, 1985]. Further, it found that a feature which this program shares with many other federal undergraduate science programs, student participation in off-campus research, was cited by students as the most influential aspect of the program. These findings suggest that an expansion of federal programs like the MARC program would be effective in increasing undergraduate science education, as would expanded efforts like the Department of Energy's programs to involve bright undergraduates in federal laboratory research [U.S. Department of Energy, 1988]. So too would an effort to link part of current need or merit based programs to science or engineering study, or to create new programs to support undergraduate science and engineering students [U.S. Congress, Office of Technology Assessment, 1988a, p. 96].

However, it should be noted that enrollments in some fields with the strongest job markets (e.g., electrical engineering and computer science) seem to be limited by capacity in most universities. For these fields an expansion of Ph.D. degrees and financial aid which helps the college or university acquire faculty and equipment is likely to be more effective than programs to stimulate student interest.

## Tax Incentives

The federal tax treatment of tuition paid by employers and of stipends paid to students clearly affects the after tax cost of education. There is ample evidence that enrollment and degree completion is affected by the level of tuition at the undergraduate level, but the evidence for graduate students is mixed [Finn, et al., 1988]. Nevertheless, the Engineering Deans' Council recommended that the federal government should restore tax exclusion for both tuition remission and graduate student stipends [Engineering Deans' Council, 1988, p. 780].

## Employee Educational Assistance

Employers currently support graduate science and engineering education for their employees in a number of ways. For example, they pay all or part of tuition costs and sometimes give release time for classes. All employers could be given greater incentive to help employees return to graduate school for full or part-time study by paying tuition and living expenses. Expansion of such benefits for federal employees and employees of federal laboratories might not only increase degree awards, but also increase the attractiveness of federal employment and the quality of the federal work force.

Preferential tax treatment of student stipends and of employer educational assistance have in the past been available to all students. It might be very expensive to reinstate such tax treatment for all in terms of the size of the impact on science and engineering enrollments. This may well be justified because of the need for more U.S. graduate students in other disciplines, but that is beyond the scope of this paper.

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