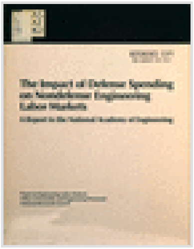

# Impact of Defense Spending on Nondefense Engineering Labor Markets: A Report to the National Academy of Engineering (1986)

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# The Impact of Defense Spending on Nondefense Engineering Labor Markets

## A Report to the National Academy of Engineering

Panel on Engineering Labor Markets
Office of Scientific and Engineering Personnel
National Research Council

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1986

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the panel responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee, consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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NATIONAL RESEARCH COUNCIL
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September 1, 1986

Dr. Robert White
President
National Academy of Engineering
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Dear Dr. White:

I am pleased to transmit to you the report, "The Impact of Defense Spending on Nondefense Engineering Labor Markets." You will recall that the Office of Scientific and Engineering Personnel was requested to undertake a study to investigate the feasibility of assessing the impact of large increases and decreases in government defense spending on the availability of engineering personnel for the nondefense, commercial sector. To accomplish this task, a Panel on Engineering was formed, three papers were commissioned, and a body of relevant data was compiled. The Panel reviewed this material and, based on it, produced the final report.

The report presents evidence about past and current experience; it describes the limitations in our ability to anticipate the future and cautions against reliance on events of the past or the present in predicting future engineering supply and demand.

The attached report represents the consensus of all members of the Panel. We hope it will serve a useful purpose in illuminating the facts and issues that must be confronted in addressing this important issue.

Sincerely,

Harrison Shull

Harrison Shull
Chairman, Panel on
Engineering

HS:jg

# FOREWORD

This report is the first of several envisioned by the National Academy of Engineering to address key issues relating to the long-term enhancement of the human talent indispensable to U.S. leadership in engineering and technology. Engineers and technologists are critical to all aspects of society: national security, economic competitiveness, and the general welfare. Ensuring appropriate flows of men and women into technological professions involves concerns at all levels, from mathematics and science education of young people through continuing education of experienced workers in mid-career, as well as their university education at undergraduate and graduate levels.

This report asks questions and provides some answers about how employment of engineers in defense industries and laboratories affects employment in civilian industries and laboratories. It does not attempt to predict future supply and demand for engineers. Indeed, it clearly points out the need for much more extensive data to evaluate such issues.

At the request of the National Academy of Engineering, the Panel on Engineering Labor Markets of the Office of Scientific and Engineering Personnel of the National Research Council has performed a most useful task in examining analytically the often controversial question of how the talent pools in the defense and nondefense sectors have interacted. The report also helps to bring into focus the broader issue that the nation must address. The challenge is provision of a sufficient number of outstanding scientific and engineering personnel in the context of the growing importance of technology to the economy in an era of steadily increasing international industrial competition and a declining number of young Americans available to enter technical careers.

In judging the adequacy of the supply of engineering personnel, it is necessary to consider both quality and quantity. Satisfying demand quantitatively can sometimes be achieved by devices, such as lowering standards, which are counterproductive in the long run. The key to maintaining a vigorous and competitive engineering and technological enterprise is in producing a supply of highly qualified and well-trained engineers for both defense and civilian activities. For that we need to place great emphasis on the quality of engineering education and training in our universities and on enlightened hiring practices in industry.

As noted in the report, the available data bases on the engineering profession have many deficiencies. Responding to shortcomings in information sources, the Panel supplemented its use of published data with information from a small sample of industrial recruiters and college placement officers. This report, which deals with engineering personnel as a whole, focuses on the larger pools of people--for example, undergraduate-level engineers. However, the report also recognizes the need for further work to examine the system at a finer scale for an improved understanding of the extremely important question of the supply and demand of engineers trained at the graduate level. We hope that the many groups concerned with engineering talent in both the defense and civilian sectors will find this report instructive and that it will stimulate further development of techniques for better anticipating future requirements for engineers at all educational levels and the policies to help meet them.

Robert M. White
Vice Chairman, National Research Council,
and President, National Academy of Engineering

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# EXECUTIVE SUMMARY

## Introduction

The National Academy of Engineering (NAE) requested that the National Research Council through its Office of Scientific and Engineering Personnel (OSEP) undertake an exploratory study to assess how recent increases in defense spending are affecting the supply of engineering personnel in civilian, nondefense labor markets. To address these issues, the Panel examined a variety of data sources and historical models, information exchanged during a two-day conference, and facts gleaned from interviews with especially knowledgeable individuals, company recruiters, and university placement counselors.

To avoid misunderstanding, the Panel wishes to emphasize that this report does not attempt to assess long-range future relationships between the supply of and the demand for scientific and engineering manpower. Further comment on the limitations of predicting the future from past and current conditions is given below (see page iv).

## Historical Overview

The rate of increase in defense expenditures during the Korean War (1950-1953) was seven times larger than the rate of the most recent increase (1980-1985); it was two times greater during the Vietnam buildup (1965-1968).

Defense and nondefense industries adjusted to the magnitude of these earlier defense expansions with little or no major dislocations. The major reason for this was the existence of a set of adjustment mechanisms that permitted the engineering labor market to accommodate reasonable changes in either demand or supply. Among these were long-term mechanisms such as a considerable increase in the supply of engineering degree recipients and short-term mechanisms such as substitution between engineering and nonengineering labor.

## The Current Situation

The Panel examined a number of sources to assess the current supply-demand relation for engineering employment. The Job Offer Index of the College Placement Council has actually decreased since 1982 for all fields except computer science, aeronautical engineering, and electrical engineering. The lower index suggests that there is no current shortage of engineers at the entry level. The High Technology Recruitment Index compiled by Deutsch, Shea, and Evans, Inc., shows that recruitment activity fell during the 1982 recession and, although currently on the rise, has not reached the peak achieved during the years 1978-1981. This suggests that, during the early 1980s when defense expenditures rose sharply, companies included in the Index were hiring at a reduced rate and had little trouble filling scientific and engineering positions.

Recruiters from 13 large corporations reported that they had no trouble filling engineering positions. Placement officers from about a dozen academic institutions indicated that currently the demand for graduates roughly matches supply and that there is less aversion to working on defense projects than during the late 1960s. Job offers from defense firms have acted to offset declines in recruiting activity by the commercial sector and to absorb increases in the supply of engineering graduates.

More significantly, the percentage of scientists and engineers working on projects sponsored by the Department of Defense in the early 1980s was, in general, lower than the percentage in the early 1970s. This is further evidence that defense outlays have not seriously affected the numbers of engineers available for nondefense work.

## Anticipating the Future

There are signs that defense spending is leveling and that, in the near future, defense demands will not stress the labor market for engineers. Current actions of Congress on the defense budget suggest that the rate of increase is likely to be less than originally projected.

Current available econometric models and available data are inadequate to make predictions of the effects of future perturbations on the engineering community. Existing models, for example, do not permit an adequate assessment of the probability of future significant over- and undersupplies of engineers.

National security, in its broadest concept, dictates having a domestic professional engineer capacity to meet both defense and commercial demands. The trend toward globalization, however, as corporations strive to maintain or establish positions in markets that are increasingly international in scope, is producing a variety of new industrial operating concepts. These include joint ventures, licensing, and sourcing--not only of finished goods, materials, tools, skilled and unskilled labor, but also of scientific research and professional engineering work. *Obviously, in such a period of dramatic industrial transformation, reliance on the events of the past quarter century and on current economic models provides an inadequate base for predicting future engineering supply and demand.*

Although the marketplace is adaptable, it is not perfectly so. Imperfections produce adverse effects on individuals, on particular industries, or on particular subfields. It is important to consider ways to minimize these adverse effects and to develop mechanisms that are cost effective. A number of potentially useful mechanisms on which attention might be focused can be listed (see also pp. 15-17):

- Encouragement of increases (or decreases) in the number of new engineering graduates produced each year.
- Promotion of occupational mobility into or out of engineering.
- Substitution between engineers and experienced nonengineers in the performance of technical work.
- More effective utilization of engineers through such mechanisms as enhanced use of new information processing technologies, reassignment of tasks that can be performed effectively by others with less education, and provision of increased or more effective support personnel.
- Provision for an increase in the number of advanced engineering degree-holders.
- Retraining and continuing education of engineers in the workplace.
- Recruiting and hiring of foreign students and engineers and sending of engineering tasks to offshore talent pools.
- Restructuring of engineering education to provide more general skills that would allow a better match to the changing needs of the nation and permit more

flexibility in responding to shorter-term fluctuations in the relation between supply and demand.

## Conclusions

The main conclusions of this report are summarized as follows:

- The engineering labor market has exhibited a high degree of resiliency to the shocks of external forces, such as wide fluctuations in defense spending (see p. 4).
- The current defense buildup represents a relatively small increase when compared with earlier buildups (see pp. 5-7).
- Although the current demand for engineering services is high, evidence drawn from a variety of sources does not suggest pervasive or serious industrial shortages. However, problems may exist in particular fields requiring highly specific training, such as optics, and shortages of engineering faculty have been well documented (see pp. 8-11).

  Current understanding of the distribution of the best-qualified engineers between defense and commercial markets is poor (see pp. 10-11).
- Quantitative models of engineering manpower supply and demand developed thus far are inadequate to predict effects of future defense program requirements on the civilian economy or other similar issues (see pp. 13-15).

In addition, the Panel suggests the following areas of further study to improve the quantity and the quality of information about the engineering labor market:

- There is a significant need to refine and improve our understanding of all aspects of the engineering labor market. Better understanding is needed of how market adjustment mechanisms work and what steps would improve their functioning (see pp. 15-17).

  Quantitative models of engineering manpower supply and demand need further improvement. There is little reason to expend large sums in using present models to predict the future. Such projections may bear little resemblance to the actual future. But basic research on the models should be aimed to provide eventually an analytic tool to make more useful projections.

  The ability to assess potential future problems depends strongly on the development of a suitable continuing empirical knowledge base about engineering personnel supply and demand. Careful attention should be given to accumulating the essential data, to bridging current gaps, and to avoiding unnecessary duplication of effort.
- Considerably more attention needs to be given to conceptualizing and developing indicators of quality and, therefore, of understanding the most effective means of improving quality of education and of engineering performance (see pp. 15-17).
- There is need to monitor the engineering labor market on a continuing basis, using both the developing empirical data base and the improving theoretical models to recognize emerging problems in a timely manner (pp. 15-17).
- A study is needed to understand the rapidly changing international character of the supply of engineering services and its effect upon the competitiveness and national security of the United States (see p. 9).

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# INTRODUCTION

The National Academy of Engineering (NAE) requested that the National Research Council through its Office of Scientific and Engineering Personnel (OSEP) undertake an exploratory study to assess how recent increases in defense spending are affecting the supply of engineering personnel in civilian, nondefense labor markets. The current expansion of the defense program coincides with recent increases in the supply of engineers. There is, however, concern about the potential impact of the decline in the college-age population on future supply. If the availability of engineers for nondefense industries were to be reduced in the future, less qualified workers may be substituted, with adverse effects on productivity and costs, contributing to a weakening of international competitiveness.

This issue is seen as part of the general problem of perturbation of the engineering labor market by major changes in government programs, the energy crisis of the 1970s, and other external shocks. To evaluate it requires reviewing recent changes in demand for and supply of engineers and the current market, as well as estimating future demand and the ability of the market's supply adjustment mechanisms to deal with it. From this review it may be possible to determine whether policy interventions are called for.

The focus of the study is on engineers; information on scientists and technicians is included because of their potential to substitute for engineers in employment.

The Research Council appointed a Panel on Engineering Labor Markets to oversee the study and to prepare this report for the NAE. For the use of the Panel, OSEP assembled relevant statistics on defense expenditures and on the engineering, scientific, and technical labor market. Three papers were commissioned.[1] The first reviews the critical incidents that affected employment of scientific and engineering personnel in the postwar period; this paper helps to identify national forces that triggered personnel changes and provides the background needed to learn from historical patterns. The other two papers review, respectively, methods of projecting demand for engineers and supply. In addition, recruiters for major companies and college placement officials were consulted to get a picture of the current labor market. The Panel met on May 1 and 2, 1986, with several of the recruiters and placement officials, authors of the commissioned papers, and staff of the NAE and OSEP to review and discuss the issues and the material assembled and met subsequently to reach consensus on the report and its conclusions.

This report first reviews the effects of the defense program on the labor market for engineers from 1945 to the present and considers prospects for the next few years. It then examines in a more general way the methods by which the effects of major shocks or perturbations may be anticipated and evaluated.

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[1] These commissioned papers are included in Appendix A of this report: Eli Ginzberg, "Scientific and Engineering Personnel: Lessons and Policy Directions"; W. Lee Hansen, "What Can Demand and Manpower Requirement Models Tell Us About the Impact of Defense Spending on the Labor Market for Scientists and Engineers?"; and Michael McPherson, "Modeling the Supply of Scientists and Engineers: An Assessment of the DauffenBach-Fiorito Work."

# HISTORICAL OVERVIEW

## Significant Events

Significant events affecting the engineering labor market in the postwar period were reviewed, and the lessons learned from them were summarized in a paper by Eli Ginzberg (see Appendix A). The events recounted had varying impacts--not surprisingly, those that were both massive in magnitude and rapid in onset had the greatest influence--but the market retained its resiliency amid these changes.

Immediately after World War II, there was simultaneously a sharp decline in defense expenditures and a huge release of personnel from service. Extraordinary educational demands were placed upon universities and colleges by returning veterans at a time of great shortages of teaching personnel.

This period was accompanied by a buildup in the civilian economy from its low level of activity during the war. The veterans' enrollment fell off just as large numbers of new young instructors became available to education, and the faculty job market was soft for several years. A sudden reversal in defense expenditures occurred to support the Korean war. In fact, the Korean War buildup was so rapid and massive that the market could not adjust quickly. In the face of a rapid increase in defense outlays, the civilian economy's continued growth could not be sustained; resources had to be redirected to defense work.

After the Vietnam War, the drop in military expenditures and a sudden decrease in graduate student support from the federal government, accompanied by a peak in the number of doctorates awarded, created a temporary oversupply in the labor market for doctorates. Not even later growth in enrollments and in faculty employment could absorb the increase. It took several years of continued economic growth before new initiatives in energy research and development, mobility out of science and engineering professions, and (later) increases in defense expenditures absorbed the surplus.

Even then, the adjustment to the sudden and dramatic decreases in demand were not without personal costs. Undoubtedly, individuals who were led to believe that there was a fruitful career waiting for them at the end of the long road to an engineering education suffered. Cutbacks in engineering demand may have caused many to abandon years of education and training in order to find any kind of employment, or to delay or abandon further education that would benefit them and the nation.

By the early 1980s, the smaller number of Ph.D.s in engineering, the very large increases in the number of undergraduate engineering students, and the attractiveness of industrial employment for engineers over advanced education through the doctorate resulted in a shortage of engineering faculty. Engineering enrollments had more than doubled during the previous decade.

## Policy Initiatives

Two major policy initiatives enabled the market to cope with these changes.

Perhaps most significant was the federal government's decision to provide educational assistance for individuals. This aid was targeted to the many families who could not afford higher education for their children. In a 1953 study cited by Ginzberg, it was found that among the small section of the population that showed high promise of scholarly ability, only half entered college, and only one-third graduated. A variety of measures helped to educate and to preserve the other two-thirds of our highly talented brain power. The GI Bill's education benefits after World War II and its successor legislation--though justified in part as an expression of gratitude to those who had done military service--made education possible for millions who would otherwise have been unable to afford it. Other federal educational initiatives at different times in the postwar period included the National Defense Education Act, student loans, fellowships, postdoctoral positions, and research grants that gave employment and research experience to graduate students. Scholarships, fellowships, and other student aid provided by the states, private contributions, and financial awards granted by the institutions themselves contributed to the extension of educational opportunities.

A second effective policy initiative after World War II was federal direct support for research grants and contracts--in such areas as military, nuclear, space, energy, environmental technology and medical research, as well as in basic scientific research. This initiative was given a further boost after the first satellite was launched into space by the Soviets in 1957. The federal government's support not only enabled the United States to achieve international leadership in science and technology (with substantial economic consequences), but helped to build up strong educational and research institutions.

The strength of the higher education system heightened the labor market's ability to adjust to the shocks, both because a flow of graduates in a particular field could be expanded to meet changing needs and because continuing education opportunities helped to give greater occupational mobility to persons already in the labor market.

Another federal initiative that has been effective in facilitating market adjustments was the revision in 1965 of the law governing immigration, which abandoned restrictions based on preferential national quotas and opened the door to more scientists, engineers, and other professional and skilled workers.

Despite these measures, some of the major shocks created temporary market problems.

## Conclusions

A major conclusion is that the market has generally shown a great degree of flexibility, adjusting to the shocks that both tightened and loosened the market. Although past swings in birth rates affected the population of college-age persons, experience showed that the population was not the major factor in influencing the supply of engineers; changes in the proportion of the population going to college and in student choices of courses were also significant.

In fact, with hindsight it has become clear that the flexible supply of students willing and able to seek higher education, the introduction of some federal policy initiatives, and the existence of a highly flexible labor market made it possible for the U.S. to expand its research and development activity dramatically in both defense and nondefense sectors. There were some costs involved; one only needs to look at the labor market conditions for scientists and engineers during the late 1960s and early 1970s. But we can undoubtedly benefit from lessons learned over the past 40 years in formulating policies to ameliorate the dislocations that may occur any time the system is required to adjust to sudden change.

# THE CURRENT SITUATION

## Defense Buildup

Compared with earlier major buildups and declines in defense expenditures in the postwar period, the present defense program is by no means the largest or the quickest to develop. There has been a substantial increase in employment of engineers since it began; but by all indications that we were able to review, there have been no major dislocations or shortages of engineers. As often happens, the situation differs among engineering fields, and some minor stringencies have been reported; but in general, the supply has adapted to the substantial increase in demand.

Defense expenditures, fluctuating as they do in response to national emergencies, are a highly volatile factor affecting demand for engineers. It is apparent that no recent fluctuations have been as large as the rapid buildup in the Korean War. Up to 1985 the current defense program has moved at a slower pace than the Vietnam buildup. More quantitatively, defense spending increased from 5.2 percent of Gross National Product in 1980 to 6.0 percent in 1985, less than in either the Korean or Vietnam war periods (see both Figures 1 and 2 and Appendix Table 1, page 69).

To be sure, the components of the defense program with the largest impact on employment of engineers have increased somewhat more than total expenditures. Research, development, testing, and evaluation expenditures were $27 billion in 1985, an increase of 55 percent since 1980. Procurement (which includes the purchase of weapons and materiel), a $70 billion item in 1985, increased by 62 percent, compared to the increase of 35 percent in total defense outlays. Growth in these expenditures, in addition to the increase in nondefense activities suggested by the 12 percent growth in real Gross National Product in the 5-year period, generated a substantial increase in the number of engineers employed--about 200,000, or 14 percent (see Figure 3, page 7, and Appendix Table 2, page 70).

The outlook for further growth in defense expenditures is not clear. The administration's intention to continue expansion is in conflict with the pressures for deficit reduction. The budget request for fiscal year 1987, now before the Congress, calls for an increase of 28 percent from 1985 to 1989 in current dollars (see Figure 4, page 7, and Appendix Table 3, page 71). The price change from 1985 to 1986 was assumed to be about 5 percent, and for 1986 to 1989 an inflation rate of about 3 percent per year in prices for these items was assumed. This means that the real increase would be about half the current-dollar increase, or roughly 14 percent. In real terms (i.e., in dollars of constant purchasing power), this translates into an average increase of about 2.7 percent annually, well below the 6.2 percent annual average for 1980-1985. The expansion in procurement outlays is estimated at slightly less than the total, while outlays for research, development, testing, and evaluation are estimated to increase at a rate 50 percent more than the rate of increase of total defense outlays (both of these in current dollars).

Those familiar with the budget prospects suggest that the real growth rate could be below that estimated in the budget. If we accept this, at least for purposes of illustration, we would conclude that the percent of the GNP represented by defense expenditures is likely to remain close to present levels or may even decline slightly. If this conclusion is correct, the greatest impact that the present expansion of defense expenditures can have on increasing demand for engineers is behind us.

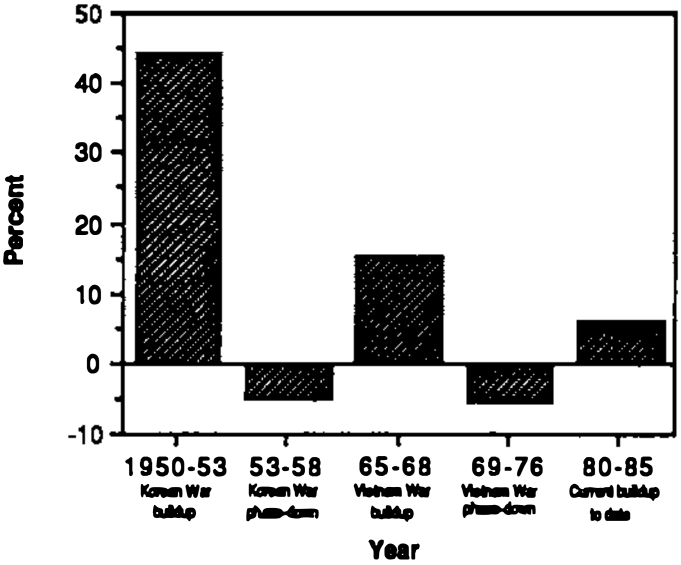

Figure 1. Average annual rates of growth and decline of defense expenditures.

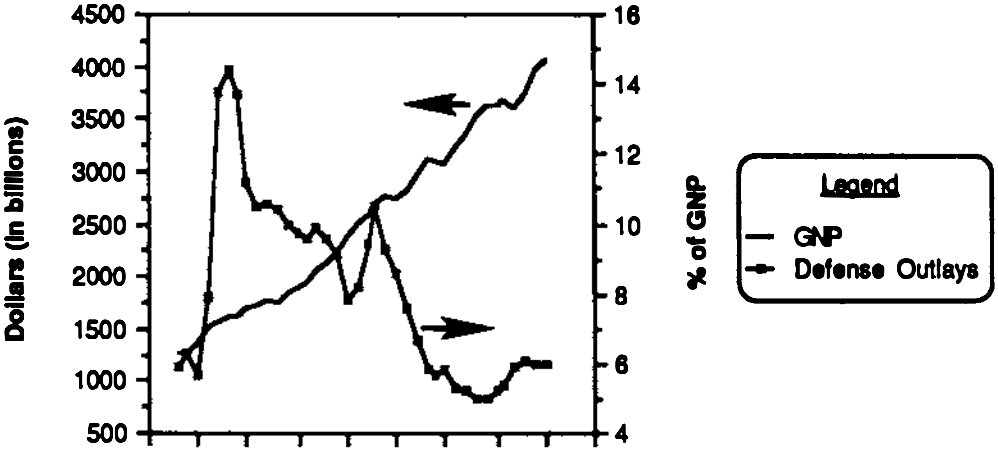

Figure 2. Gross National Product (in constant dollars) and defense outlays as a percent of Gross National Product, 1948-1985.

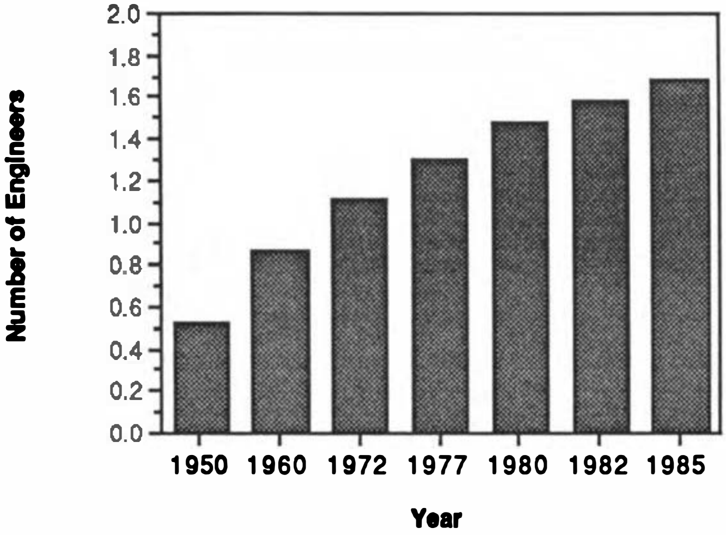

Figure 3. Employment for engineers, 1950-1985 (in millions).

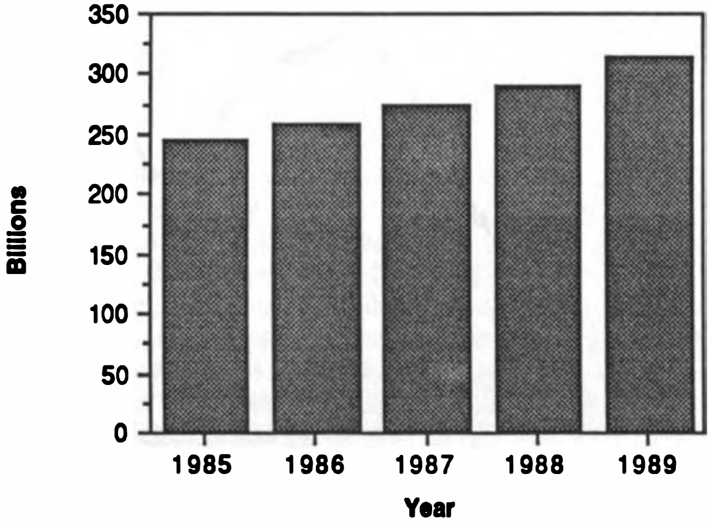

Figure 4. Total Department of Defense military outlays, 1985-1989 (in billions of current dollars).

## The Market for Engineers

The current labor market for engineers is a product of the recent growth in defense expenditures and the flexibility with which the labor market responded to that influence. To appraise these effects, the Panel reviewed information on the labor market statistics assembled by the staff, reports from college placement officers, and opinions of recruiting officials of large companies.

To gather evidence on whether the increase in demand and employment was accompanied by a shortage of engineers, several measures of labor market activity were examined. One of these is the High Technology Recruitment Index maintained by Deutsch, Shea, and Evans, Inc. From a low point in 1971, this Index rose until 1974; and after a decline in the recession of 1975, it climbed to levels roughly 40 percent higher than in 1974 for the four years 1978-1981. The Index fell to the 1974 level during the 1982 recession, and though it has risen since, it has not returned to the peak 1978-1981 levels. This suggests that in the mid 1980s, when defense production was rising sharply, the companies included in the Index did not find it difficult to fill scientific and technical positions (see Figure 5 and Appendix Table 4, page 72).

A similar picture is given by the College Placement Council's Job Offer Index for persons with bachelor's degrees. Except for computer science and aeronautical and electrical engineering graduates, job offers fell dramatically after 1982 (see Figure 6, page 9, for selected results; a more complete table is in Appendix Table 5, page 72).

Unemployment rates, however, suggest a tighter market for engineers in 1984 than at any time since 1976, with aeronautical/astronautical engineers and electrical engineers reporting the lowest unemployment rates. The most important feature to recognize from data on employment of engineers is that unemployment of engineers has been consistently low (see Appendix Table 6, page 73).

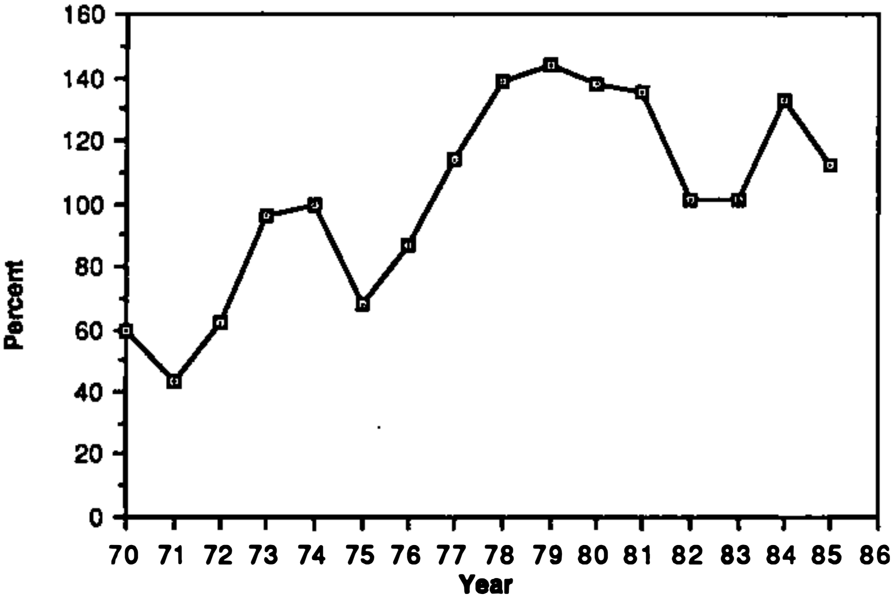

Figure 5. Annual quarterly average of the High Technology Recruitment Index, 1970-1985 (1961 = 100).

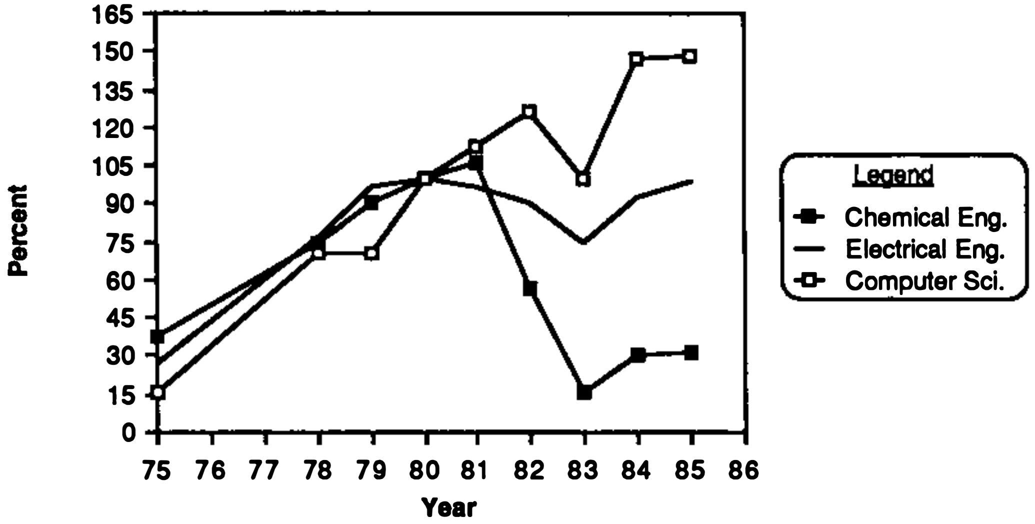

Figure 6. Job Offer Index for bachelor's-degree candidates, by selected curriculum and year, 1975-1985 (percent relative to the value of the 1980 Index).

Another area of concern is the shortage of engineering school faculty to cope with enrollments that had more than doubled in the 1970s. Fewer American students were continuing their engineering education at the graduate level; more of the doctoral graduates in engineering, normally candidates for faculty positions, were said to have been attracted to industry; and more of the faculty jobs went to foreign students, who constitute a high proportion of the Ph.D.s. The extent of this shortage varies by discipline and is greater in fields such as electrical engineering than in fields such as civil engineering.

Information obtained from a group of 13 recruiters for large corporations indicated that, in general, they had no problems in meeting their firms' recruiting goals, both in numbers of new graduates and in quality. Some recruiters reported problems in hiring electrical engineers, engineers to work on certain types of combat systems, and certain software engineers.

Recruiters also noted that when recruiting is difficult or requires raising salary offers, companies can adjust by shifting the placement of the existing engineering work force. For example, mid-level engineers might be kept in engineering positions longer rather than promoting them to managerial positions; technicians can be substituted for engineers in low-level assignments; or labor-saving technology made possible by computers--CAD/CAM, electronic networking, etc.--can be used.

Placement officers from about a dozen colleges and universities indicated that currently the demand for graduates roughly matches supply. Students tend to seek jobs not far away from their colleges, some officers said--an indication that the market is not forcing them to make long-distance relocations.

Students' motivations to enter engineering have changed recently, some placement directors observed. Whereas in the past many came from manual worker or farm families, now more come from urban, middle-class, white-collar families (in some part because more of the population is in this group). Fewer students fit the traditional technically oriented stereotype of an engineering student; more are "people oriented" with communications skills and an interest in management, and they see engineering education as a way of gaining "organizational access" and working up to management or financial jobs.

## Defense Employment

Since one of the questions of concern was whether the defense program would attract engineers to defense work at the expense of civilian industries, the Panel examined data on the extent to which scientists and engineers were working on projects sponsored by the Department of Defense (DoD).

This information is given for doctoral-level scientists and engineers in the National Research Council's biennial Survey of Doctorate Recipients (SDR).[2] The proportion of all doctoral-level scientists and engineers working on DoD-sponsored projects was lower in 1985 (8.5 percent) than in 1973 (10.5 percent), but higher than in 1981 (7.8 percent). The proportion of doctoral engineers, physicists, and mathematicians working on defense was higher than that of all scientists and indeed was higher in 1985 than in 1981, but the differences were small. Despite the increase in defense outlays in the 1980s, there is no evidence that the defense program seriously depleted the supply of Ph.D.-level engineers and scientists available for nondefense work. About 20 percent of engineers worked on defense projects in 1985; 62 percent of aeronautical and 30 percent of electrical engineers were in defense work (see Appendix Table 7, page 74).

Of "experienced"[3] engineering bachelor's and master's degree-holders surveyed by the National Science Foundation (NSF), fewer were engaged in defense work in 1984 than in 1972 and 1974. Only among those in operations research was there a substantial switch into defense work over this period. About 20 percent of the bachelors and 25 percent of the masters in engineering worked in defense in 1985 (see Appendix Tables 8 and 9, pages 75-76).

A related question is whether the defense program draws "the best and the brightest" engineers away from civilian industries. Although some preliminary evidence demonstrated that particular groupings of academic institutions were not disproportionately represented in defense employment and no gross discernible quality effects were emphasized by placement officers at academic institutions, the Panel concluded that data were inadequate to address the hypothesis. It is perhaps best to say that there is no evidence at present that either the defense sector or the commercial sector is lacking in appropriate representation of the "best" of our engineers.

There are impediments to recruitment for defense jobs, including student aversion to defense work (an aversion still evident at some schools, though it has diminished since the 1960s and 1970s). It is believed that experience in defense work confers less subsequent mobility either because the technical content of the work has limited civilian applications or because the work is organized in such a way as to give engineers narrow specializations. The reverse situation--a too narrow specialization in civilian industry making engineers unfit for military assignments--was reported in the paper by Eli Ginzberg. On the other hand, recruiters reported that it was easier to fill some defense jobs because the work is organized in teams and specialty requirements for additional team members are not as rigid as in civilian work.

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[2] The SDR provides statistical data describing the demographic and employment characteristics of individuals who have received doctorates in science, engineering, and the humanities from U.S. universities. A stratified sampling frame ensures coverage of all significant subpopulations, including representation by field and year of doctorate, field of employment, sex, racial/ethnic group, and citizenship. See National Research Council, Office of Scientific and Engineering Personnel, *Science, Engineering, and Humanities Doctorates in the United States: 1983 Profile*, Washington, D.C.: National Academy Press, 1985.

[3] "Experienced" engineers are those who were in the work force at the time of the 1970 and 1980 Census of the Population. A sample of such individuals was surveyed for NSF in 1972 and 1982, and those who met the NSF definition of an engineer are resurveyed until the end of the decade, when a new sample is drawn.

Placement officers reported that there is less aversion to working on defense projects than during the late 1960s. Rather than competing with civilian industry, placement officers felt that defense work had expanded at a time in early 1986, when some civilian industries experienced setbacks. The drop in oil prices, a slack market for farm machinery, and difficulties in the computer, forest products, and chemical industries were cited as reasons for the setbacks.

A survey of jobs taken by MIT graduates showed that most of those not entering academia or military service joined the civilian work force (commercial or nonprofit); the proportion entering civilian work dropped from 70 percent in 1980-81 to 65 percent in 1984-85. Average salaries were almost identical for those entering commercial work as for those entering government contract work (mostly defense) in 1983-84.

## Summary

In summary, the labor market situation as reported by these sources shows few strains from the expansion of defense expenditures and industrial employment of engineers, particularly at the bachelor's-degree level, in the past few years. Problems may exist, however, in particular fields requiring highly specialized training, such as optics, and the shortages of engineering faculty have been well documented (see, for example, Geils, 1982).

This general absence of stress in engineering labor markets reflects not only the limited extent and pace of the defense buildup, despite its emphasis on engineering-related expenditures, but also a flexibility in the labor market--i.e., an ability on the part of both workers and employers to make adaptations. A weakening of demand in some civilian industries, reflecting specific situations rather than a general failure of economic growth, contributed to the adjustment.

It should be recognized, however, that the recruiting and placement experiences of the large corporations and top engineering schools may not be representative of the market as a whole. Consequently, future data collections should pay increased attention to the small entrepreneurial industry side of the market.

# ANTICIPATING THE FUTURE

The findings from earlier chapters of this report indicate that the resiliency of the engineering labor market has enabled it to adjust to the post-World War II shocks of external forces with a minimum of disruption. These shocks include wide fluctuations in government programs, in particular the increase in defense expenditures that occurred in the 1980s. Although the market survived these fluctuations, the question remains as to whether it could accommodate further growth, regardless of its origin in the defense or the nondefense sectors of our society. This suggests the larger, and perhaps a more basic, question: Can we determine the point beyond which further growth strains the system? Our ability to address this issue depends in part on the adequacy of existing methods for predicting the impact on supply and demand of fluctuations in government programs.

This section of the report briefly reviews the methods by which demand and supply are anticipated and evaluates their reliability. Findings with respect to these methods draw heavily from the papers commissioned for this study. Although demand and supply interact and influence each other, they are treated separately for convenience of discussion.

## Anticipating Demand

In a paper entitled "What Can Demand and Manpower Requirements Tell Us About the Impact of Defense Spending on the Labor Market for Scientists and Engineers?" (see Appendix A) Lee Hansen identified a number of survey and analytic approaches for estimating the future need for scientific and technical personnel. He also identified an ad hoc method for estimating demand associated with a specific government program.

### *Surveys*

Questioning industrial officials about the changes they expect in labor demand is a technique long used by personnel departments. For example, state employment services used a survey to try to anticipate future employment changes in their areas. The method was abandoned more than 10 years ago as too inaccurate and too costly. A more sophisticated version has been developed more recently by the American Electronics Association and used for a 5-year forecast (National Research Council, Office of Scientific and Engineering Personnel, 1984, pages 11-25).

If it were possible to tap the information and judgment of knowledgeable industrial leaders, we might improve estimates of future changes. It is not as clear, however, that the summation of opinions obtained in a survey gives accurate results. This accuracy could be evaluated retrospectively by comparing forecasts with actual events. The evidence with respect to such evaluations is extremely limited. The Panel is not able, therefore, to judge the adequacy of this method of anticipating demand and is skeptical of the value of such surveys in anticipating demand more than one or two years into the future.

### *Analytic Methods*

Other, more analytic, methods estimate demand for workers in any sector of the economy by linking them to the rate at which the goods or services produced in that sector will be expanding--not necessarily a proportionate relationship. Some analytic methods are "microeconomic," focusing on linkages to a single sector or a few sectors of the economy. Others are "macroeconomic," seeking to anticipate how requirements for each of many different occupations in many different parts of the economy rely on estimates of the growth of the entire economy.

These models are limited in their ability to anticipate changes in engineering requirements by (1) the difficulties involved in accurately forecasting future changes in the levels and composition of the nation's output of goods and services and (2) methodological problems inherent in the estimation of the parameters used by these models to link requirements to output.

### *Ad hoc Methods*

Hansen also reviewed an ad hoc approach developed recently to predict demand for scientific and technical personnel in a component of the defense program--the Innovative Science and Technology Office, a small part of the Strategic Defense Initiative Organization (Sterling Hobe Corporation, 1986). To estimate personnel requirements for this pioneering R&D program, the analysts calculated the ratios of personnel to dollars spent by organizations engaged in each of the types of research involved in the program. These ratios were used to estimate total personnel requirements arising from budgeted growth; ratios of professional to total personnel were then used to estimate professional personnel requirements. This ad hoc approach was well adapted to estimating broad manpower needs for a highly specific R&D program. This approach, however, does not give the entire picture. It neither evaluates the effect of the program on supply of scientific and technical personnel throughout the economy nor determines its feasibility in terms of manpower.

## Anticipating Supply

The supply side of the labor market for an occupation like engineering may be characterized by flows of individuals who enter or leave through various channels. Included in this characterization are students graduating from engineering schools, experienced workers moving between engineering and nonengineering occupations in the United States, and international flows of workers migrating between foreign countries and the United States. As individuals enter or leave the engineering labor market through various channels, their responses to the market are affected by a number of social and economic variables.

Analysts of the engineering labor market try to take these flows into account in predicting future labor supply. In an attempt to develop a method that systematically relates these flows to labor market conditions, Robert DauffenBach and Jack Fiorito developed a labor supply model that starts with the stock of science and engineering personnel in one year and projects the stock for the following year, using past data on the relationship of each flow (student choices of careers, immigration, occupation mobility) to various indicators of the labor market situation (DauffenBach and Fiorito, 1983). The indicators used include (1) the level of employment in the occupation and the projected rate of employment change as variables affecting student course choices and (2) the estimated gap between projected demand and projected supply of graduates as a variable affecting the inflow from other occupations.

This model was evaluated by Michael McPherson, who calls it "the most comprehensive and analytically challenging among recent projection models of the supply side of technical labor markets" (see Appendix A). He notes that, like most other work in the field of labor supply, it is quantitative only, dealing with numbers of people but not with their quality or productivity--a subject difficult to evaluate or measure. He also notes that while supply is made responsive to demand, in order to make the model manageable, the reverse feedback--making demand responsive to supply--is not dealt with.

McPherson credits the DauffenBach-Fiorito model with comprehensively evaluating the supply system for scientific and technical personnel as a whole. He notes, however, that its very comprehensiveness limits the model to data that can be assembled with consistency across many fields and thus excludes the institutional peculiarities of individual fields--for example, the availability of NIH traineeships and postdoctoral fellowships as a variable affecting the supply in the life sciences. McPherson also points out the desirability of incorporating more specific adjustment processes in the model--for example, accounting for the various channels through which information on labor market conditions reaches the people who are presumably affected. The focus of research should not be *whether* supply and demand will be brought into balance but instead *how* and with what costs. The DauffenBach-Fiorito effort points to valuable directions for future inquiry to get better information on the dynamics of interfield movements and on the decision processes of colleges and universities affecting the production of graduates. A way of examining qualitative dimensions of this production may be to conduct follow-up surveys of the work experience of graduates, analyzing the results according to school records of grades or honors.

## An Evaluation

Because of the time and resource constraints imposed on this study, the Panel did not attempt to experiment with any of these methods of anticipating supply and demand. A study undertaken for the National Science Foundation in the early 1980s, however, found that the market would accommodate a real increase in defense expenditures from 1982 to 1987 that ranged from 3 to 8 percent per year, but that this could result in serious stress in the markets for computer specialists and aeronautical and electrical engineers.[4] However, the Panel could not forecast with a tolerable degree of certainty the labor market implications of any further growth in defense expenditures. This conclusion was based on (1) the limitations in the Panel's ability to anticipate accurately future changes in the level and composition of outputs, (2) the shortcomings in estimates of the linkages between engineering demand and supply, and (3) the current absence of a suitable data base against which estimates of anticipated engineering supply can be evaluated. The capability to illuminate this type of question needs to be developed.

## Further Issues

Although the Panel's general conclusion is that the market is adaptable, it is not perfectly so. Engineering labor markets are characterized by their cyclical nature,

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[4] The National Science Foundation (1984a) found that indicators of labor market conditions (i.e., anticipated differences between supply and requirements) suggesting possible shortages for computer specialists and aeronautical engineers were relatively insensitive to variations in the rate of change in defense expenditures or Gross National Product. Comparable indicators for electrical engineers were sensitive to changes in these variables.

suggesting the existence of overreactions to any given perturbation. Moreover, some changes can be so massive or sudden that either the entire engineering labor market or the markets for some engineering subspecialties will adapt more slowly or imperfectly, sometimes taking several years to regain a sensible steady state.

The results of such imperfections can produce significant costs. Sudden and dramatic increases can result in upward pressure on engineering wages or significant deterioration in engineering productivity. Either of these can inflate cost. Moreover, given the lags that exist in the system, some adjustments may occur at the wrong phase of the cycle. Large unexpected decreases can have significant adverse effects upon individuals caught up in these changes.

Occupational mobility and substitution between engineers and nonengineers reflect the willingness of both employers and employees to modify their standards in the face of changes in labor market conditions. The evidence indicates that such movement and substitution is substantial (see Appendix Tables 10 and 11, pages 77-78). Roughly one-sixth of the 1984 engineering work force had degrees in fields other than engineering, suggesting a nontrivial amount of inflow. The proportion of computer specialists with degrees in other fields (roughly four-fifths) indicates substantial amounts of inflow. Similarly, more than one-third of those with engineering degrees reported that they were employed in nonengineering occupations, suggesting a substantial amount of outflow. The efficiency with which this mechanism operates, however, can be further influenced through retraining or other means of increasing the fungibility of the existing engineering work force. New technologies and changes in institutional structures affecting engineering utilization are stimulating the need for such adaptability of the work force. Such adaptation will facilitate exploitation of these technological and institutional changes.

Engineering degree production responded quite well to past cyclical swings in engineering demand. These responses, however, occur with a considerable time lag, creating the potential for situations in which policies influencing this adjustment mechanism could contribute to further instability, rather than acting as a stabilizing force. The efficiency with which this mechanism operates can be influenced through financial aid mechanisms (in the form of fellowships, scholarships, research or teaching assistantships, and postdoctoral appointments) that affect the extent to which students are encouraged or discouraged from pursuing careers in engineering. Furthermore, career choices of high school students are probably heavily influenced by the media. Those choices made on the basis of media presentations of the market for engineers at one point in time may be inappropriate for the market at the time they complete their education. Varying the extent to which these mechanisms are used can help damp the swings in production of undergraduate engineering degrees and influence the decision of degree recipients to continue their engineering education at the graduate level.

In addition to mechanisms designed to influence degree production, measures aimed at more effective use of scarce engineering resources can also be considered. This report notes the increasing tendency on the part of employers to employ computer-oriented technologies such as CAD/CAM and "expert systems" to reduce the size and increase the efficiency of their technical work forces. The dominant motive for these efforts appears to stem from the desire of firms to improve their competitive positions in world markets. If so, these efforts can result in a future slowdown in the growth of industrial employment of engineers.

Some of the adjustments required to accommodate changes in supply and demand arise from the nature of preemployment engineering education. One way of ensuring a highly fungible engineering work force capable of responding to fluctuations in supply and demand and to rapid technological change is to offer a broad engineering curriculum with many core engineering courses shared by students in all disciplines. The Committee on the

Education and Utilization of the Engineer recommended such an approach to undergraduate engineering training. It noted that "... increased specialization of engineering curricula, coupled with decreased interest ... in degrees in basic sciences and mathematics, will lead to future difficulties in our ability to respond quickly to new technological challenges" (National Research Council, CEUE, 1985a, page 68). It further observed, "Extensive, in-depth disciplinary specialization does not belong in the undergraduate curriculum and should be postponed to the graduate level" (CEUE, 1985a, pages 68-69).

Such a shift in the structure of engineering education not only would introduce the possibility of more fungibility among sub-specialties inside and outside of engineering, but also would provide new possibilities of policy intervention to alleviate temporary conditions of over- or undersupply. It is probable that the concentration of a significant fraction of the professional education at the graduate level for physicists, chemists, biologists, etc., makes these occupations less susceptible to intense swings in supply/demand relationships characteristic of engineering today.

We are concerned about the state of our understanding of quality factors in engineering supply and demand in both military and commercial markets. The study was unable to find adequate information to enlighten us on the quality dimensions of engineering labor markets--i.e., dimensions describing (a) the productivity and performance of engineers and (b) the characteristics of the engineer and the work environment that contribute to high productivity and excellent performance. Nevertheless, these quality aspects of engineering labor markets are particularly important because many of the adjustment mechanisms discussed earlier in this chapter can dramatically alter these properties.

In addition, although there appears to be little cause for concern about engineering bottlenecks arising from the current buildup, it would have been difficult, given the state of the art in modeling engineering labor markets, to assess the labor market implications of further dramatic increases in real military expenditures should they continue. Past buildups were accompanied by programs designed to increase the supply of engineers. These programs are much smaller now and, with undergraduate engineering enrollments beginning to decline and the shortage of engineering faculty continuing, expansion of these programs to accommodate further growth in defense or nondefense activity may not be as feasible as it once was.

The market has been able to accommodate past changes in engineering demand and supply through the wide range of adjustment mechanisms that exist within its institutional structure. Our ability to assess potential future problems will depend strongly on the development of a suitable knowledge base about these mechanisms.

# CONCLUSIONS

The main conclusions of this report are summarized as follows:

- The engineering labor market has exhibited a high degree of resiliency to the shocks of external forces, such as wide fluctuations in defense spending (see p. 4).
- The current defense buildup represents a relatively small increase when compared with earlier buildups (see pp. 5-7).
- Although the current demand for engineering services is high, evidence drawn from a variety of sources does not suggest pervasive or serious industrial shortages. However, problems may exist in particular fields requiring highly specific training, such as optics, and shortages of engineering faculty have been well documented (see pp. 8-11).

  Current understanding of the distribution of the best-qualified engineers between defense and commercial markets is poor (see pp. 10-11).
- Quantitative models of engineering manpower supply and demand developed thus far are inadequate to predict effects of future defense program requirements on the civilian economy or other similar issues (see pp. 13-15).

In addition, the Panel suggests the following areas of further study to improve the quantity and the quality of information about the engineering labor market:

- There is a significant need to refine and improve our understanding of all aspects of the engineering labor market. Better understanding is needed of how market adjustment mechanisms work and what steps would improve their functioning (see pp. 15-17).

  Quantitative models of engineering manpower supply and demand need further improvement. There is little reason to expend large sums in using present models to predict the future. Such projections may bear little resemblance to the actual future. But basic research on the models should be aimed to provide eventually an analytic tool to make more useful projections.

  The ability to assess potential future problems depends strongly on the development of a suitable continuing empirical knowledge base about engineering personnel supply and demand. Careful attention should be given to accumulating the essential data, to bridging current gaps, and to avoiding unnecessary duplication of effort.
- Considerably more attention needs to be given to conceptualizing and developing indicators of quality and, therefore, of understanding the most effective means of improving quality of education and of engineering performance (see pp. 15-17).
- There is need to monitor the engineering labor market on a continuing basis, using both the developing empirical data base and the improving theoretical models to recognize emerging problems in a timely manner (pp. 15-17).
- A study is needed to understand the rapidly changing international character of the supply of engineering services and its effect upon the competitiveness and national security of the United States (see p. 9).

# ACKNOWLEDGMENTS

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# APPENDIX A: Commissioned Papers

"Scientific and Engineering Personnel: Lessons and Policy Directions," Eli Ginzberg (Columbia University), 25

"Modeling the Supply of Scientists and Engineers: An Assessment of the DauffenBach-Fiorito Work," Michael S. McPherson (Williams College), 43

"What Can Demand and Manpower Requirements Models Tell Us About the Impact of Defense Spending on the Labor Market for Scientists and Engineers?" W. Lee Hansen (University of Wisconsin-Madison), 53

# SCIENTIFIC AND ENGINEERING PERSONNEL: LESSONS AND POLICY DIRECTIONS*

Eli Ginzberg
*Columbia University*

## Introduction

Only a small and steadily declining proportion of the U.S. population can recall first-hand the extent to which our participation in World War II altered the directions of our national life and experiences. Nowhere was the sea change greater than in the new roles of research, research-based activity, and scientific and engineering personnel in the performance of priority work in all sectors of our national life--in government, in non-profit institutions (universities), and in the private sector.

To put the matter simply and sharply: in the prosperous 1920s--the New Era, when the optimists believed that the business cycle had been permanently eliminated--there was little interest and even less concern about the supply of college-educated personnel, including the numbers of scientists and engineers who were in the labor force or being trained to enter the labor force. A small number of U.S. companies--such as duPont, General Electric, Westinghouse, RCA, Kodak and AT&T--operated industrial laboratories, but they did not experience any particular difficulties in recruiting the numbers of young graduates for whom they had openings. In fact, some of them pursued discriminatory hiring policies that made it difficult or impossible for qualified women, Jews, or Blacks to secure positions.

The 10-year devastating Depression of the 1930s led to an even more constrained employment outlook for all who were seeking work, including scientists and engineers. The entrance of the United States into World War II in December 1941 and during the year or so preceding, when the country had begun to mobilize, altered the manpower scene radically. Recently, I found the following paragraph in a speech that I delivered to the American Society of Planning Officials in the spring of 1942:

> In peacetime, the best of our high school seniors fail to go on to college for economic reasons. Only one in four of our best students continue with their studies. President Conant of Harvard has been crying in the wilderness these last months for a large-scale subsidized program to enable the best of our high school students to go on to college and thereby contribute not only to the war effort but to the long-run improvement of our democracy.[1]

Early in World War II, the War and Navy departments enrolled into the reserves limited numbers of draft-eligible college students, particularly pre-medical and science

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*My long-term associate, Anna Dutka, played a significant role in preparing the final version of this paper, for which I am much in her debt.

[1] Eli Ginzberg, "The Coming Crisis in Manpower with Special Reference to the English Experience," in *Proceedings* of the National Conference on Planning, Chicago: American Society of Planning Officials, May 25-27, 1942, p. 89.

majors, to enable them to continue their undergraduate studies. But as the services' needs for additional uniformed personnel increased, most of these recruits were called to active duty. This was the first of what later came to be frequent instances of federal government policies intended to increase the flow of college and university-educated personnel to meet current or prospective national needs. For more than 40 years, considerations of national defense have dominated the shaping of federal manpower policies in the arena of higher education. Only two other considerations have had much weight: (1) the desirability on equity grounds of removing income and other discriminatory barriers from the paths of young people capable of pursuing higher education and (2) the national need for enlarged supplies of trained persons to assure the growth and competitiveness of U.S. industry. The purpose of this retrospective assessment is to look closely at important federal interventions in the area of scientific and engineering personnel over the last 40 years in order to extract the more important lessons that have relevance to the formulation of current and prospective policies. As one who has had a continuing, if not always intimate, relationship to these earlier interventions, it appears that many of the issues that keep resurfacing and that engage the attention of policymakers are new and challenging only to the beholders. Looked at with the benefit of hindsight, they often turn out to be old issues in new dress.

## A Retrospective of Critical Incidents

This venture at retrospective assessment will focus on a limited number of "critical incidents" affecting the formulation of science and engineering personnel policy from the waning days of World War II to the most recent concerns (1985-86), as reflected in the agendas of the Congress, the professional societies, and the National Academy of Sciences.

### *The GI Bill of Rights*

Over 15 million young Americans, most of them between the ages of 18 and 26, were called to active duty during the course of World War II. Many of them had to interrupt their education to don a uniform; and in many instances, three, four or even five years passed before they were demobilized. In recognition of their service to their country, Congress passed the Servicemen's Readjustment Act of 1944 (GI Bill of Rights), which provided wide-ranging benefits to 7.8 million World War II veterans and enabled more than 2.2 million of them to attend colleges and universities. The federal government provided tuition and maintenance support from a minimum of one to a maximum of four years, depending on the veteran's length of service in the Armed Forces.[2] While the primary interest of Congress in passing the bill was to express the nation's appreciation to those who had borne the brunt of the battle, its supporters, particularly those in the sciences, recognized that enabling large numbers of veterans to return to school to complete their educational preparation for a career would be beneficial to the nation, since it would enlarge its pool of trained persons.

### *Scientific Talent and New Horizons for Research*

The war permanently altered the place of research on the nation's agenda, for it demonstrated that our national security would henceforth depend on our technological

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[2] Eli Ginzberg and Associates, *Patterns of Performance*, New York: Columbia University Press, 1959, pp. 167 ff.

superiority. President Roosevelt had taken the big gamble to support the production of the atomic bomb, and the gamble succeeded with the speedy end of the war with Japan in early August 1945. The principal scientific advisers of the President, with Vannevar Bush in the lead, stressed the much enlarged role that the federal government must play in the future financing of research and higher education.[3] Without the participation of many European scientists who had been forced by Hitler to emigrate in the 1930s, the successful manufacture of the bomb would not have been possible. In the future, we would have to look more to our own institutions and our own population to provide the intellectual leadership required for the discovery of new scientific ideas and their successful application.

Appendix 4 to Bush's report to the President consisted of a "Report of the Committee on Discovery and Development of Scientific Talent," chaired by Henry Allen Moe, which made the following critical comments and recommendations:

> In answer to President Roosevelt's question to Dr. Bush, "Can an effective program be prepared for discovering and developing scientific talent in American youth so that the continuing future of scientific research in this country can be assured on a level comparable to what has been done during the war?" Moe's reply was: "In our judgment, the answer to the question is in all respects in the affirmative.... The intelligence of the citizenry is a national resource which transcends in importance all other national resources. To be effective, that intelligence must be trained.... Our plans, simply, are plans--as regards science and engineering--to train for the national welfare the highest ability of the youth of the nation without regard to where it was born and raised, and without regard to the size of the family income."

The Bush Report asked for a level of $122.5 million of federal funding five years into the future, with $29 million earmarked for the Division of Scientific Personnel and Education. Bush noted in passing that "the most important single factor in scientific and technical work is the quality of the personnel employed." It would be an exaggeration, however, to contend that the scientific establishment's call for federal action was responded to by all other leadership groups. In 1947, the Twentieth Century Fund concluded that "we have more than enough manpower ... to fulfill our requirements under every conceivable circumstance."[4] But that view did not survive for long. It was undermined by the events of 1950, which found the United States once again engaged on the battlefield, this time in Korea.

### *The Korean War*

Although we entered hostilities through a decision taken by President Truman without debate and approval of the Congress, the country moved slowly to gear up for combat. General Eisenhower, among others, was greatly disheartened by what he considered the inadequate response of the Washington leadership to the new national emergency. It soon turned out that we could not pursue active hostilities in Korea successfully, even with constrained goals, unless we were willing to redirect resources, physical and human, from

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[3] Vannevar Bush, *Science--The Endless Frontier: A Report to the President*, Washington, D.C.: U.S. Government Printing Office, July 1945.

[4] Twentieth Century Fund, *America's Needs and Resources*, New York, 1947.

civilian to military projects. We simply could not keep the civilian economy at full throttle and win on the battlefield.

Not all of the demands by the military were well-conceived or justified. I recall that in my capacity as consultant to the Assistant Secretary of the Army for Manpower, I reviewed with the Chief of Engineers an urgent request for 400 additional engineers. It turned out that what he really needed were recruits with a high school diploma who, with 90 days' specialized training, would be able to repair certain priority equipment.

The war also illuminated another facet of the engineering problem--the relative inflexibility of segments of the supply of engineers. At one point, after General Motors had finally been persuaded to cut back on the production of civilian automobiles in favor of expanding its military output, the corporation offered the Army 500 "surplus" engineers whom it could spare for the duration. After examining the background and competencies of the members of this group, the Army decided that it would reject the offer because most of the engineers had been so highly specialized for such a long time on a narrow sector of automotive manufacturing that most of them could not be placed on priority military assignments.

### *The Small College-Age Cohort of the 1950s*

The stalemate on the battlefield in Korea came to be accepted by all the parties and an armistice was signed in March 1953. With Eisenhower in the White House, the stage was set for a four-year period of renewed economic advance. But Korea left its mark. It was clear that the United States could no longer assume that the "Cold War" would remain cold and that it was, therefore, compelled to invest more in basic research and in maintaining enlarged defense forces at the same time that it sought to establish and strengthen its alliances with friendly nations.

The scientific and engineering personnel outlook was complicated by a number of contradictory factors that influenced the flows into and out of the college and university pool, including the graduation of the last remaining veterans; the declining numbers in the college-age group (reflecting the lowered birth rate during the Depression); and the larger proportion of the age group entering college. The situation was further complicated on the demand side by the fact that many U.S. corporations had decided to establish and/or expand their research and development operations, thereby adding a significant increment to the total requirements for scientists and engineers. Added to this expanded civilian demand were direct and indirect demands stimulated by much enlarged federal funding for basic research and for a wide variety of defense-related projects. Finally, liberal funding from the federal government led to the expansion of major research universities.

The personnel figures were volatile. The number of engineering graduates increased from 31,000 in 1948 to a peak of 52,000 in 1950, only to decline to 40,000 in 1951 and 30,000 in 1952. In 1951, there was an estimated demand for 80,000 new engineers, but by the following year the demand had declined to 40,000.[5] The demand data were no more than employers' reported intentions to hire--if the numbers were available--at a salary that the corporations were willing to pay. Apparently, when the numbers fell far short--as in 1951, when the gap amounted to 40,000--employers got on with much reduced numbers. It is worth noting that the so-called "shortage" in 1951 amounted to about 10 percent of the total number of engineers. With the end of the fighting in Korea, the tightness in the engineering market moderated.

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[5] National Manpower Council, *A Policy for Scientific and Professional Manpower*, New York: Columbia University Press, 1953, pp. 162 ff.

### *The Response to Sputnik*

The launching of the first satellite into space by the USSR in 1957 had a major unsettling effect on the self-confidence of the American people. Although the U.S. defense position had been weakened in the early 1950s, when the Russians developed the capability of manufacturing nuclear bombs, we continued to feel reasonably secure in our technological leadership. After all, the Russians had foreshortened considerably their period of developing a nuclear technology by exploiting the secrets they had stolen from us and our allies. Their success with Sputnik, however, represented a challenge to our scientific leadership that led to much introspection and criticism among our leaders--scientific, political, and educational. In 1958, Congress provided a partial answer in the form of the National Defense Education Act (NDEA).

For the first time, the federal government assumed a major across-the-board obligation to strengthen the nation's manpower pool, particularly scientists, engineers and other specialists (such as area and language experts) whose work was deemed essential to the national defense. While President Eisenhower was reluctant to expand the scope of the federal government's activities into the arena of higher education, he signed the bill because of its potential to strengthen the nation's defenses. In addition to liberal funding for college and graduate students in designated scientific fields, the bill also aimed at enlarging the pool of college-eligibles by making funds available for strengthening high school instruction in the sciences and mathematics.

It should be noted parenthetically that while the federal government had made funding available to selected groups of students through selected federal agencies, most of the earlier support via the Armed Services, the National Science Foundation and the National Institutes of Health had been directed at graduate and postgraduate students. NDEA was a much larger and broader type of federal intervention, covering many more students, mostly at the undergraduate level. In its 1953 report, the National Manpower Council (a non-governmental body established at Columbia University under funding from the Ford Foundation, of which I was the Director of Research) estimated that only about half of the college-age population with an AGCT score of 120 or above entered college and that only about one-third went on to graduate.[6] Continuing federal support in the decade after the passage of NDEA, as well as the substantial efforts of many state governments to expand their systems of higher education, led to the substantial elimination of the financial barriers that had earlier blocked high school graduates with good aptitudes from entering and graduating from college.

### *The Revision of the Immigration Act in 1965*

Twenty years after the conclusion of World War II, Congress finally acted to revise our immigration laws to bring them more into consonance with the changing role of the United States in world affairs. We moved away from preferential quotas for the countries of Western and Northern Europe and enabled immigrants from Asia to gain admission on a large scale for the first time. The new law--by permitting up to 10 percent of total immigration to consist of professionals, scientists, and artists of exceptional ability--made it easier for professionally trained persons to enter the United States and subsequently to regularize their status as permanent residents and to acquire citizenship. In the long debate leading up to the revision of the act, it was pointed out repeatedly that the United States had been the beneficiary of the forced emigration to this country of many professionals whom Hitler and Mussolini had persecuted; the contribution of many displaced European scientists to the success of the atom bomb was widely recognized.

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[6] *Ibid.*, p. 82.

The long period of largely uninterrupted economic expansion--a quarter of a century since 1940--unquestionably contributed to the willingness of the Congress to revise the immigration statute, in particular for individuals whose education and experience made it likely that they would add to the nation's pool of competence and stimulate rather than detract from its future economic development. The revised rules and regulations also set the stage for a much expanded inflow of students from abroad, particularly graduate students, to undertake advanced study. While many would eventually return to their native country to help speed its development, new opportunities were created whereby those who preferred to remain in the United States would be able to do so, even if they might have to leave and re-enter to comply with the law.

### *Cutbacks in Space and Defense*

The period 1968-1972 represented the first substantial shock to the expansionary environment that had dominated the employment prospects of scientists and engineers since the onset of mobilization in 1940, three decades earlier. The completion of the successful "moon shot" in 1969 and the decrease of the defense budget led to large-scale reductions in the employment of many engineers and scientists, especially among aerospace contractors on the West Coast but also in plants located elsewhere, including those on Route 128 in the Boston area. Many were caught by surprise, including employers, universities, Congress, the professional societies, and still others. Although the federal government, with the passage of the Manpower Development and Training Act in 1962, had begun to fund training and retraining programs for unemployed persons, these programs were aimed at assisting individuals with limited education and skills. As chairman of the National Manpower Advisory Committee (NMAC) from the inauguration of the effort, I can state unequivocally that we never addressed the unemployment of engineers and scientists until the severe cutbacks at the end of the decade.[7] That was the first time that the problem had surfaced; and as it grew, we found ourselves poorly positioned to respond. The training programs that were in place did not fit the needs of unemployed professionals.

The National Academy of Engineering established a special committee to explore the issues and to make recommendations and I was asked, in my capacity as chairman of the NMAC, to accept membership. We recruited a senior manpower analyst, Seymour Wolfbein, to develop the relevant statistics and to help us formulate possible lines of remedial action. By the time our report was ready, the worst of the recession and its accompanying unemployment had passed.[8]

The late 1960s-early 1970s represented a confluence of three negative forces: the peaking of the expansion in the student body; the significant reductions in defense and space research and development; and an economic recession. Any one or two of the above would have put some part of the scientific and engineering personnel under stress, but the simultaneity of all three occurrences led to a serious reversal in the hitherto expansionary trends. While earlier shifts in the financing of space and defense projects and the weakening in the civilian economy had resulted in selected cutbacks, this was the first time so large a segment of the market for trained personnel--literally tens of thousands of scientists and engineers--was affected. Further, the concentration of so many aerospace activities on the West Coast--and the unwillingness of most of the displaced professionals to relocate--intensified the problems of designing and implementing remedial programs.

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[7] National Manpower Advisory Committee, *Manpower Advice for Government: Letters to the Secretaries of Labor and of Health, Education and Welfare*, Washington, D.C.: U. S. Department of Labor, 1972.

[8] National Academy of Engineering, Committee on Engineering Manpower Policy, *Engineering and Scientific Manpower: Recommendations for the Seventies*, Washington, D.C.: National Academy of Science's Printing and Publishing Office, 1973.

One important by-product of the NAE explorations was a deepened perspective on the limitation of professional retraining. We were informed repeatedly, by those in a position to know and act, that it made little sense to retrain a mechanical engineer who had spent eight or ten years on a narrow job assignment. He no longer had the knowledge base and the intellectual flexibility to justify the investment of sizable funds that would be required to retrain him, for instance, for electrical engineering. The Committee accepted this explanation. The industry's lack of broad investment in keeping its engineering work force up to date squared with the evidence of many engineers' having become superannuated after 10 years of aerospace employment. Fortunately, the economy expanded in the early 1970s--in fact, our highest rates of real growth in the entire post-World War II era occurred in 1971-72--and what had earlier appeared to be a difficult, almost an insoluble problem disappeared while remedial actions were still being explored.

### *Weakening of the Academic Labor Market in the 1970s*

The vast increase in the number of college and graduate students in the 1960s, combined with greatly enlarged public and private expenditures for research and development and further stimulated by world-wide economic growth in which research-based industries were in the lead, set the stage for the much enlarged and sustained demand for scientists and engineers. This occurred in all sectors--especially in the academic world, where large numbers of scientists were needed for both the classrooms and the laboratories.

Allan Cartter had raised the issue about faulty projections for ever-increasing numbers of faculty during the explosive 1960s, warning that the deeply entrenched view of continuing shortages of professional personnel failed to take into account the prospective leveling off of college and graduate student enrollments, as well as more constrained governmental funding for research and development. However, Cartter's was a minority view. In late 1963, the Subcommittee on Science, Research and Development of the House of Representatives held hearings on "Government and Science," which elicited agreement from most of the nation's scientific leadership that we needed to enlarge our pool of qualified researchers. This was the view of Jerome Wiesner, the President's science advisor, as well as of the Vice President of Research for duPont, the advocates of a strong space program including Dr. Werner von Braun, and many others in academic and public life. Only Nobel Laureate Harold Urey took a different view: in a written communication he noted, "I have a belief that we are training as many scientists as can reasonably be expected from the crop of students coming from our high schools and colleges. What we need is better scientists than we have--not more of them."[9]

Since 1967, evidence was accumulating that jobs in science were more difficult to obtain. By 1970, the American Institute of Physics recognized that physics was confronted with a changed labor market. But even in 1970 (a catastrophic year in the employment history of physicists), the market was not weak across the board, but rather had turned down for particle and nuclear physics, while the demand for specialists in acoustics and optics remained strong. At the end of the 1970s, the results of an American Physical Society study of the present and projected employment of physicists pointed out that a high proportion of the best-trained young physicists who had failed to obtain a tenured academic position were unsettled about the ways in which their careers had developed.[10]

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[9] U.S. Congress, Committee on Science and Astronautics, Subcommittee on Science, Research and Development, *The National Science Foundation: A General Review of its First 15 Years: Hearings,* 88th Congress, 1st Session, October 15-16, 18, 22, 24, 29; November 5, 19-20, 1963, no. 8, Appendix A, Washington, D.C.: U.S. Government Printing Office, 1964, p. 427.

[10] American Physical Society, Physics Manpower Panel, *The Transition in Physics Doctoral Employment, 1960-90,* New York, August 1979.

There was considerable turmoil as well among young mathematicians, many of whom were also forced by a much tightened academic environment to forego a professorial career and seek out alternative employment opportunities. The Ad hoc Committee on Resources for the Mathematical Sciences found four general reasons why "mathematics" seems to have been the field hardest hit by the general post-1968 trends:

- Research in the mathematical sciences is concentrated almost entirely in universities and colleges; hence, it is very strongly affected by any general weakening of the support of academic research.
- Much (but not all) mathematical research has long-term payoffs; thus, the field will be strongly affected by federal policy shifts which emphasize mission relevance or immediate applicability to technologies.
- The long periods of time involved in developing many important mathematical tools make it unlikely that the commercial sector will support large fractions of the research; therefore, relatively little help will be found from industry when there is a weakening of federal support for fundamental research in the field.
- Mathematical scientists require relatively little in the way of facilities, equipment or technical staff to conduct their research; hence, their needs are less visible and often seem postponable.[11]

### *The Energy Crisis and the Computer Revolution*

But all was not gloomy in the 1970s and early 1980s. In 1973, OPEC took control of the international oil market as a consequence of which the search for new oil accelerated, a search further intensified by the second oil price increase that OPEC instituted in the late 1970s. As a consequence of this roiling of the oil market, a vastly increased demand for petroleum engineers, geologists, and related specialists was met not by only attracting scientists and engineers from related fields, but also by stimulating the expansion of key college and university departments that were in a position to respond.

More important in terms of the numbers involved was the growth in "computer sciences," including the allied fields of electrical engineering and applied mathematics. The steadily growing demand on the part of industry for larger numbers of computer specialists, as well as the efforts of many institutions of higher learning to establish and expand departments in this new area, created a host of new opportunities for talented young scientists and engineers.

The demands created by the oil crisis were over by the early 1980s with surpluses of specialists replacing the earlier shortages as drilling for new oil was severely reduced and as the seven large U.S. oil companies sought to shrink their swollen work forces in line with the new, unfavorable market realities.

On the engineering front, aside from recurrent modest surpluses or shortages as the numbers in the educational pipeline led or lagged fluctuations in new hiring, a long-term difficulty arose--namely, the recruitment/retention of qualified faculty members. The nub of these faculty problems was centered in electrical engineering and computer sciences. Most universities found themselves increasingly outbid by industry for recent doctorates whom they would have wanted to add to their faculty. While the most acute imbalances were centered in recruiting assistant professors, many engineering schools found themselves increasingly exposed also in the higher ranks. The issue of faculty shortages is not

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[11] National Research Council, Commission on Physical Sciences, Mathematics and Resources, *Renewing U.S. Mathematics: Report of the Ad hoc Committee on Resources for the Mathematical Sciences*, Washington, D.C.: National Academy Press, 1984, pp. 34 ff.

amenable either to simple definition or solution. The Engineering Faculty Shortage Project, a 1984 joint study by the American Society for Engineering Education and the American Association of Engineering Societies, concluded that there was a faculty shortage of about 20-25 percent. This conclusion was predicated on the evaluations by the deans of engineering schools and further supported by the deteriorating ratio over the decade between faculty and students. While faculty salaries have increased and outside consulting provides some additional source of income to faculty members, the ratio of academic to industrial salaries, particularly in electrical engineering and computer sciences, is still inadequate to provide an adequate supply of faculty personnel.

Furthermore, many of the topmost talented undergraduates, confronting multiple job opportunities, are not pursuing the Ph.D; and among those who do, only a minority are interested in an academic career. The total output of Ph.D.s in engineering is well below the 1972 level and there has been a precipitous decline in the ratio of native Ph.D.s to the total. The pool of young faculty members is increasingly composed of foreign nationals who, whatever their competence, often have limited communication skills essential for effective teaching. Finally, a decreasing proportion of engineering schools, according to the Accreditation Board for Engineering and Technology, are now receiving a full six-year accreditation because of curriculum deficiencies, faculty shortages, and inadequate facilities and equipment.[12,13]

A number of leading corporations, individually and collectively, decided to make special gifts of money and equipment to leading universities to enable them to offer higher salaries and other benefits to their staff. In the absence of such help, the corporations recognized that their future recruitment of competent employees would be at risk. Even this special response, however, failed to encourage large-scale increases in the number of native-born Americans willing to pursue their studies to the completion of a doctorate and to acceptance of an academic appointment. Foreign-born students account for a steadily increasing proportion of all doctoral students in engineering and computer science. In fact, in 1980, only one in 12 bachelor's degrees in engineering, but more than one in four of all master's degrees and more than one in three of all doctorates were earned by foreign nationals.[14] By 1983, more than one-half of all postdoctorals in both mathematics (excluding computer sciences) and physical sciences were granted to foreign students and about one in three in the biological sciences.[15] These ratios make clear why foreign national students dominate the entry ranks of faculty in science and engineering departments.

### *A Decade of Defense Buildup (1976-1986)*

With the winding down of the Vietnam War, Congress reduced the defense budget by about one-third in real terms between 1970 and 1976. President Carter succeeded in reversing this trend, but it was during President Reagan's administrations that the defense budget rose not only to its 1970 level but increased to a level about 20 percent higher. National defense purchases grew from a low of $157.5 billion in 1976 to $171.2 in 1980

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[12] National Research Council, Office of Scientific and Engineering Personnel, *Labor-Market Conditions for Engineers: Is There a Shortage? Proceedings of a Symposium*, Washington, D.C.: National Academy Press, 1984.

[13] Office of Technology Assessment, *Demographic Trends and the Scientific and Engineering Work Force--A Technical Memorandum* (OTA-TM-SET-35), Washington, D.C.: U.S. Government Printing Office, December 1985.

[14] Edith Fairman Cooper, *United States' Supply and Demand of Scientists for Defense Research and Technology* (part I), Washington, D.C.: Congressional Research Service, Library of Congress, 1981, p. 9.

[15] Betty M. Vetter, *The Technological Marketplace--Supply and Demand for Scientists and Engineers* (3rd ed.), Washington, D.C.: Scientific Manpower Commission, May 1985, p. 23.

and then moved upward at a more rapid rate, reaching $236 in 1985. In 1973 and 1974, the percentage declines in national defense expenditures were respectively 6.8 and 4.5; in the first four budget years under the control of President Reagan, the year to year percentage increases amounted to 7.5, 7.0, 6.3, and 7.1.[16]

The second half of the 1970s has seen the economy in a strong recovery, followed by a deep recession in the early 1980s, strong recovery beginning in 1983, and a reduced rate of growth in the last two years (1985-86). The fact that except for the recession years 1979-80 and 1981-82 the defense budget was expanding rapidly at a time when the civilian economy was also expanding would lead one to expect that the demand-supply relations affecting scientists and engineers might have become quite strained. The second oil crisis of 1979, which was followed by a feverish expansion in the demand for petroleum engineers, geologists, and other professional personnel required for expanded oil exploration and alternative energy sources, could have been expected to place additional strain on the scientific-engineering pool.

There is little question that the scientific-engineering market tightened at least selectively in response to the upward tilt in both the civilian and the defense sectors. The Deutsch, Shea & Evans High Technology Recruitment Index (1974 base of 100) stood at 114 in 1977 and moved to a high of 144 in 1979, remained high until the depression year of 1982, and moved back up to 133 in 1984, only to decline to 112 in 1985 and strengthen at the beginning of 1986. The Job Offer Index for bachelor degree candidates by curriculum, with 1980 as 100, records that 1981 saw a strong demand for most engineering and science graduates, but a distinct weakening in the following years right up to 1986, with aeronautical engineers and computer scientists the only two exceptions.

If the focus is shifted to the changes in the employment status of doctoral S/Es involved in DoD work between the mid 1970s and the mid 1980s, this is what one finds: total employment in the four fields--mathematics, computer science, physics and engineering--increased from 18,963 to 22,533, a gain of 3570 or slightly under 20 percent. In each of these two time periods (1973-75 and 1983-85), there was considerable movement between the defense and nondefense sectors: in the 1983-85 period there was a net inflow of 740 doctoral personnel into DoD-type work but an outflow of 537 engineers into non-DoD work.

The explanation for the relative ease with which the nation was able to accommodate the steep buildup of defense in the 1980s without experiencing any serious S/E shortages must be sought in the following: (1) the dominance of such personnel in the nondefense sector, which provided a pool to draw on; (2) the softness of the nondefense sector of the economy in 1981-82 and the aftermath of caution in investment and hiring decisions; and (3) the large output of new engineers from bachelor degree programs.

In 1981-82, with a total pool of approximately 1.2 million engineers, defense requirements came to about 140,000; in the case of scientists, defense work accounted for only 3 percent of the total supply. Although the proportion of scientists and engineers in defense work is relatively much greater than in nondefense work--on the order of 5:1--the nondefense sector continues to dominate the U.S. economy.

In 1976 the number of engineers graduating with a bachelor's degree was slightly below 38,000; in 1985 it was just under 78,000, an increase of over 100 percent in the decade. A sizable increase, from 16,500 to 22,500, also occurred in master's degree recipients, a gain of just under two-fifths. The output of engineering doctorates declined slightly from the 3,000 level in 1976, but by 1985 had increased to 3383.

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[16] Electronics Industries Association, *The Military Electronics Market: Perspectives on Future Opportunities--The 21st Annual EIA Ten-Year Forecast,* Washington, D.C.: The Requirements Committee, 1985.

For the reasons identified above, the U.S. was able to cope with the additional S/E demands engendered by the sustained defense boom without major difficulty. With the defense budget as a percentage of GNP likely to level off in the remainder of the 1980s, if it does not decline, there is little risk of any serious imbalances in the engineering and scientific manpower market in the near and middle term.

## Continuing Concerns: Supply and Utilization

### *Women and Minorities*

In the decade 1963-73, major governmental and non-governmental initiatives were undertaken to remove barriers from the paths of women and minorities seeking to pursue educational and career objectives in science and engineering. There were strong responses to diverse federal initiatives by business, the academic community, foundations, and the professions, as well as by women and members of minority groups. More recently, legal and institutional pressures aimed at lowering discriminatory barriers have weakened, but the earlier momentum has enabled many more women and some minorities to make sizable progress in pursuing professional careers.

There have been striking increases in the number and proportion of women entering and completing college, as well as increases in the numbers earning masters' or doctorates, including those entering a course of study in engineering or one of the natural sciences. True, men continue to outnumber women in the hard sciences and in engineering by a factor of three, four or five, but these differences have narrowed considerably over the last 20 years. For instance, in 1965 women accounted for around one percent of engineering school students, but in 1985, they represented over 15 percent of the entrance class.

With the exception of Asian-Americans, the increase of minority group members, particularly Blacks and Hispanics, into engineering and the natural sciences shows only modest gains. The explanations for the slow progress seem to be embedded in a galaxy of reinforcing negative factors, including weak family supports; weak basic schooling; weak science and mathematics departments in segregated colleges; lack of role models; and attractive alternative career opportunities for talented minority students. While the foregoing ad hoc explanations may go far in accounting for the continuing large-scale underrepresentation of minority students in science and engineering, a parallel challenge is to explain the marked overrepresentation of Asian Americans in these fields.[17]

The following factors underpin the reason that the public and private sectors should continue to be concerned with structural transformations in the future supply of women and minorities into science and engineering. Women now represent the majority of all college students; but despite the strikingly higher proportion enrolled for an engineering degree, they still account for only about 15 percent of the class, and they continue to be substantially underrepresented in the physical sciences at all degree levels. The long-term persistence of a relatively stable ratio among college men as between science and non-science majors, roughly 30 percent vs. 70 percent, underscores the desirability of encouraging more women to pursue a career in engineering or the sciences.

Several reinforcing factors support this view. The demographic trends point to a substantial decline in the college-age group, particularly the white, college-age group that

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[17] Gail E. Thomas, *The Access and Success of Blacks and Hispanics in U.S. Graduate and Professional Education*, a working paper for the Office of Scientific and Engineering Personnel, National Research Council, Washington, D.C.: National Academy Press, 1986. Also, Office of Technology Assessment, *Demographic Trends, op. cit.*, pp. 114-127 and Appendix B.

represents the major source of future candidates for baccalaureate and higher degrees. Further, enrollments in engineering schools peaked in 1981-82 at slightly above 115,000, declined since then to 112,000 in 1985, and in light of the above demographic trends, are likely to decline further. Other than a radical change in our immigration policies aimed at admitting larger numbers of students and graduates in science and engineering, women represent the only large potential pool that could yield over the next years significant additions to the nation's supply.

### *Scientific and Engineering Personnel and the Competitiveness of the U.S. Economy*

When the U.S. was eclipsed by the USSR in the space race in 1957, analysts looking for an explanation made much of the fact that the Russians had both a much larger absolute number of engineers and a higher ratio of engineers to their total work force than did the United States. Some concluded, therefore, that the U.S. might lose out in the struggle with the USSR unless it moved quickly and strongly to increase its output of scientists and engineers. Much the same argument has resurfaced in recent years as Americans have explored the reasons for the superior performance of the Japanese economy. Many analysts have pointed to the much larger relative number and proportion of engineers in the Japanese, as compared with the American, economy. Since the Russians were unable to repeat their triumph in space in other technological spheres, the supposed vulnerability of the U.S. stemming from an insufficient number of engineering personnel lost credence. Time also revealed that many Russian engineers were so narrowly trained that many were more technicians than professionals.

Simple numerical comparisons of the proportions of engineers in their respective work forces can also be misleading in assessing the relative economic strength of the United States and Japan. A more sophisticated analysis suggests that numbers aside, Japan has important advantages in the continuing attention that its top management has paid to process engineering, in the heavy investments that it continues to make in the education of its engineering work forces, and in the excellent relations that it has encouraged between engineering supervisors and the technician work force.

Additional factors need to be considered, including the relatively much larger defense and defense-related activities in which the United States engages. Many observers have noted that even after allowing for positive spill-over effects on the civilian economy from our large defense sector, we have a smaller proportion of our total specialized personnel resources focused on output for the civilian market.

The heavy concentration of S/E personnel in the 700 federal research laboratories and the sizable amount of all federal dollars that these laboratories spend on basic research--approximately 1/3--have raised questions from time to time concerning the impact of this sizable federal effort on the competitiveness of the U.S. economy. The questions have been two: Is too high a proportion of our nation's total investment in basic research being devoted to military goals? Secondly, do the laboratories make effective use of their S/E personnel? The answer to the first must be sought in the budget proposals of successive administrations and the subsequent actions by the Congress. Over the years, the question as to whether the federal government makes effective use of its S/E personnel has been repeatedly raised, most recently (1982) by the White House Science Council's Review Panel of federal laboratories, chaired by David Packard.[18] The Panel found that the laboratories had difficulty recruiting and retaining mathematicians, electrical engineers, and computer specialists and recommended more flexibility in salaries for "superstars," in the belief that such action might offer some relief. Broad-banding of civil service grades to give supervisors greater flexibility in setting initial salary offers and subsequent in-grade

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[18] *Labor-Market Conditions for Engineers, op. cit.*, pp. 123 ff.

increases was also recommended as a way to permit supervisors to link salary to performance, rather than to seniority.[19] A recent newspaper report indicates that the President favors the above action, and the administration has begun to implement it.[20] The Government-University-Industry Research Roundtable also suggested (1986) that since federal laboratories are generally perceived to be of variable quality, reassessment of the scope and mission of some of these may be warranted, particularly where the programs could be carried out equally well in universities.[21]

In early 1986, the National Academy of Science set about to explore the issue whether, and to what extent, much enlarged appropriations for defense, including the Strategic Defense Initiative program, may have a dislocating, retarding effect on the capacity of our civilian research and development firms to strengthen their competitive position. This is not the first time that the subject of diversion of our research and development resources from the civilian sector due to sudden and large increases in defense activities has been raised. In the early 1960s, the Vice President of Research for duPont (quoted earlier) had called attention to this intersectoral competition and pointed out that sudden increases in defense spending had the inevitable result of drawing resources from civilian firms and concurrently raising the costs of civilian research and development.

But the fact that informed persons have repeatedly expressed concern about the consequences of sectoral distortion, following upon large increases in defense spending, cannot be accepted at face value. The opposing argument emphasizes that a high level of, and ever more steeply rising, defense expenditures send a signal to the colleges and universities that there will be more good jobs for scientists and engineers, which in turn will lead to an expansion in the supply.

But an interval of four to five years occurs between the sending of the signal and the outflows of new streams of engineers with a bachelor's or master's degree. Our feast-famine approach to defense appropriations introduces substantial instability into the flows of engineering and scientific personnel to both the civilian and defense sectors. The aerospace companies with new large contracts often raise salaries to attract additional personnel, most often creating problems for nondefense firms and the universities. But if and when defense expenditures are reduced, there are likely to be untoward reductions in the new supply some years down the road. While the numbers and quality of engineering and scientific personnel available to private sector industries on occasion may place the U.S. economy at a comparative disadvantage, there is little evidence to conclude that this handicap is the core of our difficulties in maintaining our international competitive position. There is, instead, mounting evidence that many large U.S. companies have been poorly organized and poorly managed to respond quickly and effectively to what is rapidly becoming a world economy. These systemic weaknesses have also reduced the effectiveness with which many U.S. companies utilize their scientific and engineering personnel. If this explanation has merit, then the challenge that we face may be less connected with the size of the pool than with the more effective utilization of the available supply.[22]

Considerable efforts have been expended over the years to develop and improve estimates of the future supply and demand for engineers. A recent critical review of these

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[19] David Packard, "The Loss of Government Scientific and Engineering Talent," *Issues in Science and Technology*, Spring 1986, pp. 126-131.

[20] "Reagan Asks Civil Service Pay Changes," *The Washington Post*, April 30, 1986, pages A1, A7.

[21] Government-University-Industry Research Roundtable (sponsored by the NAS, the NAE and IOM), *What Research Strategies Best Serve the National Interest in a Period of Budgetary Stress? Report of a Conference*, Washington, D.C.: February 26-27, 1986.

[22] Eli Ginzberg and George Vojta, *Beyond Human Scale: The Large Corporation at Risk*, New York: Basic Books, 1985.

efforts by Professor W. Lee Hansen concluded that the extant models simply do not possess the requisite power, given the many weaknesses in the data bases, to yield reliable forecasts.

## Lessons

On the basis of the foregoing brief consideration of 10 critical incidents on the science-engineering horizon that surfaced over the last four decades, we are now better positioned to extract the "lessons" that can usefully inform present and future policies relating to the supply and utilization of scientific and engineering personnel. Since such personnel issues are directly and closely related to the effectiveness of our defense and to the competitiveness of our economy, they clearly warrant continuing consideration.

- The U.S. has been strikingly successful in the post-World War II period in removing financial barriers in the path of qualified young people to pursue a college or higher degree. Moreover, all three sectors--the federal government, state governments, and philanthropy--have cooperated to expand and improve the infrastructure of higher education, in order to accommodate the much enlarged inflows of students.
- The federal government and selected sectors of the private economy recognized the importance of vastly expanding their investments in research and development as a result of which this country became a leader in a great many industries including aircraft, nuclear power, computers, electronics, space, telecommunications, biotechnology, and many others.
- Once it became clear to the American people in the early 1950s that the international situation pointed to a long "cold war," the nation decided that it had to make a large and continuing commitment to defense and defense-related activities, no matter what the cost in diverted resources. In retrospect, one can argue that except for the perturbations resulting from years of active hostilities in Korea and Vietnam, which strained the civilian economy, the resources required by defense have been secured more by an expansion in the supply and operating the economy closer to full employment than in deflections from the nondefense sectors. The substantial appropriations of the Congress for defense have played a major role in expanding and maintaining a much enlarged infrastructure of scientific research and higher education, far larger than would have been likely in the absence of the "cold war."
- The fluctuations in defense expenditures had greater or lesser consequences on particular organizations, groups of specialists, and locations that were directly affected by the start-up or completion/cancellation of a major defense program. But for the most part, the two major nondefense sectors--the higher educational establishment and the civilian economy--were able to adjust reasonably well to these fluctuations, the early 1970s alone excepted. In that period, the defense cutbacks coincided with an economic recession and the end of a boom in college entrants, which created a softness in the academic market with long-term dislocations among doctoral candidates and graduates who had looked forward to an academic career but faced instead a broadscale hiring freeze.
- The explanations for the remarkable adjustment potential of the U.S. economy over the last four decades must be sought and found in the following: (1) the substantial and sustained period of economic growth, which provided the

necessary resources to expand the educational and training infrastructure and which created a great number of new alternative jobs and careers for scientists and engineers; (2) the availability of an untapped talent pool, which could be attracted to the rapidly expanding professions once the financial barriers to the pursuit of a higher education were lowered or removed; (3) the willingness of trained personnel, as well as those in training, to follow the signals of the market; and (4) the willingness of employers to modify their hiring criteria when they encountered tightness in their conventional sources of supply, as regards both the gender and race of prospective employees and their prior experience.

- With the advantage of hindsight, it becomes clear that the elasticity in the supply of students who are able, willing, and eager to pursue higher education--together with the long-term flexibility in the U.S. labor market, which reflected the behavior of both employers and employees--made it possible for the U.S. to expand by orders of magnitude its involvement in R&D activities in both the defense and nondefense sectors. It was clearly not a process without some "transaction costs," witness the unsettlements of the S/E labor market in the early 1970s, but for the most part these costs were not excessive. The question that must still be explored is how these lessons might inform policy in the years ahead.

## Policy Directions

On the basis of our analysis of the critical incidents and the lessons extracted therefrom, we are now better positioned to call attention to directions that should inform our future policy affecting the supply and utilization of scientific and engineering personnel.

Two points are worth exploring at the outset. First, we cannot follow the same policies and practices of the earlier decades and anticipate on balance the same favorable results. The reason is simple: many prior existing conditions have been permanently altered, as for instance, the proportion of the college age-group that enters higher education. At the same time, it would be an error to assume that the lessons of the past cannot be used to provide constructive guidance for the future. The real challenge to the policy analyst is to select the "right" lessons and to apply them with due consideration for the changes in the parameters and infrastructure that have occurred and that will inevitably continue to change, though only time will reveal in what direction and with what speed. To structure the following discussion of policy directions, we will take up issues connected first with supply and then with the utilization of scientific and engineering personnel and conclude with some broader considerations bearing on policies affecting the educational and research infrastructure.

With respect to the future supply, it is important to note the following:

- It will prove much more difficult in the decade or two that lie ahead for the United States to expand its supply among the native population. The best yield would come from encouraging more women to select science or engineering as a college major, and later on to pursue a career in these sectors; but under the best of circumstances, it would be wrong to assume that significant increases are likely in the near or even middle term. With widespread and continuous encouragement from the larger society, the educational system, and employers, increases are likely; but the rate of change will, at best, be relatively slow.

- When it comes to the Black and Hispanic minorities who will represent an increasing proportion of college-age youth in the decades that lie ahead, the challenge is much greater, since these groups are seriously underrepresented among high school graduates capable of pursuing higher education and, more particularly, higher education in science or engineering. Hence, any substantially enlarged flow will require a longer time period than a decade, sufficient time to see a substantial improvement in the economic status of minority families, improved schools in ghetto areas, and other basic adjustments that require long lead times.

The best prospects for any significant increase in the size of the pool could come about if larger numbers of college students were encouraged to improve their mathematical skills, after which they would have the tools to pursue majors in science, engineering, computer science, or technology. But the prospects of such a reform would depend upon the existence and maintenance of a much enlarged demand for such scientific personnel as reflected in higher beginning salaries as well as more attractive career opportunities. Neither of the above preconditions appears at this time to be on the horizon. There are two further ways in which the pool could be expanded: the present retirement age could be increased and the immigration laws could be amended to provide a higher priority rating for persons with the desired skills.

What the above helps to make clear is that if a combination of presently unforeseen circumstances requiring a substantial increase in the number of scientists and engineers were to arise, considerable elasticity remains to accommodate such an increase over a reasonable number of years, primarily by encouraging more women college students to opt for such training; by encouraging some part of the large non-physical science groups to shift to science; by promoting delayed retirements; and by modifying our immigration regulations. Over a long time period, the yield from better prepared Black and Hispanic cohorts should also be expandable.

The other major area for potential adjustment to a much enlarged demand for scientific and engineering personnel would involve improvements in the utilization of the existing supply which, it must be remembered, in the case of engineering is roughly 15 times the number of annual new entrants. The following paragraphs suggest some of the important areas where significant gains in utilization should prove possible:

- A more systematic effort by large employers to provide more in-service and external opportunities for continuing education of their S/E staff.
- A review by large employers aimed at preventing excessive "lock-in" of S/E personnel on highly specialized work to a point where they lose their capacity to shift to other work.
- More attention to the appropriate division of work responsibilities, as between scientists and engineers on the one hand and technicians on the other, to be sure that the latter have the responsibility for most routine assignments.
- Larger capital investments by employers, particularly in the rapidly advancing computer technologies, which will enable scientists and engineers to increase their productivity substantially.
- Improved direction and leadership of large scientific and engineering groups in both the defense and nondefense sectors. A considerable body of evidence points to potentially large gains in utilization that would follow upon improved organizational and managerial practices.

The foregoing does not pretend to exhaust the many existing opportunities that have long been present and that continue to exist for significant gains in utilization . The fact that many of them have not been addressed, or addressed only half-heartedly, points to the absence of any acute long-term shortages that senior management has recognized to the point where it is willing to devote effort and resources to their elimination.

Since the cycle of preparation for entering upon a career in science and engineering is elongated and since many, especially scientists, look forward to pursuing a life-time career in their chosen field, the following improvements in the educational and research infrastructure could have positive results:

- Since the federal government plays such a dominant role in the financing of most basic research, as well as most research and development that is defense-related, it should seek more than heretofore to avoid wide fluctuations in its funding cycles. Large and sharp fluctuations in government spending impose heavy costs by encouraging many people to respond to the new signals by sudden shifts in their educational plans and their professional work.
- Since scientists and engineers are trained by colleges and universities, it is essential that all the parties involved in the financing and direction of higher education--the federal government, the states, and business--strive to strengthen and stabilize the academic base to ensure that requisite faculty and other resources such as equipment are available to provide a flow of graduates properly prepared to pursue careers as successful professionals.
- Since the problems involved in assuring an adequate national supply of well-educated scientists and engineers and their effective utilization have come center stage not once but repeatedly since the end of WW II, and since the successive debates concerning these issues have repeatedly suffered from inadequate data, weak models and faulty analyses, the knowledge base required for sound policy formulation urgently needs to be strengthened. Accordingly, the National Academies of Engineering and Sciences should take the lead to obtain the resources required for an ongoing and enlarged research effort that could improve the decision-making process with respect to S/E personnel both inside and outside the federal establishment.

# MODELING THE SUPPLY OF SCIENTISTS AND ENGINEERS: AN ASSESSMENT OF THE DAUFFENBACH-FIORITO WORK

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## Introduction

This paper reviews the present state of our knowledge in modeling the supply of scientists and engineers. It focuses especially on what we know about the capacity of the supply system to respond to shifting defense requirements. Such shifts might either be temporary, requiring rapid and flexible response, or longer term, requiring more lasting adjustments in levels of supply. This paper doesn't discuss the likely magnitude of such shifts, or the impact of spending shifts on demand for personnel--those are demand-side questions. The question here is "*If* significant shifts occur, how well equipped are we to assess the consequences?"

Although this paper, like the DauffenBach and Fiorito work it focuses on, comments on all science and engineering fields and on personnel with advanced degrees as well as entry-level degrees, its main concerns are with engineers and with bachelor's level supply. This is in keeping with the overall concerns of this project and is also where there is greatest concern about the adequacy of the supply system.

There are several reasons for giving most attention to the work of Robert DauffenBach and Jack Fiorito (D-F hereafter). Theirs is the most comprehensive and analytically challenging among recent projection models of the supply side of technical labor markets. They are comprehensive both in coverage of fields and degree levels and, more important, in sources of supply. In particular, their work includes serious attempts to come to grips with "occupational mobility" as a source of supply. Since in recent years less than half the additions to engineering employment have been persons with fresh engineering degrees, mobility is obviously a key problem to analyze. D-F's work is important also because it is a central component in the influential NSF model of science and engineering labor markets.

Some general limits on the aims of work in this area should be noted. The D-F work (as well as other supply projections) focuses on the supply of personnel to particular occupations, narrowly or broadly defined. They do not attempt to examine relative supplies to different kinds of employers within an occupation (e.g., government, industry, and academics; or military and non-military). This work, then, doesn't address one important range of *utilization* issues--in particular, it doesn't address the important question of how personnel might be reallocated between military and industrial uses in response to changing defense requirements. Such reallocations could have important effects on industrial productivity. The D-F work and similar models also neglect issues about *quality* of personnel, at least in their formal modeling. The models measure stocks and flows of numbers of personnel and make no attempt to distinguish, for example, the quality or productivity of top-ranked and lower ranked graduates, or of entrants from other occupations and newly degreed personnel within the occupation. D-F's informal discussions include some perceptive comments on these matters, as we shall see, but they are not embodied in their models. These are generic limits to what quantitative supply models do; some limits specific to the D-F efforts will be noted below.

## General Features of the D-F Models

### *Modeling Components*

Figure 1 (reproduced from D-F, 1983) provides a useful overview of the D-F modeling framework. Starting from the stock of science and engineering personnel in a given year (disaggregated by field and education level), movements into and out of that stock are projected for the following year. Additions to the stock--additions to the supply of personnel--are analyzed through three model components. The basic strategy in each component is to estimate relationships based on past experience with that component and to use those relationships to project future values of the component.

(1) New entrants to a field are newly degreed personnel (the degree need not be in the employment field). In their 1980 and 1983 models for the National Science Foundation (NSF), the production of new entrants was analyzed through four subcomponent models: projecting the number of persons obtaining degrees, their distribution among curricula, their choice to enter the labor market, and their choice of occupation. Two of these steps--the choice of curriculum and the choice of occupation--were made responsive to labor market conditions [as projected by the Bureau of Labor Statistics (BLS)], so that students were projected to be more likely to enter large or growing fields. In a more recent projection of engineering degree attainment for the Engineering Manpower Commission (EMC), D-F adopt a similar approach, relating levels of degree production in various engineering fields to demographic variables and the level of demand for engineering employment (as projected by BLS).[1]

(2) Occupational mobility flows measure the entry to a science and engineering profession by persons previously employed in another science and engineering profession or in another part of the labor force. Mobility includes persons reentering a field after a time spent out of it. In their 1980 effort for NSF, D-F developed a model that projected occupational mobility on the basis of the age and education of a field's members and the size of the labor force in that field. This model did not make mobility depend on labor market conditions. That dependency is introduced in the 1983 model, but other features of the 1980 model are dropped, for reasons discussed below.

(3) Immigration to the U.S. science and engineering work force is handled through a simple model that links rates of immigration to a field to the rate of employment growth as projected by BLS. This component is not further discussed here.

### *Structural Features*

It is important to underline some of the key structural features introduced by D-F in welding these components into a model of supply:

(1) Their models make the supply of personnel responsive to demand, thus incorporating a key feature of real-world labor markets. The reverse feedback, from supply to demand, is, however, suppressed in their models to keep them manageable. This raises some technical problems in their estimation procedures, since employment is treated as an exogenous measure of demand, rather than as the endogenous outcome of supply-demand equilibration. But their approach is, in this respect, a reasonable compromise in keeping the project manageable.

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[1] These are "intermediate run" projections. Their short-run "pipeline" projections in the same study are not discussed here.

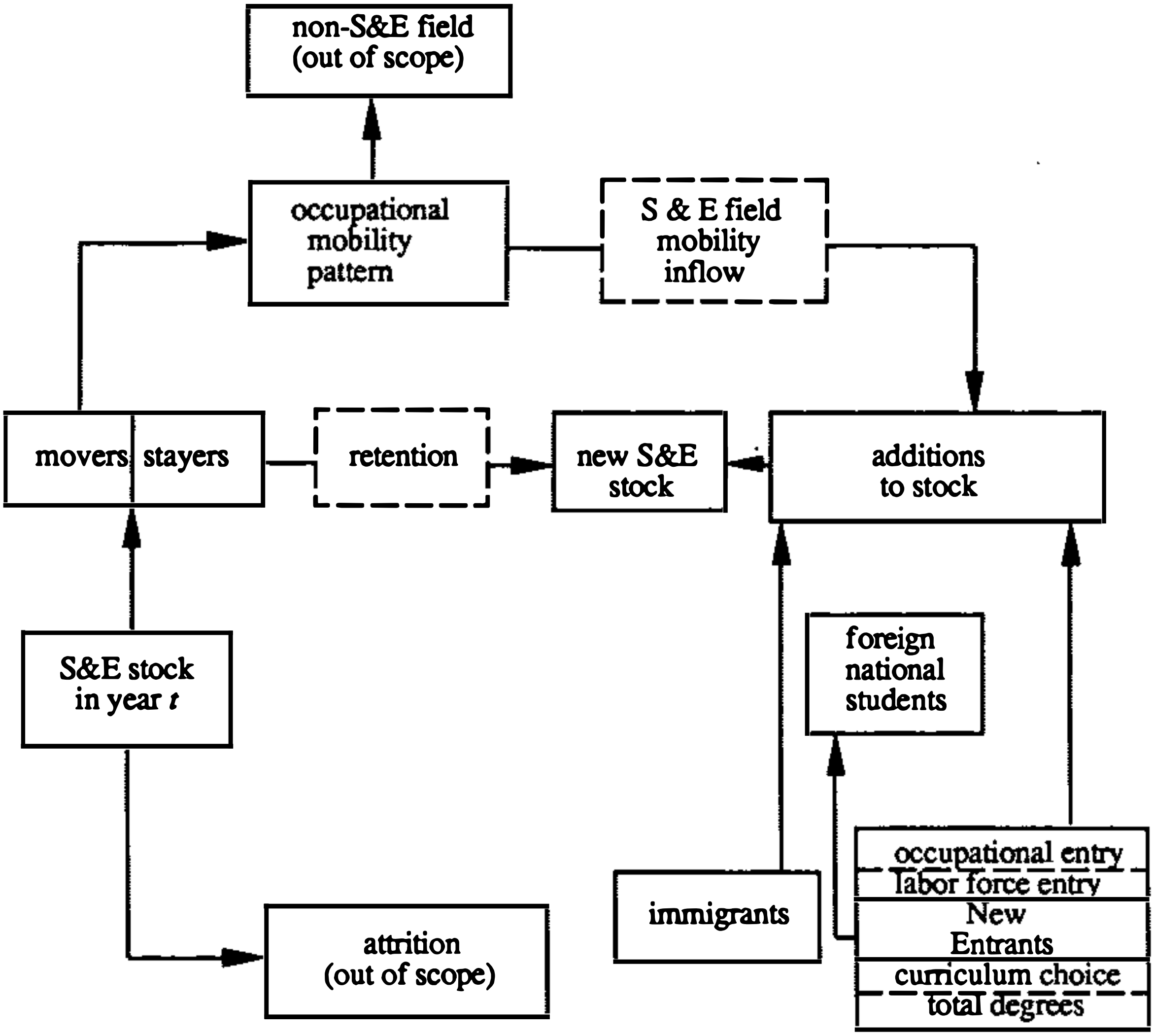

Figure 1. Schematic representation of the S/E labor supply system.

(2) D-F do not model the *process* by which supply accommodates to demand. When shortages occur in reality, the effect is to raise wages, stimulate firms' recruiting efforts, and so on. As Hansen (1984, p. 94) notes in commenting on D-F, this sort of adjustment "is not made explicit in the model." (In economics jargon, this is a "reduced form" rather than a "structural" model.) Explicit modeling of these adjustment processes would lend more confidence that the projections capture the forces at work and might give a more adequate feel for the dynamics of adjustment. For example, as Hansen notes (1984, p. 95), an explicit model of the adjustment process might reveal a tendency for supply to overshoot or undershoot in response to shifting demand [compare Freeman (1976) on cobweb adjustment in engineering].

(3) D-F treat the components of their model as independent or as sequentially determined. For example, in the 1983 NSF model, the level of new entrants is eternined

prior to the determination of mobility flows: new entrants can influence mobility, but not vice versa. This suppression of interaction among model components (like the treatment of demand as exogenous) simplifies the operation of the model but may miss significant phenomena.

These limitations are not pointed out in a spirit of finding fault. No manageable model can be fully general, and the compromises D-F have made are sensible ones. They are also admirably explicit about the choices they have made. Still, these limits do bear on the interpretation and uses of their results.

## The New Entrants Component

A key feature in assessing the usefulness of the D-F model for projecting the consequences of changes in military spending is the linkage of supply to demand. In the NSF version of the D-F model, that linkage appears in two subcomponents of the new entrants component (as well as elsewhere in the model): (1) the choice of curriculum by students and (2) the choice of occupation by labor-market entrants. Curricular choice is linked to the level of demand by occupation, with a lag (so that, for example, the distribution of bachelor's degrees by major field depends on the distribution of employment four years earlier). Choice of occupation by degree recipients is linked, however, to the rate of change in employment. It's not clear why one choice is linked to the level and the other to the rate of change in employment. In conceivable circumstances, this could produce odd results: a large field that was not growing would attract many majors who would then avoid the occupation.

The estimated relationships in the equations underlying the projections suggest fairly strong relationships between labor-market variables and student choices--stronger for graduate level than undergraduate choices. In the NSF projection results, however, these links don't show up very strongly. We can, for example, compare two demand scenarios considered by D-F in which employment of aeronautical engineers differs by about 25% (or 23,715 people) in the final projected year (1987). New entrants in 1987 in the two scenarios differ quite modestly (2270 vs. 2029), only about 11%. No doubt a major reason for this is the lag in effect on curricular choice. The projection is only for six years; and for bachelor's students, there is a four-year lag assumed in the effect on choice of major.

It is difficult to judge whether the dynamic adjustments implied in these relationships would look sensible over a longer projection period, when the lag effects could work themselves out more fully. One way to find out would be to run longer term simulations with the D-F model. The recent D-F work on engineering for EMC examines only the degree attainment and curricular choice subcomponents of a new entrants' model, but it considers those over a longer time frame. This interesting study links rates of degree production by field of engineering and level of degree to demographic trends (number of 18-year-olds) and lagged employment levels. This work shows quite strong responsiveness of student interest to increases in demand for engineers, especially at the bachelor's level. Thus, BLS projects a rise in engineering employment of about 50% between 1980 and 1995, and D-F project this would cause an increase in bachelor's degree production between 1981 and 1995 from 63,000 to 113,000--nearly an 80% increase.

D-F speak of this as an estimate of the "need" for new B.S. engineers, but this may be somewhat misleading. It actually projects the extent to which student entry to engineering would be induced by job growth at the rate BLS projects. This might over- or under-shoot actual needs. Thus in 1981, new bachelors were about 5% of overall engineering employment. In 1995, on these projections, they would be about 6.3% of overall employment. If job openings as a fraction of employment remained constant over this period, then these projections would imply that new bachelors would be filling a larger fraction of job openings in 1995 than in the recent past. If needs were roughly being met in the early 1980s, this might be taken as a sign of oversupply at the later date; alternatively, if one sees the recent past as a time of shortage, this implies that supplies would be somewhat more adequate in 1995.

Both the NSF and the EMC work model only the student choice aspect of new entrants. As D-F emphasize, institutional constraints on educating the number of students who may seek degrees in engineering or science are not modeled. But currently, many engineering schools report faculty shortages and face various difficulties in expanding engineering enrollments. It would clearly be desirable, in principle, to project the capacity of colleges and universities to supply places in engineering (there do not seem to be capacity problems in most science fields). This is a difficult job, since it would require modeling the behavior of individual non-profit institutions in deciding on the size of their engineering enrollments, as well as modeling the potential entry of new engineering schools. A needed subcomponent of such a model would be a model of the academic market for engineering Ph.D.s, since their availability is an important constraint on expanding engineering schools. The importance of this problem is noted in informal discussion in D-F (1984) and DauffenBach (1984), but it has not been incorporated into their models.

## Occupational Mobility

As noted above, the two versions of the supply model D-F developed for NSF (1980, 1983) treat occupational mobility quite differently. The earlier effort focused on the heterogeneity of the pool of potential movers: not all personnel are equally likely to make a switch. The model they developed tried to account for historical patterns of movement as a basis for making projections and found that the most important factors influencing movement were the age of the worker (older workers are less mobile) and his or her education (more educated workers are less mobile). Their model also captured the greater likelihood of movement between fields that were closer in the skills they drew on.

However, a key drawback of the early NSF model was that it did not make mobility rates sensitive to market conditions. Since it is clear empirically that changes in movement patterns among experienced workers are closely linked to shifts in demand, this was a very important omission. Unfortunately, D-F's attempt in their 1983 study to add market condition variables to their earlier model failed: they were not able to capture this market sensitivity empirically in a way that led to empirically plausible results.

D-F (under considerable time pressure) responded by introducing a wholly different analysis of mobility. Their new analysis in effect shifted the focus from the sources of supply of mobile workers to the size of the demand gap that needed to be filled. For each field they were modeling, D-F in effect estimated from historical data the correlation between the hiring of mobile workers and (a measure of) the degree of excess demand for workers in that field and used this estimate to project future reliance on mobile workers.

This analysis (as the authors recognize) comes very close to *assuming* that all otherwise unfilled demand will be satisfied by mobile workers (compare Hansen, 1984, p. 96).[2] This approach has the virtues of capturing the close empirical relation between the state of employment demand and the degree of reliance on mobile workers, as well as

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[2] The link is made tighter by the facts (a) that the authors treat demand as exogenous (so that all of the correlation between supply and demand is treated as supply adjustment) and (b) that the authors' demand measures don't include any allowance for unfilled vacancies.

calling attention to the importance of the phenomenon of field mobility, which has been widely neglected in work on supply.

It's clear, however, that the approach embodied in the recent D-F work for NSF leaves a great deal to be desired. Unlike their earlier work, this model sheds no light on the composition of the mobile work force. Had D-F succeeded in adding mobility to their earlier model, they could have learned something about how the composition of the groups mobile to a field shifted with the state of excess demand. We might hypothesize, for example, that when excess demand is moderate, most mobility is from workers in closely allied fields, or from workers trained in the field but working elsewhere; as excess demand increases, workers may be drawn from further afield, with attendant implications for training costs and quality. The D-F model sheds no light on this question.

The earlier work also includes an explicit model of the pools from which mobile workers are drawn. The long-run implications of reliance on mobility plainly depend heavily on the rate at which these pools are being replenished. This question is not raised in the recent D-F work.

Analysis of occupational mobility and its implications is clearly of great importance. In recent years, more than half of the new hires in engineering as a whole have been in-mobile workers. The Office of Technology Assessment reports that similarly high rates held throughout the decade of the 1960s (1985, p. 97). The recent D-F work suggests what is almost certainly true, that this sort of mobility has proved and will continue to prove a very effective means of solving short-run labor shortages in technical fields. In fact, in periods too short to train new workers, mobility is essentially the only way to respond to unanticipated demand increases. (It also provides a valuable alternative for workers in fields that experience short-run demand declines.)

The longer-run implications of reliance on mobility to respond to growing demand may, however, be quite different. There is clearly the possibility of "using up" stocks of qualified mobile personnel if high in-mobility rates to a field or set of fields are sustained over time. Thus, in the early 1970s a sluggish market for engineers sent many into other occupations, and they have been available to meet some of the rising demand of recent years. That stock may eventually be depleted. On the other hand, physicists, mathematicians and even social scientists are also among the in-mobile to engineering, and the stocks of such personnel tend to be replenished over time.

We know very little empirically about the relationships among these stocks and flows. D-F have good informal discussions of these issues in their work (DauffenBach, 1984; D-F, 1983), but their recent empirical and modeling work does not illuminate them.

One further perspective on the mobility issue may be worth bringing to bear here. In the short run, reliance on mobility means drawing down available stocks of workers in other fields. But if mobility is a stable part of the long-run supply of personnel to a field, it may be useful to view "occupational mobility" and "direct training" as alternative technologies for producing new workers. For example, midlevel management in a technical firm may be produced either directly, as when the firm hires a freshly-minted M.B.A., or through occupational mobility, as when the firm promotes a bachelor's-level engineer. Bachelor's-level engineering jobs can similarly be filled either directly by new engineering graduates or indirectly by persons with general science degrees who are hired into engineering jobs after several years' experience in scientific work in industry.

Which technology is superior for "producing" workers in a given case depends on many factors. Among them are the precise character of the job requirements, the relative costs (including opportunity costs) of alternative training routes, and the risks involved in acquiring more general versus more specialized training. It's possible to see the current situation as one in which universities perceive the costs of expanding engineering enrollments and degree production as high and are, therefore, in effect forcing industry to rely on the "alternative technology" of hiring experienced workers trained in other fields. Whether this is a sensible long-run response requires investigation.

## Conclusion: Uses and Limits of the D-F Modeling Efforts

My conclusions address two questions. First, how well do the D-F models handle the specific questions about the capacity of the supply system to respond to shifts in military spending raised at the outset? Second, what are the broader strengths and limitations of the D-F framework?

Short-run surges in military requirements for science and engineering personnel raise quite different issues from longer-run secular increases in military requirements. Regarding the short-run questions, the D-F work gives a sensible qualitative picture of how the supply system would respond. There would be little short-run supply response from new entrants. Their models assume lags in the response of curricular choice to demand shifts (four years for bachelor's and Ph.D.s; two years for master's), which rule out much quick response. There could be in their model more response from shifting occupational choices of new graduates, but this is fairly limited too. It's more limited, of course, the broader the set of fields for which demand rises.

The D-F model implies that the short-run response to higher demand will come largely through occupational mobility and that response will be rapid and strong. This seems clearly right as a general matter, and it underlines the short-run flexibility that mobility lends to the science and engineering supply system. Unfortunately, the D-F model doesn't tell us much about where these mobile personnel come from; nor, as noted earlier, is it designed to say anything about the reallocation of personnel within a field between defense and nondefense uses.

Finally, in regard to the short run, the dynamics of the model are not rich enough to give reliable answers to questions about whether the supply response will overshoot longer-run requirements. Suppose, for example, that engineering employment rose abruptly for two years and then dropped back to an earlier level as a result, say, of shifting Congressional attitudes toward defense R&D. The D-F model would predict a surge in engineering bachelor's degrees in the second year of the slowdown, followed by a drop in degree production two years later. There would be a sharp increase in in-mobility when demand expanded, followed by a very sharp drop in in-mobility when the drop in demand met up with the surge in supply of new entrants. One shouldn't put much confidence in this sort of projection, since the model was really not designed to track quick responses to such fluctuations.

Turning to the long run, the basic concern is with the implications of long-run growth in military requirements for science and engineering personnel, especially if accompanied by strong growth in industrial needs for such workers. Putting together the D-F work for NSF (1983) and for EMC (1984), one would reach the following assessment: degree production in the affected fields--or rather decisions by students to seek such degrees--would be strongly encouraged by rising demands. The EMC projections suggest that the response might be strong enough in the long run actually to increase relative supply to fields in sustained high demand. However, possible institutional constraints on the production of such degrees are not modeled in the D-F framework and might lead actual degree production to fall well short of their projection.

If new degree production falls short of demand, their model projects that occupational mobility will make up the gap. But as a long-run projection--in contrast to the short-run response discussed above--this may not be a convincing or reassuring response (as D-F clearly recognize). The model does not tell us where the mobile people are coming from, or whether long term reliance on these sources will deplete available "reserve stocks" of qualified personnel. Nor do D-F have any means in their model to capture the process by which (we may suppose) employers move from hiring more qualified to progressively less qualified personnel as excess demand pressures increase or persist. These are issues which future supply models must find ways to address.

Let me turn finally to the general strengths and weaknesses of the D-F modeling work. In some ways the strengths and weaknesses are the same. Thus, the hallmark of the D-F work is the effort to provide a *comprehensive* framework for modeling the supply of science and engineering personnel. The strengths of this ambitious approach are clear: it provides an overview of the supply system, especially of the interconnections among science and engineering fields--and between them and the rest of the labor market--that are created through occupational mobility. At the same time, the ambition of comprehensiveness limits D-F to data that can be assembled on a consistent basis across the range of fields and degree levels and constrains their ability to incorporate the institutional peculiarities that may apply within specific fields. If, for example, one set out to construct a model of the supply of Ph.D.s in the life sciences, one could draw on more refined data and take better account of institutional features like NIH traineeships and the prevalence of postdoctoral fellowships, which a broadly gauged model is forced to ignore. These special features will matter more for some fields and degree levels than others. To note this is not to criticize D-F but simply to observe an inescapable trade-off.

The second broad ambition of the D-F model is to incorporate feedback from demand to supply. Such feedback effects are clearly important to capture in supply models, and the only drawback of the D-F effort is that it makes one so aware of how much further it is still necessary to go. The D-F model makes us aware of the various points at which supply can respond to excess or deficient demand--through choice of curriculum and of occupation by new entrants and through the mobility decisions of experienced workers--and brings out their differing importance in shorter and longer runs.

But the D-F efforts whet the appetite for more. It would be desirable to have a better dynamic specification of market responses--one that explicitly models adjustment processes, examines the channels through which information about demand conditions is communicated to the supply side of the market (e.g., wages and recruiting efforts), and accounts for the influence of expectations. A more structured, but still market-sensitive, analysis of mobility processes would also be very desirable. D-F underline the critical importance of mobile workers in filling demand gaps. But that analysis must be integrated with a picture of where the mobile workers come from, of which workers from the potential mobility pools tend to move, and of the processes by which pools of potentially mobile workers are replenished as well as depleted.

None of this is to denigrate the very substantial achievements D-F have to their credit. Their work has provided an improved understanding of how these labor markets respond. Not least among their accomplishments is providing models that direct policy discussions to the right questions and direct future research in promising directions. From the policy perspective, D-F stress, rightly, that the issue in labor markets is not *whether* supply and demand will be brought into balance, but *how,* and with what costs, the adjustment will be accomplished. This has directed the policy discussion away from questions about supply-demand "gaps" toward discussion of quality, of adjustment strategies, and of training and retraining costs. This is where discussion belongs.

From the research perspective, D-F's work points to valuable directions for future inquiry. Among these are the need for better dynamic specification and for better understanding of interfield movements, which have already been discussed. D-F have also begun the process of recognizing the heterogeneity of the science and engineering labor force, in terms of likely mobility and quality and character of training, which must be incorporated in future work. Finally, D-F's work highlights the need for better understanding of the role of colleges and universities in influencing the supply of science and engineering personnel. It's clear that their decisions about such matters as limiting engineering enrollments, expanding or constricting Ph.D. production, and so on play critical roles in the overall workings of the supply system and are poorly understood.

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# WHAT CAN DEMAND AND MANPOWER REQUIREMENTS MODELS TELL US ABOUT THE IMPACT OF DEFENSE SPENDING ON THE LABOR MARKET FOR SCIENTISTS AND ENGINEERS?

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## Introduction

This paper reviews the demand and manpower requirement models for scientists and engineers (S/E). Its purpose is to examine the usefulness of these models for assessing the impact of defense spending, particularly the Strategic Defense Initiative (SDI) program, on the nondefense labor market for S/E personnel. Of special interest is the ability of these models to indicate whether, in light of the prospective supply of S/E personnel, enough manpower resources will be available so that defense spending programs can move ahead at their projected rates without curtailing productive activity in the nondefense sectors of the economy.[1]

Present and projected levels of defense spending and the advisability of initiating the SDI program have been the subject of enormous discussion and analysis (Congressional Budget Office, 1983, 1984, 1986; Office of Technology Assessment, undated; Aspin, 1984; Penner, 1984; and Thurow, 1986). The reason for our interest is concern that the heavy utilization of highly specialized S/E personnel will divert these resources from the nondefense sector of the economy, thereby slowing our rate of technical progress, reducing our capacity to compete effectively in world markets, and limiting our ability to accelerate the nation's rate of economic growth.

Of particular concern is the rapid projected growth of the SDI program, which will be intensive in its utilization of highly specialized S/E personnel. By way of illustration, the SDI program--as a percentage of the Department of Defense's (DoD) Research, Development, Test, and Evaluation (RDT&E) budget--rises from less than 4 percent of the 1984 plan for RDT&E to almost 16 percent by 1989 (CBO, 1984). Thus, it is possible that the SDI program could not only intrude on nondefense activity but also restrict other defense activity.

For these reasons it is essential to have a better understanding of the S/E demands generated by the defense and nondefense sectors. To the extent that the objectives of these various activities conflict, we have two alternatives. One is to live with these conflicts, letting market and perhaps political forces resolve them; the other is to devise policies and take actions designed to reduce, if not eliminate, these conflicts. Whether much can be done through policy measures to reduce them is moot.

## Setting the Background

Ideally, a full assessment of the supply and demand for S/E personnel would have been an integral part of planning new defense initiatives. The idea of developing

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[1] Preliminary discussion of these models took place at a January 1986 workshop sponsored by OSEP-NRC and summarized in OSEP, 1986.

manpower impact statements to accompany new programs received considerable discussion in the 1960s with the elevation of manpower concerns to national importance. Producing such statements is a formidable task, however; so much so that the idea of manpower impact statements never took hold.

In view of the importance attached to recent proposals for increasing defense spending and implementation of the SDI program, it is surprising that so little analysis has been done.[2] Not only is the narrow technical feasibility of the SDI program at issue, but there is also uncertainty about whether the unique constellation of S/E personnel required by this program will be available. Considerable effort has gone into developing a system for exploring these issues, but the system has not yet evolved to the point that anyone can be reasonably confident about resolving them. Thus, it is hoped that the Office of Scientific and Engineering Personnel study will help to fill the void. Whether the results can influence decisions already made or yet to be made remains unclear.

Why should we ask the question posed in the title of this paper? The simplest answer is curiosity: how big an effect will the defense and SDI programs exert on the S/E labor market, and how do we go about estimating this effect? The size of the effect is far from obvious, and the method of measuring its size poses an interesting challenge. A more complicated answer is that we need to know the magnitude of the effects on S/E personnel so that we can determine whether output in other sectors of the economy will have to be curtailed. This requires a more diligent effort because we must establish both the nature and the extent of the interdependencies among the sectors. A still more complicated answer, but one of primary interest to most people in Washington, is the policy response to whatever we can learn about the effects of the defense and the SDI programs. Put another way, to what extent can the available policy instruments, or new ones that might be created, help ensure that the objectives of defense programs are achieved, that neither the SDI nor the non-SDI defense programs are compromised, or that both such programs can go forward unaffected by each other?

The natural and rapid gravitation to policy concerns exemplified by the query about what federal policymakers can do raises the intriguing and as yet unanswered question: What policy instruments are available to deal with direct and indirect effects of defense spending, especially SDI, as they affect the labor market for S/E personnel? A widely prevalent view is that these instruments are quite limited. Indeed, we would have difficulty producing a list of policy instruments that could have any substantial effect on the S/E labor market.[3]

Were there an extensive list of policy instruments available, we could use its essential elements as a focus for evaluating the various demand models. For example, we might want to determine whether the various demand models generate information that would feed into and potentially trigger one or more of the available policy instruments. Were this possible, this paper could have a sharp and direct focus that would obviate the need subsequently to translate into a policy context our findings on the demand models. Of course, this assumes that the federal policy instruments can be utilized with reasonable speed and produce their advertised effects. Neither of these assumptions should be accepted as fully plausible, however.

In the absence of this inventory, we face a quite different task. We must try to identify the effects of interest from the standpoint of the S/E labor market, determining to

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[2] This point has been emphasized by Aspin (1984), and Thurow (1984 and 1986)).

[3] For an effort to show what federal policy instruments are available to affect graduate education in science and engineering, see Alan Fechter, "The Effectiveness of Federal Programs for Science and Engineering Graduate Education," a paper presented to the U.S. House of Representatives Committee on Science and Technology, Task Force on Science Policy, July 9, 1985.

what extent the various demand models can illuminate how the S/E labor market operates. The results should still be of interest to decisionmakers--namely, those individuals and firms who find themselves participating in or affected by the defense program. The labor market information produced will not only reveal what is happening but may also produce responses that will alter the condition of the S/E labor market and eliminate imbalances that might otherwise be a matter of concern. If this is the case, then the best of all possible outcomes may be achieved.

In a sense, we have been asking, "Who is the audience for projections of employment?" The policymakers have too few levers to press. Employers must respond to current market pressures regardless of what the projections indicate. Prospective workers may be ill-advised to place much faith in projections of requirements because past ones have usually been considerably off-target. In any case, monitoring current and prospective labor-market conditions is something that the private sector already does and, hence, one could argue that the demand models are of relatively little use to most people in the S/E sectors. This does not, of course, preclude our interest in the topic.

## Establishing the Criteria for Evaluating the Demand Models

Rather than plunging immediately into a detailed analysis of the various demand models that might be employed to examine the impact of the SDI program on S/E personnel, it is important to try to characterize what kinds of information that we want about the operation of the S/E labor market and then to contrast this with what the different models provide. We draw upon the knowledge and experience of labormarket analysts and their efforts to identify key information to analyze labor markets (OSEP, 1984; COPAFS, 1985).

Our list of information is presented below, phrased in the form of questions. We act as if we are back in 1984, when the SDI program was first proposed; this helps to avoid complications that arise because the SDI program is already under way.

1. What is the planned and what is the likely pace of *annual growth* in the SDI program and overall defense spending over each of the next five years and through the five years beyond that? We recognize that SDI is a major developmental effort that will extend over a long period. However, the pace of development each year depends critically upon progress achieved through the previous year. The only way of dealing with this is to understand the evolution of the program from year to year. This requires not only longer-term projections of, say, five and even ten years but also annual updates to track new developments.

2. What is the likely *variance* in the pace of the program's development? The technological difficulties appear to be enormous, with the result that delays in accomplishing certain critical tasks are likely to slow the development of the entire program. The uncertainties appear to be far more substantial than those encountered in most sectors for which demand projections are made. As a result, we want to know the likely annual range in expenditures and utilization of S/E personnel arising solely because of these uncertainties.

3. What kinds of *knowledge and skills* will be required of S/E personnel to assure the technical progress necessary to keep the SDI and other defense programs on schedule? What type of scientific and engineering knowledge will be needed and in what sequence over time? For example, the need for basic research may be heavier in the earlier years of the program's development, with developmental-type activities coming later. Since these activities will undoubtedly require different knowledge and skills, the impact on labor markets will surely change over time.

4. What level of *occupational detail* describing manpower requirements is needed for the various actors in the program--the firms that will be hiring S/E personnel and also the new and existing S/E personnel who are working or might work on the SDI program? Will it be sufficient to produce estimates of manpower requirements based on the traditional occupational classification system that is related to the kinds of collegiate training people obtain? Or will we need much finer classifications of the kind shown by the 3- and 4-digit occupational codes in order to highlight the increasingly specialized nature of manpower demand? Or do we need some entirely different classification system? How do we answer this question?

5. To what extent can these models reflect prevailing elasticities of *substitution among different types of S/E personnel?* We know there is considerable flexibility in what many S/E personnel can do. At the same time the technologies involved in developing SDI may be highly specific and thus limit substitution of one type of S/E for another. By utilizing a broad classification system for S/E personnel, these substitutions can be ignored. And yet the critical labor market problems are likely to arise because of shortfalls of particular types of specialized personnel. Thus, we need to know how easily employers can shift workers across classification lines and also the extent to which they can shift workers among different job functions, such as research, development, management of research, and the like. Again, this may require a different system for classifying S/E personnel. To the extent that easy substitutability exists, the likelihood of specific S/E labor bottlenecks is reduced.

6. To what extent can these models encompass changes in the elasticity of *substitution between labor and capital resources*? As a result of recent advances in computer technology, for example, it is plausible to believe that capital can be substituted for labor more easily and quickly in SDI than in other parts of the defense and nondefense economy. If this is the case, requirements for S/E personnel may rise at a slower rate than anticipated. How can these changes be incorporated into demand models? And what estimates of elasticities emerge?

7. Can these models capture the extent of *substitution between new and recent entrants into the S/E labor market*? If experienced workers and experienced scientists are in limited supply, then perhaps two new degree recipients can be utilized to do what a more senior person would do if available. What do we know about these possibilities?

8. How can we be certain that the demand models capture the effect OF *changes in defense spending*, particularly spending on the SDI program? Most of the models are built on average relationships from which marginal impacts are inferred. Yet the essence of the SDI program is its uniqueness and the fact that it will require a constellation of S/E personnel that may differ appreciably from the present stock of S/E personnel. Unless the particular nature of these marginal impacts can be identified, the results of the models will be off target in pinpointing the very problems that they are designed to help uncover.

Some may object to these criteria because they impose severe standards on existing demand models. Indeed, because of their many limitations, these models may not receive high marks when evaluated against these criteria. The only way to remedy this is to make efforts to enrich these models, to develop alternative models, and to find new approaches so that more effective assessments can be made of the impact of SDI and other defense spending on S/E labor markets.

## An Inventory of Demand and Requirements Models

What types of models or approaches are available? It is useful to list and then to review each approach to gain an appreciation for its potential effectiveness in providing estimates of the impact of the SDI and other defense programs.

### *Macroeconomic Approaches*

We have a number of approaches that are all closely related but yet differ in significant ways. Each approach is summarized briefly here:

1. *Bureau of Labor Statistics (BLS): Employment Projections.* Every five years or so, BLS produces employment projections on a 10-year horizon for 550 detailed occupations in each of 378 industries. These projections are generated by combining its labor force projection model, aggregate economic projections derived from the Wharton Econometrics macroeconomic model, its own industry demand model, its own industry employment model, and its own occupational employment model, which relies on the BLS industry-occupation matrix. The results of these studies are published in the *Monthly Labor Review* and also in various BLS Bulletins.[4]

2. *Data Resources Incorporated (DRI): Interindustry Forecasting Model.* This private firm produces employment forecasts[5] for 163 occupation categories in each of 82 industries. These forecasts are generated by DRI's Occupation by Industry Model, which combines the results of the BLS occupation by industry data, and by DRI's 400-sector employment forecasts, derived from its Interindustry Model, all of which are based on its Macro Model. These results are proprietary and thus not generally accessible.

3. *Data Resources Incorporated: Defense Interindustry Forecasting System (DIFS).* This system, developed for the Department of Defense, produces employment forecasts for 163 occupational categories in each of 81 industries. The DIFS Model combines five-year projected defense outlays and already authorized expenditures for 50 budget accounts, which are then converted into final demand by commodity through the Defense Industrial Share Matrix and integrated into the Standard Industrial Classification industry groups. Combined with the results of the DRI Quarterly Model of the U.S. Economy, production for defense and nondefense sectors is estimated and then converted through a dynamic input-output model into estimates of direct and indirect production. Subsequently, these production estimates are converted into industry employment through a series of production equations. The final step is to distribute industry employment across occupations with the help of the Occupational Employment Statistics (OES) matrix developed by BLS. These results are not easily accessible.[6]

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[4] U.S. Department of Labor, *Monthly Labor Review,* November 1985; Bureau of Labor Statistics, "BLS Economic Growth Model System Used for Projections to 1990," BLS Bulletin 2112, 1982; and Bureau of Labor Statistics, "The National Industry-Occupational Matrix, 1970, 1978, and Projected to 1990," Bulletin 2086, 1981.

[5] Data Resources Incorporated, *The DRI Interindustry Service: Occupation by Industry Model*, Washington, D.C.: February 1983. See also Otto Eckstein, *The DRI Model of the U.S. Economy*, Englewood Cliffs, N.J.: McGraw-Hill, 1983.

[6] Institute for Defense Analysis, *The Defense Translator*, IDA Record Document D-62, June 1984.

4. *Department of Defense: Labor Defense Economic Impact Modeling System (LDEIMS).* This approach, according to the available documentation, is quite similar to the DIFS model. The only real difference is that the DIFS model is based on the more highly aggregated budget data published by DoD. The LDEIMS model, by contrast, is based on quite detailed 5-year projections of expenditures that Congress is expected to approve. These two models are likely to produce quite similar results because of aggregation and the fact that the published and unpublished data do not differ substantially. Again, the results are not easily accessible.[7]

5. *National Science Foundation Model.* This model examines the impact of defense and nondefense needs on the science, engineering, and technology labor market, using demand or requirements estimates from the DIFS model and supply projections from the DauffenBach/ Fiorito/Folk (DFF) Model, and the Stock Flow Model of Science and Engineering Labor Supply. Two aspects of this approach deserve mention. First, the defense and nondefense requirements are estimated over a five-year time horizon. Second, annual projections of supply estimates are developed for 21 occupational groups and distinguish between new entrants, occupationally mobile experienced workers, and foreign immigrants. The results have been published by NSF; the DFF results appear in a series of unpublished papers and reports.[8]

6. *Institute for Economic Analysis (IEA): Dynamic Input-Output Model.* This model was developed by Wassily Leontief, Faye Duchin, and their associates at New York University for the purpose of estimating the employment effects of automation for 53 different occupations in 85 different industries over a long-run time horizon--e.g., to the year 2000. No explicit attention is given to the defense and nondefense sectors but, in principle, there is no reason why this model could not be adapted to estimate defense employment impacts, something that Leontief has done in earlier work.[9]

*Microeconomic Approaches*

These approaches are more difficult to describe, largely because we have few examples that are linked to the defense sector. Nonetheless, several different approaches have been employed, and they are described briefly below.

1. *Production Function Model.* This approach in one of its various forms has been applied to particular industries to measure such things as productivity increases and elasticities of substitution; it can also produce employment forecasts. This family of models is limited in its ability to differentiate among various types of labor; typically, this model focuses on one and perhaps two categories of labor, such as "the more and the less educated" or "the more or less skilled." These models are less useful for prediction than for explaining what happened in the past. Because these models require fairly extensive time-series data, they

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[7] Department of Defense, *Defense Economic Impact Modeling System--DEIMS: A New Concept in Economic Forecasting for Defense Expenditures*, Office of the Secretary of Defense, July 1982; Department of Defense, *Defense Use of Skilled Labor: An Introducion to LDEIMS*, undated. See also Department of Defense, *Defense Purchases: An Introduction to DEIMS*, undated.

[8] National Science Foundation, *Projected Response of the Science, Engineering, and Technical Labor Market to Defense and Nondefense Needs: 1982-87*, (NSF, 84-304), Washington, D.C.: U.S. Government Printing Office, 1984.

[9] Institute for Economic Analysis (Leontief-Duchin), *The Impacts of Automation on Employment, 1963-2000*, New York: New York University, New York, April 1984.

are often difficult to estimate. It should be noted that production function equations constitute part of several macro models, most notably the BLS and DRI models.[10]

2. *Recursive Model.* This approach has been popularized by Richard Freeman and is typically applied to a single occupational group, with the purpose of not only explaining the past but also forecasting the future. Numerous applications have been made to highly trained occupational groups, including engineers, and college faculty members. Essential features of this approach are lags in the production of new entrants who respond to changing wage levels. As with the production function approach, extensive time-series data are required.[11]

### *Survey Estimates of Future Demand by Sector*

A standard technique used over the years entails surveying strategically placed people in an occupation or industry for their best estimates of the level of future demand or requirements for specific types of personnel in the short run. In this case, respondents might be asked to estimate the impact of increased defense spending and the SDI program on employment requirements.

1. *Engineering Manpower Commission.* Periodically since the Korean war, the Engineering Manpower Commission has initiated surveys of individual engineers and also employers to ascertain expected employment changes over the next year or several years. The purpose of its most recent surveys is to provide information for short-term planning purposes. The assessments from both employers and employees of expected demand conditions over the next year make this an especially interesting approach. Typically, however, responses are heavily affected by current conditions and do not do a particularly good job of identifying the magnitudes of actual demand changes.[12]

2. *National Science Foundation Survey Studies.* These annual surveys initiated in the early 1980s ask large firms to indicate the recent, current, and prospective status of the labor market for 8 types of scientists, 15 types of engineers, and 8 categories of technicians. Respondents can be grouped by industry and, within that, by whether they are in defense-related work. This permits the tabulation of results showing the relative shortage condition for each occupational group, along with projected hiring and an assessment of shortage conditions for the following year.[13]

3. *American Electronics Association.*[14] Another example of a more focused effort, though not explicitly on the defense sector, is the survey by the American Electronics Association on annual hiring plans by the electronics industry for the next five years. Essentially,

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[10] Richard B. Freeman, "A Cobweb Model of the Supply and Starting Salary of New Engineers," *Industrial and Labor Relations Review*, vol. 30, no. 2, January 1976.

[11] W. Lee Hansen, *et al.*, "Forecasting the Market for New Ph.D. Economists," *American Economic Review*, vol. 40, no. 1, March 1980.

[12] Engineering Manpower Commission, *The Demand for Engineers: 1982*, New York: American Association of Engineering Societies, Inc., 1983.

[13] National Science Foundation, *1985 NSF Science and Engineering Labor Market Study*, Washington, D.C.: Market Facts, Inc., April 1986.

[14] Pat Hill Hubbard, "Technical Employment Projections, 1983-1987: A Summary," in *Labor-Market Conditions for Engineers: Is There A Shortage? Proceedings of a Symposium*, Washington, D.C.: National Research Council, 1984, pp. 11-28.

respondents are asked to estimate changes in employment for several different categories of engineers and other technical professionals, their perceptions of the economy and the particular labor markets, and methods of accommodating to shortfalls of particular types of personnel.

### *Ad hoc Models*

Because the cost of developing the macro approaches is so high and because of the generally unsatisfactory nature of the micro and survey approaches, other approaches have been devised that set out in quite pragmatic ways to estimate in some systematic fashion the future demand for particular types of personnel. One such approach described below attempts to estimate scientific and technical personnel requirements for the research, development, and engineering activities connected with the SDI Innovative Science and Technology Office (ISTO). The developer of this approach is Ivars Gutmanis, a manpower expert in the Washington, D.C., area. Prepared under contract with the Department of Defense, the Sterling Hobe Corporation Model[15] develops annual estimates of scientific and technical personnel requirements for the ISTO component of SDI for the period 1986-1990. The approach is quite straightforward and is described as an empirical methodology. The circumscribed nature of this study, which can be viewed as a pilot approach to estimating personnel requirements for other aspects of SDI, did not warrant developing a more elaborate model.

A summary of the complex methodology used follows. To develop estimates of the personnel required to carry out research, development, design, and engineering activities that would be undertaken by ISTO, the study examines the experience of research organizations that were already performing similar activities. From the data for these organizations, it is possible to calculate a set of coefficients showing the average number of employees per unit of operating expenditures necessary to staff a research operation. After matching this information with the ISTO categories and the appropriate levels of operating expenditures, the total personnel requirements for each ISTO area are calculated. The professional component is then estimated for each area, and this is disaggregated into different occupational groups based on data obtained from the research organizations. These estimates are then developed for each year to reflect the buildup of ISTO activity. The approach seems like a plausible one, but it is necessarily crude. How accurate this approach will prove to be cannot yet be ascertained.

### *Informed Judgments by Knowledgeable Experts*

Despite the formal and less formal approaches outlined above, we frequently find long-time experts who possess the institutional background and know the data so well that they can provide qualitative assessments of the effects of complex changes and do so with reasonable speed and accuracy. The judgments reached by such individuals are not easy to replicate and, hence, can be no more than judgments. This approach is the antithesis of that employed by the model builders, who in extreme cases know little or nothing about the world their models attempt to describe. As examples of knowledgeable experts in this field, one cannot help but think of people such as Harold Goldstein and Harold Wool. Undoubtedly, the names of others should be added to this list.

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[15] Sterling Hobe Corporation, *Scientific and Technical Personnel Requirements Related to Activities of Innovative Science and Technology Office, Strategic Defense Initiative Organization*, Washington, D.C., January 1986.

## Evaluating the Various Models

Because the various models and approaches differ so considerably, it will be easier to separate them in two groups. Accordingly, we first examine the macro approaches and then turn to the remaining approaches.

*Macro Models*

We list in Table 1 each of the macro approaches and then indicate how they stack up against the various evaluation criteria outlined earlier. First, the capacity to produce annual projections of the impact of defense and other spending on S/E personnel exists for DRI, for DIFS band LDEIMS, and for NSF. Each is limited, however, to a five-year time horizon because of linkages to the DoD budget, which covers only the next five years. The likely accuracy and timeliness of these projections is limited by lags in the data but even more important by the use of essentially fixed coefficients. The actual relationships are quite likely to change in response to cyclical conditions, among other factors, and as a result the accuracy of these projections is suspect. Only the BLS and IEA indicate that they do not produce short-run projections; they restrict themselves to a 10-year or longer time horizon. To sum up, only two of the six models--DIFS and LDEIMS--can provide much help in illuminating the short-run impact of the expansion of defense spending.

The uncertainties connected with SDI and other defense programs appear to be recognized but are largely ignored by these models. Perhaps more important, the actual path of development may be affected by delays in essential technical developments, material shortages, testing difficulties, and labor bottlenecks. The only way to deal with these uncertainties is to indicate some range in the levels of projected manpower demand. None of the approaches pay attention to the kinds of knowledge and skills required except insofar as they are captured by occupational designations. Nor is it clear from these models how the mix of personnel by occupational category may change as spending programs evolve. Hence, the range of uncertainty is large.

Second, a severe limitation of the various approaches is that they stick with the traditional occupational categories. These categories are not descriptive of the kinds of knowledge and skills required of S/E personnel. The usual categories of engineers (civil, mechanical, electrical, etc.) reflect, to a large extent, the collegiate degree programs from which these people emerge rather than the categories of engineering skills used by employers in their search for both new and already experienced personnel. As an example, one national recruiting firm that specializes in placing engineers utilizes a 55-item position code, a 37-item listing of areas of competence, and a 10-item function code--permitting identification of both what employers seek and what individual job seekers can do. Without such detailed information, it would be difficult, if not impossible, for the firm to make appropriate job matches. If this amount of detail is essential to S/E labor markets as they actually operate, one cannot help but wonder about the utility of the usual macro approaches for estimating the impact of defense spending on S/E personnel.

The abundant substitution possibilities that exist are given little or no attention by these models. For example, labor substitution across occupational lines is completely ignored. Moreover, substitution between labor and capital is typically hidden behind adjustments made in the input-output matrix, capital-output ratios, and productivity assumptions. Because these adjustments reflect the informed judgments of the projection team, based on a wide array of information, and because these adjustments are not explicit, students of occupational projections experience difficulty knowing whether actual projected figures capture adjustments on the demand side that are of interest. In other words, it would be more informative to have projections made with and without the various

TABLE 1: Criteria for Evaluating Macro Models of Demand for Scientific, Engineering, and Technical Personnel

| | Names of Models | | | | |
|---|---|---|---|---|---|
| Criteria | BLS | DRI | DIFS | LDEIMS | IEA |
| 1. Horizon | 10 years | Annual | Annual<br>5-years | Annual<br>5-years | 10 years |
| 2. Range of uncertainty | Macro | Macro | Macro; Defense not specified | Macro; Defense not specified | Macro |
| 3. Knowledge and skills | None | None | None | None | None |
| 4. Occupational categories | Traditional | Traditional | Traditional | Traditional | Traditional |
| 5. Labor substitution across occupations categories | None | None | None | None | None |
| 6. Labor-capital substitution | Not Explicit | Not Explicit | Not Explicit | Not Explicit | Not Explicit |
| 7. Substitution of new entrants for experienced personnel | Not Considered | Not Considered | Not Considered | Not Considered | Not Considered |
| 8. Marginal versus average effects | Not Considered | Not Considered | Not Considered | Not Considered | Not Considered |

NOTE: For explanation, see text and list of references.

adjustments so that changes on the demand side could be isolated. This is particularly important if some of these demand side adjustments are responses to labor-market conditions, such as sudden supply-side shifts. Nor is any attention given to substitution between older and younger S/E personnel. One solution is to simulate different situations and to incorporate into them a range of substitution possibilities so that the sensitivity of the result can be established more precisely. This complicates presentation of the results because it is ordinarily necessary to allow for several different sets of assumptions.

Finally, no effort is made to distinguish between average and marginal effects. Because of what we already know about the sensitivity of estimates to even small differences, it seems essential to take account of the unique character of new programs because they are so likely to diverge from the average character of existing programs. In a session this point sums up all of the above points.

In summary, these models are no doubt useful first efforts, but they do not take us very far in understanding how the S/E labor markets operate. It is not even clear in what sense they reflect requirements for S/E personnel. The basic problem with these models is that their complexity makes it difficult to elucidate the assumption underlying them. Moreover, these models also entail a host of judgments that are difficult to detail.[16] For example, in using the input-output table to project industry employment, adjustments are made for anticipated technological change and attendant labor-capital substitutions. It is difficult to know exactly how these adjustments are made. It is even more difficult to know whether they are truly exogenous adjustments dictated by the on-going pace of technology, or whether instead they reflect, at least in part, responses to future changes in labor-market conditions and alterations in the relative prices of labor and capital. The basis for adjustments in the industry-occupation matrix to reflect prospective changes in utilization of different types of skills is also unclear: do these adjustments reflect the impact of exogenous factors, or are they too in part endogenous?

Another problem is the failure to develop a more explicit modeling of both the demand and the supply sides of the labor market. The term "requirements" suggests a demand-side orientation. Yet projected requirements are taken to reflect what actual employment will be, given the assumptions underlying the projections. This interpretation is substantiated by subsequent comparisons made by BLS between its projected requirements for some year and actual employment for that year, with discrepancies being characterized as errors (Carey, *et al.*, 1982). In fact, the various ad hoc adjustments in the input-output coefficients and in the industry-occupation matrix very likely reflect the implicit introduction of supply-side considerations so that the projections represent something closer to forecasts. If that is the case, they should be described as such.

A superior approach might be to generate projections of requirements based on unchanged input-output coefficients and an unchanged industry-occupation matrix. By then introducing a separate supply model, it would be possible to generate results that, when combined with the requirements models, would produce something that we might describe as reflecting "requirements-supply balance." Adjustments in input-output coefficients and the industry-occupation matrix would then become endogenous and help to reconcile differences in prospective requirements and supply. Whether such a balance would flow out of the interaction of the requirements and supply models is not apparent; they might have to be forced to produce such a balance.

The NSF model goes further in specifying shortage occupations by contrasting requirements with available supplies that take into account interoccupational shifts as well as flows of new entrants. Unfortunately, we don't know to what extent supply adjustments are already embodied in the projections of requirements. Nor is it clear that requirements or supplies are as inflexible as implied by the model.

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[16] The following paragraphs draw on Hansen, 1984.

The ultimate test of these models is to determine how accurate they are. As pointed out earlier, with respect to BLS projections, they are not very accurate if they are intended to predict future employment levels. But if they are indeed estimates of the demand side of the markets, there is no reason to expect accuracy because supply forces may dominate over demand forces. Yet the common practice is to compare projected requirements with realized employment totals. Somehow this conflict has to be resolved.

### *The Other Models*

The other models are more difficult to evaluate, largely because of their great diversity and the fact that their use in analyzing the S/E labor market with respect to defense and nondefense impacts has been quite limited. Hence, we provide no table comparable to Table 1.

The micro models, both production function and recursive, can be applied quite flexibly but, unlike the macro models, can do little to reflect interdependencies among markets for different types of S/E personnel or the defense and nondefense sectors. These models can generate annual projections, reveal the extent of uncertainty through measures of variance or through simulations, and identify a very limited range of substitution possibilities. Offsetting these advantages is the fact that the required data needed to implement these models are unlikely to be readily available. Moreover, the macro environment within which projections are made must be imposed based on other research. To sum up, the partial nature of these micro approaches limits their applicability except for quite stable and well-defined occupational groups.

The survey approach is also quite flexible. The responses to such surveys are no better than the knowledge and judgment of those who respond. To the extent that respondents differ in their position within the firm and as a result do not have access to the same information, it is difficult to know how to interpret survey results. An additional difficulty comes from the tendency of respondents to project ahead from the time they respond, without recognizing that the current environment captures a variety of seasonal and cyclical conditions as well as an overlay of unique events. The combination of these conditions often prevents respondents from offering an informed and informative assessment of the S/E labor market (Hansen, 1984).

Only one so-called ad hoc model is presented here; perhaps there are others that have not come to the author's attention. In any case, the Sterling Hobe study provides a sharp contrast to anything else we have reviewed. The fact that its scope is so limited, being confined to the ISTO portion of the SDI program, makes generalizing difficult about the wider applicability of this approach--to the entire SDI program, to the entire defense program, and to the nondefense sector. Perhaps the most important contribution of the study is its effort to use marginal rather than average relationships. This shows up in the assumption that the personnel requirements for the ISTO program will approximate those of firms already doing similar type work. This is a far cry from imposing the BLS occupation-industry matrix on changes in industry employment to produce occupational requirements. This approach still does not overcome some of the shortcomings mentioned above: the occupational categories are the traditional ones; there are still elements of the fixed coefficients approach embodied in the method; and the approach does not reflect the interplay between SDI and other defense programs, much less interaction with the nondefense sector. Thus, while not a solution, this approach does highlight the impact of SDI. In this sense, it is a building block for a larger effort to estimate the effect of SDI.

## Conclusion

It is difficult to come away from this review with a sense that we can describe with any certainty the magnitude and perhaps even the directions of labor market effects on S/E personnel resulting from acceleration of the defense and SDI spending program. Whether the demand for S/E personnel will adversely affect the nondefense sector is difficult to say. We do not yet have the knowledge, the data, and the models necessary to help understand this very complex subject.

However, we do have an opportunity to learn more about these matters. Soon it should be possible to evaluate the BLS projections for 1985. Two years from now the 1987 data will be available, making possible a careful retrospective on the NSF study embracing the 1982-1987 period. And similarly with the other models. Still, the task of trying to reconcile the projections with what happened will not be easy because these models neglect so many elements. Excluded are wage changes, utilization rates, changes in how work is scheduled, overtime, and alterations in hiring standards.

None of this is meant to disparage the work that is now done. A wide range of existing and new approaches is required to help us comprehend what is happening and why it is happening. We need additional research work at all levels--conceptual, modeling attempts, new data collection, expanded analyses of existing data, and the like. Unfortunately, the answers will not be easy to obtain.

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# APPENDIX B: RELATED TABLES

1 Gross National Product and Defense Outlays, 1948-1985 (in current dollars), **69**
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TABLE 1: Gross National Product and Defense Outlays, 1948-1985 (in billions of constant dollars)

| Year | Gross National Product | Defense Outlays | Defense Outlays as % of GNP |
|---|---|---|---|
| 1948 | 1,260.6 | 74.2 | 5.9 |
| 1949 | 1,260.9 | 79.1 | 6.3 |
| 1950 | 1,368.6 | 77.6 | 5.7 |
| 1951 | 1,510.2 | 119.3 | 7.9 |
| 1952 | 1,569.1 | 216.8 | 13.8 |
| 1953 | 1,631.9 | 234.3 | 14.4 |
| 1954 | 1,610.2 | 220.5 | 13.7 |
| 1955 | 1,699.7 | 190.5 | 11.2 |
| 1956 | 1,734.6 | 182.6 | 10.5 |
| 1957 | 1,763.6 | 186.8 | 10.6 |
| 1958 | 1,750.1 | 182.4 | 10.4 |
| 1959 | 1,852.3 | 185.3 | 10.0 |
| 1960 | 1,893.4 | 184.3 | 9.7 |
| 1961 | 1,942.8 | 187.1 | 9.6 |
| 1962 | 2,045.9 | 201.6 | 9.9 |
| 1963 | 2,129.9 | 205.0 | 9.6 |
| 1964 | 2,243.6 | 203.6 | 9.1 |
| 1965 | 2,373.6 | 185.0 | 7.8 |
| 1966 | 2,510.8 | 204.7 | 8.2 |
| 1967 | 2,582.6 | 241.7 | 9.4 |
| 1968 | 2,689.7 | 283.1 | 10.5 |
| 1969 | 2,755.3 | 255.8 | 9.3 |
| 1970 | 2,747.2 | 235.5 | 8.6 |
| 1971 | 2,825.2 | 213.7 | 7.6 |
| 1972 | 2,965.9 | 198.9 | 6.7 |
| 1973 | 3,120.0 | 181.8 | 5.8 |
| 1974 | 3,103.2 | 177.9 | 5.7 |
| 1975 | 3,064.2 | 177.5 | 5.8 |
| 1976 | 3,214.0 | 171.8 | 5.3 |
| 1977 | 3,363.9 | 174.9 | 5.2 |
| 1978 | 3,542.0 | 176.0 | 5.0 |
| 1979 | 3,629.8 | 183.1 | 5.0 |
| 1980 | 3,623.7 | 188.7 | 5.2 |
| 1981 | 3,693.9 | 197.7 | 5.4 |
| 1982 | 3,599.7 | 213.1 | 5.9 |
| 1983 | 3,726.7 | 228.6 | 6.1 |
| 1984 | 3,970.4 | 238.3 | 6.0 |
| 1985 | 4,063.1 | 245.3 | 6.0 |

SOURCES: *Defense Outlays: 1948-84:* National Defense Budget Estimates for FY1986, OASD Comptroller; *Defense Outlays, 1985-86:* Budget of the United States Government, FY1987, p. 5.5 (all figures in 1986 dollars); Department of Commerce, Bureau of Economic Analysis.

TABLE 2: Employment in Selected Scientific, Engineering, and Technical Occupations, 1950-1985 (in thousands)

| Occupations | 1950 | 1960 | 1972 | 1977 | 1980 | 1982 | 1985 |
|---|---|---|---|---|---|---|---|
| TOTAL, all occupations | 56,435 | 64,639 | 82,153 | 92,017 | 99,303 | 99,526 | 107,150 |
| Engineers | 527 | 861 | 1,111 | 1,295 | 1,472 | 1,574 | 1,683* |
| Life & physical scientists and mathematicians | 117 | 150 | 232 | 281 | 309 | 320 | 378 |
| Engineering & science technicians | 261 | 532 | 835 | 915 | 1,127 | 1,114 | 1,115 |
| Computer specialists | - | - | 276 | 381 | 598 | 751 | 923 |

*Estimates by the National Science Foundation show a somewhat larger increase of about 300,000 for the period 1980-1983.

SOURCES: 1950, 1960: Bureau of the Census, *Changes between 1950 and 1960 Occupation and Industry Classifications,* Technical Paper 18 (1960), Table 1; 1972, 1977, 1980: Bureau of Labor Statistics, *Labor Force Statistics Derived from the Current Population Survey: A Databook*, vol. 1, Bulletin 2096 (Sept. 1982), Table B-20; and 1982, 1985: Bureau of Labor Statistics, *Employment and Earnings*, January 1983 and January 1986 (data are from the Current Population Survey).

TABLE 3: Department of Defense Military Outlays, 1985-1989* (in millions of dollars)

| | 1985 | 1986 | 1987 | 1988 | 1989 | %increase 1985-89 |
|---|---|---|---|---|---|---|
| TOTAL | 245,371 | 258,425 | 274,265 | 290,700 | 313,300 | 27.7 |
| Military personnel | 67,842 | 71,438 | 73,610 | 78,842 | 75,548 | 11.4 |
| Operation & maintenance | 72,348 | 74,137 | 80,872 | 81,023 | 87,163 | 20.5 |
| Procurement | 70,381 | 75,702 | 76,708 | 81,243 | 88,881 | 26.3 |
| Research, development, test, and evaluation | 27,103 | 28,702 | 31,618 | 36,649 | 38,447 | 41.9 |
| Military construction | 4,260 | 4,545 | 4,592 | 5,473 | 6,590 | 54.7 |
| All other (mostly pay and benefits) | 3,437 | 3,901 | 7,165 | 7,470 | 16,671 | 385.0 |

*Actual, 1985; estimated, 1986-89 (in current dollars).

SOURCE: Executive Office of the President, Office of Management and Budget, *Budget of the United States Government, Fiscal Year 1987*, p. 5-5.

TABLE 4: High Technology Recruitment Index, 1970-1986

| Year | Annual Quarterly Average | Year | Annual Quarterly Average |
|---|---|---|---|
| 1970 | 60 | 1978 | 139 |
| 1971 | 43 | 1979 | 144 |
| 1972 | 62 | 1980 | 138 |
| 1973 | 96 | 1981 | 135 |
| 1974 | 100 | 1982 | 101 |
| 1975 | 68 | 1983 | 101 |
| 1976 | 87 | 1984 | 133 |
| 1977 | 114 | 1985 | 112 |

*1961=100; seasonally adjusted.
NOTE: The High Technology Recruitment Index is an index of the number of square inches of space devoted to the advertisement of available vacancies in a given set of technical journals and magazines.
SOURCE: Deutsch, Shea, and Evans, Inc.

TABLE 5: Job Offer Index for Bachelor's-Degree Candidates, by Curriculum and Year

| Field | 1975 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 |
|---|---|---|---|---|---|---|---|---|---|
| Engineering | | | | | | | | | |
| Aeronautical | 35 | 93 | 103 | 100 | 118 | 94 | 74 | 69 | 109 |
| Chemical | 38 | 75 | 90 | 100 | 106 | 57 | 16 | 30 | 32 |
| Civil | 62 | 84 | 106 | 100 | 106 | 56 | 21 | 28 | 33 |
| Electrical | 27 | 77 | 97 | 100 | 97 | 90 | 75 | 93 | 99 |
| Industrial | 29 | 61 | 79 | 100 | 83 | 72 | 37 | 50 | 60 |
| Mechanical | 30 | 76 | 94 | 100 | 100 | 69 | 37 | 47 | 55 |
| Engr Technology | 31 | 76 | 107 | 100 | 97 | 61 | 34 | 46 | 50 |
| Other | 14 | 69 | 91 | 100 | 137 | 107 | 35 | 46 | 46 |
| Science | | | | | | | | | |
| Computer Science | 16 | 70 | 70 | 100 | 112 | 126 | 100 | 147 | 148 |
| Mathematics | 49 | 83 | 107 | 100 | 89 | 86 | 63 | 65 | 69 |
| Other Physical & Earth Sciences | 36 | 89 | 69 | 100 | 199 | 131 | 47 | 66 | 58 |

NOTE: This index was constructed on the basis of job offers to bachelor's degree candidates reported in the College Placement Council salary surveys. Offers in 1980 were set to 100 for each curriculum.

TABLE 6: Unemployment Rates by Field, 1976-1984

| | Year | | | | |
|---|---|---|---|---|---|
| Field | 1976 | 1978 | 1980 | 1982 | 1984 |
| TOTAL, All Fields* | 3.4 | 1.9 | 1.9 | 2.3 | 1.6 |
| Physical scientists | 3.0 | 2.2 | 2.1 | 2.6 | 1.8 |
| Physicists/astronomers | 3.1 | 2.1 | 2.0 | 1.9 | 1.2 |
| Mathematical scientists | 4.9 | 2.2 | 2.0 | 2.1 | 2.1 |
| Mathematicians | 5.2 | 2.5 | 2.3 | 2.2 | 2.1 |
| Statisticians | 2.3 | 0.5 | 0.5 | 1.8 | 2.1 |
| Computer Specialists | 2.4 | 1.0 | 1.0 | 1.1 | 0.6 |
| Environmental scientists | 2.1 | 2.1 | 2.3 | 3.0 | 3.1 |
| Engineers | 3.2 | 1.4 | 1.5 | 1.9 | 1.2 |
| Astronomical/aeronautical | 4.0 | 1.6 | 1.4 | 1.9 | 0.6 |
| Chemical | 2.3 | 2.5 | 2.6 | 3.1 | 2.4 |
| Civil | 2.7 | 1.4 | 1.5 | 2.0 | 1.6 |
| Electrical Engineering | 1.8 | 0.8 | 0.9 | 1.2 | 0.9 |
| Mechanical | 4.3 | 1.2 | 1.4 | 2.1 | 1.4 |
| Other | 3.7 | 1.7 | 1.8 | 2.0 | na |

*"All Fields" category includes social scientists.

SOURCE: Unpublished data, National Science Foundation.

TABLE 7: Bachelor's-Degreed Scientists and Engineers Working on DoD-Sponsored Projects, by Employment Field and Year: Experienced Samples (in percent)

| Employment Field | 1972 | 1974 | 1982 | 1984 |
|---|---|---|---|---|
| TOTAL, All Fields | 18.6 | 19.0 | 15.0 | 15.5 |
| TOTAL, SEC (Scientists, Engineers, Computer Specialists) fields only | 20.6 | 21.5 | 17.0 | 17.2 |
| Engineers | 23.1 | 22.6 | 19.6 | 19.9 |
| Aeronautical, aerospace, or astronautical | 63.8 | 59.3 | 58.3 | 59.8 |
| Computer | ** | ** | ** | 27.8 |
| Electrical or electronic | 34.6 | 33.1 | 27.8 | 27.6 |
| Marine engineers or naval architects | ** | ** | 44.2 | 52.4 |
| Mechanical | 23.0 | 22.2 | 16.4 | 17.2 |
| Metallurgical or materials | 21.6 | 18.1 | 22.5 | 16.0 |
| Nuclear | 17.6 | 32.1 | 32.0 | 32.1 |
| Systems | ** | 40.5 | 37.4 | 41.6 |
| Other engineering fields | 11.1 | 13.0 | 11.8 | 11.2 |
| Computer Specialists | 17.6 | 17.0 | 11.5 | 11.3 |
| Computer programmers | 19.6 | 23.3 | 13.0 | 13.7 |
| Computer scientists | 13.8 | 31.4 | 26.4 | 19.5 |
| Computer systems analysts | 13.5 | 15.1 | 11.2 | 10.0 |
| Other computer specialists | 25.3 | 12.6 | 8.6 | 9.9 |
| Mathematical Scientists* | 14.5 | 44.3 | 17.5 | 19.3 |
| Mathematicians | .0 | 56.6 | 39.8 | 39.6 |
| Operations research analysts | 4.4 | 54.3 | 38.7 | 52.7 |
| Systems analysts, except computer systems or data processing | ** | ** | 25.2 | 32.7 |
| Other mathematical scientists | 17.6 | 14.1 | 3.3 | 6.2 |
| Physical scientists | 11.2 | 12.0 | 8.2 | 7.5 |
| Atmospheric scientists | ** | 15.3 | 4.1 | 5.1 |
| Oceanographers | ** | 42.6 | 45.9 | 58.8 |
| Physicists/astronomers | 34.9 | 49.3 | 31.7 | 14.2 |
| Other physical scientists | 10.0 | 8.8 | 7.0 | 7.1 |
| Non-SEC | 15.0 | 11.2 | 10.8 | 11.5 |

*Mathematicians, statisticians, and other mathematical scientists, including professors and instructors.
** Data not available.

SOURCE: Unpublished data, National Science Foundation.

TABLE 8: Master's-Degreed Scientists and Engineers Working on DoD-Sponsored Projects, by Employment Field and Year: Experienced Samples (in percent)

| Employment Field | 1972 | 1974 | 1982 | 1984 |
|---|---|---|---|---|
| TOTAL, all fields | 23.8 | 24.5 | 18.4 | 19.0 |
| TOTAL, SEC (Scientists, Engineers, Computer Specialists) fields only | 24.8 | 26.7 | 20.5 | 20.6 |
| Engineers | 28.4 | 30.1 | 25.1 | 25.5 |
| Aeronautical, aerospace, or astronautical | 52.6 | 65.6 | 55.5 | 63.0 |
| Computer | ** | ** | ** | 18.7 |
| Electrical or electronic | 42.0 | 40.3 | 33.9 | 36.8 |
| Marine engineers or naval architects | ** | ** | 35.7 | 67.7 |
| Mechanical | 28.7 | 26.1 | 18.9 | 20.2 |
| Metallurgical or materials | 23.0 | 21.3 | 33.1 | 28.7 |
| Nuclear | 9.5 | 9.0 | 9.3 | 13.9 |
| Systems | ** | 55.4 | 48.3 | 43.1 |
| Other engineering fields | 13.7 | 15.4 | 14.3 | 12.8 |
| Computer Specialists | 26.8 | 21.7 | 15.4 | 11.0 |
| Computer programmers | 31.7 | 21.6 | 13.2 | 10.3 |
| Computer scientists | 23.9 | 21.5 | 32.4 | 22.3 |
| Computer systems analysts | 21.3 | 24.6 | 13.8 | 10.0 |
| Other computer specialists | 23.3 | 13.3 | 14.2 | 9.1 |
| Mathematical Scientists* | 19.7 | 21.2 | 18.6 | 23.1 |
| Mathematicians | .0 | 18.3 | 11.0 | 15.7 |
| Operations research analysts | 9.6 | 31.9 | 46.6 | 62.6 |
| Systems analysts, except computer systems or data processing | ** | ** | 42.9 | 39.4 |
| Other mathematical scientists | 22.1 | 16.0 | 4.4 | 12.1 |
| Physical scientists | 12.5 | 13.7 | 9.4 | 9.2 |
| Atmospheric scientists | ** | 18.1 | 11.8 | 14.0 |
| Oceanographers | ** | 57.0 | 65.0 | 41.1 |
| Physicists/astronomers | 14.3 | 38.2 | 25.8 | 30.4 |
| Other physical scientists | 12.4 | 8.0 | 6.5 | 6.1 |
| Non-SEC | 21.6 | 15.1 | 12.9 | 14.5 |

*Mathematicians, statisticians, and other mathematical scientists, including professors and instructors
**Data not available.

SOURCE: Unpublished data, National Science Foundation.

TABLE 9: Doctoral Scientists and Engineers Working on DoD-Sponsored Projects, by Employment Subfield and Survey Year (in percent)

| Employment Subfield | Survey Year 1973 | 1975 | 1981 | 1983 | 1985 |
|---|---|---|---|---|---|
| S/E, TOTAL | 10.5 | 9.0 | 7.8 | 9.0 | 8.5 |
| Mathematics, Total | 11.5 | 9.4 | 10.2 | 11.5 | 11.8 |
| Applied | 21.7 | 20.8 | 20.9 | 25.3 | 24.6 |
| Probability/Statistics | 21.2 | 15.2 | 10.1 | 16.6 | 14.9 |
| Operations Research | 37.5 | 28.4 | 12.3 | 26.6 | 34.5 |
| Computer Science, Total | 18.7 | 16.6 | 19.1 | 18.6 | 19.2 |
| Physics/Astronomy, Total | 25.3 | 21.5 | 19.5 | 21.6 | 21.9 |
| Atomic & Molecular | 24.8 | 25.2 | 22.7 | 26.4 | 26.6 |
| Classical | 45.4 | 47.7 | 28.7 | 54.3 | 54.7 |
| Plasma | 34.1 | 15.8 | 30.4 | 28.3 | 33.1 |
| Nuclear | 6.6 | 4.7 | 15.3 | 4.2 | 10.2 |
| Solid State | 33.0 | 24.4 | 23.8 | 19.0 | 19.6 |
| Other Physics | 22.9 | 18.4 | 18.3 | 16.6 | 17.7 |
| Chemistry, Total | 6.2 | 5.1 | 6.1 | 5.3 | 5.8 |
| Earth/Environ Science, Total | 13.4 | 12.2 | 10.2 | 12.3 | 9.4 |
| Geophysics | 27.4 | 20.9 | 15.5 | 12.9 | 13.9 |
| Earth | 5.4 | 6.8 | 4.9 | 8.6 | 4.7 |
| Atmosphere | 24.1 | 25.4 | 26.7 | 21.7 | 13.2 |
| Environmental | 12.1 | 11.5 | 4.1 | 10.3 | 11.8 |
| Hydrology/Oceanography/ Marine Science | 32.7 | 26.1 | 21.9 | 25.7 | 19.9 |
| Engineering, Total | 26.2 | 23.1 | 16.8 | 22.0 | 19.8 |
| Aeronautical & Astronautical | 59.0 | 59.5 | 44.4 | 50.5 | 61.9 |
| Electrical/Electronics/Computer | 40.3 | 36.0 | 29.0 | 36.1 | 29.6 |
| Industrial | 30.8 | 33.1 | 4.4 | 18.0 | 18.7 |
| Nuclear | 16.7 | 13.2 | 12.0 | 17.6 | 15.4 |
| Engineering Mechanics | 39.5 | 36.6 | 21.3 | 30.5 | 25.2 |
| Mechanical | 21.4 | 16.8 | 20.8 | 16.7 | 14.0 |
| Materials Science | 25.2 | 18.8 | 13.1 | 18.0 | 17.6 |
| Other Engineering | 31.4 | 24.2 | 32.3 | 21.2 | 24.7 |

SOURCE: National Research Council, Survey of Doctorate Recipients.

**TABLE 10: Inflow into the Sciences from Other Fields, by DoD Support-Status and Year: Experienced Samples**

| | Total, All Fields | Total, with SEC** field | Engineering | Computer Science | Math Sci*** | Physical Science |
|---|---|---|---|---|---|---|
| TOTAL | | | | | | |
| 1972 | 54.0 | 32.2 | 16.2 | 95.9 | 49.8 | 33.6 |
| 1974 | 32.0 | 12.3 | 6.9 | 85.9 | 19.2 | 7.4 |
| 1982 | 52.4 | 30.6 | 15.4 | 81.4 | 39.5 | 17.5 |
| 1984 | 49.9 | 30.1 | 16.8 | 79.5 | 37.4 | 16.9 |
| DoD Support | | | | | | |
| 1972 | 50.1 | 31.5 | 19.3 | 95.4 | 52.9 | 27.6 |
| 1974 | 26.3 | 14.4 | 9.4 | 87.0 | 34.2 | 11.2 |
| 1982 | 45.1 | 28.6 | 17.5 | 83.8 | 51.3 | 12.0 |
| 1984 | 43.0 | 27.4 | 18.3 | 80.4 | 50.3 | 16.2 |
| No DoD Support | | | | | | |
| 1972 | 55.0 | 32.4 | 15.2 | 96.0 | 49.3 | 34.3 |
| 1974 | 33.4 | 11.7 | 6.1 | 85.7 | 15.4 | 6.9 |
| 1982 | 53.7 | 31.0 | 14.8 | 81.0 | 37.3 | 18.0 |
| 1984 | 51.3 | 30.7 | 16.4 | 79.4 | 34.5 | 17.0 |

*Percent of those employed with degrees in different fields.

**Scientists, Engineers, and Computer Specialists.

***Mathematicians, statisticians, and other mathematical scientists, including college professors and instructors.

SOURCE: Unpublished data, National Science Foundation.

**TABLE 11: Outflow of People with Degree in One Field and Employment in Another, by DoD Support-Status and Year: Experienced Samples**

| | Total, All Fields | Total, with SEC* field | Engineering | Computer Science |
|---|---|---|---|---|
| TOTAL | | | | |
| 1972 | 54.0 | 48.1 | 44.8 | 57.6 |
| 1974 | 32.0 | 32.0 | 25.6 | 37.2 |
| 1982 | 52.4 | 47.0 | 39.8 | 22.8 |
| 1984 | 49.9 | 43.8 | 36.1 | 29.6 |
| DoD Support | | | | |
| 1972 | 50.1 | 45.0 | 39.5 | 58.9 |
| 1974 | 26.3 | 26.3 | 17.8 | 50.6 |
| 1982 | 45.1 | 40.6 | 29.7 | 30.9 |
| 1984 | 43.0 | 37.7 | 26.3 | 34.5 |
| No DoD Support | | | | |
| 1972 | 55.0 | 48.8 | 46.3 | 57.2 |
| 1974 | 33.4 | 33.4 | 27.7 | 33.3 |
| 1982 | 53.7 | 48.3 | 42.0 | 21.7 |
| 1984 | 51.3 | 45.1 | 38.3 | 29.0 |

*Scientists, *E*ngineers, and *C*omputer Specialists.

SOURCE: Unpublished data, National Science Foundation.

# APPENDIX C: Views of Placement Officers

Summary: College Relations Discussion Group Meeting, April 17, 1986," 81

"Defense and Nondefense Employment: The View from Engineering School Placement Offices," Robert K. Weatherall (Massachusetts Institute of Technology), 83

# SUMMARY: COLLEGE RELATIONS DISCUSSION GROUP MEETING

On April 17, 1986, a meeting was held with the College Relations Discussion Group to discuss the NAE project. The participants were as follows:

Dr. Robert K. Armstrong, E.I. du Pont de Nemours & Company, Inc.
Mr. George Berryman, Texas Instruments
Mr. Allen G. Bormann, Rockwell International
Mr. Edwin A. Butenhof, Eastman Kodak Company
Mr. Alan Fechter, National Research Council
Mr. Russ Johnson, Digital Equipment Corporation
Mr. William J. Kucker, RCA Staff Center
Mr. George Lehocky, TRW, Inc.
Mr. Walter J. O'Neill, Exxon Corporation
Dr. Douglas W. Pelino, Xerox Corporation
Dr. Francine Riley, GTE
Mr. Gregory A. VanErt, IBM Corporation
Ms. Linda D. Villa, AT&T
Ms. Jennifer H. Weixel, 3M Corporation

The following points were raised:

- In general, the firms represented by those attending the meeting had no problems in meeting quantity and quality goals; potential problems are met by adjusting standards (depending on the position being recruited for)--i.e., difficulties in recruiting in one field are met by recruiting engineers in closely related fields or engineering technologists, or by altering standards set for GPA. It was generally recognized that these adjustments can involve significant costs, but it was also noted that failure to meet recruiting goals can also have costs, and it is not obvious which type of cost is greater. Problem fields identified included electrical engineering, engineers to work in certain types of combat systems, and certain software engineers. Some of the recruiting problems were attributed to the "image" of the company. For example, DuPont has problems recruiting electrical engineers because it is not viewed as a prestigious position by these engineers--but DuPont has never had problems recruiting chemical engineers.
- While these firms may not face major recruiting problems, it was noted that the same conclusions may not apply to smaller firms; it was hypothesized that recruiting problems arising from increases in demand are more likely to be encountered by these firms because they do not possess the image and the "glamour" (which is presumably valued by graduating engineers) associated with larger firms.
- In response to a query about sources of supply that are tapped during buildup of demand (defense or commercial), they noted that they increased their reliance on technologists (a form of quality adjustment) and foreign engineers (although a

difficulty in utilizing them in defense activity was noted) and then, if that was not enough, they would consider raising the salaries of the positions for which they are recruiting.

- With respect to defense impact, it was observed that there appeared to be considerably less aversion to work in defense-related activities today than there was in the late 1960s and early 1970s, during the height of the Vietnam conflict. It was also observed that the actions of competitors have a more significant impact on the recruiting environment for these firms than does any change in defense-related activity.
- In response to a question about possible transfers of employees between defense and nondefense activity when the composition of demand changes, it was noted that it was difficult to affect such shifts of personnel in most fields (the fields of electrical engineering and computer science were identified as notable exceptions to this difficulty). The difficulty was noted especially within firms that engage in both defense and commercial activity. It was stated that engineers who engage in defense work become narrowly specialized in their skills and are therefore not easily shifted to commercial activity when relative demand shifts. To illustrate the lack of mobility, the representative from Rockwell noted that his company "job-shopped" many of its experienced engineers to other aerospace firms when the Carter administration cancelled the B-1 bomber project; they were therefore able to gear up quickly by recalling these engineers when the project was reinstated. A possible origin of this difficulty is that skill requirements differ significantly between defense and commercial activity, with defense activity more oriented to system/design skills.
- It was also observed that much of the work in defense activity is undertaken in teams and, as a consequence, recruiters do not feel as constrained in the types of fields they require for these jobs; specialty field is a much more important qualification for most commercial work. Thus, it is easier to recruit new graduates for defense work.
- They noted that an alternative to increased recruiting and salaries or adjustments in the requirements for filling their increased quotas would be to alter the utilization of the existing engineering work force. Examples cited of such modifications in utilization policy included keeping mid-level engineers in engineering functions longer, substituting technologists for engineers (in low-level assignments), and increased use of labor-saving technology (e.g., computer aided design/computer-aided manufacturing (CAD/CAM), electronic networking, and artificial intelligence (AI). There was also a general expectation that the combination of new technology and the desire to reduce costs to remain competitive could result in reduced work forces (including the engineering work force) in the future (implicit in this expectation is the assumption that the output produced by these firms will probably remain constant or will not grow substantially).
- It was also observed that trend increases in the relative costs of relocating experienced workers have been pushing these firms toward greater reliance on new graduates to fill their recruiting needs.
- In response to a question about whether differences between defense and commercial activity in institutional environments (in particular, the extensive use of cost-plus contracting by DoD) resulted in higher wages paid in defense activity, some participants noted that their experience was quite the opposite--i.e., that salaries and costs were less controlled in the commercial side of their firms.

# DEFENSE AND NONDEFENSE EMPLOYMENT: THE VIEW FROM ENGINEERING SCHOOL PLACEMENT OFFICES*

Robert K. Weatherall
*Massachusetts Institute of Technology*

One of the candidates to take Tip O'Neill's place in Congress as representative of the Massachusetts 8th Congressional District, which includes MIT and Harvard in its borders, has chosen as one of her issues the impact of defense spending on the nondefense engineering labor market. "Every time we buy a Japanese tape recorder or German car," she told MIT students recently, "we're doing it in part because the best of our skilled high-tech people are focusing their attention on weapons systems." Whether her diagnosis is right or wrong, someone calling placement offices at engineering schools around the country quickly finds that what is seen as an issue at MIT is seen as much less of an issue elsewhere, and on some campuses is not seen as an issue at all. Geography greatly affects how an engineering school sees the employment market. During April I telephoned 11 placement directors to seek out their views on this subject. In the following summary of what they told me, I have tried to be as faithful as possible to the emphasis they put on things. If I have misconstrued them, the blame is entirely mine.

## Purdue University

Richard Stewart reports from Purdue that the biggest recruiter there is General Motors. Many students come from automotive families. Students see GM as high tech. An enormous and highly automated Delco Division plant making chips for automobiles is only 30 miles from Lafayette. Most Purdue students find jobs within a 300 mile radius. Some, who come from what they call "the Region," the area of heavy manufacturing east and south of Chicago, return there. Others interested in electronics go to the electronics firms around Chicago, such firms as Magnavox, Zenith, Northrop, and Motorola. Purdue students refer to them collectively as "Corn Valley." The companies are engaged in defense work and in manufacturing commercial products. To the extent Purdue students are taking jobs with defense firms, it is chiefly with firms in the Midwest. California, with its concentration of aerospace companies, is "pretty far down the list," Stewart says, when it comes to ranking the states where Purdue graduates go to work. Far more students go to work with Northrop in Chicago than with Northrop in California. Similarly, relatively few Purdue graduates make their way east to Route 128. If there is one company which overcomes the geographic bias, it is IBM: its appeal competes with that of GM. Unfortunately, this year and last, IBM has reduced its recruiting significantly. The placement offices at many other schools commented on IBM's pull as an employer and on the sad fact that its recruiting is down.

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*I wish to thank my placement colleagues--Richard Stewart, Chenits Pettigrew, James Patterson, Kathleen Stanton, Herbert Harmison, Tony van Vliet, Robert Mosberg, James Osborne, Vicki Lynn, Anthony Franzolino, and Linda Gast--for giving me their perspectives on this issue.

## University of California at Los Angeles

In contrast with Purdue, UCLA looks down from its hillside campus on a landscape filled with defense contractors--Hughes, TRW, Aerospace Corporation, McDonnell Douglas, Lockhead, Rockwell, and Northrop, to name a few. According to Dr. Chentis Pettigrew, placement officer for the engineering school, 45 percent of UCLA graduates stay in southern California; and for them the defense sector, and in particular the aerospace industry, is a fact of life. A major portion of every defense dollar (up to 30 or 40 cents, he believes) flows through Los Angeles county. This may be an accurate statistic if it includes the subcontracts performed elsewhere for the prime contractors in Los Angeles. Add or subtract a few percentage points, it is not a business which people in Los\Angeles conceive of going away. As Dr. Pettigrew puts it, "There is no turning away from defense." The two leading recruiters of engineers at UCLA are Hughes and TRW. Then comes IBM, which does not have a major facility in southern California. The next largest recruiters are other defense companies in Los Angeles. Recently, aeronautics and astronautics has gained popularity among the engineering departments at UCLA. The ranking of the departments by size of enrollment used to be (1) EE, (2) mechanical engineering, (3) chemical engineering, and (4) aero and astro. EE is still first, but the subsequent ranking is now (2) aero and astro, (3) mechanical engineering, and (4)\chemical engineering.

## Stanford University

Move up the coast to Stanford, and the story is different again. There, it is Silicon Valley that beckons, and the exciting companies in the eyes of Stanford students are the entrepreneurial ones, the likes of Intel, Advanced Micro Devices, and Apple--companies venturing their capital and their skills in the civilian market. The most popular large firms are Hewlett-Packard and IBM, both of which are big in the Valley. According to Dr. James Patterson, coordinator of engineering and science advising in the placement office, there is a considerable debate among Stanford students about working in defense. He thinks that the best students seek out the entrepreneurial civilian companies. He says that with the defense buildup and softness in the civilian high-tech market, there has probably been an increase in the number of graduates joining defense companies, but he does not think this means that they will stay there. The technologies on the two sides of the line are similar enough so that when things improve on the civilian side, those who want to move will be able to do so.

## University of California at Berkeley

Across the bay at Berkeley, the issue of defense versus nondefense is seen in much more lively terms; perhaps it is geography again. Silicon Valley and Lawrence Livermore are roughly an equal distance away--the one an hour's drive south over the Bay Bridge, the other an hour east over the Berkeley hills. And Livermore is part of the University of California. Or perhaps it is simply Berkeley being true to itself. Students have been increasingly concerned about recruiting by the defense sector. Kathleen Stanton, an advisor in the university placement office, told me that there had been recent demonstrations against General Dynamics and the CIA. The placement office has "several huge binders," she says, containing news clippings and other material on the social implications of technology to defense. A professor of physics who has been active in collecting data on the percentage of the nation's technical graduates going into defense work has reduced his teaching to give less help to the defense companies. Berkeley students are drawn strongly to Silicon Valley (Kathleen Stanton says the students favor Hewlett-Packard and other civilian high-tech companies there), but the current slow-down in the semiconductor and computer industries has led an increasing number to take jobs with the defense companies in southern California. The availability of a job is a more important factor with many engineering students than whether it is in defense or not.

## Iowa State University

Other engineering schools stand at various points along this spectrum. Iowa State, for example, has been affected by the loss of jobs at such local companies as John Deere and Caterpillar Tractor. At the same time, as Herbert Harmison puts it, Iowa is near the bottom of the list of states in defense spending. With the local employment market in poor shape, graduates have been going out of state, some to Illinois but more heading west to Colorado, California, Washington, and Oregon. Harmison thinks that half, or more, of the electrical engineers have been going with defense companies, such firms as Boeing and McDonnell Douglas. There has been very little concern about defense company recruiting. He has no sense that students are "turned off" by defense work.

## Oregon State University

Oregon State has two different industries in its backyard--forest products and high-tech. The forest products industry is depressed, depressing the Oregon economy in general, while the high-tech sector has been a boon to Oregon during the past decade but just now is in a holding pattern. Dr. Tony vanVliet, Oregon State's placement director, says that the local high-tech companies--such firms as Intel, Hewlett-Packard, Floating Point Systems, Tektronix, and Mentor Graphics--are highly appealing to Oregon State students. A number of students declare an aversion to working in defense and will steer away from it if they can. Although Dr. vanVliet has not seen a jump in defense recruiting, he believes that opportunities in the defense sector have been providing a counterweight to the reduced opportunities on the civilian side: 30-40 percent of Oregon State's graduates go out of state, and a fair share go to such firms as Hughes and McDonnell Douglas.

## University of Illinois

Acording to Robert Mosberg, assistant dean and placement director at the University of Illinois engineering school, employers in Illinois get the largest fraction of the school's graduates, and California receives the next largest group. Individual companies hiring large numbers of graduates include IBM, General Motors, McDonnell Douglas, Motorola, AT&T, Hughes, Commonwealth Edison, Westinghouse, GE, Northrop, Arthur Andersen (in its management information systems consulting division), United Technologies, Harris, and Rockwell. McDonnell Douglas has a major facility in St. Louis; Motorola and Commonwealth Edison are outside Chicago, and Northrop, as we have seen, also has a plant near Chicago. Dean Mosberg says that there has been some student concern about working in defense.

## Georgia Institute of Technology

Dr. James Osborne, placement director at Georgia Tech, says that he has seen a definite increase in defense company recruiting. Several of the most active recruiters this year were defense companies from the southeast and from California. IBM, which had been the most prominent recruiter on campus, stepped aside this year. In Dr. Osborne's view, recruiting by the defense sector made up for reduced recruiting by the computer industry. On the other hand, Georgia Tech has a major interest in manufacturing systems R&D, and this was a good year for students in that area. In Osborne's words, "manufacturing is more sexy than it used to be." The most exciting applications of the new manufacturing technology are in high-volume production, which means chiefly civilian industry, of which the automobile industry is a prime example. In contrast with other engineering schools in the South, Georgia Tech draws up to 40 percent of its students from out of state, and 50 percent of the graduates go out of state to work. Dr. Osborne thinks there is a hesitancy about working in the defense sector, but chiefly because students are wary of the defense sector's ups and downs. The big layoffs in the early '70s are still remembered. The students favor companies with a record of stability, Dr. Osborne says and mentions such companies as Dow, Proctor & Gamble, DuPont, IBM, and GE. He concedes that GE is on both sides of the line, having both defense and nondefense divisions.

### University of Maryland

Like UCLA, the University of Maryland is surrounded by organizations involved in defense work. Indeed, the Pentagon itself is only 10 miles away. Dr. Linda Gast, director of the university's career development center, reports that 60-70 percent of the students in engineering take jobs either with defense contractors in the area or with federal agencies. The ratio is up to 35 percent in computer science and mathematics. A very large proportion of the students come from the Washington area and most want to stay. They can be enticed to Baltimore, but a company like McDonnell Douglas has a devil of a time persuading any to go to St. Louis or to California. Gast says that students at Maryland hold the defense establishment in very high esteem: if anything, they are prejudiced in favor of government agencies and contractors. She wonders how Gramm-Rudman will affect the picture. She wrote her Ph.D. thesis on the career decisions of graduating engineers, and she agrees with other placement directors I called that their ambitions have been changing: they want broader advancement opportunities, they want work that will involve people interaction, and they want a good and rising income. Many take a look at both technical and nontechnical opportunities. It is less and less easy to find the stereotypical engineer of the past who was happy to be given a project and left alone.

### Rensselaer Polytechnic Institute

The companies hiring the most graduates at RPI according to the placement director, Vicki Lynn, are in rough order the following: IBM, GE, Raytheon, Digital Equipment, General Motors, United Technologies, AT&T, Arthur Andersen (for MIS consulting), Procter & Gamble, Boeing, Hughes, McDonnell Douglas, and General Dynamics. A year or two ago, the list would have included Signetics. The list includes many defense contractors; and Lynn thinks that while some students are unwilling to work for a defense company, many others are excited by state-of-the-art defense technology. She says ROTC is big at RPI, "there is a resurgence of patriotism," and students are "gung-ho." They talk about wanting to work on the design of fighter planes, about the excitement of Star Wars. She thinks they are attracted to the very hugeness of these undertakings. Seventy-five percent of RPI students come from the northeast. Roughly 70 percent find jobs in the northeast, another 12 percent take jobs in California, and the southeast attracts the smallest percentage.

## Massachusetts Institute of Technology

As Vicki Lynn often tells me, MIT is very different. MIT sees the defense nondefense issue in much the same terms as Berkeley. However much Berkeley feels the pull between the defense sector and civilian high-tech, MIT certainly does. It is the university receiving the most research support from the Department of Defense and at the same time it has provided much of the technical inspiration and leadership behind Route 128. Preoccupations with defense technology are balanced by intense anxieties about defense policies and the impact of defense spending on civilian needs. The faculty includes individuals who have advised the Pentagon at the highest levels and individuals who have been leading critics of the military-industrial nexus; in some cases they are the same people. The Strategic Defense Initiative has sharpened these polarities, and last year the faculty appointed a committee on MIT's military involvement under the chairmanship of Carl Kaysen.

I became interested several years ago in the question, "To what extent does a student body that got a training in research funded out of government research grants and contracts go to work with establishments funded in the same way?" In 1981 I began sorting out the destinations of students who provided enough information on their graduation questionnaire to let us distinguish between a division of a company doing government-contract work (like IBM at Manassas, Virginia) and a division making civilian products (like IBM at Burlington, Vermont). I now have results for four years--1981, 1982, 1984, and 1985. Table 1 includes graduates in all the fields of engineering and science represented at MIT, at all degree levels, who did not take strictly academic jobs

TABLE 1: Destination of MIT Science and Engineering Graduates Not Taking Strictly Academic Jobs or Entering the Military (in percent)

| Employer | 1980-81 | 1982-83 | 1983-84 | 1984-85 |
|---|---|---|---|---|
| Private firms* selling primarily to a commercial market | 68.0 | 64.7 | 62.9 | 60.5 |
| Private firms* working primarily on government contracts | 21.6 | 25.9 | 26.4 | 26.9 |
| Federally-funded laboratories (Lincoln, Draper, Sandia, etc.) | 5.0 | 3.1 | 4.3 | 5.5 |
| Government agencies | 3.8 | 4.1 | 3.7 | 2.6 |
| Non-profit organizations (e.g.,hospitals) | 1.6 | 2.2 | 3.7 | 4.5 |
| | 100.0<br>N=504 | 100.0<br>N=456 | 100.0<br>N=375 | 100.0<br>N=506 |

*Or division of private firms.

TABLE 2: Distribution of MIT Science and Engineering Graduates Between Companies Primarily in a Commercial Market and Companies* Doing Government Contract Work, 1983-1984

| Degree | | Commercial | Government Contract |
|---|---|---|---|
| Bachelor's | N = | 100<br>73.5% | 35<br>26.5% |
| | median salary = | $28,000 | $28,000 |
| Master's | N = | 78<br>62.4% | 47<br>37.6% |
| | median salary = | $31,400 | $31,800 |
| Doctorate | N = | 35<br>72.9% | 13<br>27.1% |
| | median salary = | $40,000 | $40,008 |

* Companies or divisions of companies.
NOTE: Data based on graduating students reporting salary.

(e.g., as faculty members, academic research staff, or postdocs) and who were not in the military (e.g., ROTC students, military officers sent to MIT for an advanced degree, etc.) The table includes foreign students taking jobs in this country but not foreign students returning abroad. The majority of students take jobs with private firms selling products or services in the commercial market, but there clearly has been a drift away from the commercial to the government-contract side, which for the most part means defense firms.

MIT draws its students, undergraduate as well as graduate, from all over the country, and they scatter all over the country when they get their degrees. In spite of Route 128, only 30 percent of the electrical engineers stay in Massachusetts, and less than a quarter of the graduates in the other S&E disciplines stay in the Bay State.

In making my calls I asked if the best students sorted themselves differently between the defense and nondefense sectors than the generality of students. Some of the placement directors said quickly that the best go to graduate school. Several commented that the difference between the best and the less-than-best was a fine one in electrical engineering because enrollment restrictions had raised the standards for entry into the field. Dr. Pettigrew reported that the verbal aptitude scores of engineering majors at UCLA, as well as their math scores, were the highest among all the undergraduate schools at UCLA. Many directors thought the best students sorted themselves no differently than the generality. More than one pointed out that the most esteemed place to go in terms of the quality of its R&D was Bell Laboratories. They thought that the pull of such places as Murray Hill and Yorktown Heights was more than a match for the defense laboratories. James Osborne at Georgia Tech volunteered the thought that students considered IBM more exciting than any of the big aerospace companies. Some rather skimpy data from MIT showing destination by degree level (which perhaps can be taken as a proxy for academic ability) suggests that master's degree graduates may be more inclined than bachelor's to choose the defense sector, but that Ph.D.s sort themselves in the same way as bachelors (see Table 2).

## Summary

Several placement directors clearly saw the current demand for people in the defense sector as a fortunate counterweight to diminished opportunities on the civilian side. Most conscious of all the softness on the civilian side was Anthony Franzolino, placement director at the University of Texas engineering school, who commented on the sad state of the petroleum industry. I called him the same day Exxon reported that it had sent notices to 40,000 employees inviting them to leave the company. Others remarked on the withdrawal of the chemical industry from campus recruiting. The defense sector has helped to maintain a demand for graduating engineers and scientists. It is not the only sector which has been recruiting actively, but it is an important one. Richard Stewart drew attention to the fundamental vitality of the market for engineers, from whatever source it draws its strength. Out of 650 companies who recruited at Purdue in 1984-85, 130 were there for the first time.

I also asked about the motivation of students in choosing engineering. Several talked about the good starting salaries in engineering, the influence of parents and guidance counselors, and the way in which a student was likely to be nudged towards engineering if he or she enjoyed mathematics and physics in high school. Surprisingly few talked about students being fascinated with engineering or wanting to study engineering so that they could improve the world. Those who carried the topic further suggested complex motives. Dr. Pettigrew at UCLA, after mentioning the high verbal scores of engineering students, said that students saw an engineering education as a way of gaining "organizational access." They were not passionate about engineering; the choice of engineering was a practical matter with them. They looked beyond the entry-level job to where it could lead them up the organizational ladder. Robert Mosberg at Illinois and James Osborne at Georgia Tech echoed this idea that the organizational ladder was important. Tony vanVliet at Oregon State and James Patterson at Stanford pointed to students' entrepreneurial ambitions and their desire to manage. Both alluded to students' interest in the opportunities for technically-trained people in the financial community. I see many of these traits among the engineering students at MIT, quite a few of whom come from engineering families. Some have shared with us their observations of their parents' careers: in many cases they see their fathers "stuck" in mid- to late career in jobs which have not evolved significantly over the years, with similarly stagnant salary growth; and they are anxious to find broader, more varied work and more glamorous, rewarding careers.

It is widely agreed that the character of engineering students has been changing. Last year's National Academy of Sciences report, ***Engineering Education and Practice in the United States***, made the following statements:

> Professors and employers alike refer to the dramatically higher communication and social skills of engineering students and recent graduates as compared to past stereotypes of the engineer. This trend may relate to a long-term shift in student socioeconomic levels overall. In the view of engineering deans and professors on the committee, today's engineering student (i.e., since the mid-1970s) tends increasingly to come from a middle-class, professional family background rather than the noncollege background that characterized many young engineers in the period after World War II. The predominance of such young people in engineering schools is now very strong. On balance, they have a richer

> educational and cultural background and are more confident, more assertive than engineering students of years past.[1]

Our mind-set is still to think of engineers "unidimensionally," as an MIT student complained to me, as if they are one-track people wholly and solely committed to doing engineering. We perpetuate the image at meetings like these when we construct models of the flow of engineers into and out of the labor market as if they were as undifferentiated as barrels of oil or pork bellies. Engineering faculty perpetuate the image when the only career goal they recognize is being an engineer. If the only thing an engineering graduate wants is to do engineering, then (assuming salaries are in reasonable equilibrium) the choice between the defense sector and the civilian sector depends entirely on which offers the most exciting, or interesting, engineering. On this basis the defense sector may be the winner, although there is lots of engineering on the civilian side today which is exciting enough--e.g., the development of faster and faster integrated circuits, the architecture of parallel processing computers and of local area networks, the introduction of increasingly intelligent automation in manufacturing, other applications of artificial intelligence, bioengineering. It is worth thinking, "What symbolizes high-tech these days?" In the '60s the symbol was Project Apollo, a government project, and the people we wanted to beat in the race to the moon were our military rivals, the Russians. Today the symbol is the million-gate computer chip, and our rivals are the commercial Japanese.

But if the engineer is a more complex person and wants more from his or her career than simply the opportunity to do engineering, thenthe choice between companies is based on multiple criteria. In my experience, engineering students are increasingly interested in employment in which they will be interacting with other people. They also want to become managers and decision-makers. They are attracted to the fast track and the front office. Many would like to start their own companies. Napoleon used to say that every corporal in the French army carried a field marshal's baton in his knapsack. I am persuaded that at least one in two MIT students has a draft of a business plan. Evidence of the interest in management is the large proportion of engineering students who are interested in business school. For the last two years during the mid-winter break, I have run a series of talks on jobs for technical graduates which do not involve hands-on technical work. Up to a hundred students have turned out to hear young technical graduates talk about their work in investment banking, management consulting, management information systems consulting, and international finance. This spring two recruiters from Wall Street who told of the excitement of using MIT skills to model the financial markets were recent Ph.D.s in physics. An engineering student whose ambitions are of this sort is more likely to seek out a commercial company than a defense contractor. It offers a greater variety of challenges, from straight technical work to opportunities in manufacturing, product management, sales and marketing, and business planning.

Other factors also tilt the scales against the defense sector. Many of the best-known defense contractors have the reputation of being overwhelmingly large and bureaucratic, of putting hundreds of engineers together in rooms the size of playing fields, of giving the young engineer very little chance of calling any product his own. Few are known for the quality of their management. A recent book which purports to list the 100 best companies to work for in America includes 19 high-tech firms, but only 3 (GE, Control Data, and Moog) are into defense work in a significant way.[2] Often the product line of one defense

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[1] National Academy of Sciences, *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future*, Washington, D.C.: National Academy Press, 1985, pp. 73,74.

[2] Robert Levering, Milton Moskovitz, and Michael Katz, *The 100 Best Companies to Work for in America* , New York: Addison-Wesley, 1984, p. 370.

contractor is hard to distinguish from that of another. Aerospace firms can point to their planes or satellites, but there is little for an outsider to latch onto when it comes to different systems of vehicle control, or different radar systems, or different systems for battlefield communication. The names that insiders know them by, consisting so often of acronyms, are gibberish to an outsider. And defense companies, by and large, are not noted in placement offices for being particularly skillful or discriminating in their recruiting. The firms who put the most thought and effort into it are mostly firms competing in the commercial marketplace. For all kinds of reasons, the civilian sector is not a pushover in the contest for good engineers.

Contrary to comments in the press and the expectations of many who have not looked at the data, the defense sector does not pay larger salaries. The College Placement Council, which collects information on starting salaries from placement offices, tabulates the offers to bachelor's degree recipients by industry. This year's offers to bachelors in electrical engineering, computer science, and mechanical engineering are shown for selected industries in Table 3. When one looks at data from the professional societies on the salaries of their members (for example, the IEEE's biennial salary survey), one does not find the defense sector ahead there either.

TABLE 3: Monthly Salaries for Bachelor's Degree Recipients, 1986

| | Field of Bachelor's Degree | | |
|---|---|---|---|
| Industry | Electrical Engineering | Computer Science | Mechanical Engineering |
| Aerospace | $2390 | $2262 | $2333 |
| Automotive & Mechanical Equipment | $2420 | $2214 | $2333 |
| Chemicals, Drugs, & Allied Products | $2482 | $2272 | $2448 |
| Computers & Business Machines | $2381 | $2213 | $2326 |
| Electrical & Electronic Machines & Equipment | $2375 | $2278 | $2323 |
| Petroleum & Allied Products | $2468 | $2262 | $2508 |
| Utilities | $2367 | $2220 | $2353 |

SOURCE: *CPC Salary Survey,* Bethlehem, Pennsylvania: The College Placement Council, March 1986, pp. 6, 7.