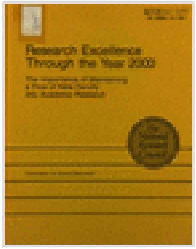

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Research Excellence Through the Year 2000

The Importance of Maintaining a Flow of New Faculty into Academic Research

A Report with Recommendations of the Committee on Continuity in Academic Research Performance

Commission on Human Resources
National Research Council

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D. C. 1979

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 Committee 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 ACADEMY OF SCIENCES

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August 31, 1979

Dr. Richard C. Atkinson
Director
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

Dear Dr. Atkinson:

It is a pleasure to transmit to you the report of the Committee on Continuity in Academic Research Performance, prepared in response to your request of January 26, 1979 and supported by the National Science Foundation under Contract SRS79-13501.

The report makes a significant contribution to our understanding of the magnitude and potential consequences of the anticipated decline in job openings for new faculty members at major universities during the next decade and a half. The program of Research Excellence Awards which the Committee recommends is an interesting and potentially effective response to the threat of declining research vitality posed by the shortage of positions for young faculty in science and engineering. I am sure the National Science Foundation will give these analyses and recommendations the careful attention they deserve.

Under Robert Bock's able leadership, the Committee succeeded in performing its task on an extraordinarily rapid schedule. Less than five months elapsed between the committee's initial organizational meeting on April 10 and the transmittal of the report to you. This rapid response was possible only because of the members' willingness to devote a solid seven days to work on the report during their workshop at Williamsburg, Virginia, on May 30 through June 5, and because of their sustained interest in and attention to the report throughout the summer. The Committee's work was also substantially aided by the results of the Workshop for Specialists in Forecasting Demand for Scientists and Engineers which was held under the committee's auspices in Washington, D.C. last April 30 to May 1. Members of the staff of the National Science Foundation provided useful information to the Committee.

We hope you will find the report helpful in dealing with an extremely significant and urgent national problem. We shall be glad to discuss the report with you and your staff.

Sincerely yours,

PHandler

Philip Handler
President

EXECUTIVE SUMMARY

The Problem

Recent and anticipated declines in openings in universities for new faculty in some fields of science and engineering have generated widespread concern about potential impairment of the vigor and effectiveness of the academic research enterprise. This report assesses the nature and magnitude of the problem and recommends appropriate national policies to counteract it.

Causes of the Problem

Recent projection studies provide clear evidence that, in the absence of policy intervention, there will be a substantial and sustained decline in openings for new faculty in a number of science and engineering fields. This decline stems from two key forces:

(1) an absence of growth in total faculty size, resulting from low present growth and projected decreases in college and university enrollments and a comparatively steady level of research funding; and

(2) low rates of retirement of present tenured faculty, resulting from low rates of faculty growth during the 1940's and 1950's compared to the 1960's, and from changed laws affecting retirement policies.

Magnitude and Timing of the Problem

(1) The extent of the expected shortfall in hiring differs considerably by field. Some fields (such as physics) already have an accumulated hiring shortfall of several years duration; in others a shortfall is just emerging; in still others significant reductions in hiring new faculty may not emerge at all.

(2) The sudden change from rapid growth in the early 1960's to no growth in the 70's has left universities with a faculty age profile that peaks between ages 40 and 50. This provides a current retirement rate of less than 1%, whereas for the same size of faculty a steady-state replacement rate would be about 2%. This means there is a shortage in new openings of at least 1% of the total faculty per year, or about 600 positions per year at the Ph.D. granting institutions.

(3) Retirement rates are expected to rise to steady-state levels by the late 1990's, roughly the same time that enrollments are projected to turn up. Thus the duration of the problem (averaging over fields) is roughly fifteen to twenty years.

(4) Divergence of enrollment trends from those projected and responses of the university system to changing conditions may tend either to mitigate or to worsen the expected shortage in new faculty openings. In the light of the outlook as it can reasonably be foreseen today, we regard the above estimate of the magnitude of the problem as conservative.

Implications for the Vitality of Science

Damage to the nation's research effort is likely to result from the expected constriction in the flow of new faculty, in the absence of countervailing policies, for at least three reasons:

(1) the rate of research innovation, the inflow of new ideas, and the vitality of the research environment will be impaired;

(2) continuity in the education and socialization of succeeding generations of researchers will be threatened; and

(3) the perceived lack of opportunities for an academic career may discourage able and creative young people from pursuing careers in basic scientific research.

Principal Recommendation

Research Excellence Awards

To ensure an adequate flow of new faculty into research producing universities and to foster the research efforts of outstanding present faculty, the Committee on Continuity in Academic Research Performance recommends that the National Science Foundation establish a program of Research Excellence Awards. These are to be five-year, non-renewable awards for tenured or non-tenured faculty members nominated by their departments. The awards will provide partial salary support (including summer support for research time) to award recipients. The employing university will commit itself to devote funds freed by these awards to the hiring of additional faculty in the recipient's department.

The number of awards should be chosen so as to eliminate half the hiring deficit in fields suffering a serious hiring shortage as determined by NSF on the basis of several indicators. Present indicators of the severity of the problem suggest that at its peak level of operation in the late 1980's the scale of the program should be set to create approximately 250 positions per year, summed over the eligible fields of science and engineering. The total program cost is estimated to be $381 million in 1979 dollars assuming a 20 year period of operation.

ACKNOWLEDGMENTS

The report of the Committee on Continuity in Academic Research Performance was prepared for the National Science Foundation under the auspices of the Commission on Human Resources of the National Research Council. Financial support was provided by the National Science Foundation.

We acknowledge many forms of assistance. The committee wishes to thank Frederick Balderston, Associate Dean for the Graduate School of Business Administration at the University of California at Berkeley, for chairing the Workshop of Specialists in Forecasting Demand for Scientists and Engineers, which provided advice and background information to the committee. We are grateful to the Workshop participants, as well, whose names are listed in Appendix B.

Charles Dickens of the National Science Foundation was helpful to the Committee in his role as project monitor. We are also grateful to the professional societies and corporations who kindly responded very quickly and helpfully to our request for information.

Within the Commission on Human Resources, Michael McPherson directed the day-to-day activities of the Committee and had primary responsibility for drafting a report which accurately reflected the long and detailed deliberations of the Committee. Kathryn E. Swafford assisted in these activities and had primary responsibility for organizing the Committee's workshop and meetings. Dorothy M. Gilford served as the principal investigator for the project and was responsible for the general administration of the study. Harold Goldstein, Charles Kidd, and Joan Snyder served as consultants. Harrison Shull, Commission Chairman, and Albert H. Clogston, a Commission member, offered guidance during the study as did

William C. Kelly, Executive Director of the Commission. The Committee especially wishes to thank Porter Coggeshall, Project Director for the NRC's Study on Postdoctorals and Doctoral Research Staff for his generous contributions of advice, analysis, and data. This Committee benefitted greatly from data and analyses that had already been prepared for the Committee on Postdoctorals and Doctoral Research Staff and we are grateful for their willingness to share those results with us. Peter Syverson and Allen Singer of the Commission's staff also provided much help in the initial phase of the project. The committee is indebted to Laurie Robinson for her superior administrative and secretarial support, and to Joanne Rogers and Shirley Davis for their assistance in text preparation.

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CONTENTS

CONTENTS

LIST OF TABLES

CHAPTER I. INTRODUCTION AND BACKGROUND

The notion that there is a "young investigator" problem in academic science and engineering in the United States is becoming increasingly widespread. Studies based on several different data sources indicate substantial declines in the percentage of "recent" Ph.D.'s on college and university faculties in a number of science and engineering fields. A "recent" Ph.D. is defined as one who has obtained the degree within the last seven years.1/ Rates of growth of faculty in a wide range of fields have fallen sharply from the levels of the 1960's. Given the realities of the impending downturn in the size of the college age population, low rates of retirement among present faculty, and a political environment unfavorable to public spending, many expect these trends toward low faculty hiring rates and declining proportions of "young"2/ faculty in universities and colleges to continue and probably worsen over the next decade. Such projections, of course, underlie often expressed worries about the state of the academic job market for science and engineering (and other) Ph.D.'s in the 1980's. (See Freeman, 1976; Cartter, 1976)

But these projections give rise to a distinct, though not unrelated worry: will the "aging" of faculties and the shortage of

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1/ The figure of seven years has been employed in these studies largely because it corresponds to the "normal" time to tenure under American Association of University Professors guidelines. The trends are not notably affected by the use of a different number of years to define "recent." The relevant data are reported in Chapter II. (It should be noted that the group of "recent" Ph.D.'s defined in this way and the group of non-tenured faculty are not equivalent, since tenure decisions frequently occur earlier or later than the seventh year after the Ph.D.)

2/ "Young" in this context is best regarded in terms of "academic age" -- years since Ph.D. or some comparable measure.

positions for new faculty members impair the health and vitality of the American scientific enterprise?

The potential threat to the vitality of science can be seen in several different lights. Perhaps it is the case that young scientists are uniquely creative or productive in the research enterprise, and hence a decline in their representation on faculties will reduce the effectiveness of research. Or perhaps the point is less that youth *per se* is a source of creativity and more that, given the social structure of the scientific enterprise, a constant flow of new talent is needed to import new techniques, ideas, and lines of research to academic departments. Young people, that is, may be important not just because of their individual contributions to research but because they have traditionally been relied on to promote a stimulating research environment in their departments. Still another concern is that a lack of career opportunities may turn the best young minds of a generation away from research careers in science and engineering.

Exactly what stands to be lost from a constriction in the flow of new Ph.D.'s into academic positions is a question we shall examine more carefully in chapter III below. But the fact of widespread anxiety about the declining numbers of young people in academic science is unmistakable. The anxiety was well captured by a physics professor who was interviewed by David Breneman, (1978, p. 158): "I know what everyone in this department thinks about the research problems that interest me, and the thought of having no new colleagues to talk with is chilling." Smith and Karlesky gave the problem prominent attention in their survey of the state of academic science (1978, pp. 179-185). A National Science Foundation Task

Group chaired by Howard Schachman (National Science Foundation Advisory Council, 1978) addressed the young investigator problem as one among a series of threats to the continued viability of universities as centers for basic research. The problem is also being examined by the Carnegie Council on Policy Studies in Higher Education and by the Association of American Universities. The issue has even received some attention in Presidential messages and in the popular as well as the scientific press. (Abelson, 1979; Carter, 1979; Cooney, 1979; Greenberg, 1979)

Nor is the concern confined to the United States. The underlying causes of the drop in numbers of positions for new faculty -- rapid growth of faculties in the 1960's and early 70's followed by slow or no growth since -- have been common to most industrial nations. A number of countries have launched studies of the problem and a few have proposed and in one case (France) even implemented policies to counteract adverse effects of faculty aging.3/

In recognition of the importance of these concerns, the National Science Foundation requested the National Academy of Sciences to prepare a study to guide public policy in relation to the employment of new Ph.D.'s in academic research over the coming decades. The Academy was asked to "assess recent studies that project the numbers of higher education faculty and non-faculty research positions that will become open," and to "compare the findings of various studies in terms of the estimated future numbers

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3/ The French situation is described in OECD (1977) and Redfern (1979). Charles Kidd developed background information on studies for France and a number of other countries for this committee.

of academic [positions] which may be available and the estimated numbers of junior to total academic faculty and non-faculty researchers." NSF asked the Academy to report its findings by broad field of science and engineering (i.e., physical sciences, life sciences, mathematical sciences, and behavioral and social sciences) and, to the extent possible, by discipline (chemistry, physics, etc.) within those broad fields. The Academy was further asked to "evaluate possible alternative public policy actions, if any, in the science and engineering area in light of the assessment," and to "recommend alternative Federal or national actions deemed necessary on the basis of this work." (NSF "Statement of Work," January 26, 1979.)

The Committee on Continuity in Academic Research Performance was formed under the auspices of the National Research Council's Commission on Human Resources to undertake the study requested by the NSF. The Committee has a broad interdisciplinary base, including representatives from the fields of chemistry, physics, biosciences, mathematics, statistics, engineering, economics, psychology, and sociology. The Committee membership represents an array of institutions with differing degrees of research commitment and includes representatives of institutions that have a large number of doctoral (non-faculty) research staff members. The Committee includes among its members a demographer, a statistician, and a sociologist of science. One of its members brings the experience gained from a long career in public service in an elective office.

In approaching its tasks, the Committee has been able to rely on the work of other committees of the National Research Council dealing with related problems. The Committee on a Study of National Needs for Biomedical and Behavioral Research Personnel has examined similar questions in the fields under its purview for several years. The Committee on a Study of Postdoctorals and Doctoral Research Staff in Science and Engineering has prepared an interim report on the postdoctoral population and a report on non-faculty doctoral research staff which we have found helpful. The work of the Committee on the Education and Employment of Women in Science and Engineering and of the Committee on Education and Employment of Minority Group Members in Science has also been of use to the Committee. The Commission on Human Resources is currently in the planning stages of a study of the young faculty problem in the humanities.

The Committee is aware of several existing programs supported by private foundations and federal agencies which have the purpose of supporting and encouraging the academic careers of young Ph.D.'s. These include fellowship programs supported by the Sloan Foundation, the Research Corporation, and the Kellogg Foundation, the recently announced program of support for young scholars in high energy physics sponsored by the Department of Energy, and the Research Career Development Awards offered by the National Institutes of Health. We have learned from these programs in designing the program of awards we recommend below.

Several NSF advisory and policy-making groups are also examining issues related to this committee's concerns, including committees of the National Science Board and the NSF Advisory Council Task Group on "Alternative Support Mechanisms for University Research" chaired by Dr. Matina Horner. To assist these groups a small NSF Staff Group on Young Investigators/Young Faculty was formed. This group was asked to develop some materials to be shared with the present committee, including an annotated bibliography, an inventory of federal programs relevant to these problems, and the results of a study of the degree of success of young investigators in the competition for research funds. Although much of this material became available rather late in the committee's schedule, we have been glad to have the opportunity to review it.

Our task, as we understand it, goes considerably beyond the appraisal of forecasts of future academic positions for scientists and engineers. In order to make policy to offset the "problems" created by a decline in the number of positions available it is necessary not only to determine the likely extent (if any) of the decline, but also to determine whether and why such a decline in proportions of young academic researchers constitutes a "problem."

In approaching our assignment, we therefore decided it was essential to examine very carefully the role played by young scientists in the research enterprise. This was essential not only in deciding whether indeed there was a problem, but also in recommending appropriate remedies to whatever problems we found. Our concern is with the vitality of university science, not with the employment of young scientists as an end in itself. We did not assume _a priori_ that the only or the best way to offset any threat to scientific vitality stemming from a loss of continuity in faculty development had to come in the form of encouraging additional hiring of young faculty. In fact, one of our conclusions is that renewal and sustained vitality of all faculty should be an important component of an effective strategy to maintain scientific vitality in the coming decades.

The organization of our report reflects these concerns. In chapter II, we provide our assessment of recent forecasts of demands for new Ph.D.'s in science and engineering. Our central conclusion is that reductions in rates of hiring and of proportions of young researchers below recent levels and below those that would be sustainable over the long run with a faculty of present size can be expected in some but not all fields of science and engineering in the next decade.

Chapter III is an intensive examination of the implications of this expected decline in numbers of young faculty for the effectiveness of scientific research. Our analysis of the process by which first class research is produced in universities leads us to conclude that an interruption in the flow of new faculty hires over a period of years may seriously impair the vigor and effectiveness of the academic research enterprise. Given the key role of the university as a producer of basic research for the entire U.S. research and development system, we conclude that federal action to offset the threat to academic research effectiveness is warranted.

Chapters IV through VI turn to the assessment of alternative national policies. Following a survey of possible policies in chapter IV, we describe in chapter V a program of Research Excellence Awards which will work both to enhance the research effort of selected members of the existing faculty and to provide openings for new faculty in science and engineering departments. Chapter VI discusses some related matters, including the role of institutions other than the major research producers, the need for better data and monitoring of the Ph.D. labor market, and the means of maintaining the vitality of the present faculty.

A summary and conclusions appear in chapter VII.

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CHAPTER II. PROJECTIONS OF NEW FACULTY HIRING

Several recent projection studies indicate that significantly reduced rates of growth in total faculty size and low anticipated rates of retirement will lead to quite substantial declines in rates of hiring of new faculty over the next two decades. The purpose of this chapter is to review the evidence underlying these projections, to assess their validity, and to determine their implications for the numbers and percentages of young faculty involved in research in academic science and engineering.

We first review the roles played by enrollment demographics and current faculty age distributions in shaping the future demand for new faculty. The analysis is supported with evidence from recent projection studies, and qualifications and limitations to the projection results are reviewed. We then examine briefly the overall supply-demand balance for science and engineering Ph.D.'s, incorporating non-academic as well as academic positions. Finally, since conditions differ considerably among different areas of science and engineering, we examine the issues raised by distinguishing among expected developments in such broadly defined fields as the life sciences, the physical sciences, mathematics, the social sciences, and engineering.

Future Demands for Young Faculty: An Overview

Concern about an impending shortage of academic positions for young scientists and engineers which may impair the vitality of science has its roots in the peculiar dynamics which the academic marketplace began to exhibit several decades ago and will continue to exhibit through the remainder of the twentieth century. While differences among subject matter fields and classes of institutions must not be neglected, the broad outlines of this story can usefully be sketched at the aggregate level.

The first key fact is the very rapid expansion in university faculties which began in the late 1950's in response both to rapidly expanding enrollments and to sharp increases in federal funds for research. While the expansion was not shared evenly among all fields of higher education, or all categories of institutions, the data in Table 1 indicate that growth in faculties was widespread and substantial through about 1970 in most of higher education. Since then, a substantial slowdown in enrollment growth and in the growth of research support has set in, leading to much reduced growth in the size of faculties. Table 1 shows that major public and private universities participated in these trends.

There is almost no doubt that the slowdown in total enrollment growth will continue, and the prospect is very real that such enrollments will actually decline. Figure 1 recalls the basic demographic fact: the number of 18 year olds will decline to about 81 percent of its present level by the year 1986.1/ By 1991, the number of 18 year olds will have fallen to less than three-quarters of its 1979 level. Conceivably, increases in rates of college attendance might prevent actual declines in total college attendance, but no reasonable observer expects a return to growth rates anything like those of the 1960's.2/

1/ Note that the range on the vertical axis in Figure 1 has been compressed to show the changes more clearly. This may lead to an exaggerated visual impression of the magnitude of the change.

2/ For discussion of enrollment projections, see Bowen (1974); Carnegie Foundation (1975); Cartter (1976); Dresch (1975a,b); Freeman (1976).

Table 1

NUMBER AND PERCENTAGE GROWTH RATE OF FULL-TIME FACULTY, a/ ALL COLLEGES AND UNIVERSITIES AND SELECTED GROUPS OF COLLEGES AND UNIVERSITIES, 1957-58 THROUGH 1977-78

	All Higher Education Institutions		Selected Major Public Universities b/		Selected Major Private Universities c/		California State University System d/	
	Number	Annual Growth Rate e/	Number	Annual Growth Rate e/	Number	Annual Growth Rate e/	Number	Annual Growth Rate e/
1957-58			6,363		5,821		(n.a.)	
1961-62	162,000		8,921	10.1%	7,407	6.8%	4,341	
1965-66	248,000	13.2%	12,545	10.2%	8,389	3.3%	6,410	11.9%
1969-70	350,000	10.3%	16,435	7.8%	10,094	5.1%	10,235	14.9%
1973-74	389,000	2.8%	19,000	3.9%	10,268	0.0%	11,074	2.0%
1977-78	449,000	3.8%	18,444	-0.1%	10,394	0.0%	11,296	0.1%

a/ All faculty with rank of instructor or above.

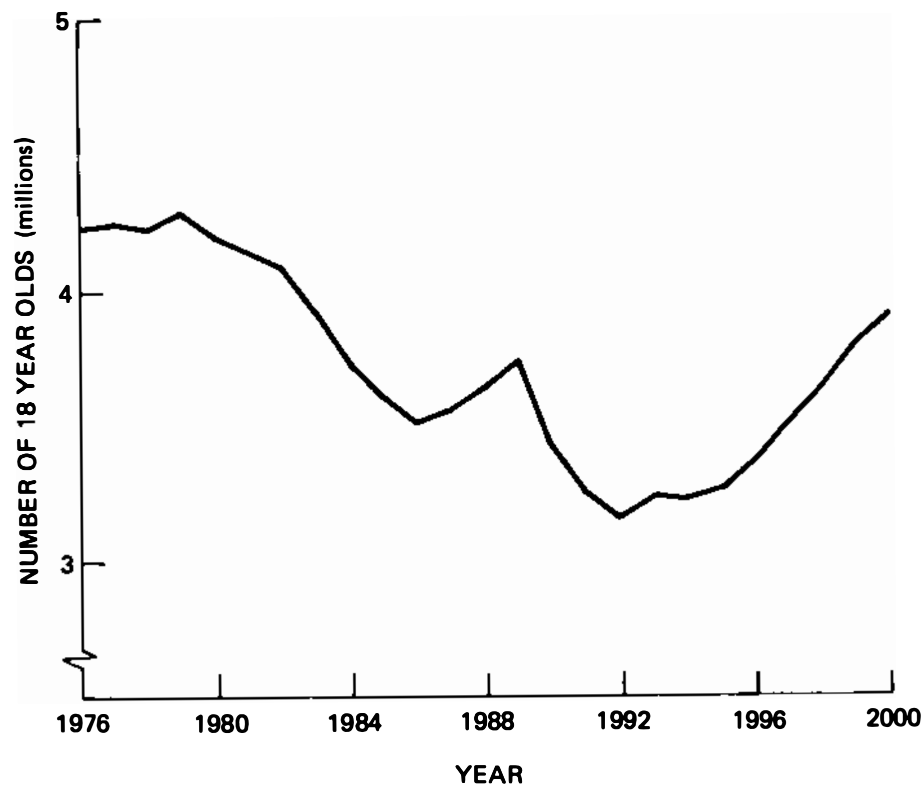
b/ Sample includes: the Universities of California, Illinois, Michigan, Minnesota, Washington, and Wisconsin.

c/ Sample includes: Brown, California Institute of Technology, Case Western Reserve, Cornell (Endowed Colleges), Dartmouth, Harvard, Johns Hopkins, Massachusetts Institute of Technology, Northwestern, Oberlin, Princeton, University of Pennsylvania, University of Rochester, Stanford, Washington University (Mo.), Yale, and Columbia.

d/ Sample includes: California State Colleges at Bakersfield, Dominguez Hills, San Bernadino, Sonoma, and Stanislaus; California State Universities at Chico, Fresno, Fullerton, Hayward, Long Beach, Los Angeles, Northridge, and Sacramento; Humboldt, San Diego, San Francisco, and San Jose State Universities; and the California State Polytechnic Universities at Pomona and San Luis Obispo.

e/ Annual average growth rate over four years preceding.

SOURCES: National Center for Educational Statistics, Projections of Educational Statistics to 1986-87; American Association of University Professors' Data Bank.



SOURCE: U.S. Census, Projections of the Population of the U.S.: 1977-2050, Series P-25, No. 704 (July 1977), Table 2. Based on Census Series II. (Cited in Radner and Kuh, 1978, p. 39.)

FIGURE 1 Census Projection of Number of 18 Year Olds, 1976-2000.

A relatively optimistic and much cited forecast of enrollment trends, developed by Allan Cartter for the Carnegie Commission, has been updated by Roy Radner and Charlotte Kuh (1978). As shown in Table 2, it projects a decline in total degree-credit full-time-equivalent (F-T-E) enrollment of 6% between its peak in 1982 and its trough in 1987. A decline of an additional 10%, following a brief rise, is projected by 1994. Individual fields or types of institutions may buck the trends by getting a larger share of the available students, but realistically such fields and institutions ought to think in terms of avoiding enrollment declines rather than expecting significant sustained growth in student population. Since requirements for teaching faculty are closely linked to enrollment levels, these enrollment trends alone thus point toward a cessation in the growth of faculties, with serious consequences for the rate at which new faculty can be hired.

It further seems unlikely that growth in research funding will permit universities to expand their faculties substantially. Given the short-term nature and instability of most research funding, research funds do not generally provide an acceptable base for establishing regular faculty positions. Furthermore, while trends in research funding are hard to predict, and are highly field dependent, there is little reason for confidence that growth rates of spending like those of the 1960's can be expected in most -- if any -- fields.

Viewed in the aggregate, then, the 1970's are a period in which the higher education system has begun to make a rather abrupt transition from conditions of rapid growth to conditions of steady, or perhaps modestly declining, demands for its services. This trend

Table 2

PROJECTIONS OF FULL-TIME-EQUIVALENT
DEGREE CREDIT ENROLLMENTS, 1976-2000
(IN THOUSANDS)

YEAR	UNDERGRADUATE ENROLLMENT	GRADUATE PROFESSIONAL ENROLLMENT	TOTAL FTE ENROLLMENT
1976	4899	875	5774
1977	5012	867	5879
1978	5115	868	5983
1979	5233	870	6103
1980	5322	885	6207
1981	5358	901	6259
1982	5378	913	6291
1983	5323	938	6261
1984	5224	979	6203
1985	5106	981	6087
1986	4993	990	5983
1987	4953	992	5945
1988	4984	975	5959
1989	5051	962	6013
1990	5006	928	5934
1991	4876	919	5795
1992	4756	923	5679
1993	4680	935	5615
1994	4662	935	5597
1995	4651	911	5562
1996	4710	884	5594
1997	4807	873	5680
1998	4992	873	5865
1999	5178	881	6059
2000	5374	887	6261

Source: Radner and Kuh (1978), p. 39

is almost certain to produce a significant reduction in the number of academic positions opening up for new Ph.D.'s.

A very important point to stress here is that it does not take an actual decline in total enrollment or faculty size to cause a quite substantial negative impact on rates of hiring of new Ph.D.'s. The simple fact of moving from the smaller faculty size of the 1940's and 1950's to the larger total faculty required more recently is enough to depress hiring rates not just below those experienced during growth, but also below those which would be experienced under long run "steady-state" conditions.3/ We define a steady-state as a situation of balance between numbers recruited into and numbers leaving academic positions, with a stable total faculty size and unchanging age distribution. Such an equilibrium steady-state age distribution would tend to evolve naturally over a long enough period of time if the rate at which new faculty were hired remained constant. While such a steady-state may or may not emerge in reality, it provides a useful benchmark for comparison with the existing and prospective situation, and it has become a common device used by university planners who have adopted the target of maintaining a constant faculty size as a reasonable goal in the period ahead.

The relevant point here is that the transition to the steady-state, in the absence of explicit "smoothing" policies, can involve sharply reduced rates of hiring. The reason is that the past period of growth tends to produce a bulge in the center of the age distribution of the tenured faculty. Retirement rates after

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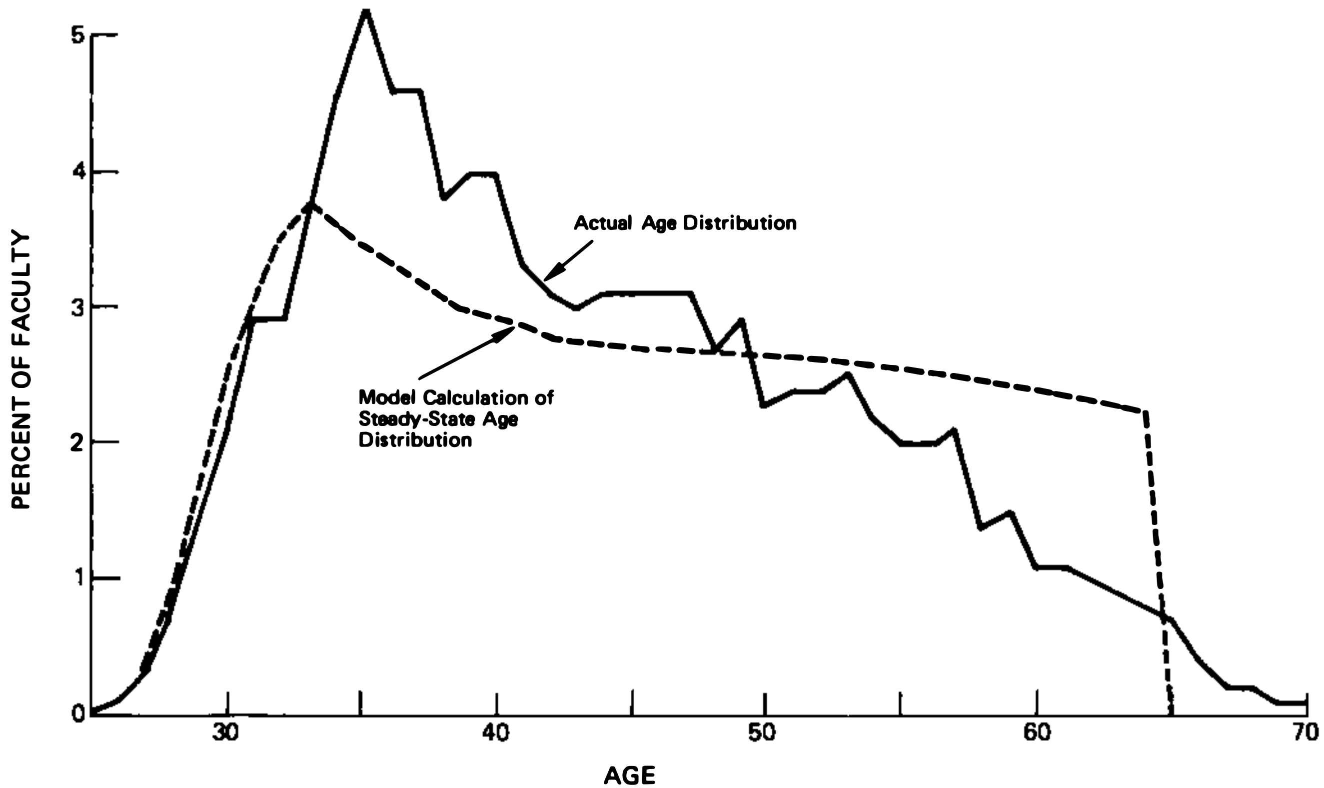
3/ A parallel phenomenon which arises with regard to investment in capital goods is referred to in economics as "the accelerator effect." See Samuelson (1977), pp. 260-263.

growth ceases are therefore below their steady-state levels, depressing the need for replacements during the transition to a balanced age distribution, as the bulge "moves through the system."

The prospective shortage of new academic positions can, then, be separated into two parts. One corresponds to the actual decline in total faculty size which may occur as the enrollment crunch is felt with increasing severity through the mid-1980's.4/ The other reflects the low level of "replacement" hires that will result simply from the growth-induced "age-bulge" coupled with cessation of further growth in faculty size. This second problem, although perhaps less dramatic than the first, is actually more immediate and palpable. It is a problem, furthermore, which will exist even if the demographic effects on enrollments are less severe than some predict, and which will exist even for those institutions where enrollments remain steady through the 1980's.

The problem in fact exists now, as the following data demonstrate. Figure 2 compares the existing age distribution of doctoral faculty in science and engineering at Ph.D. granting institutions with a model age distribution characteristic of a

4/ Although demographically induced enrollment declines will not begin for a few years, some institutions have already reduced faculty hiring in anticipation of such declines.



See Appendix D for description of steady-state model.

SOURCE: NRC, Survey of Doctorate Recipients.

FIGURE 2 Actual and Steady-State Age Distributions, Full-Time Doctoral Faculty at Ph.D. Granting Institutions, 1978.

steady-state equilibrium with constant faculty size.5/ One sees that there is a "hump" in the actual age distribution, compared to the steady-state, between the ages of 35 and 50. But more striking and significant is the very low proportion of faculty aged 55 and above. Those are faculty for the most part who were hired in the years preceding Sputnik, and, compared to those hired in the post-Sputnik era, they are few. Thus, there will be few retirements in the next five to ten years or more.

Retirements will be further depressed by recent changes in laws governing mandatory retirement. It will be illegal after July 1, 1982 for universities and colleges to establish a mandatory retirement age of less than 70 years. It is not known what proportion of faculty who under previous law would have been required to retire at age 65 will instead choose to stay on longer. However, especially in light of the tendency of inflation to erode pension benefits, the proportion is likely to be high. The principal effect is then likely to be the delaying of retirements from the mid-1980's to the late 1980's and early 1990's. The result

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5/ The model assumes (1) that the age distribution of entering faculty is the same as that of 1978 Ph.D.'s planning employment at Ph.D. granting institutions; (2) that 50% of new faculty earn tenure at Ph.D. granting institutions after five years, and the rest leave for employment elsewhere; (3) that age-specific death rates for the total U.S. population apply to faculty; and (4) that all faculty retire at age 65. A fuller description of the model and an analysis of these assumptions appears in Appendix D.

It should be noted that the data on the existing age distribution employed in Figure 2 and data cited at several other places in this report are drawn from the NRC's Survey of Doctorate Recipients, a longitudinal survey based on a stratified sample representative of the population of doctorates residing in the United States. In 1977, the survey sample consisted of 79,375 individuals, of whom 64,742 were in science and engineering. Population estimates inferred from these sample data may be subject to sampling error and error of other kinds. For a comprehensive discussion of sources of error in the Survey of Doctorate Recipients, see NRC (1978b), Introduction and Appendix E.

will be a shifting of retirements from a point when they would already be quite low to a point when, in many fields, they would have begun to recover. Thus the effect will be to extend and intensify the retirement shortage.6/

While enrollment declines will vary among fields and types of institutions, the age distribution problem among existing faculties is more nearly universal. Table 3 shows the proportion of doctoral faculty near retirement age at Ph.D. granting institutions by field for 1977 and compares anticipated retirements to steady-state retirements on the assumption of a retirement age of 65.7/ There are only two science and engineering fields where retirements can be expected to stay consistently close to steady-state levels in the next decade -- namely, agriculture and earth sciences. The approximate projections of anticipated retirements reported in Table 3 are corroborated by more sophisticated projections of death and retirement rates prepared for this committee by Roy Radner and Charlotte Kuh. The Radner-Kuh results by broad field of science and engineering, which are derived from a dynamic model of faculty demand and aging, are reported in Table 4. Since in the steady-state deaths and retirements combined average 2.5% to 3%

6/ For discussion of the impact of changing retirement laws, see Hansen (1979a), Palmer (1979), and Patton (1979a,b).

7/ The prospective change in mandatory retirement age has a smaller impact on the steady-state retirement rate than on actual retirement rates in the near term. These calculations therefore tend to underestimate the extent of the retirement shortfall.

The data on faculty age distribution in Table 3 (and in Figure 2 above) pertain only to doctoral faculty. It is likely that non-doctoral faculty are somewhat older on average than doctoral faculty, implying that the percentages of older faculty reported may be underestimates. But since non-doctoral faculty comprise less than 4% of total full-time faculty at Ph.D. granting institutions (NSF, 1979, p. 12), any underestimate from this source must be quite small.

Table 3

AGE DISTRIBUTION AND ANTICIPATED RETIREMENTS OF FULL-TIME FACULTY AT PH.D. GRANTING INSTITUTIONS, BY FIELD OF SCIENCE AND ENGINEERING, 1977

	Percent of Full-Time Faculty With Age			Anticipated Retirements as Proportion of Steady-State Retirements		
	Greater than 60	56-60	51-55	1978-82	1983-87	1988-9
ALL FIELDS	5.5	8.1	11.5	.60	.66	.88
MATHEMATICS	4.5	4.2	7.6	.49	.34	.58
PHYSICS	3.3	7.0	13.5	.36	.57	1.03
CHEMISTRY	8.0	8.0	8.5	.87	.65	.65
EARTH SCIENCES	7.4	7.0	14.0	.80	.57	1.07
ENGINEERING	4.0	7.8	13.2	.43	.63	1.02
AGRICULTURE	7.5	14.2	14.0	.82	1.15	1.08
BIOSCIENCES	5.9	8.0	12.1	.64	.65	.93
PSYCHOLOGY	4.7	6.6	9.9	.51	.54	.76
SOCIAL SCIENCES	6.2	8.8	11.1	.67	.72	.85
STEADY STATE	9.2	12.3	13.0			

SOURCE: NRC, Survey of Doctorate Recipients.

Table 4

PROJECTED COMBINED DEATH AND RETIREMENT RATES AS PERCENT OF TOTAL FACULTY, BY BROAD FIELD OF SCIENCE AND ENGINEERING, 1976-2000

Year	Mathematics	Physical Sciences	Engineering	Life Sciences	Social Sciences
1976	1.06	1.11	1.07	1.27	1.20
1977	.94	1.41	.79	1.28	1.21
1978	.93	1.22	.61	1.35	1.26
1979	.71	1.13	.61	1.21	1.23
1980	.69	1.05	.72	1.22	1.34
1981	.67	1.03	.80	1.21	1.31
1982	.76	1.16	.80	1.22	1.24
1983	.81	1.30	.96	1.40	1.48
1984	1.12	1.38	.98	1.44	1.64
1985	1.04	1.49	1.29	1.44	1.73
1986	.98	1.49	1.40	1.74	1.97
1987	1.02	1.88	1.48	1.68	2.21
1988	1.57	2.15	1.55	2.08	2.19
1989	1.45	1.97	1.67	1.97	2.30
1990	1.43	2.14	1.90	1.98	2.45
1991	1.58	1.96	1.78	2.18	2.71
1992	1.53	2.24	2.28	2.05	2.73
1993	1.96	2.50	2.13	2.23	2.80
1994	2.06	2.46	2.05	2.52	2.98
1995	1.98	2.53	2.33	2.45	2.90
1996	2.07	2.64	2.22	2.47	3.00
1997	2.32	2.58	2.34	2.70	3.24
1998	2.44	2.98	2.63	2.70	3.08
1999	2.57	2.95	2.54	2.60	3.16
2000	2.84	3.03	2.50	2.55	3.12

SOURCE: Special tabulations prepared by Charlotte Kuh, based on the Radner-Kuh projection model and data from the NRC, Survey of Doctorate Recipients.

per year, the Radner-Kuh data confirm that faculty vacancies from these sources will be below steady-state levels until well into the 1990's.8/

The data in these two tables also provide a rough feel for the relative size and timing of the shortage of new positions in various fields, insofar as the shortage results from low retirements rather than from enrollment declines. In most fields, retirements will be at their lowest levels over the next several years, and will begin a slow recovery in the late 1980's. In fact, by the end of the century, retirements in some fields are expected to exceed steady state levels, potentially leading to a new round of cyclic hiring. But fields do differ. In mathematics, the shortage of retirements is quite severe, and recovery comes several years later than in other areas. In chemistry the problem is less severe in the near term than in some other fields, with retirements over the next five years projected to be at over 80% of the steady state rate, but the situation then worsens in chemistry at a point where recovery begins in other fields. And agriculture, as noted, appears not to have a problem at all.

A useful index of the magnitude of the shortfall in retirements can also be obtained from the data in Tables 3 and 4. Total doctoral faculty size in science and engineering at Ph.D. granting institutions is about 78,000. In terms of a steady-state model, retirements over the next five years would total about 9.2% of the faculty, but they will actually amount to only 5.5%. Thus

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8/ National Science Foundation estimates of death and retirement rates to 1987 are roughly consistent with these figures. See NSF (1979), Table 2, p. 4.

approximately 2900 fewer positions will become available through retirements at Ph.D. granting institutions over the next five years than would be true in the steady-state with the same total faculty size. This implies a shortfall of almost 600 positions per year at Ph.D. granting institutions, for all science and engineering fields combined.

Low rates of retirement and markedly slowed rates of growth in total faculty have been present for some years now in several science and engineering fields, and their effects on the proportions of young faculty in those fields can be measured. Figure 3, based on a survey of selected academic departments conducted by the American Council on Education, displays the decline in proportions of recent doctoral faculty (defined as those within seven years of the Ph.D.) over the last decade. Over that period most of the science and engineering fields surveyed experienced significant declines in the proportion of young faculty, with the largest declines appearing in electrical engineering, mathematics and physics. Figure 4, based on survey data maintained by the National Research Council, shows a more detailed picture of recent trends. The latter figure reports trends in the proportions of recent Ph.D.'s both among doctoral faculty (Figure 4a) and among all doctoral academic staff (Figure 4b), including postdoctoral appointees and non-faculty doctoral staff as well as faculty, at major research producing institutions9/ and at all Ph.D. granting

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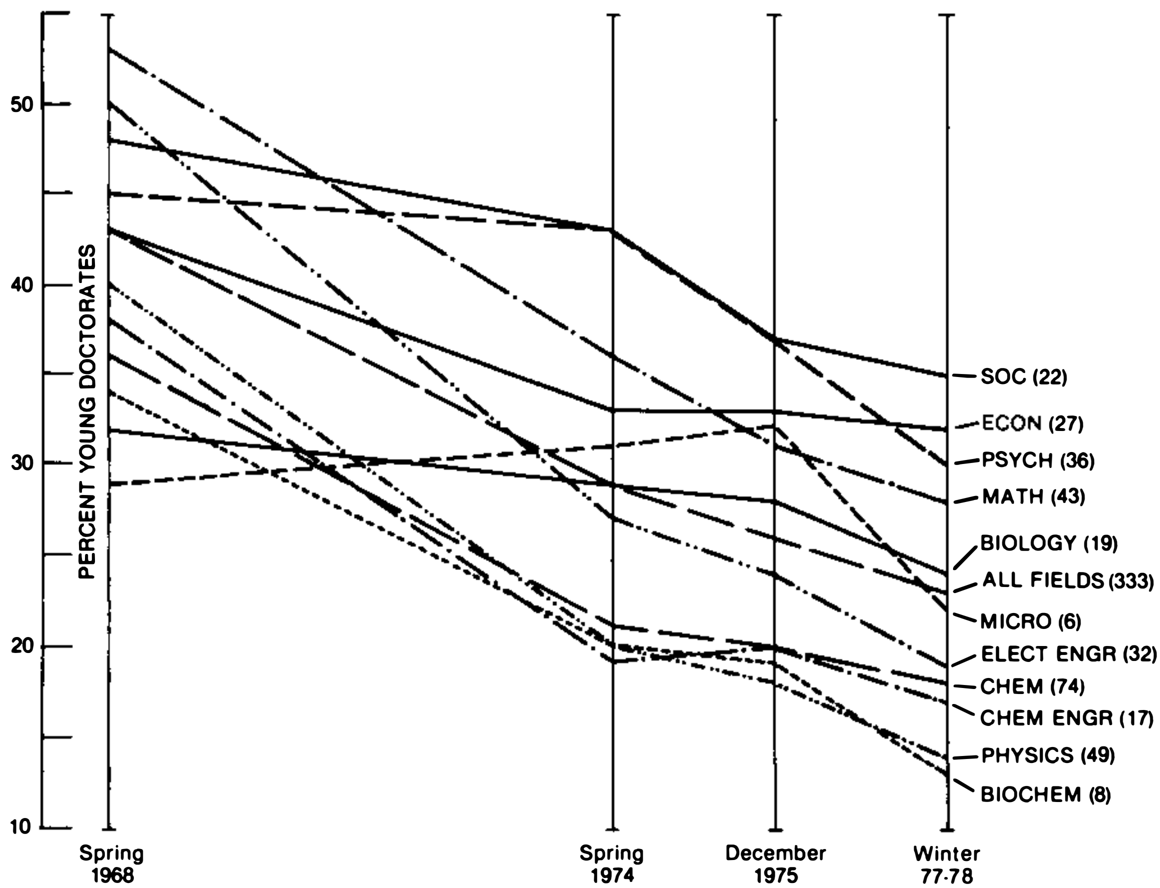
9/ For statistical purposes we have defined "major research producing universities" in terms of total research and development expenditures. They include the largest universities in R & D expenditures which collectively account for two-thirds of all university R & D expenditures. In 1977 these 59 universities awarded over 60% of all Ph.D.'s in science and engineering.

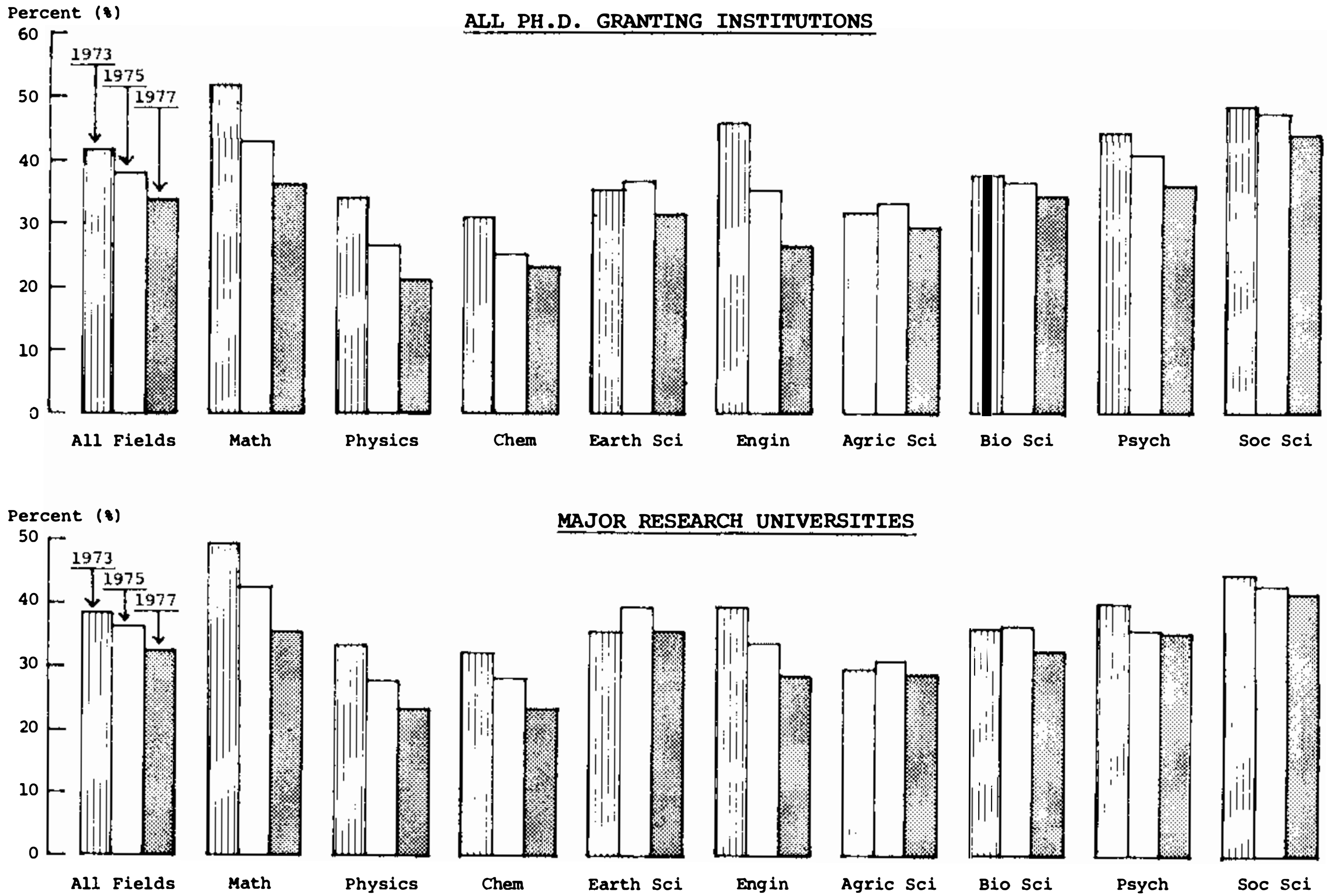


NOTE 1: Numbers in ( ) following fields refer to the numbers of departments that responded to all four surveys.

NOTE 2: The lines connecting the points are intended as visual aids only. The values for years between surveys may not lie on these straight lines.

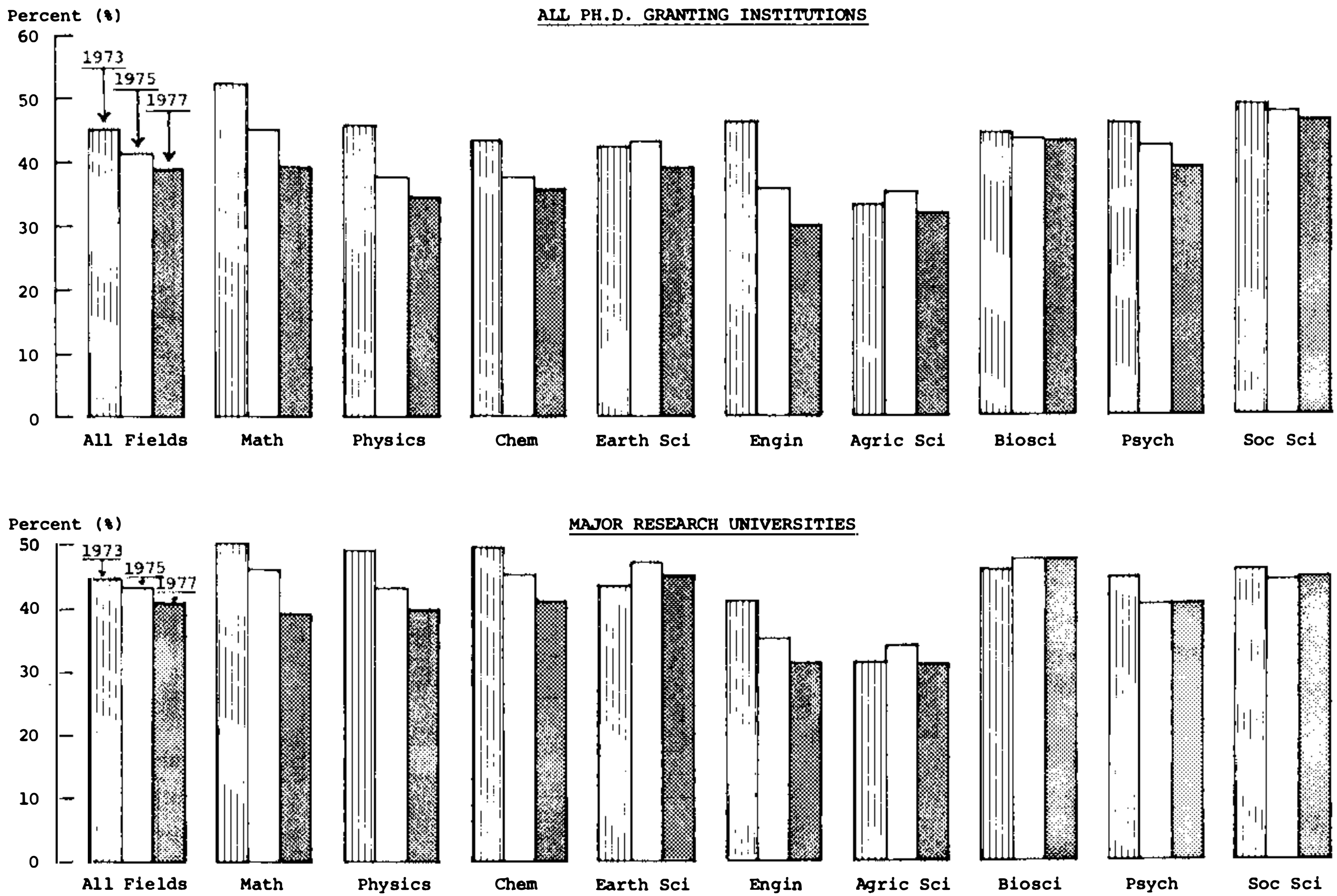
SOURCE: Atelsek and Gomberg (1979), p. 10.

FIGURE 3 Trends in Proportion of Young Doctorates Among Full-Time Faculty in Selected Science and Engineering Departments, Spring, 1968 - Winter, 1977-78.



SOURCE: National Research Council, Survey of Doctorate Recipients, 1973, 1975, 1977.

FIGURE 4a Percent of Total Doctoral Faculty in 1973, 1975, and 1977 Who Had Earned Their Doctorates in the Preceding Seven Fiscal Years.



SOURCE: National Research Council, Survey of Doctorate Recipients, 1973, 1975, 1977.

FIGURE 4b Percent of all Ph.D. Staff in 1973, 1975, and 1977 Who Had Earned Their Doctorates in the Preceding Seven Fiscal Years.

institutions.10/ Again, the sharpest declines are observed in physics, mathematics, engineering and chemistry. Notice that while inclusion of non-faculty staff increases the proportions of young in any one year, it has not to this point had a significant effect on trends in the proportion of recent Ph.D.'s over time.

Low rates of retirement in the immediate future and declines in enrollment later in the decade make it likely that these trends toward low rates of hiring and hence more rapid aging of faculties will continue in the fields that have been experiencing them, and may well emerge in other fields. Before turning to the discussion in chapter III of the implications of these trends for the continuity and vitality of the scientific research enterprise, it is necessary first to examine more closely recent studies which have attempted to forecast these trends quantitatively, to examine possible offsetting factors, and to describe more accurately developments in specific fields.

Evidence from Recent Studies

The view of the market for young faculty in the coming decades which we have just sketched is consistent with the findings of the major projection studies of the demand and supply for Ph.D.'s which have appeared in recent years. Our conclusions in this regard are based both on a careful survey of published studies and on the results of a Workshop for Specialists in Forecasting Demand for Scientists and Engineers which was convened by this committee on

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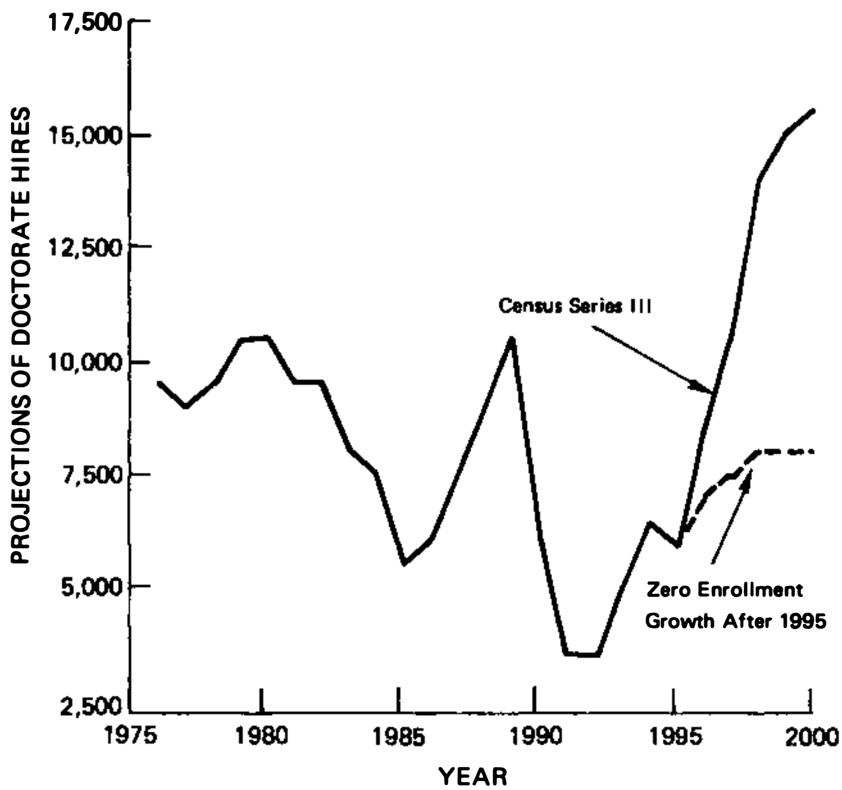
10/ Differences in data base and definition of variables account for differences between the ACE and NRC data in estimated proportions of young faculty. An analysis of the differences is in Appendix F.

April 30 and May 1, 1979 and which was attended by the authors of most of the major studies. Several of the participants prepared papers for the Workshop extending their earlier work and comparing it to other studies. Only a few central points are summarized here; the agenda of the workshop and a detailed review of the relevant studies appears as Appendix B.

Radner and Kuh's study (1978) prepared for the Carnegie Council on Policy Studies in Higher Education, and their companion study prepared for our workshop (Kuh and Radner, 1979), focus most explicitly on job opportunities for young faculty. They assume that enrollments in four-year colleges and universities depend mainly on the number of people in the college ages, that science and engineering enrollments will move approximately as total enrollments do, and that enrollment levels are the main determinant of faculty size. They do not take account of changes in R & D funding as a possible source of variation in faculty size. Their assumptions are used to derive a model which projects aging, promotions and attrition of existing faculty year by year, and consequent openings for new faculty. They conclude that the enrollment squeeze coupled with the low retirement rates of the 1980's will cause the annual academic demand for new science and engineering Ph.D.'s at all colleges and universities to drop by nearly 50% between 1978 and 1985, with a further drop in the early 1990's. (See Figure 5 for a summary of their projection.)

The Radner and Kuh projections imply that total doctorate faculty in science and engineering will be roughly the same in 1987 as in 1978. The National Science Foundation (NSF, 1979), on the other hand, projects roughly a 6% growth in total faculty over the



SOURCE: Radner and Kuh (1978), p. 9.

FIGURE 5 Radner and Kuh's Projections of Doctorate Hires, 1976-2000.

same period. The difference in projections results from more optimistic assumptions by NSF about trends in science and engineering enrollments, the faculty-student ratio, and proportions of faculty holding the Ph.D. But despite these more optimistic assumptions, the NSF, in a special study prepared for the Workshop, still concluded that there will be a significant drop in the proportion of young faculty by 1987. Radner and Kuh estimate that the ratio of recent to total Ph.D.'s on science and engineering faculties will fall by about 33% between 1978 and 1987 (from .30 to .20); NSF, with its more optimistic assumptions, estimates a drop of roughly 20%. Both projections imply a significant drop not only in the proportion but in the absolute numbers of young faculty, because they anticipate little growth in total faculty over the period.

This similarity in the overall trend forecast by both Radner and Kuh and the NSF is more significant for this Committee's work than the quantitative difference between them. Since Radner and Kuh explicitly tried to err on the side of pessimism (see Radner and Kuh, 1978, p. 13) and since the NSF assumptions, especially about enrollment trends, are probably somewhat more optimistic than the demographic facts justify (see Appendix B), we believe the two forecasts can properly be viewed as bracketing the most likely extent of the decline in proportions of young faculty in science and engineering as a whole, in the absence of policy intervention or sharp changes in the functioning of the university system.

While the NSF and Radner-Kuh studies are the only two recent ones which explicitly forecast proportions of young faculty for science and engineering as a whole, other studies tend to support their results. Thus the Bureau of Labor Statistics (Braddock, 1978;

BLS, 1975) study of utilization of Ph.D. scientists and engineers leads to projections of total academic employment which are very close to the NSF projections. This should imply similar movements in the proportions of young faculty as well. And Richard Freeman's work (1976 and 1977), although it does not contain any quantitative projections of academic positions for new Ph.D.'s, presents a strong analytical case, based on economic as well as demographic forces, for expecting the demand for new Ph.D. faculty to fall. Finally, studies for specific fields, including Grodzins' on physics (1979a,b,c), Hansen's (1979b) on economics, and the National Research Council's (1978a) on biomedical and behavioral sciences support the overall analysis presented here. Some of these field-specific findings are further discussed below.

Qualifications to the Projection Results

The fact that the projections tend to agree about the future status of young faculty does not, of course, prove they are right. All the projections rely on certain common assumptions about the operation of the higher education system, and some of those assumptions may prove wrong. Herewith we present a brief review of the most vulnerable assumptions and their potential importance.

Voluntary Exits from Tenured Positions

Lagging growth in academic demand for Ph.D.'s is likely to lead to a worsening of working conditions and salaries for academic relative to alternative occupations open to science and engineering Ph.D.'s. It may therefore be expected that more tenured professors will elect to leave academic positions than have in the past. This will tend to create openings for non-tenured people and thereby ease the age distribution problem. This factor is already taken into account to some degree in the Radner-Kuh analysis, which assumes such "tenured quits" will run between one-half and one percentage point higher in the 1980's than in earlier years, during which exits of tenured people have been roughly balanced by new hires of tenured people from outside of academia. But if the rate of exits goes substantially higher than that, it could significantly improve the academic employment picture for new Ph.D.'s, relative to Radner and Kuh's and other projections. So far, net rates of exit of faculty from tenured positions remain quite low, and no evidence has yet emerged of a significant trend toward increasing exits of tenured personnel.11/

Very high rates of exit of tenured faculty will come about only if the financial condition of universities worsens sharply in the 80's, leading to serious real or relative salary deterioration in academia, and if the non-academic job market is strong. The number of non-academic jobs available to Ph.D.'s is very difficult to forecast -- it depends heavily, for one thing, on the overall condition of the economy -- but both the NSF and BLS forecasts of the non-academic labor market for Ph.D.'s (based largely on past trends in employment growth) suggest that new job opportunities will be more abundant in the non-academic than in the academic sector.

The availability of such non-academic opportunities is also plainly quite field dependent. Table 5, showing the distribution by field of academic and non-academic employment of Ph.D.'s in 1977, provides an indicator of these field differences. Should large

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11/ This is corroborated by Grodzins' work in physics (Grodzins, 1979b, Table V) and by estimates obtained by Kuh and Radner from data in the Survey of Doctorate Recipients (Kuh and Radner, 1979 and unpublished results).

Table 5

NUMBER AND PERCENT OF PH.D. SCIENTISTS AND ENGINEERS
BY ACADEMIC vs. NON-ACADEMIC EMPLOYMENT AND FIELD, 1977

Field	Total Labor Force	Employed in Academia Number	Employed in Academia Percent	Employed Elsewhere Number	Employed Elsewhere Percent
Total, All Fields	261,182	146,603	56	111,369	43
Mathematics	19,102	13,268	69	5,666	30
Physics	17,627	10,677	61	6,686	38
Chemistry	32,819	13,055	40	19,312	58
Earth Sciences	12,262	5,808	47	6,373	52
Engineering	42,302	14,538	34	27,511	65
Agriculture	13,848	8,015	58	5,765	42
Biosciences	54,357	36,466	67	16,974	31
Psychology	31,950	16,058	50	15,477	48
Social Sciences	36,915	28,718	78	7,605	21

SOURCE: NRC, Survey of Doctorate Recipients.

numbers of tenured faculty begin leaving academia, the hiring situation for new faculty in the affected fields would be eased, but other problems would arise. If, as can be expected, those who leave are among the abler and more productive faculty (since they have the best non-academic opportunities), such exits might have a strong negative effect on academic research vitality.

Rates of Promotion to Tenure

Other things being equal, the larger the fraction of new faculty who are promoted to tenure, the fewer the openings there will be for hiring of new faculty later, and hence the more rapidly the faculty as a whole will age, and the fewer young faculty there will be. Thus arises the possibility that universities will institute a "revolving door" policy of not tenuring young faculty as a way of assuring a continued source of openings for young faculty.12/ Radner and Kuh have incorporated this factor in their model to some degree, by including an assumption that rates of promotion tend to fall when market conditions for new Ph.D.'s worsen. But if this tendency is substantially stronger than they have assumed, new hires would not fall as much as they project. One reason that NSF projects a smaller decline in the proportion of

12/ In the past, assistant professors not receiving tenure at one institution were very likely to be able eventually to receive tenure elsewhere, perhaps at an institution of lesser rank. This possibility becomes more doubtful as growth in overall faculty size slows. In fact, Grodzins has found that in physics the likelihood of a faculty member turned down for tenure remaining in academia has declined sharply in recent years (Grodzins, 1979b, p. 9). Further, a "revolving door" policy at research universities might increase the number of openings for new faculty at those institutions, even if the faculty turned down for tenure at the research universities eventually obtain tenure elsewhere in the higher education system.

young faculty is that they assume a lower promotion rate than do Radner and Kuh. Notice that a side effect of a "revolving door" tenure policy would be an even more rapid aging of the tenured faculty and hence a widening age gap between tenured and non-tenured faculty.

The Faculty-Student Ratio

A rising faculty-student ratio increases hiring and reduces faculty aging. Such a rise might occur in the 1980's and 90's for either of two reasons. First, increased research funds relative to enrollment-generated funds might lead to the hiring of more Ph.D.'s in universities in research positions (although whether they would have full faculty status is doubtful). Second, reduced relative wages for faculty members might induce colleges and universities to employ relatively more faculty. There is some econometric evidence, in Richard Freeman's work (1977) and in Allen Singer's work (1979) in the biomedical fields, that faculty-student ratios are responsive to both these variables. However, university budgets are likely to be under great strain in the 1980's, owing to enrollment declines and inflation in energy and other costs, and it may be doubted that any significant increase in the faculty-student ratio will emerge in the absence of new sources of funding. The NSF projection, as noted above, projects an increase in the faculty-student ratio and still projects a decline in new hires.

Ph.D. vs. Non-Ph.D. Faculty

Universities in the 1980's may try to "upgrade" their staffs by hiring more Ph.D.'s relative to non-Ph.D.'s. The potential impact on hires of young Ph.D.'s is, however, rather limited, since tenured non-Ph.D.'s can be replaced by Ph.D.'s only when they depart the system through normal attrition. Furthermore, the fraction of non-Ph.D. faculty hires at research producing institutions is already so low that no significant increase in positions for new Ph.D.'s at such institutions can be expected from this source.

Major Research Producing Institutions vs. Others

Expected declines in enrollment are one basis for predictions that new hires in academic science and engineering will fall over the next decade. But it is doubtful that these demographic effects will be felt with as much force at the major research institutions, which tend to have strong student markets relative to the rest of higher education. The major universities have not in the past had on the average as close a link between their faculty size and enrollment demographics as have other colleges and universities.

The extent to which more prestigious institutions will in fact share in the overall anticipated decline is quite difficult to predict. For private institutions especially, the result will depend on the willingness of students and their families to bear rising tuition costs. At public institutions, the outcome will turn on (among other things) how state budget funds are reallocated in response to enrollment drops. It does indeed seem likely that major research producers will not be among the worst affected by the impending decline, but the impact that some of them will feel is likely to be significant.

Summary of Qualifications

It is undoubtedly true that these qualifying factors will, on net, soften somewhat the impact of enrollment demographics on the hiring of new Ph.D. faculty, especially at the research universities. But we believe, despite these mitigating factors, that the impact will be real and substantial and will be broadly felt in academia.

Moreover, it is necessary to reemphasize that the hiring problem has two sources. Even if enrollments and numbers of faculty stay constant and R & D support keeps up with inflation -- and more optimism than that would be unwarranted even at the most prestigious institutions -- the current age distribution of the faculty implies a significant reduction in new hires over the next ten years in some fields. The extent of the enrollment problem at the major research producers remains somewhat speculative; the faculty age distribution problem is clear and present.

The Supply-Demand Balance

Several of the studies we have surveyed project supply as well as demand for new doctoral scientists and engineers.13/ The NSF and

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13/ Studies of the supply-demand balance need to account for international flows of Ph.D. scientists and engineers. In 1978, approximately 15% of science and engineering Ph.D.'s educated in the United States were foreign nationals on temporary visas (NRC, Survey of Earned Doctorates). In engineering, the figure was 32%. Since few of these persons on temporary visas are expected to become permanent U.S. residents, the supply of Ph.D.'s to the U.S. labor market tends to be less than U.S. Ph.D. production. There is also some flow of U.S. citizen Ph.D.'s abroad, and of foreign-trained Ph.D.'s to the U.S. While complete data are not available on these migrants, their number is apparently not sufficient to affect significantly the overall projection results (NSF, 1979, pp. 3 and 4). These international flows do not in general seem to have important implications for the variables of major concern in this study, although the very substantial proportion of engineering graduate students who are foreign nationals needs to be taken into account in planning for that field.

BLS projections which examine non-academic as well as academic demand for Ph.D.'s imply that by the mid-1980's approximately 16% of all science and engineering Ph.D.'s will be employed in positions other than those traditionally occupied by science and engineering Ph.D.'s. (See Appendix B for further discussion.) The situation of course varies greatly by field, as Table 6 shows. Subfield variations, if projections were available, would be even greater.

It is important to stress that the primary charge given to this committee was not to examine the employment problems of young Ph.D.'s nor the need to achieve overall balance in supply and demand of scientists and engineers -- however important these issues are in their own right. Rather, our mission is to assess the impact on scientific vitality of a shortage of positions for young faculty, and to recommend policies to avert or lessen any such impact. Nonetheless, this projected oversupply of young Ph.D.'s may be relevant to our concerns.

There is first the obvious point that an adequate number of educated people will be available to fill additional faculty positions, if it is decided to create them: we face a shortage of positions, not of adequately educated candidates. Further, the potential effect of a sustained oversupply of science and engineering Ph.D.'s on the career decisions of gifted young people may be deleterious to science. If bright and dedicated potential scientists cannot see a clear path to a successful traditional career, their career decisions may divert them from research. Even if opportunities remain reasonably strong for the best students, they may not perceive them as such, and thus overreact to the market signals, with a resultant lowering of the quality of new research performers. Empirical evidence on the relative responsiveness of

Table 6

ALTERNATIVE PROJECTIONS OF UTILIZATION OF PH.D. SCIENTISTS AND ENGINEERS, BY BROAD FIELD OF SCIENCE

	BLS Projection			NSF Projection		
	Labor Force (thousands)	Requirements (thousands) a/	% Excess of Labor Force over Requirements	Labor Force (thousands)	Requirements (thousands) b/	% Excess of Labor Force over Requirements
Physical Sciences	90.0	81.1	10%	95	87	8%
Engineering	60.5	65.7	none	72	59	18%
Life Sciences	109.4	87.5	20%	103	91	12%
Mathematics	24.8	17.4	30%	28	22	21%
Social Sciences	128.0	94.0	27%	113	84	26%
All Science and Engineering	412.7	346.0	16%	412	342	17%

a/ Projected Ph.D. scientists and engineers in "traditional employments."

b/ Projected "science and engineering utilization of science and engineering Ph.D.'s."

NOTE: BLS projection is for 1985; NSF projection is for 1987.

SOURCE: For BLS projection, Braddock (1978)
For NSF projection, NSF (1979)

students of differing ability to changing employment opportunities is lacking, so it is difficult to know how serious this potential worry is.

Field-Specific Analyses

Forecasting the market for faculty in specific fields is more difficult than anticipating overall movements in faculty demand.14/ We can be reasonably confident that overall science and engineering enrollments will be shaped in significant measure by demographic trends, and that overall staffing levels are linked to overall enrollment trends. But it is not at all clear that the distribution of majors and course selections among fields of science and engineering will be stable over time; nor is it clear that the linkage between undergraduate enrollment levels and staffing levels is as tight within individual fields of science and engineering as it is overall. The availability of R & D support within academia also varies among fields. One major theme of our Workshop on Forecasting was the desirability of good projection work at the field and sub-field level, and the inadequacy of existing efforts at field-specific forecasting.

Most available projections of enrollment demand by field rely on projections of past trends in enrollment, sometimes adjusted in more or less *ad hoc* ways to make the results seem plausible. Since they do not incorporate any theory to explain the trends, they do not inspire much confidence. An alternative analytical approach has

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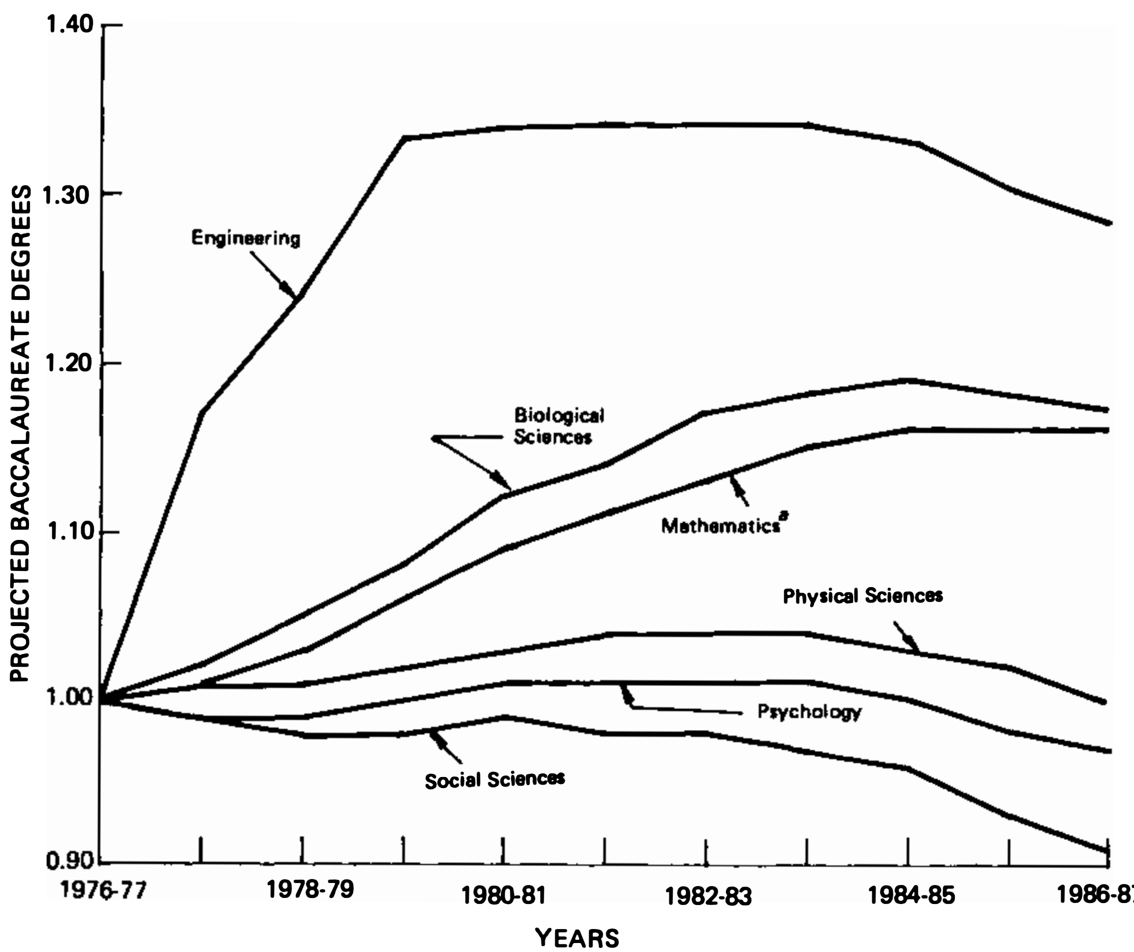
14/ It is necessary to acknowledge the possibility that new scientific fields may emerge during the projection period, and that existing fields and sub-fields may be redefined or even cease to exist. This possibility has not been taken into account in the projection studies under review nor in the following discussion.

been developed, principally by Richard Freeman, which attempts to link undergraduate enrollments by field to market conditions for graduates in that field. This approach probably makes most sense in engineering, where there is a clear vocational tie to the choice of major and a more or less regular cycle in the employment market. But since forecasts based on this approach require projecting employment markets by field, which is itself extremely difficult, their practical effectiveness is also rather limited in most areas.

So, despite their limitations, enrollment projections based on extrapolation of past trends are about all we have to go on at the field specific level. National Center for Education Statistics projections (NCES, 1979) of bachelor's degrees by broad field of science and engineering, which may be taken as a rough index of enrollment trends, are displayed in Figure 6. These trends show an increasing share of bachelor's degrees being awarded in life sciences and engineering, a decreasing share in social sciences, and little change in the share of mathematics and the physical sciences. These trends are an imperfect indicator of instructional demand by field, since in fields like mathematics with large "service course" loads the demand for instruction is not closely linked to the number of majors. Ideally one would want measures and projections of credit hours, but these are not systematically collected by field. The projections in Figure 6 appear to be roughly consistent with the projections of trends in baccalaureate degrees used by NSF in forecasting faculty demand by field.15/

15/ NSF links staffing levels in the physical and life sciences to total science and engineering baccalaureates, excluding social sciences, "to reflect the service function performed by faculty in these two fields from students majoring in other science/engineering fields." (NSF, 1979, p. 80) NSF uses NCES baccalaureate data, but does its own projections.



[a] Includes statistics and computer sciences.

SOURCE: National Center for Educational Statistics, *Projections of Educational Statistics to 1986-87.*

FIGURE 6 Projected Baccalaureate Degrees, as Fraction of 1976-77 Value, 1976-77 to 1986-87.

The data presented earlier in this chapter on faculty age distribution (Table 3 and Figure 4) and on the overall supply-demand balance by field (Table 6) can be combined with these projected trends in enrollment shares to provide a summary of expected developments by broad field of science.

Life Sciences

Currently, the proportion of young faculty in the life sciences is relatively high (35% in 1977), reflecting the continued expansion of the field. Expected retirements, while below the steady-state level, are at a higher rate than in some fields in the physical sciences. And trends in enrollment demand are relatively favorable. Present indications are, then, that the life sciences may face a less severe shortage of young faculty than some other fields. If, however, the life sciences' share of undergraduate enrollments fails to rise, and if research-producing universities suffer declining enrollments overall as a result of demographic forces, the picture in the life sciences could worsen significantly by the end of the decade.

Despite this relatively optimistic picture both NSF and BLS still predict a significant excess supply of candidates for jobs traditionally requiring a Ph.D. in the life sciences by the mid-80's. This conclusion is corroborated by the projection made for the life sciences by the National Research Council's Committee on a Study of National Needs for Biomedical and Behavioral Research Personnel. A special problem which seems to face the life sciences has also been highlighted by that committee. This is the concern that the large pool of postdoctoral appointees in that field may contain significant numbers of qualified personnel who are unable to obtain permanent research positions (Coggeshall, Nowell, Bogorad, and Bock, 1978). This situation is being closely monitored by that committee.

One factor contributing to the relatively large proportion of young faculty in the life sciences is the existence of several programs in NIH, including the Research Career Development Awards program, which aid in the support of young faculty.

The Physical Sciences

Faculty in physics, astronomy, and chemistry, which expanded greatly two and three decades ago, have grown slowly since then, and slow growth is projected to continue. As a result, the proportion of recent Ph.D.'s on physics and chemistry faculties is already low (20% in 1977) and is expected to fall further. The situation is worsened by low retirement rates, especially in physics. Exits of tenured faculty to non-academic positions can be expected to ease the hiring situation to some degree, especially in some areas of chemistry where non-academic alternatives are abundant, but there are also important subfields - particularly in physics - where relief cannot be anticipated from this source.

Lee Grodzins has carefully documented the situation in physics through the use of detailed information from individual departments. His results strongly support the conclusion that even if slow growth continues in the total size of physics and astronomy faculties, gradual aging of the faculty will continue and the proportion of recent Ph.D.'s will continue to fall. A simple projection model he developed indicates that the proportion of non-tenured faculty could become as little as 10% by 1990, and that promotion rates are also likely to drop considerably (Grodzins, 1979c).

Although separate projections have not been made for the earth sciences, those disciplines seem likely to fare significantly better through the 80's. They have a relatively favorable present proportion of young faculty (30% in 1977) and a relatively favorable retirement picture. Academic and non-academic demand for Ph.D.'s in many earth sciences fields also seems likely to remain strong because of the energy problem.

The supply-demand situation for physical sciences Ph.D.'s as a whole is projected by both the BLS and the NSF to be one of moderate surplus by the mid-1980's, despite substantial recent reductions in the rate of production of physical sciences Ph.D.'s.

Mathematics

This field is projected to have a serious shortage of positions for young faculty in the 1980's, although some sub-fields including computer sciences may experience rapid growth. The current proportion of recent Ph.D.'s on mathematics faculties is relatively high (35% in 1973) but has been falling rapidly, and anticipated retirements over the next decade are lower as a percentage of total doctoral faculty than in any other field of science and engineering. A larger proportion of Ph.D. mathematicians is employed in academia than is true of any science and engineering field outside the social sciences, implying a relative lack of non-academic alternatives (although movement into non-academic employment has increased recently among mathematicians.) For all these reasons, as Richard Anderson (1979) has argued, mathematics is likely to suffer particularly from a shortage of tenured openings for at least the next decade.

Consistently with these facts, both BLS and NSF project significant non-traditional employment of Ph.D. mathematicians by the mid-1980's.

Social Sciences and Psychology

The picture for these disciplines is mixed. While the current proportion of young faculty (45% in 1977) is higher than in most science and engineering disciplines, and the retirement picture is less unfavorable than in some other fields, projected enrollment trends are relatively unfavorable to the social sciences. While these fields are not likely to experience a severe shortage of openings for new faculty in the immediate future, they may prove quite vulnerable later in the decade, as the effects of the demographic trends come to be felt more strongly.

Experience is likely to differ markedly among the individual social science disciplines. The market for psychologists and economists has been relatively strong, partly because non-academic alternatives in those disciplines are good. Markets in other social science disciplines have been weaker, and in many of them fewer non-academic positions are available.

The aggregate picture for the social sciences, according to both BLS and NSF, is one of substantial excess supply of candidates for jobs traditionally requiring the Ph.D.

Engineering

The projection methods employed in most studies of the market for Ph.D.'s are probably least appropriate for engineering. The bulk of employment at the Ph.D. level is outside of academia, so that the heavy emphasis on enrollment demographics as a principal determinant of demand for Ph.D.'s is not warranted. Furthermore, wide market-influenced swings in undergraduate science and engineering enrollments render demographics of doubtful usefulness even in projecting the academic demand for Ph.D. engineers.

The aggregate supply-demand projections for engineers prepared by NSF and BLS differ widely, which is perhaps a reflection of the limited usefulness of current projection methods for engineering. The data on retirements do suggest that few new academic positions will open from this source in the near future. However, given the wide and rapid swings in both academic and non-academic demand for Ph.D. engineers -- and the wide differences between engineering sub-fields -- the usefulness of these retirement data as an index of future employment possibilities is probably less in engineering than in other fields. As we note in chapter V, further study is needed to understand better the forces influencing the hiring of research faculty in engineering.

Conclusions

The qualifications to the basic argument and the complications surrounding the situation in specific fields are important, but they must not be allowed to obscure the basic message of this chapter: enrollment growth is essentially over, and demands for new faculty are going to fall. In some fields, hiring has already been below steady-state levels for some time; in others, hiring rates below steady-state levels are very likely to develop. Some fields of science and engineering will experience less significant drops than others; some fields -- certainly some sub-fields -- may be able to continue to hire at rates greater than steady-state rates throughout the 1980's. The exact magnitude of the drop to be expected in any field depends on a number of considerations which cannot be forecast with precision; therefore it is possible to be more confident of the direction of change than of its magnitude. Close monitoring of developments in specific fields is called for to keep track of these trends as they develop.

The significance for public policy of the reduction in new faculty hiring rates remains to be considered. Certainly it poses a significant employment problem for young Ph.D.'s. Probably it presents a significant administrative problem for universities. But does it pose a threat to the vitality of the American science and engineering research enterprise? We turn to that question in chapter III.

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CHAPTER III. THE ROLE OF YOUNG FACULTY IN THE VITALITY OF SCIENCE

The previous chapter concluded that there will be a significant decline in the rates at which young investigators in science and engineering will be hired into universities, and that this decline will continue well into the 1990's.

In this chapter we assess the implications of these trends for the effectiveness of the American research and development effort. We consider first the implications of a constricted flow of new Ph.D.'s into faculty positions for the vitality of university science, and then the consequences for the overall research effort of a potential decline in the effectiveness of academic research. Our conclusion is that young researchers are indeed of great importance to the effective functioning of university science, not because of higher productivity associated with youth *per se*, but because there are certain roles and tasks in the university research process which young scientists are especially likely to perform. The special relation of young faculty to innovation in research topics and to the spread and implantation of new ideas and techniques are crucial to the academic research effort, and that effort in turn, as we argue later in the chapter, is essential to the overall health of science and engineering.

Extensive quantitative evidence to support our analysis is lacking. There are in the first place well known problems with measuring science productivity and especially the quality of research contributions. Furthermore, our belief is that a steady influx of young people is important largely because of its impact on the vitality of the research environment of the department and research team, and not simply because of high individual productivity of young researchers. In fact, such evidence as exists on the dependence upon age of individual productivity in academic research suggests that productivity has peaks and valleys which are larger than any systematic late career drop (at most 25%).1/ There are few if any sociological studies designed to capture the interactive effects which we believe are crucial.

Fortunately, while we have found existing quantitative studies to be of limited relevance, the Committee has been able to rely instead on the experience and judgment of its members and on their broad understanding of the academic research process in assessing the role and contributions of young faculty. We have been fortunate as well to have the benefit of responses to inquiries made by this committee to the professional societies in various fields of science and engineering concerning the role of young investigators.2/ And we have also relied on available published analyses on the role of young people in science research performance and on the role of academic science in the overall research effort.

Young Faculty Researchers and the Vitality of Academic Science

While graduate students, postdoctoral fellows and associates and non-faculty doctoral research staff all make substantial contributions to the research effort in academia, it is the faculty who serve as the core of the research enterprise. It is they who carry the principal responsibility for initiating new research

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1/ A survey of the literature relating age to scientific productivity appears in Appendix C.

2/ A copy of the letter that was sent to 44 corporations and professional societies appears in Appendix A.

programs, for obtaining funds and coordinating research projects, for disseminating research results through the professional journals, and for developing new courses and in other ways improving the undergraduate and graduate curricula. A serious impairment of the flow of qualified doctoral scientists and engineers into faculty positions at research universities would, we believe, seriously damage the vitality of both the research and the instructional components of the academic enterprise.

The "young faculty researchers" on whom we shall focus are typically assistant professors in tenure track positions who perform significant amounts of research. At research universities such people are expected as a part of their normal activities to initiate a program of research, to obtain funds for it, and to develop and publish significant new research results. The normal process of tenure review involves an evaluation of their creativity, their contributions to knowledge, and their potential for future productivity. It is from the group who are promoted to tenure that the leading academic scientists and researchers come. The considerations described below argue for ensuring a steady flow of such persons into academic careers; we know of no other way to serve the purpose they do.

Encouraging Innovation in Academic Departments

One very important function of these young researchers is to provide new starts on scientific research projects in their departments. This function is well built into their jobs as assistant professors, which involve expectations of innovative research effort. As the head of a major industrial research center observed in a letter to this committee, "young researchers of necessity . . . look for new areas to open up, new fields with which they can be identified and hence establish themselves in the academic community." The continuing introduction of new perspectives, new approaches and new directions of research and teaching into academic departments is, we believe, essential in keeping departments current, exciting and vital as centers of research activity. The performance of this function is by no means uniquely associated with youth as such. The movement of more established faculty among departments and the phenomenon of older faculty reorienting their research interests cannot be neglected. But the hiring of young faculty has traditionally been a major source of such renewal in departments. Evidence that this function is highly valued in academia can be found in the vigorous search many universities have undertaken to find ways internally to ease the problem of increasing percentages of faculty on tenure which limits their flexibility and stifles innovation in departments (see Furniss, 1973; Hopkins and Bienenstock, 1975).

This potential threat to research vitality parallels another reported by Smith and Karlesky (1977) -- pressures toward conservatism in research project choice. Tight funding and shorter terms for research grants (reduced from, say, 3-5 years to 1-2 years) result in pressure on scientists to undertake low-risk short-term research projects. In their survey of selected graduate departments, Smith and Karlesky reported that investigators whom they interviewed in all science fields "voiced concerns during our site visits that they and their colleagues were beginning to 'play it safe' in this generally more austere funding environment, sticking to established lines of inquiry and taking fewer chances on novel and potentially high-payoff investigations that could fail" (p. 85). This approach to conducting scientific inquiry does not lead to thoughtful, creative, and innovative research, especially because groundbreaking work is often accomplished over a number of years. All investigators, senior or young, are subject to the pressures that result from short-term funding practices.

Conservatism in research project choice can spread over into personnel choices. In their report to the Carnegie Council on Policy Studies in Higher Education (1978) Radner and Kuh state:

> When fewer and fewer people can be hired, the predictors of creative and lasting scholarship chosen are likely to become more and more conservative. The young Ph.D. who has two published articles in addition to his thesis is likely to be chosen over the young Ph.D. who has an interesting area of research with a longer gestation period. 'Mistakes', after all, are much more costly when they can be spread over fewer people. (p. 3)

Such developments may reinforce the potential tendency toward stagnation inherent in reductions in numbers of new appointments.

Fostering Introduction of New Techniques and Methodologies

In some fields young faculty also perform an important function in introducing their departments to new techniques and methodologies, both through research practices and classroom instruction. In the social sciences, for example, quantitative techniques have developed rapidly in the post-World War II period. Each successive generation of new graduate students has been trained in ever more sophisticated quantitative techniques. The continued influx of these successive generations into faculty positions has helped to spread knowledge and use of these techniques beyond the relatively small number of graduate institutions where many of them were first developed, and has served as well as a way of introducing older faculty to the new techniques as they emerge. The Committee has noted the widespread role played by young faculty in the introduction of computer techniques to the physical and biological as well as the social sciences. Examples abound as well of new assistant professors bringing powerful new technologies like those involved in genetic engineering and DNA sequencing to their departments, and of their central role in applying ultrasensitive analytical tools such as new spectroscopic and chromatographic techniques for the solution of outstanding problems. A reasonably smooth flow of new faculty may also be important, in the context of rapidly evolving methodology, in helping the profession to assimilate new techniques and incorporate them with maximum effectiveness into the larger aims and concerns of the discipline.3/

Motivation and Enthusiasm for Research

Several other benefits flow from the fact that young scientists have just received their training. They are often intensely involved in research at the frontiers of their discipline and have a strong motivation and incentive to push ahead to new contributions. The American Geological Institute and the American Institute of Industrial Engineers have said in their letters to this committee that the more recent graduates have training that is

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3/ Thus Benjamin Ward (1972) has argued that the assimilation of mathematical techniques into effective policy-oriented research in economics after World War II was impaired by the sharp break between the pre-War "Old Guard" and the post-War "Young Turks." Members of the intermediate groups, Ward argues, were diverted by war work and thus failed to play the role of integrating the technical virtuosity of the new generation with the broader understandings of the old.

multidisciplinary. They are therefore able to study more complex problems than older investigators, whose training in these fields was more typically oriented toward a single discipline. Also, the lack of commitment to established lines of thought associated with a young mind may open young researchers up to possibilities more experienced scientists would reject out of hand. Nobel Laureate Chen Ning Yang has said, "[a]s you get older, you get less daring. You have seen so much - therefore, for every new thought you have, you immediately marshal a large number of counter-arguments," (quoted in Pelz and Andrews, 1966, p. 197).

Older scientists view young researchers as adding enthusiasm, competition, and daring to research teams. An industrial researcher wrote to the committee that "the unique contributions of young investigators are unbiased attitude, vitality and desire for recognition which adds life to the research team." And the president of a scientific society commented, "an influx of young people is important both for the new knowledge and insight they bring, and also because they enliven the interpersonal relationships which we all know (but rarely acknowledge) are important to the productivity of a research group."

Ensuring Continuity Across Generations

Another set of reasons for ensuring an adequate number of positions for young faculty members relates more closely to the concept of "continuity." As each generation of students moves through the academic career cycle, they serve at each stage as examples, guides and mentors to the generation to follow. At the extreme, a "missing generation" of young faculty in the next decade would mean an absence of successful role models and mentors for the succeeding generation of graduate students and young faculty. (See Zuckerman and Merton, 1973, on the role of mentors.) It would also lead to a distinct gap in the age structure of leading scientists and academic science administrators in later years. Such a gap would tend to impair leadership and communication across generations of research performers.

Preserving and Extending Progress in the Participation of Women and Minorities in Academic Science and Engineering

A sharp reduction in the rate of hiring of new Ph.D. faculty might pose a serious threat to continuation of the progress that has recently been made in expanding the participation of women and minorities on science and engineering faculties.

Only a small minority of doctoral scientists and engineers are women, and they are further underrepresented in proportion to their numbers in tenured university positions. Although the professional opportunities for female scientists have expanded considerably in recent years, with the greatest gains in those highly ranked universities which have traditionally employed the fewest women, sex differences persist in rank and tenure status and in salaries (NRC, 1979). In the 25 largest institutions in terms of research and development expenditures, for example, almost two-thirds of all male science and engineering faculty are associate or full professors whereas fewer than one-fourth of the female faculty are (NRC, 1979, p. 60). Across all institutions, women science and engineering faculty are substantially less likely than men to hold tenured appointments within each rank (NRC, 1979, p. xiv).

Anticipated contractions in the academic job market could eliminate most of the gains women scientists have made during the past decade. Because increases in numbers and employment of female doctoral scientists are recent phenomena, for the next several years women will continue to be concentrated in non-faculty postdoctoral positions and non-tenured junior ranks. Hence, as a group, women scientists are particularly vulnerable to cuts in tenure track positions resulting from projected enrollment declines and tenure overload. The numbers of women in most scientific fields are so small that even if reductions affect the sexes proportionately (that is, if no discrimination against women occurs in hiring and promotion), projected declines in the number of tenure track positions could result in the loss of a whole generation of female scientists. In view of the small number of women already holding tenured positions in major research departments, this would mean that the contexts in which most scientific research is conducted would again be almost completely segregated by sex, with few women teaching graduate students or holding positions in which they can develop and carry out their own research programs.

In addition to our concern with equity, we wish to ensure that both male and female graduate and undergraduate students have an opportunity to learn from and work with active researchers of both sexes. Evidence suggests the importance of female role models for women students in professional training, and students of both sexes need examples of collegial relations between equal-status female and male scientists (Gilford and Snyder, 1977).

Although the situation of minorities differs from that of women in important respects, a sharp decline in new hiring will also make it more difficult to achieve university affirmative action goals for minorities. The present underrepresentation of minorities in science and engineering has been well documented: in 1975 less than 2% of doctoral scientists and engineers were non-Asian native born minorities (Gilford and Snyder, 1977); the same group accounted for approximately 12% of the U.S. adult population (age greater than 18). A principal source of difficulty in increasing these proportions has been the low rate of production of minority Ph.D.'s, even though academic employment opportunities for qualified minority Ph.D.'s are strong (Gilford and Snyder, 1977). It is important in encouraging the production of minority Ph.D.'s to ensure that readily perceived job opportunities for minority Ph.D. researchers are available. As with women, a substantial slowdown in the opening of new academic positions is likely ultimately to slow the rate at which minority group representation in academia is increased.4/

Continued progress in these areas is important to science and to society. The possible negative impact on affirmative action goals, if something is not done, thus provides an additional reason for action to avert reductions in the hiring of young faculty at research universities.

Attracting High Quality Students to Academic Careers

As was noted in chapter II, a serious constriction in the number of new regular faculty positions may significantly discourage able young people from choosing an academic career in science and engineering. Even if, as seems likely, the academic job prospects of the best young minds deteriorate less than those of other job candidates, it is also true that these able people have the best

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4/ Hopkins (1974) analyzes the effect of changes in hiring rates of women and minorities on their long-term representation on university faculties.

non-academic alternatives. Furthermore, the effects of adverse publicity about job prospects may lead to a stronger reaction away from academia than the facts warrant.

As we noted in chapter II, empirical evidence bearing on the existence and strength of any such reaction is lacking. However, major sustained progress and major innovations in basic research are extraordinarily dependent on the contributions of a small number of unusually talented people. If academic science and engineering should lose the cream of a generation because of a perceived lack of jobs for them, the impact on research vitality would be unmistakable.

A Note on Non-Faculty Researchers

The above discussion has been concerned with the flow of young scientists and engineers into faculty positions in universities. As we noted, however, important contributions to research are also made by doctoral scholars in postdoctoral and other non-faculty research positions in universities. Postdoctoral associates are extremely important to the research effort in those scientific disciplines which rely on complex equipment, where they have come to serve as an integral part of research teams. They give day-to-day instruction to graduate students involved in a research project, they conduct experiments and often design new ones using available equipment, and they obtain valuable training themselves in the conduct of research. But they cannot, as holders of temporary positions generally lacking independent investigator status, be expected to substitute for a flow of new faculty in performing the functions described above, particularly those of initiating research efforts in new areas and ensuring continuity across generations in research performance. An important policy implication is that simply expanding the number of temporary postdoctoral positions available is not by itself an effective response to the vitality problem, despite the important contributions made by postdoctoral associates.

Similar comments apply to the non-faculty doctoral research staff -- "those scientists and engineers who are neither postdoctoral appointees nor members of the faculty and who are primarily engaged in research."5/ This group, which has been growing very rapidly at some universities and in some disciplines, is capable of contributing very effectively to the research effort. Present institutional arrangements, however, imply that non-faculty researchers generally contribute to the technical execution of a senior faculty member's research project, often over an extended period of time. They do not typically compete for funding at the national level.6/ Non-faculty researchers are not generally evaluated with the same scrutiny as faculty, either when hired or afterwards. Typically they have less job security than regular faculty members and their long term career prospects seem doubtful.7/ This situation is in part a consequence of the present short-term pattern of research funding by federal agencies, which makes it very difficult for universities to provide persons supported on research grants with the same degree of commitment and

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5/ NRC (1978), p. iii. This report includes an extensive description and analysis of this group.

6/ A recent survey of departments in biomedical research fields showed that less than one-fifth of their non-tenure track personnel had applied for federal research funding over the three year period 1974-77, and that only 11% had received federal funds during that period. Gomberg and Atelsek, 1978.

7/ See NRC (1978), pp. 54-61.

job security accorded the regular faculty. Thus, as things stand now, we cannot look to this group to perform the important functions traditionally associated with younger faculty.

Over time, funding practices and university institutional arrangements may well evolve in ways which will enhance the opportunities of non-faculty researchers to make independent contributions to the research effort. Longer term and more stable federal research funding would certainly help in that regard. Universities and policy-makers concerned with fostering this evolutionary process may be able to learn from the example of some American universities which have been working to redefine and improve the status of the non-faculty group, as well as from experience at some European institutions, including the Centre National pour la Recherche Scientifique in France. The Committee on Postdoctoral and Non-Faculty Doctoral Research Staff of the National Research Council is presently engaged in a study of non-faculty researchers, and their analysis and recommendations will be worthy of close attention.

Summary of Young Faculty Roles

While we have pointed to a number of factors relating the flow of young researchers to research vitality, we have put little emphasis in our analysis on the premise that young researchers are, as a class, uniquely creative or productive. In our view, a steady flow of "new blood" and in part "young blood" into academic departments is important in large part because of its impact on the overall research environment of the department and on the maintenance of a generational mix conducive to good communication and the most effective motivation of successive cohorts of independent investigators. Some of the effects we have pointed to are subtle and indirect. They have not for the most part been quantified in the existing literature on sociology of science -- and perhaps some of them cannot be in the present state of the art.8/ We believe further research on these questions to be highly desirable. But in the absence of definitive research, we have based our analysis on our experience and understanding of the functioning of the academic research system and on the testimony of other experienced observers. That experience leads us to believe that the vitality of academic science would be seriously impaired by sharp restrictions on the hiring of new faculty.

Criteria of Adequacy in Rates of Hiring of Young Faculty

What rate of hiring, or what proportion or number of young faculty, is "enough" to ensure vitality and continuity in an academic field? While we feel confident in asserting that "too low" a rate of new hires can be damaging to research vitality, we have no formula for determining an optimal faculty age distribution or a precise threshold below which harmful effects set in.

Nevertheless, we believe some useful things can be said. One useful criterion of "normality" in the hiring of young faculty situation is the comparison to a steady-state equilibrium with a constant faculty size and unchanging age distribution. Calculations from several different specifications of such a model suggest that a young faculty proportion of 25% to 33% (with a young faculty member defined as one within seven years of the Ph.D.) can be considered

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8/ See Appendix C for further discussion.

normal.9/ A different way of establishing a notion of a "normal" proportion of young faculty is through surveying department chairmen about what they consider to be a desirable proportion. A recent survey of department chairmen at selected departments in various science and engineering fields led to estimates of desirable percentages of young faculty ranging from 26% in botany to 37% in sociology, with the estimates for most fields clustering closely around 30% as a desirable or normal percentage of young faculty (Atelsek and Gomberg, 1979, p. 7).

Much of the analysis above emphasized the importance not just of an adequate proportion of young faculty but even more of a reasonably steady flow of new hiring. This is important in maintaining a steady flow of new research starts into departments, in encouraging good quality among the new faculty hired, and in preserving continuity. Steady-state models, allowing for significant attrition of young faculty at the time of the tenure decision, indicate that an annual rate of hiring of new Ph.D.'s on the order of 5% to 7% of the total faculty is consistent with equilibrium.

It should be noted that the problem as we have analyzed it is one that occurs in specific departments, not in a field as a whole. Appendix E reports data on distributions by rank of faculty in selected departments in the fields of mathematics, physics, chemistry, and psychology. It is clear from the data that a number

9/ Variation between 25% and 33% results as assumptions about the parameters of the steady-state model change (e.g. promotion and attrition rates). It is also true that the steady-state proportion of faculty within seven years of their Ph.D. will be lower in fields where postdoctoral appointments are common than in other fields.

of departments are already close to being "tenured in" even as the proportion of young faculty in these fields continues to drop.

The determination that a field is "in trouble" must clearly be based on a variety of indicators, including, where possible, data on individual departments. We suggest that the prospect of hiring rates and proportions of young faculty substantially below steady-state levels for a significant period of time is *prima facie* evidence of a problem. A more thorough discussion of indicators, and a comparison with the present and prospective hiring situation by field appears in chapter V in the context of our recommended program.

Importance of University Science for Research and Development in the United States

Having argued that impending developments pose a threat to the vitality of academic science and engineering, we must complete the picture by discussing the importance of university science to the national research effort. The significance of university science can be properly understood only in the context of its role as a vital partner in the overall research and development system of the United States, along with industry, national laboratories, research institutes, governmental intramural laboratories and other specialized research centers. University science is beginning a 20 year period of stresses associated with the possible loss of the important contributions of young faculty researchers and a longer term stress with a possible loss of continuity through the loss of a cohort in the teaching and conduct of science. This, coupled with other potential productivity problems discussed in recent reports on the health of science (National Science Foundation Advisory Council, 1978; Smith and Karlesky, 1978) underlies the committee's concern for the future vitality of university science, and in turn for continuity in level of performance for the U.S. research and development system as a whole.

Within our system, universities have had a special historic responsibility for carrying out fundamental research at the frontiers of science, and for teaching the succeeding generations of scientists and engineers. (For an effective discussion, see Wolfle, 1972.) The role of the university in supplying the doctoral scientists and engineers needed for employment throughout the research and development system is obvious and central. The importance to this educational effort of the maintenance of a vital research atmosphere is widely recognized.

The university's commitment to the performance of basic research is also strong, and so is its record of contributions. The National Science Foundation recently compiled a list of 85 significant advances over the last 20 years in four fields (mathematics, chemistry, astronomy, and the earth sciences). University scientists were found to have been responsible for over 70% of these innovations (National Science Board, 1977).

Many of the nation's most distinguished scientists, including most Nobel Prize winners and National Academy of Sciences members, are associated with universities. The capacity of the leading universities to contribute to basic research also results in part from their possession of some of the nation's best libraries, computers, and scientific equipment. But universities are major centers of basic research not only because of their excellent research personnel and physical facilities, but because they provide a uniquely appropriate environment for basic research. The university, through its reward system and the freedom it provides, allows its faculty to conduct research in ways that are difficult to replicate outside of academia. The criteria for promotion in academia emphasize creativity, novelty, and widespread dissemination of research findings. The university environment fosters uninhibited questioning of prevalent dogma, encourages free expression of ideas, and tolerates error as an unavoidable feature of learning. The university has a distinctive and well developed communication system ranging from formal lectures and seminars to casual discussions among the students. Departmental colloquia and frequent contacts with visitors help keep university researchers abreast of current developments in their fields. More importantly, this constant exchange of ideas provokes the discussion, excitement and controversy that lead to new directions. The educational function further provides constant and needed review and evaluation of existing knowledge. More than one research project has been significantly advanced by a student asking an important new question.

Although most of the nation's basic research is performed on the university campuses, only about 52% of total national expenditures for basic research are attributed to work performed at universities and colleges (see Table 7). Including expenditures for basic research at federally funded research and development centers (FFRDC's) associated with universities, the figure rises to 59%. Both figures understate the university's role because research at universities is subsidized as part of their educational role.

Other members of the R & D system provide an essential and complementary role to the university's basic research interests.

Table 7

PERCENTAGES OF BASIC RESEARCH SPENDING

BY PERFORMER, 1968-1978

Year	Federal Government	Industry	Universities and Colleges	Associated FFRDC's	Other Nonprofit Institutions
1968	12.5%	19.6%	50.4%	8.4%	9.1%
1969	15.1	18.0	50.0	8.0	8.9
1970	15.4	17.1	51.1	7.7	8.7
1971	13.7	16.5	53.5	7.3	9.0
1972	14.4	15.8	53.9	6.7	9.2
1973	13.8	16.3	53.0	7.7	9.2
1974	14.7	16.9	52.0	6.9	9.6
1975	15.1	15.9	53.2	6.8	9.0
1976	14.7	16.7	52.2	7.4	9.0
1977(prelim.)	15.9	16.7	51.2	7.4	8.8
1978(est.)	16.1	16.1	52.3	6.8	8.6

Source: National Science Foundation, National Patterns of R&D Resources, 1953-1978-79 (NSF78-313).

Table 8

PERCENTAGES OF RESEARCH AND DEVELOPMENT SPENDING BY PERFORMER, 1968-1979

Year	Federal Government	Industry	Universities and Colleges	Associated FFRDC's	Other Nonprofit Institutions
1968	14.2%	70.8%	8.7%	2.9%	3.3%
1969	13.7	71.4	8.7	2.8	3.4
1970	14.9	69.7	9.0	2.8	3.5
1971	15.6	68.9	9.4	2.7	3.4
1972	15.8	68.8	9.4	2.7	3.4
1973	15.1	69.4	9.6	2.7	3.3
1974	14.7	69.9	9.2	2.6	3.6
1975	15.3	68.6	9.7	2.8	3.5
1976	14.7	69.3	9.6	3.0	3.4
1977(prelim.)	14.3	69.7	9.5	3.2	3.3
1978(est.)	13.9	70.3	9.7	2.9	3.2
1979(est.)	13.4	71.2	9.6	2.8	3.0

Source: National Science Foundation, National Patterns of R&D Resources, 1953-1978-79 (NSF78-313).

Federal intramural laboratories, non-academically related FFRDC's, and independent research institutes such as the Rand Corporation obtain substantial funding either directly from the federal government or through contracts with the government. These institutions perform basic as well as applied research. The bulk of their federal funds come from mission-oriented agencies such as the National Institutes of Health, and the Department of Defense. Research centers involved in applied research take the knowledge that was generated through basic research in their own centers and in universities, and develop that knowledge to a stage necessary to help resolve an issue of national concern -- be it going to the moon or controlling disease.

Industrial funds accounted for an estimated 71.2% of research and development spending in 1979 (see Table 8) and yet this spending accounted for only 16% of the total national spending in basic research (the rest was for applied research and development). Industrial spending for basic research has traditionally been low because of the high risks and long pay-back periods involved and because of the difficulties often involved in protecting a proprietary interest in basic research findings. Indeed, this is part of the rationale for federal support of basic research efforts -- to advance the state of knowledge to the point that it will be useful to industry (and government) in planning development efforts.

This research and development system, with universities providing the core of the basic research effort in a complex research and development system, was not consciously planned, but it is almost unique to the United States. It allows individuality and diversity in the conduct of basic research and in the ways in which fundamental knowledge is transferred and developed to meet this nation's public and private needs. The linkages between the various kinds of research institutions are close and important. They come not only from the widespread publication of scientific information, but from the movement of personnel among institutions, and the competitive and entrepreneurial aspects of scientific research which provide incentives for making bold jumps intellectually. Anchoring basic research in the universities also encourages valuable interconnections among fields of science. Informal links among scholars in different fields, as well as between academic and non-academic researchers, are easily arranged. Advances in one field often cause striking transformations in others. These advances can also assist in the development of new basic and applied research programs by government laboratories and contractors, industry, and universities.

An extended example will illustrate this key point. A complex and expensive instrument called a "nuclear magnetic resonance" (NMR) apparatus is a standard item in chemical and biological laboratories. Instruments of this kind are mainstays in the inventories of many manufacturers and suppliers of scientific equipment; they come with varied characteristics, tailored to specific industrial processing needs and the less restricted demands of researchers. These devices originated from the pioneering research in the 1930's of I. I. Rabi of Columbia University, who was awarded a Nobel Prize in physics for measuring a fundamental property of atomic nuclei with a technique he invented. His technique was extended in the 1940's by two other young physicists, Felix Bloch and Edward M. Purcell, who shared a Nobel Prize in 1952. It was soon noticed that the measurement of this property was influenced slightly by the chemical environment surrounding the nucleus. This observation suggested that different chemical environments could be distinguished through their effects on a given nucleus. For a time, research papers originating from many physics laboratories had a chemical emphasis. Soon the scene of action passed to chemical laboratories and the instrument manufacturers. Next, improvements in the reliability of the instruments and the ease of their operation took them from the "state of the art" category to their appearance in manufacturers' catalogs. It was not long before they were being used to follow reactions in industrial processes and in biological systems. An example of the latter is the use of the NMR in identifying the amino acids in the peptide isolated from pig and sheep brains (hypothalamic area). This peptide, which causes the release of the reproductive hormones of the pituitary gland, has now been synthesized and is in human clinical use; in 1976 Drs. Guillemin and Schally of the U.S.A. shared the Nobel Prize in Physiology for this endeavor. The NMR story, which is a particularly easy one to trace, demonstrates that a development in what at one time was "pure" science in one field, physics, can have far-reaching practical consequences in another field, biology, through the intervention of chemistry and the industrial world, with Nobel prizes marking contributions at both ends of the chain.

It is not only the materials, techniques, and instruments of science that provide cross-disciplinary stimulus. When an advance in one field promises applicability in another, there is usually a crossing of individuals trained in the first into the second. The first generations of scientists in a new discipline have come from older ones. This mixing of persons having diverse scientific backgrounds and a common present interest has been a fruitful source of innovations.

An extensive study of foreign research systems by the Organization for Economic Co-operation and Development (OECD, 1972), indicates that our research system with its institutional links is envied by other nations. The partnership between education and basic research which has developed in the United States has been perceived as a highly successful model. This is especially true in countries that have separate teaching and basic research institutions.

For example, before 1949 China had an educational and research system that resembled that of the United States. When the People's Republic of China was established, the system was changed to the Soviet model with the universities under a ministry of education and the research institutes under an academy of sciences and mission-oriented agencies. The current Chinese system separates education from research, and fragments both education and research into narrowly defined mission-oriented areas. The Chinese now see this system as having created barriers to cross-fertilization between fields, and are working to reorganize their research and development system on the American model.

The remarkable effectiveness of this complex American system of research and development would surely be weakened by impairment in the vitality of academic science. It is unlikely that any major "slack" that is created by a decline in the effectiveness of basic research in universities can or should be taken up by expansion in the basic research efforts of the federal government or industry. The profit constraint inherent in industrial research and the mission-orientation which can never be entirely or permanently escaped in government-conducted research, impose inherent limitations on the degree of genuine, uninhibited basic research which is likely to be performed in these settings.

The American science system continues to evolve. There is a good likelihood that industry and government will expand their basic research effort in some areas -- notably in energy related areas -- in the decades ahead. The future may possibly bring further changes in research orientation and structure, such as the development of European-style research institutes. We are not opposed to such developments, which are being widely debated in the scientific community, and whose value in meeting long term national research needs must be judged on the scientific merits. But we see great value in the American system in which the university functions fundamentally as the home of basic research. Universities also play a significant role within this system as producers of applied, policy-oriented research, particularly in the social sciences. And so we believe that policy to meet the short-term problems posed by a reduction in the number of openings for new faculty should focus on preserving the vitality of academic research in science and engineering, rather than on attempting to transfer the basic research function elsewhere.

Conclusions

The great strength of the American approach to research and development as it has evolved in the post-World War II period has been its ability to combine diversity of purpose and initiative with strong interconnection and interdependence of the elements of the system. Thus, each part of the system has been able to flourish and play its essential roles, while the overall system has contributed in an unprecedented way to the economic productivity of the country.

The principal role of the university has been to foster, as an integral component of its overall mission, the provision of basic research for the nation. Government and private industry have also contributed to the establishment of basic knowledge and, they, in particular, have developed it to meet specific social needs. With the university now reaching its limit of growth within the nation's economy, special measures may need to be taken to maintain the thrust and vigor of its basic research effort. Of particular concern is the problem of declining proportions of young faculty researchers that are predicted for the next 20 years during the transition to a steady-state. Steps to offset the harmful effects of a constriction in the flow of new faculty into research universities are vital to the academic research effort. Such steps must be taken if the universities are to continue as the principal source of fundamental research upon which all other parts of the system depend.

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CHAPTER IV. ALTERNATIVE POLICIES TO PROMOTE RESEARCH VITALITY

The committee sees the central objectives of policy as the preservation of the continuity and vitality of the basic scientific research enterprise in academia. By continuity, we understand the maintenance of a sustained, consistent and improving level of quality in this research enterprise. Vitality is understood as describing the essential effort to generate new ideas and insight in established fields, new solutions of basic problems and discoveries of important new phenomena, new techniques of analysis and measurement, and the sense of excitement that such achievements provide. Considerations of quality and vitality in a field of science are best evaluated by a peer group of the most able and productive investigators in that field.

The analysis in chapters II and III has shown that the impending abrupt transition from rapid growth to no growth in the nation's university-based research poses a serious threat to the vitality and continuity of academic science and engineering. Steady infusion of new faculty has been in the past an essential component of the vitality in academic departments. It is a characteristic way in which a department starts and sustains new thrusts in its field and by which new ideas and techniques are transferred among academic research environments.

Unless ways are found to ensure a continued flow of young scholars into academic positions during the transition to a steady-state -- or unless other ways are found to stimulate the flow of new ideas and new research thrusts into academic departments -- academic research in the United States is likely to suffer serious erosion in the coming decades. In this chapter we survey briefly a variety of kinds of policies which might be undertaken in response to this problem.

Federal Awards to Support Faculty Positions in Universities

Since the principal threat to research vitality in academia comes from the impending constriction in the flow of new faculty hiring, a straightforward and effective response to the problem is a federal program to enable research universities to maintain more acceptable hiring rates of Ph.D.'s into regular faculty positions in the years ahead. Such a program might be organized in different ways.

One approach would be to make awards in support of salary for a period of years on a competitive basis to new or recent Ph.D.'s, with candidacy for the award contingent on the willingness of a specified university to appoint the award winner to a regular tenure track faculty position. The university would be required to provide assurances that this federally supported assistant professor position was an addition to other hiring that would have been done. The principal drawback of this approach lies in its interference with the normal university process for selecting assistant professors. If NSF mounted such a program, it would be basing its judgment on a review of relatively untried investigators, and its judgments might well have a significant impact on university hiring decisions, since there would be a substantial financial benefit to the university in hiring an award winner.

A second approach, which we favor, is to make the award to an existing faculty member at a university, and to require the university to use the salary funds released to hire additional faculty. This approach allows the award to be made to investigators who have had more opportunity to prove themselves. At the same time, it stimulates the hiring of new faculty while allowing the university selection process to operate in the normal way in determining whom to hire. A properly designed program of this kind can have a double impact in sustaining research vitality: it would both enable (and require) the university to increase its hiring of new faculty and, at the same time, recognize and encourage the research contribution of the faculty member receiving the award. A detailed description of such a program is in chapter V below.

Early Retirement and Career Change Options

Such programs would create new positions for junior faculty by encouraging the voluntary exit of more senior people from full-time academic appointments. Program alternatives include financial incentives for early retirement, arrangements for part-time academic employment coupled with receipt of partial retirement benefits, provisions for part-time placements outside of academia, and subsidized mid-career retraining and relocation opportunities for other occupations, both inside and outside academia. A number of these alternatives have been discussed in considerable detail in recent publications.1/

Experience to date with the above schemes has been mixed. Those plans which are most attractive to the faculty member involved tend to be least attractive to the institution and vice versa. Those plans which would be moderately attractive to both run the risk of departure of the most competent and productive older faculty, who tend to have the best non-academic alternatives. Programs in this

1/ See Patton (1979 a,b), and Furniss (1973).

arena which contain any hint of compulsion run the risk of legal challenge based on age discrimination.

Our conclusion is that effective retirement and career change programs which can surmount these difficulties can only be designed and implemented at the level of the individual institution, with careful attention to the peculiar needs and situation of that place. We urge universities and colleges to pay serious attention to these alternatives, but the direct federal role should for the present be limited to disseminating information about program alternatives.

Policies to Maintain the Vitality of Existing Faculty

As expansion of faculty size comes to be less available as a means of stimulating innovation and renewal in academic research, the importance of looking to existing faculty members to perform these functions increases. The aim here is to encourage faculty members to keep abreast of developments in their fields, and to facilitate efforts by faculty members to shift their research interests toward new fields when that is warranted.

NSF already supports such efforts to a significant degree, and we commend them for it. But we also believe NSF should explore ways to expand and improve these efforts. More study and experience will be needed to determine what programs work best. Chapter VI includes some further discussion of this problem, with recommendations to NSF about approaches to try.

Expanded Federal Postdoctoral Fellowship Programs

The federal government could increase the number of temporary positions for young scholars during the period of academic job shortage through increased use of postdoctoral fellowships. Some other programs which have been recommended to counter the "young investigator" problem, including the Radner-Kuh "Junior Scholar" program and one aspect of the program described by Morton Baratz, are variants of the postdoctoral fellowship mechanism.2/ The number of persons on postdoctoral appointments varies greatly among fields (see Table 9). In physics, chemistry and many areas of the life sciences it is already relatively large. Some of these people receive portable fellowship support, though most are supported through the research-grant and training-grant mechanisms (NRC 1978a).

Postdoctoral appointees play a very important role in the research process in their disciplines, and the postdoctoral appointment has come to be a nearly essential first step in a productive academic career in many areas of science. We note that the NSF National Needs Postdoctoral Fellowship program is being maintained and that categorical programs are being introduced in some fields. We encourage NSF to consider expanding this program. NSF should also consider whether the present maximum term for a postdoctoral fellowship should not be extended for a year or two, to a total period of three or four years, to make better use of the available young research scientists, and whether the postdoctoral fellowships can be structured to include an optional teaching component, to be supported with university funds. The purpose of such a teaching component would be to facilitate entry into academic careers for those who seek them.

We do not, however, consider the expansion of such fellowship programs to be in itself a sufficient response to the central issue

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2/ See Radner and Kuh (1978), Baratz (1978).

Table 9

ESTIMATED TOTAL NUMBER OF PH.D. RECIPIENTS ON POSTDOCTORAL APPOINTMENTS IN EACH FIELD OF SCIENCE, 1972-1977

	1972	1973	1974	1975	1977	5-year Growth
Total, all fields	7664	9160	8991	10,051	11,818	54.2
Mathematics	131	144	191	173	144	9.9
Physics	1223	1390	1294	1189	1225	.2
Chemistry	1394	1620	1842	1757	1835	31.6
Earth Sciences	238	289	305	323	441	85.3
Engineering	324	456	375	344	521	60.8
Agricultural Scis.	81	134	131	216	196	142.0
Biosciences	3650	4301	3968	5141	6180	69.3
Psychology	394	458	520	547	738	87.3
Social Sciences	229	368	365	361	538	134.9

SOURCE: NRC, Survey of Doctorate Recipients, 1973, 1975, 1977; NRC, Survey of Earned Doctorates, 1973, 1975, 1977.

of research vitality. First, in many scientific fields, the postdoctoral mechanism is already in place, used frequently, and functioning with great effectiveness. The problem in these areas is a lack of more permanent academic positions following the postdoctoral appointment. Expansion of postdoctoral fellowship or research associateship programs may therefore be more helpful in those areas such as mathematics and the social sciences where it has been less used in the past. Effective utilization of more postdoctorals in such areas may require some redefinition and restructuring to make them more appropriate to the research styles of those disciplines.

But there is a more fundamental problem with reliance on the postdoctoral fellowship as the main response to the vitality problem. Our earlier analysis implied that the key threat to vitality resulting from a shortage of young scholars lay in the loss of the new starts, the influx of new ideas, and the introduction of new research areas and techniques which such scholars bring. These contributions are, as we argued in chapter III, more likely to have lasting effect if made by full-time members of the regular faculty, who are well integrated with the teaching and research of their departments and who function as independent investigators. Post-docs play an enormously valuable role as producers of research, but they cannot be looked to as the principal source of innovation and renewed vitality in academic departments.

Expansion of Non-Faculty Doctoral Research Staff in Universities

Increasing numbers of Ph.D.'s hold non-faculty research appointments in universities in positions "parallel" to the normal faculty career ladder.3/ At some institutions, such as MIT and the University of Wisconsin, the rules governing these appointments are carefully codified, while at others they are more informal. As discussed in chapter III (pp. 63-65), such appointees typically have less job security than regular faculty members and typically have significant restrictions on their ability to function as independent investigators. These institutional limitations are closely linked to the fact that non-faculty positions are mainly financed on so-called "soft" money -- research funds which do not provide the stable basis needed for providing positions carrying the degree of university commitment and job security associated with regular faculty positions.

The pool of non-faculty researchers is likely to continue to grow in the decade ahead even in the absence of policies to encourage such growth. We see the need to establish viable and attractive careers for people in such positions as a major policy issue facing universities in the coming years. We do not, however, advocate federal programs to encourage the development of non-faculty doctoral research career tracks as the most effective and immediate response to the vitality problem. Under present institutional arrangements, such people are, like post-docs, likely to play a more valuable role as producers of research on projects initiated by others than as initiators of new scientific projects. Changing the predominant role of non-faculty doctoral researchers to

3/ A recent National Research Council Committee report examines the growth in numbers of this group, their role in the research enterprise, and their status in the university. See NRC, 1978b.

that of research initiators would require important and demanding changes in administrative practices, patterns of university governance, and self-perceptions among non-faculty researchers. Furthermore, the capacity of universities to make the financial and other commitments required to give non-faculty researchers more independent status is handicapped by the short-term nature of the funding for most non-faculty positions. As we noted in chapter III, encouraging a desirable evolution of the situation of this group is an important long-term objective for universities and policy-makers, and we expect the recommendations of the Committee on Postdoctorals and Non-Faculty Doctoral Research Staff to have an important bearing on this goal.

Expansion of Research Institutes and National Laboratories or Creation of New Ones

Institutes and laboratories which decouple the conduct of scientific research from the education of students are a possible response to the threat of reduced vitality of academic science posed by demographic developments. Our discussion in chapter III argued that university science is only one component, but an indispensable one, in the nation's overall research and development effort. We pointed to several unique aspects of the university environment, relating to its communication system, its reward structure, and its traditions of academic freedom, which are not readily duplicated outside the academic environment.

Clearly, however, there are some research tasks that might be as well or better performed in national laboratories or research institutes as they are in universities, and we believe proposals to expand such facilities or to create new ones should be evaluated on their own merits. But we do not believe that a general movement to transfer the basic research mission out of the academic environment would be a desirable response to impending problems in any major field of science or engineering. Such a program would be enormously expensive, and it would fail to come to grips with the essentially transitional nature of the problems addressed in this report. We do not discourage development of such institutions where they promise to respond effectively to a long-term research need. But we have concluded, in regard to the problems with which this Committee is concerned, that the stress should be on programs to ensure the vitality of academic research during the transition to a steady-state, rather than on programs to move research out of academia.

Expansion of the Basic Research Effort in Industry and Government

Similarly to the alternative just described, such programs would seek to create research positions outside academia to accomplish research in a vital environment during a period of university decline. Our response is also similar. While there are important research tasks, including some tasks in basic research, for which government and industry are well equipped, we believe, as we argued in chapter III, that the university environment is uniquely well suited for the performance of many kinds of basic research. While attractive proposals to develop research capabilities in industry and government should be appraised on their merits, it seems unnecessary and undesirable to divert federal funds from universities for this purpose.

Conclusion

The pressures and challenges of the 1980's and 1990's are likely to call forth a number of significant changes in the organization and conduct of academic research. We have noted above several potential policy areas where universities and colleges may need to act in the years ahead, and where a sustained or expanded federal role is called for. Further study of a variety of policy alternatives and close monitoring of the evolving situation in academic science will be needed in order to guide federal and institutional policies intelligently through the coming decades.

We believe strongly that a principal element in such an evolving group of policies and programs should be a program of awards to support faculty positions in universities under carefully defined conditions. Such a program can be implemented promptly and effectively by the federal government on the basis of existing knowledge, and it can have a significant and rapid impact on maintaining academic research vitality at moderate cost. Action on a program of this kind should receive high priority in the federal government. In chapter V we spell out our recommended program in detail.

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CHAPTER V. A PROGRAM FOR IMPROVING THE FLOW OF NEW FACULTY INTO RESEARCH UNIVERSITIES

There is need to maintain an adequate flow of new faculty into research universities as academic science and engineering make the transition from the rapid growth of the 1960's to the conditions of slow or no growth which have begun and are likely to worsen.

We have analyzed in chapter III the contributions made by young faculty to research vitality. We found that what is really important to academic research is (a) the continued introduction of new ideas, techniques, and lines of research in academic departments; (b) the opportunity and incentive for excellent young people to opt for scientific careers; and (c) the maintenance of sufficient continuity in the age structure of faculties to sustain healthy communication and cooperation across generations. All these factors argue not so much the importance of youth *per se* to scientific creativity; rather they stress the importance of an adequate flow of new faculty in ensuring the regular introduction of new people and ideas, as well as the evolution of a balanced age distribution over time.

The evidence in chapter II supports the case that serious constrictions on the hiring of new faculty are felt already in some fields and will arise soon in others unless preventive action is taken. The problem as we see it is essentially transitional. Hiring for replacement is low because retirement rates, while gradually rising through the 1980's, will be below steady state levels until well into the 1990's. Hiring for growth is small or non-existent because of enrollment trends. A program to encourage some additional hiring of new faculty at research universities in anticipation of future retirements will avert the most serious effects of a constriction in hiring of new faculty and allow a smoother transition to a steady-state age distribution.

Quite recently, a number of alternative programs have been advanced as ways of permitting universities to augment their hiring of young Ph.D.'s. Based on our analysis of the nature of the problem and of the process by which first class scientific research is produced, we urge the following as basic criteria which any proposed program of this kind should meet:

(a) the mechanism by which additional hiring will be generated should be clearly spelled out;

(b) to enhance the contribution to research vitality, those employed as a result of the program should be appointed to academic positions which permit them to be independent investigators and active, contributing members of their departments;

(c) the program should ensure that the additional positions created are filled by scholars with high research potential;

(d) the program, while making more faculty positions available in universities, should interfere as little as possible with the normal processes by which universities select among candidates for available positions;

(e) the program, so far as possible, should increase the effectiveness of the research effort of existing faculty as well as encouraging the hiring of new faculty;

(f) the program should be responsive to variations over time and across fields in the number of positions needed, and should be readily phased out when the need for it has ended.

These criteria are best met, we believe, by a program which provides research awards in support of salary for existing faculty members and requires the university to use the funds thereby released to hire additional faculty. Direct fellowship awards to new Ph.D.'s, while seemingly a more straightforward solution, are not compatible with bringing those people into the university faculty development process in the normal way. Achieving this end seems very important to us, both from the standpoint of preserving the autonomy of the university selection process and in order to maximize the research effectiveness of those hired.

The Research Excellence Award Program (REAP)

General Description

The principal goal of this program is to enable universities to hire additional young faculty in fields of science and engineering where the vitality of research is threatened by a shortage of positions for such people. An additional, and very significant, benefit of the program is to recognize and encourage the research activities of the most able, productive and promising scientists and engineers presently employed in academia. The program will provide a five-year stipend in support of salary to award recipients selected from existing faculties, with the released university funds going to support the employment of new faculty members.1/

1/ The Committee considered both shorter and longer time periods for the award, and concluded that five years offered the best balance among competing considerations. It is adequate time for a new faculty member to be brought into the faculty development process and for the award winner's research efforts to be substantially assisted, and it is also long enough to give institutions a substantial incentive to participate in the program. At the same time, five years is short enough to allow the magnitude of the program to respond effectively to changing needs and to allow the program to be effectively administered. It is possible that considerations specific to certain fields of science or to administrative practices of agencies other than NSF which may wish to participate in a similar program might argue for a shorter or longer award period.

The key features of the Research Excellence Award Program are as follows (detailed provisions are elaborated in the following sections):

Nominees must be full time faculty members on regular appointments (either tenured or non-tenured in a tenure track position) in departments in those research fields announced by NSF as eligible for awards. A nomination will be made by a department but must include a five-year research plan prepared by the nominee and a staff development plan prepared by the department or equivalent employing unit and endorsed by the university.

The research plan and department plan are to be reviewed by recognized leaders in the relevant field. The department plan must have the effect of bringing at least one more new young faculty member into the faculty development process (i.e., the tenure track) than would have started through normal replacements for retirements and attrition.2/ The department plan should identify clearly the source of the tenure track opening for which the new faculty hired under the program will be eligible to compete. Selection of the new faculty and their review for tenure are to be carried out according to the normal university process. The university must provide assurance that the new faculty hired have a normal, adequate opportunity for the development of a strong research and teaching program, and that they have a meaningful opportunity (defined in more detail below) to compete for the tenure track opening committed

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2/ The tenure track position may be one which would otherwise have opened five or more years after the date of application due to a projected retirement or other attrition of any member of the departmental faculty or it can be created by net growth of departmental faculty.

by the university as part of this program. Teaching and service loads for award recipients are to be specifically defined in the award proposal and are to be justified in terms of successful accomplishment of the research plan. The stipend will be set at a level that will release sufficient funds to enable the university to hire a new young faculty member and will also provide summer salary support for the award recipient.

Program Rationale

REAP responds directly and effectively to the threat of reduced vitality in science posed by the shortage of young researchers in academia. The awards provide support to enable the most effective and creative researchers presently in science and engineering departments to devote more of their energies to research. And, by freeing university funds for the specific purpose of hiring more young scholars into tenure track positions, the awards will enable universities to hire in anticipation of retirements and other turnovers, thereby enabling those departments to accomplish a smoother transition to a balanced age distribution.

The program ensures that universities will have normal freedom in selecting the new persons to be hired, thus taking full advantage of the universities' sophisticated and effective recruitment and evaluation process, and avoiding any hint of NSF interference in university hiring decisions. Because the individuals to be hired will have full faculty status, and therefore be well integrated into their departments, they will be in the best position to perform their essential function as innovators and sources of "new starts" in basic research. Further, the obligation the university is under to identify a meaningful tenure track opening for which the new faculty member will compete should encourage universities to focus attention on their age distribution problem and where possible to make tenure openings available sooner through anticipating retirements and perhaps by encouraging early retirement and other turnovers.

The program will further serve as a highly visible encouragement to the best young prospective scientists and engineers that excellence in research in science and engineering continues to be valued and rewarded in our society.

Application Procedure

(a) Award nominees must submit a five-year research plan. The plan should include a detailed description of their research plans in the near future and a less detailed description of longer term plans. At least three letters of recommendation are to be supplied by qualified scientists acquainted with the nominee's research.

(b) The nominating department must endorse the nominee's research plan, including plans for teaching and other departmental responsibilities. In endorsing the plan, the institution will agree to supply space, access to necessary equipment, opportunity for major involvement in research, and a teaching arrangement consistent with execution of the research plan.

(c) The nominating department must submit a faculty staffing plan including the past five years hiring, promotion, and anticipated retirements and anticipated new hires for the next six years. The plan should indicate how the award is expected to influence the vitality of the department's research activities. This staffing plan is to be endorsed by the department, the appropriate dean and the principal academic officer of the institution.

Award Conditions and Regulations

(a) As the intent of the award is to encourage faculty development, continuity, and vitality, award recipients are expected to serve as regular members of their departments, and especially to carry out innovative research. Appropriate assignments of teaching and of committee and other departmental and university-wide service are to be explicitly defined in the research proposal and are to be justified in terms of successful accomplishment of the research plan. These arrangements should be reflected in the staffing plan to be submitted with the award nomination.

(b) An annual report is to be submitted by the award recipient and his/her department. The report is to include a description of progress on the awardee's research program and a description of the department's actual staffing in relation to the staffing plan stated in its original proposal.

(c) A department receiving an award must undertake to hire a new faculty member in a non-tenured tenure track position, additional to those who would have been hired in the absence of the award. The department and university must provide assurance that the new faculty hired will have a reasonable opportunity to achieve tenure. For this reason, the department staffing plan must indicate how many other members of the institution's faculty are expected to be candidates for the tenure track opening committed by the university as part of the program. Inclusion of more than three members of the faculty (including the new faculty member hired under the program) among the candidates for the tenure track opening is to be taken as evidence that the new faculty member's opportunity to achieve tenure is unacceptably low.3/

During the period of recruitment for the new faculty member, the university is permitted to use funds released by the award to hire temporary, non-tenure track employees to cover the research and teaching needs generated by the department's participation in the program. However, failure to fill the new tenure track position within two years after commencement of the award will result in the award's termination.

The obligation to maintain the additional position continues through the term of the award. Hence, if the first person hired leaves the department during the term of the award, the department must again initiate hiring.

(d) The award will be administered by the department chairperson (or equivalent) and will provide a fixed sum of partial support toward the academic year salary of the award recipient. In addition the cost of two months' summer research salary and fringe benefits for the award recipient will be provided (if requested). An 8% allowance for indirect costs to cover administrative expenses will also be awarded to the department.

The fixed sum is to be calculated annually by the NSF as equivalent to typical new faculty academic year salary and fringe benefits at research universities in NSF supported fields (approximately 22-24 thousand dollars).

3/ The university will of course be free at the time of the tenure appointment to include candidates from outside the university in its search.

For both the award recipient and the new faculty member hired, the salary and salary adjustments are to be set by normal university review procedures.

(e) Should an award holder elect to move to a second institution, the award to that individual may continue if the second institution reapplies to the NSF and satisfies all the necessary conditions for the award, including the required expansion in the junior faculty ranks.

(f) The award will be terminated if the recipient accepts a major administrative assignment (i.e., half-time or over) which might lessen the research impact of the award.

(g) The award recipient remains fully eligible to compete for research funds through all regular channels.

Criteria for Assigning Priority among Competing Applications

(a) The primary criterion for making awards is the nominee's potential for making important contributions in science during the term of the award, as judged by the quality of the research plan and the nominee's record of past research performance, with major emphasis on productivity within the last five years.

(b) The nominating department's need and commitment to additional junior faculty in order to maintain or enhance research vitality should be weighed on the basis of the department's current staff and staffing plan, and staffing actions over the last five years. This staffing plan should describe the opportunity provided by the nominating department for additional faculty to develop productive research programs and thereby enhance the research vitality of the department. It is plain that providing this opportunity necessitates a substantial commitment on the part of the university to provide space and access to equipment for the new faculty.

(c) In evaluating younger candidates for awards, major attention should be given to the potential of the award to aid in the nominee's career development. Recent Ph.D.'s nominated for the award need not have an extensive list of publications, but neither should awards be made to untried investigators.

(d) In evaluating more experienced candidates for awards, special attention should be given to prospects for a favorable impact on the research field, including opening of new areas or bringing the investigator's established expertise to bear on a new problem which could benefit from his or her special skills.

(e) In determining the balance of awards between younger and older scientists, the special importance of encouraging the contributions of younger scholars should be recognized. Applications should be encouraged from younger scholars, and the review process should attempt to ensure that a substantial number of younger faculty will be among the award recipients.

(f) The adequacy of the department and university facilities and environment for performing the research described in the nominee's plan should be weighed.

(g) In making the awards, the special roles that female and minority scientists have in training graduate students and the special role of institutions that train disadvantaged students who are underrepresented in scientific careers should be considered. NSF should therefore make clear that nominations of women and minorities are to be vigorously encouraged. New hires generated by the program must be made in compliance with university affirmative action commitments, and this program offers the university an excellent opportunity to achieve these objectives.

Program Magnitude, Timing and Implementation

We describe below the principles and criteria that should be employed in determining the size of the program, the distribution of awards among fields, the timing of phase-in and phase-out, and the funding and administration of the program. Where appropriate, approximate numbers are suggested. Actual implementation will, of course, require close knowledge and careful monitoring of the situation in specific fields and sub-fields.

Criteria Concerning Eligibility of a Field for Awards

We expect that Research Excellence Awards will be made in only some fields in the near future. Eligibility of a broad field for awards should be based fundamentally on the severity of the shortage of places for new faculty. However, in recommending a program to NSF, we also need to recognize that the degree of responsibility NSF carries for funding research varies considerably by field (see Table 10). The program we describe is premised on NSF responsibility and NSF funding. We strongly urge that other federal agencies which support significant amounts of research consider developing parallel programs in the areas they support, or that they consider participating with NSF in providing financial support for an expanded version of the program described here. To determine the severity of the shortage of new positions in a field, NSF should

TABLE 10

FEDERAL OBLIGATIONS FOR BASIC RESEARCH IN UNIVERSITIES AND COLLEGES BY SELECTED SUPPORTING AGENCIES AND BY FIELD, 1973-1976

[Dollars in millions]

Field of science[1]		Five-agency[2] total	Department of Agriculture	Department of Defense	Department of Health, Education, and Welfare	Energy Research and Development Admin.[3]	National Science Foundation	NASA
		Current dollars						
All fields	1973	$847.2	$37.2	$105.0	$317.9	$59.9	$327.2	$41.8
	1974	887.4	38.1	97.4	388.4	56.5	306.9	54.3
	1975	967.2	43.3	95.3	392.3	57.5	378.7	64 5
	1976(est.) .	1,070.7	49.1	107.1	445.0	61.7	407.7	52.9
Life sciences	1973	366.3	26.2	8.3	263.5	11.1	57.2	NA
	1974	430.7	26.6	7.2	326.6	5.6	64.7	NA
	1975	451.5	30.3	9.8	332.1	—	79.3	3.7
	1976(est.) .	506.8	35.0	9.9	377.0	—	84.9	3.9
Physical sciences	1973	177.3	1.9	19.9	18.0	43.0	94.5	NA
	1974	176.2	1.9	18.1	22.4	45.7	88.1	NA
	1975	201.6	2.0	18.7	26.2	48.6	106.1	33.2
	1976(est.) .	220.6	2.4	21 7	29.9	51.8	114.8	27.7
Astronomy	1973	9.4	—	1.6	—	—	7.8	NA
	1974	9.0	—	.2	—	—	8.8	NA
	1975	8.8	—	.2	—	—	8.6	17.9
	1976(est.) .	9.5	—	.3	—	—	9.2	17.1
Chemistry	1973	62.7	1.9	4.4	18.0	8.3	30.1	NA
	1974	64.5	1.9	4.7	22.4	5.6	29.9	NA
	1975	79.5	1.9	5.1	26.1	7.6	38.8	3.1
	1976(est.) .	90.3	2.3	6.8	29.8	8.5	43.0	1.9
Physics	1973	99.7	([5])	13.3	([5])	34.7	51.7	NA
	1974	101.6	([5])	12.7	([5])	39.4	49.5	NA
	1975	112.1	.1	12.9	([5])	40.4	58.7	9.7
	1976(est.) .	119.0	([5])	13.6	([5])	42.6	62.7	6.8
Other physical sciences	1973	5.5	—	.6	—	—	4.9	NA
	1974	1.0	—	.4	—	.7	—	NA
	1975	1.1	—	.4	—	.6	—	2.5
	1976(est.) .	1.8	—	1.0	—	.7	—	1.9
Environmental sciences	1973	80.5	.4	28.9	([5])	—	51.2	NA
	1974	89.2	.7	20.6	—	.4	67.5	NA
	1975	102.6	.8	21.7	—	.5	79.6	16.5
	1976(est.) .	113.2	.8	23.7	—	.6	88.1	12.8
Engineering	1973	75.5	1.2	26.4	3.3	3.5	41.1	NA
	1974	76.6	1.4	31.8	3.5	3.7	36.2	NA
	1975	94.4	1.8	27.6	3.8	6.8	54.4	8.4
	1976(est.) .	99.1	1.5	31.6	4.3	7.5	54.0	6.9
Social sciences	1973	45.7	7.5	.1	16.2	—	21.9	NA
	1974	41.8	7.4	.2	15.1	—	19.2	NA
	1975	40.1	8.4	.3	8.5	—	23.1	.1
	1976(est.) .	46.0	9.4	.1	9.8	—	26.8	.1
Psychology	1973	29.0	—	5.3	14.3	—	9.4	NA
	1974	29.6	—	7.1	17.2	—	5.3	NA
	1975	29.3	—	4.4	17.0	—	7.9	.8
	1976(est.) .	34.0	—	5.8	19.6	—	8.6	1.1
Mathematics	1973	40.9	([5])	16.2	1.1	2.4	21.2	NA
	1974	36.3	.1	12.5	2.0	1.1	20.5	NA
	1975	41.6	([5])	12.8	2.3	1.6	24.9	.5
	1976(est.) .	44.9	([5])	14.0	2.6	1.8	26.5	.3
Other sciences[4]	1973	32.1	—	—	1.4	—	30.7	NA
	1974	7.1	—	—	1.6	—	5.4	NA
	975	6.2	—	.1	2 5	—	3.6	1 3
	1976(est.) .	6.1	—	3	1 9	—	3.9	.1

Source: NSB, Science Indicators, 1976

consult various indicators and keep abreast of expert judgments about conditions in the field. The following are among the key indicators the NSF should monitor:

(a) The ratio of recent doctoral faculty (those having received their degree in the last seven years) to total doctoral faculty. This time-dependent measure, compared to its steady-state value, is a simple indicator of the degree to which hiring has been restricted in the recent past.

(b) Proportion of the faculty aged greater than sixty. This is a useful and objective measure of openings likely to become available through retirements in the near future.

(c) The rate of change (as contrasted with present value) of the ratio of recent to total doctoral faculty. As Grodzins (1979b) has argued, the rate of change in this proportion is a more sensitive measure of current developments in the field than is its level.

(d) The annual rate of change in total doctoral faculty over a representative recent period. This is an indication of the number of positions in the field becoming available through faculty growth.

Recent values of these indicators by broad field of science for all Ph.D. granting institutions and for the major research producers are shown in Table 11. NSF should also, where possible, examine data by individual departments within a field. As the data for mathematics, chemistry and physics departments in Appendix E indicate, the distribution of young faculty among departments in a field is highly uneven, and data aggregated by field could potentially mask a serious difficulty at a subset of institutions.

A decision about the existence of a problem in a particular field should be based on a determination that all or most of the

Table 11

INDICATORS OF SEVERITY OF SHORTAGES OF POSITIONS FOR NEW FACULTY

	TOTAL ALL FIELDS	MATH	PHYSICS	CHEM	EARTH SCI	ENGIN	AGRIC	BIO SCI	PSYCH	SOC SCI	STEADY STATE VALUE a/
A. All Ph.D. Granting Institutions											
1. Ratio of recent to total doctoral faculty, 1977 (%)	33.7	36.5	20.7	23.2	31.6	26.7	29.2	34.1	36.0	44.5	33
2. Ratio of full-time faculty aged greater than 60 to total full-time faculty, 1977 (%)	5.5	4.5	3.3	8.0	7.4	4.0	7.5	5.9	4.7	6.2	9.2
3. Annual rate of change in ratio of recent to total doctoral faculty, 1973-77 (%)	-4.6	-7.2	-9.4	-6.0	-2.7	-10.4	-2.0	-2.1	-4.6	-2.1	0
4. Annual rate of change in total doctoral faculty, 1975-77 (%)	3.4	.8	1.7	2.2	0	2.8	0	4.0	0	10.0	0
B. Major Research Universities											
1. Ratio of Recent to total doctoral faculty, 1977 (%)	32.3	35.4	23.5	23.0	35.7	26.2	28.1	32.1	35.0	41.5	33
2. Ratio of full-time faculty aged greater than 60 to total full-time faculty, 1977(%)	6.3	4.5	3.2	6.8	6.5	4.8	8.2	6.8	5.7	7.6	9.2
3 Annual rate of change in ratio of recent to total doctoral faculty, 1973-77 (%)	-3.9	-7.0	-7.1	-7.0	0	-8.3	-0.8	-2.8	-3.1	-1.9	0
4 Annual rate of change in total doctoral faculty, 1975-77 (%)	3.1	0	6.6 b/	0	2.0	2.2	0	3.2	0	10.1	0

Source: NRC, Survey of Doctorate Recipients.

a/ See Appendix D for derivation of steady-state parameters.

b/ This high growth rate from 1975 to 1977 follows a significant drop in faculty size in physics at major research universities from 1973 to 1977. The annual growth rate in physics faculties over the four years 1973-77 is just 2.4%.

indicators point toward a prospective shortage of positions for new faculty. Using this criterion, it is clear from Table 11 that the fields of mathematics, physics, chemistry, and engineering are in a significantly worse position for the near term than other fields.

In all four of these fields, the ratio of recent to total faculty has been declining rapidly (at a rate of between 6% and 10% per year) and growth in total faculty has been slow or non-existent (on the order of 2% per year or less at the major research producers4/). In physics, chemistry, and engineering, the present ratio of recent to total faculty is also low (ranging from 20% to 26% across these fields). In mathematics, that ratio is still relatively high (36%), but the departmental data suggest that a significant fraction of the junior people in mathematics are instructors, many of whom are probably not on a tenure track.

Although a reasonable case can be made that all four of these fields have a shortage of young faculty, we recommend that the REA program be started immediately only in mathematics and physics. In both these fields the retirement shortfall is very severe, with retirements in both fields expected to run at less than half the steady-state rate for the next five years. The implied shortfall in replacement hiring, coupled with the other indicators of a shortage of young faculty in mathematics and physics, support our recommendation for an immediate start in those two fields. In chemistry, on the other hand, the retirement situation remains

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4/ As footnote b in the table indicates, the high rate of growth in physics faculties at the major research institutions is probably anomalous.

relatively favorable for the next few years, and will then begin to worsen.5/ It therefore seems advisable to delay two or three years before beginning the program in chemistry.

We have decided against recommending the program for engineering at present because, as noted in chapter II, the underlying forces shaping the market for Ph.D. engineers are quite different from the demographically driven forces we have stressed. Powerful cyclic components in the market for engineers strongly affect both undergraduate enrollments (and hence requirements for engineering teaching faculty) and the non-academic employment prospects for Ph.D. engineers. While we believe a mechanism like the REA program could potentially be of use in smoothing the academic hiring of Ph.D. engineers, we feel unsure about how to analyze the proper timing and magnitude of its deployment. We therefore recommend further study of the special problems of the academic market for Ph.D. engineers.

Magnitude of the Program in a Specific Field

The following principles should be observed in determining the annual number of new REA awards to be made in a specific field which is declared eligible for the program:

(a) The number of awards should be keyed to the size of the problem in that field. The size of the problem can be measured by the departure of the key indicators cited above from their steady-state values at research producing departments in that field. The program should aim only partially to correct deviations from

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5/ See Table 3 in chapter II for confirmation.

these steady-state values, for at least two reasons. First, this will ensure against over-correction which would only cause the problem to reappear later. Second, partial correction will avoid the danger of maintaining the status quo in a field which is declining because of a loss in potential for productive research. Partial correction -- amounting perhaps to half the departure from the steady-state value -- will allow the relative size of different research fields to adjust over time to changing patterns of research interest, while smoothing the transition to slower growth rates in academic research as a whole.

(b) The number of new starts in each field funded should be kept small enough to ensure that high quality can be maintained among award recipients.

(c) The program in each field funded should be large enough to permit cost-effective operation and to ensure that the success rate among highly qualified applicants will be sufficient to keep good people applying. Success rates in postdoctoral fellowship competitions are in the range of 10% to 20%; they should be at least that high in this program to attract excellent faculty applications.

Application of these criteria to the fields of physics and mathematics, where we urge that the program be begun immediately, suggests initial award levels of approximately 30 per year in physics and 30 per year in mathematics. This amounts to roughly 50% of the difference between actual and steady-state retirements over the next five years at the Ph.D. granting institutions.6/ These numbers are small enough to ensure high quality among award recipients. If new starts were made at this rate every year for ten years, a total of 300 awards would be made in each field. This would probably be enough to ensure that a reasonable proportion of applicants was funded over the period, but if early experience indicated that the success rate was disproportionately high or low, the number should be adjusted after two years. These are, we believe, conservative estimates of a desirable program size. Larger numbers of awards would not be difficult to justify.

Overall Magnitude and Cost of Program

This will depend on how many fields ultimately require support and on the magnitude of support needed in each field. That in turn will depend very heavily on the extent to which the effects of the demographic downturn come to be felt at research producing institutions. Since retirements are expected to be low in most fields, even a leveling of enrollment would be enough to produce a significant shortage of positions for young faculty in most fields. Clear evidence on the extent to which the demographic downturn will be felt at the major research institutions will not be available for several years. But it is essential that the program mechanism be in place in order to respond as needs become evident in specific fields.

6/ In mathematics, actual retirements over the next five years at the major research producers (assuming retirement at age 65) will be 4.5% of faculty compared to 9.2% under steady-state conditions. Total doctoral faculty size is 7434. There will be a shortfall of 348 retirements over five years; half of that difference per year is 34. In physics, the actual retirements are expected to be 3.3% of a faculty of 4803. The shortfall is 284 over five years; half the annual difference is 29.

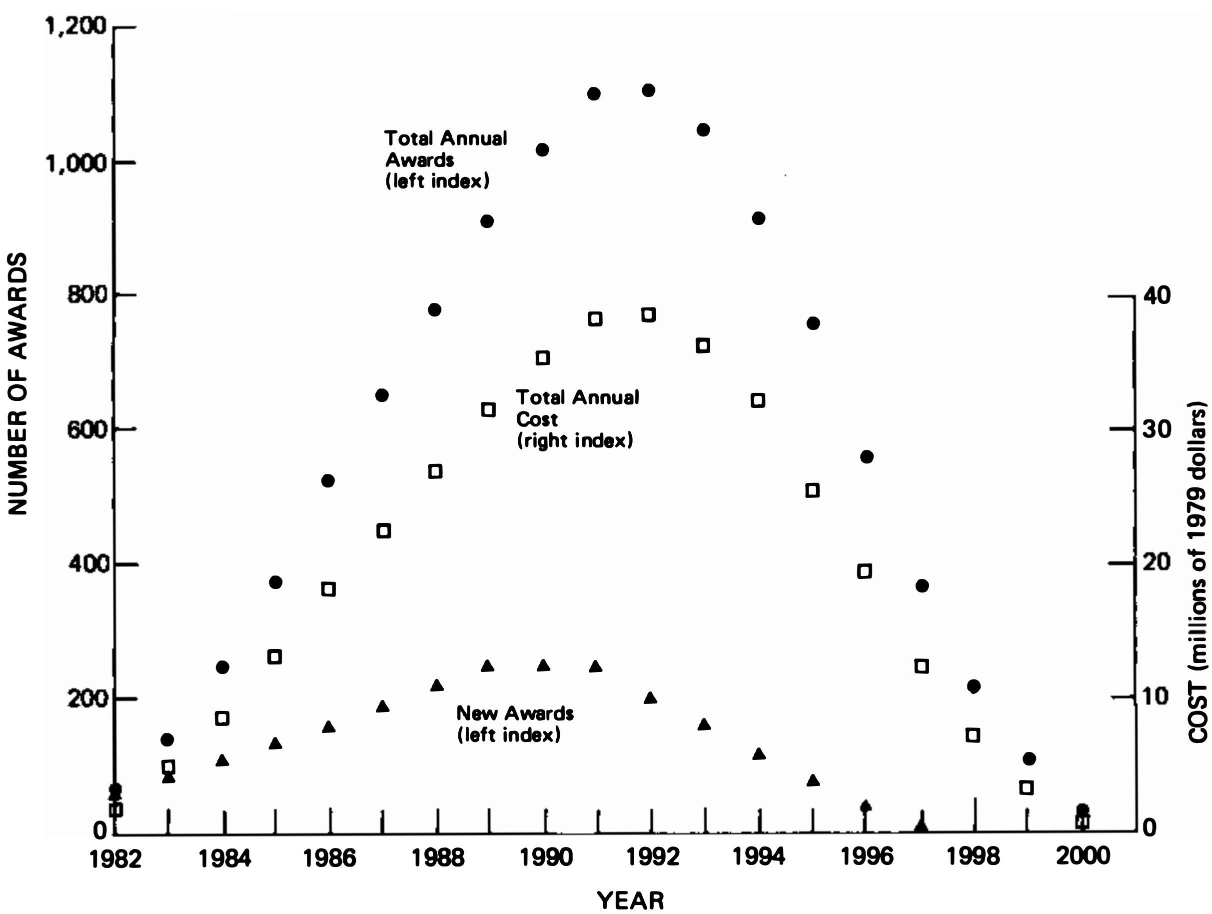
It seems to us almost certain that the program should be extended to chemistry fairly promptly and very likely that extension to at least some areas of the social sciences will become necessary later in the 1980's. In chemistry, retirement rates are expected to be relatively high in the immediate future. But other indicators are quite unfavorable and, as Table 3 in chapter II shows, the retirement situation is expected to worsen later in the 1980's. The social sciences as a group have been able to maintain a healthy situation recently because of rapid faculty growth. But at least some social science areas are likely to be adversely affected by the enrollment decline of the latter half of the 80's, and this may well make them eligible for awards. Most areas of the life sciences receive the bulk of their funding from NIH, and we do not récommend that the NSF take over responsibility for funding a program in those fields. (It is important to note that there are areas in the life sciences which receive little NIH support, and extension of REA's to these fields would be appropriate should they meet the criteria.) It seems unlikely that either agriculture or earth sciences will be eligible for the program for reasons that inspection of Table 11 will make clear.

The shortage of positions due to low retirements will begin to ease in most fields by the early 1990's, and soon after that the enrollment demographics turn up as well. We would therefore expect new starts in the program to begin to decrease around 1990, and complete phase-out of new starts to occur no later than 1995. Once again, proper timing will differ by field: mathematics retirements, for example, do not arrive at steady-state levels until several years later than physics retirements.

A reasonable scenario for award levels might then be as follows (recognizing that actual award levels must be tailored to the developments in specific fields as they occur). The program would begin in 1981 with 60 new awards in physics and mathematics. After that new fields would likely become eligible, beginning probably with chemistry, so that the number of new awards would grow. The number of new awards per year might also need to be adjusted up or down (most likely up) in fields already receiving awards as events unfold. The number of new starts per year would reach a peak in the late 1980's at perhaps 250 new awards per year. After 1990, the number of new awards should begin to decline, with the timing of the decline dependent on the hiring situation in the various fields. The last year for new awards would be around 1995, with the program completely phased out before the year 2000. Figure 7 illustrates the projected time path of new awards, total awards, and program costs.

The cost calculation is based on 1979 dollars. It assumes an annual award cost of $35,000 per year, and an attrition rate from the program of 3% per year. First year costs are $2.1 million; peak annual costs are $39 million. Total costs over the 19 years of the program's existence are $381 million. These calculations do not include costs to NSF of administering the program.

This time profile of awards and costs should be appropriate if the main cause of reduced hiring proves to be the lack of retirements, and if enrollments stay roughly constant. Even on that relatively optimistic assumption, the program we have outlined is of minimum size to address the expected difficulties. Significant declines in enrollment occurring at research universities might



Assumptions:
(1) 3% annual attrition rate for awardees;
(2) Annual award cost is $35,000 (in 1979 dollars).

FIGURE 7 Projected Time Profile of Costs and Number of Awards for Research Excellence Award Program, 1981-2000.

require a substantially larger program, and depending on the time pattern of enrollment changes, a significantly different time path of awards.

Administration and Sources of Funding

We feel that this program is of sufficient urgency and value, and sufficiently modest in total cost, that it would be worth funding out of existing research funds if necessary. However, we also believe that the program would be a highly justifiable use of incremental funds by the NSF. We are aware that financing the program dollar for dollar out of existing research funds would significantly dampen its impact on the employment of young researchers, since undoubtedly part of the present research funds which would be lost provide salary support for faculty and finance post-doctoral appointments for young Ph.D.'s. Also, the full program, if fully funded from existing research dollars, would have a noticeable impact on research programs which are already becoming tighter in many fields.

The ideal scheme, and the one which we recommend, would have the program partly financed from new funds appropriated to the NSF for this purpose and partly funded from moneys advanced by the individual research directorates. This scheme would encourage the advice and participation of program officers at NSF who have detailed knowledge of their fields, without requiring that every dollar of support for this program come at the expense of their existing projects. Such an arrangement should also be attractive from the standpoint of obtaining additional funding for the program, since it would make clear that its priority is high enough to justify the diversion of some present research funds.

Program funding levels and allocation among fields should be readjusted yearly on the basis of close monitoring of developments in specific fields. Careful and systematic evaluation of the program should be undertaken at appropriate intervals throughout the period of its operation.

CHAPTER V REFERENCES

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National Science Board. Science Indicators, 1976. Washington, D.C.: National Science Foundation, 1977.

CHAPTER VI. FURTHER CONSIDERATIONS

The central concern of this committee is to preserve the continuity and vitality of American science and engineering research at a time when demographic and other developments threaten to impair them. The program recommended in the last chapter aims to meet this concern by maintaining the flow of new Ph.D.'s into academic positions while at the same time encouraging the research efforts of outstanding present faculty. But it is a mistake, as we argued in chapter III, to assume that vitality can be equated in any simple way with youth. A continuing flow of new young scholars into academic research is one essential component, but not the only one, in a strategy to keep academic science and engineering vital.

This chapter will address three additional areas related to the continued vitality of science and engineering. We examine first ways of maintaining the vitality of present faculty; second, possible consequences of the projected demographic changes for the contributions of universities and colleges other than the major research producers; and, third, recommendations on improved data and monitoring of the Ph.D. labor force.

Maintaining the Vitality of Established Faculty

An additional component of a strategy to maintain vitality should be programs directed toward established scientists. Productivity should be maximized at all ages. It seems only sensible to provide additional avenues for learning and stimulation, especially at a time when the flow of new people into academia is diminishing.

In the past the NSF has supported research study leaves which provide opportunities for established investigators to develop new skills in research methodologies. Also funded have been special topics workshops and research conferences, in which scientists have gathered for the purpose of pooling information on specific research endeavors and methodologies. These kinds of programs encourage the academic community to take full advantage of the special skills, knowledge, and perspectives that result from experience that only comes from age. The committee feels that continued NSF involvement in these programs is extremely important, especially during the upcoming period when it is vital that senior faculty be encouraged to contribute to the functions of innovation and cross-fertilization that have often come from young faculty.

As stated in chapter III, one of the major functions of young researchers is to provide new starts in research projects. The committee believes that the NSF could go further in encouraging established faculty to perform this function through a small scale experimental program of Career Transition Awards. The purpose of such awards would be to provide partial NSF support for one year for senior faculty members who wish to make a major change in the direction of their research or in the nature of their professional activities.1/

The proposed program would have the NSF provide half of a full year's support for faculty members proposing to undertake such a shift in emphasis. The value of NSF support for a program of this kind is suggested by the following discussion of developments at Stanford University (Hopkins and Bienenstock, 1975, p. 45):

1/ NSF may also wish to consider providing partial support for more extended leave for proposals that justify it.

> . . . /T/he University has recognized that some tenured faculty are making less effective contributions because their fields of concentration are less interesting than they were at the time of the tenure decision. In many cases these faculty members are highly motivated and have the capability to shift emphasis into more interesting areas, but they have not had the opportunity to do so because of other demands upon their time. A traditional mechanism for achieving such shifts of emphasis has been the sabbatical period. Unfortunately, Stanford's present sabbatical policy does not formally provide a mechanism that allows a faculty member to take off a full academic year at full pay. Yet, it is frequently such an extensive period that is required if a scholar is to make a successful shift. There are, of course, a number of outside awards that supplement pay so that the sabbatical can be extended. However, a common characteristic of these awards is the expectation that the awardee work within the field his or her major contributions have been made in. Most outside awards do not provide funds for faculty members who desire to change fields.

It is the aim of these awards to provide this opportunity for scientists to shift their career emphasis in a way that cannot be done with a traditional sabbatical.

Candidates for awards would be persons who had demonstrated significant scientific productivity since receiving tenure. Administratively, the applicant's institution should agree to provide one-half the applicant's salary for the redirection period, and permit the leave, and the host institution/department/sponsor to receive the faculty member. NSF awards would cover half the applicant's salary for a full year, including payment of fringe benefits and an 8% allowance for administrative costs on the NSF paid portion of the salary, to be paid to the host institution. The criteria for NSF support would be the previous record of the applicant and the quality of the proposed redirection program, as evaluated on the basis of a carefully constructed plan submitted jointly by both applicant and sponsor. Because of the requirement that a candidate for the award have demonstrated significant scientific productivity since receiving tenure, we would expect that relatively few awards would be made to people less than ten years from the Ph.D. Also, since a major aim of these awards is to provide for continued research productivity, it is expected that few awards would be made to people very close to retirement.

As previously stated, the committee recommends that the Career Transition Awards be initially established by the NSF as a small scale experimental program. This would give the NSF the opportunity to evaluate the effectiveness of such a program and to develop guidelines and modifications to increase its effectiveness. This program is seen by the committee as one which may assist university departments in maintaining their vitality through the development of new research projects. It is also seen as a program which will provide opportunities for individual scientists to maintain or increase their productivity with new research skills.

Universities and Colleges Other Than the Major Research Producers

The program of Research Excellence Awards described in chapter V can be expected to have its major impact at universities and colleges where research is a large component of activity. That program is by no means solely restricted to any "elite" class of institutions, and we certainly expect awards to be made to members of a wide variety of departments. Nonetheless, the clear aim of the program is to support the research effort, and some degree of concentration of awards at the major research producers is to be expected. The REA program we have proposed can, we believe, have a significant effect in maintaining the vigor of the research effort in American higher education.

The larger problem of the impact of the changing enrollment picture on the whole of American higher education goes clearly beyond the scope of this study. Nonetheless, the problems deserve some attention here, especially because many institutions which do not make major direct contributions to the research effort perform tasks which are important to American science and engineering.

These institutions play an important role in encouraging young people to enter scientific careers. This can happen at the undergraduate level, as some students take their first research steps, perhaps while writing an honors thesis. And some institutions which are not major research producers have graduate programs in science and engineering, often at the master's level, in which students receive good foundations for work in some professional fields or for later doctoral study.

Such institutions also play a significant role in the dissemination of scientific results. Sometimes this is accomplished through the hosting of regional or national scientific conferences. These institutions are often effective in educating the lay public and non-science undergraduates about important scientific and technological developments. This function is vital if we are to have an informed electorate capable of making rational decisions about the future course of society.

Further it must be recognized that these institutions at times include among their faculties researchers of great ability who in some cases had not been identified as such earlier in their careers.

Stephen Dresch has argued in a memorandum prepared for this committee (1979) that such "late identification" of research performers may be of great importance to the health of the scientific system.

Historically, the undergraduate origins of black and other minority Ph.D.'s have differed markedly from those of white Ph.D.'s, including in particular unusually heavy representation from black colleges and universities in the South (see Table III-4 in Gilford and Snyder, 1977). Training of black Ph.D.'s has also been relatively concentrated in a small number of institutions. For example, Howard University alone accounted for a significant fraction of all the black Ph.D.'s produced in the U.S. in the fields of chemistry, physics, zoology, pharmacology and physiology between the years 1973 and 1976 (Gilford and Snyder, 1977, and unpublished data from Howard University).

While it may be expected that other institutions will play an expanded role in minority Ph.D. production in the future, the institutions that have played this role in the past will undoubtedly continue to be a major source of minority Ph.D.'s. Women's colleges likewise have been historically a major source of women Ph.D.'s, and this is likely to continue. These institutions are an important national resource which has made a substantial contribution to our society.

The impact of the impending demographic decline is likely to be much greater at many of the institutions we are describing here than it is at the major research universities. The threat to the continuity and vitality of their educational mission runs parallel to the analysis of academic research performance earlier in this report. The roles these primarily instruction-oriented universities and colleges play in science education and, in some cases, training of minority and women Ph.D.'s, are varied and important. The committee recommends that the NSF and the U.S. Office of Education recognize these important roles and develop a policy to maintain the delivery of these significant contributions during the next 20 years. This policy may take the form of special science education projects aimed at upgrading the scientific faculty at these threatened institutions, or faculty development grants to specific institutions. Programs such as the Biomedical Programs of NIH and the Resource Center programs of NSF are extremely important to the survival of many of the institutions which have been important in the training of minority scientists and engineers. We recommend that federal agencies should be encouraged in their efforts to support these institutions.

Improved Data and Monitoring of the Ph.D. Labor Force

Better data and closer monitoring of the academic hiring situation are needed in order to maximize the effectiveness of the policies described in earlier chapters and to further advance our understanding of developments in the market for young faculty at research universities. As we noted in chapter III, the severity of the shortage of new positions in a specific field of science or engineering should be a key determinant of whether that field is eligible for the Research Excellence Awards Program, and, if so, of how many awards should be made in that field. While existing data are adequate to provide indications of the existence and magnitude of such a shortage in some broad fields of science, more complete data would be very desirable in actually implementing the proposed policy. Discussions at the Workshop of Forecasting Specialists convened by this committee also revealed important limitations on the adequacy of existing data for the purpose of developing more detailed and reliable projection models.

There are basically two potential sources of data about the academic hiring situation -- the employers and the employees -- and we recommend improved use of both sources. The employers, of course, are universities and colleges. The personnel situation in academic science and engineering departments, the major employing units for scientists and engineers at such institutions, is already regularly surveyed by the National Science Foundation's Division of Science Resources Studies.2/ The employees are individual science and engineering Ph.D.'s. About 10% of them are surveyed biennially by the National Research Council's Commission on Human Resources.3/ Our recommendations center on improving and extending these existing data-collection activities rather than beginning new ones.

Recommendations

(a) We recommend that the National Science Foundation's human resources survey of academic departments be expanded to include questions on numbers of persons entering and leaving departments. The present survey asks about total numbers of persons employed, but not about job turnover. Questions on number and rank of persons enterint departments, on number and rank of persons leaving, and on employment destination of those leaving (other academic employment, non-academic employment) or on reasons for separation from the work

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2/ The NSF Survey of Scientific and Engineering Personnel employed at Universities and Colleges.

3/ The Survey of Earned Doctorates and the Survey of Doctorate Recipients.

force (death, retirement) should be added to the survey. These data would make it possible to know accurately the number and status of persons being hired into academic positions annually by field of science and by class of institution -- information not now available for most fields. The data gathered on sources of vacancies in academic departments would be helpful in projecting future openings.

(b) We also recommend to the Commission on Human Resources (CHR) and to the agencies that sponsor its surveys two additions to its present Survey of Doctorate Recipients. First, we urge that the Commission include additional questions on the job mobility of Ph.D.'s, both between fields and departments within academia, and in and out of academia. Mobility patterns are likely to change considerably in response to changing market conditions for Ph.D.'s and, as noted in chapter II, these changes in mobility rates may have large effects on academic hiring of new Ph.D.'s. Questions to identify those who have recently changed jobs and to learn more about the nature of and reasons for their job change will help in monitoring these developments and in forecasting academic job openings for new Ph.D.'s more accurately.

(c) We further recommend that the CHR seek funding to make it possible to survey larger samples of persons from several recent cohorts of Ph.D.'s over a period of years and to add questions to the survey specifically directed to their employment history and opportunities. Career paths and employment patterns are likely to shift rapidly in the decade ahead, with important implications for the number and kinds of academic positions becoming available. A biennial survey of individuals from different cohorts over perhaps the first ten years of their careers is an excellent source of information on how these patterns are changing. Such a survey should keep close track of the kinds of positions recent Ph.D.'s are obtaining within and outside of academia, how long they keep such positions, what alternative job opportunities they have, and where and why they move. To be maximally effective in permitting longitudinal analysis of individual career paths by field of science, such a survey must achieve a significantly higher response rate as well as involve a larger sampling rate than the present Survey of Doctorate Recipients. While some of the additional costs of this more intensive survey could be avoided by appropriate coordination with the present survey, we recognize that the cost of the expanded survey would be substantial. But we believe the added cost would be well justified, and we attach high priority to this recommendation.

(d) We wish to express our support for efforts to improve the reliability and sophistication of forecasting models for the Ph.D. labor market. The results of our Forecasting Workshop suggest that much progress has been made in recent years, but more remains to be done. Several points of special relevance to this committee's concerns may be worth stressing. More effective disaggregated modeling, to take account of differences among fields and sub-fields of science and engineering, and also of differences in expected developments at different types of colleges and universities, would be highly desirable. The value of such disaggregation was a consistent theme at the Forecasting Workshop. It may be that this work can best proceed through efforts at detailed analysis of particular fields, rather than through more extensive disaggregation of wide-scale forecasts like that now done by NSF. Further improvements in the analysis of the behavioral responses of individuals and institutions to changing market conditions, including the role of financial incentives versus other motivations in making career choices, are called for. Especially important in this regard is analysis of the differential impact of changing market conditions on students of different talents and training. We currently have no systematic evidence on the crucial question of the degree to which the most able potential academic scientists may be turned away from careers in basic research by the perception of poor employment opportunities.

These and other possible improvements in forecasting models and methods are the subject of a joint Commission on Human Resources-Committee on National Statistics study currently in the design phase.4/ We encourage this effort to go forward. We also wish to express our encouragement for the efforts underway within NSF's Division of Science Resources Studies further to improve their forecasting work. We note as well the very valuable work done in forecasting for particular fields by experts in those fields, such as Lee Grodzins in physics and Richard A. Anderson in mathematics. Such work, sometimes done in conjunction with the relevant professional societies, is of great value both in its own right and in acting as a prototype for and check on broader studies. NSF and other appropriate agencies should seek to encourage and, where appropriate, to support such efforts.

4/ Study of Methodologies for Projections of Supply and Demand for Doctoral Personnel.

(e) Finally, we recommend that data monitoring procedures be established in order to provide information for evaluation of the REA program. The research careers and publication records of Award recipients should be followed, as should those of a sample of unsuccessful applicants. This would provide data on the effect of the Award on research performance. Another measure of the program's performance can be obtained by tracking the careers of the young faculty members hired into tenure track positions as a result of the REA program. Of interest would be the numbers eventually receiving tenure, and their research performance. Other relevant data could include institutional clustering of Awards. Most of this information will be available from the application and annual report documents that are to be submitted by the department whose faculty member receives the REA. Follow up studies beyond the term of the award and information on unsuccessful applicants will have to be developed separately.

CHAPTER VI REFERENCES

Dresch, S. P. On the Predictability of Individual Scientific Productivity, Career Patterns and Queue Formation: Consequences for the Discovery of Prodigious Scientific Talent. Memo prepared for the Committee following the Workshop for Specialists in Forecasting Demand for Scientists and Engineers. Washington, D.C.: National Research Council, April 30-May 1, 1979.

Gilford, D. G. and J. Snyder. Women and Minority Ph.D.'s in the 1970's: A Data Book. Washington, D.C.: National Academy of Sciences, 1977.

Hopkins, D. S. P. and A Bienenstock. Numerical Models for Faculty Planning. New Directions for Institutions Research, No. 6: 23-47, 1975.

CHAPTER VII. CONCLUSIONS AND RECOMMENDATIONS

During the 1960's academic science and engineering faced the enormous challenge of responding rapidly and effectively to national demands for the training of greatly increased numbers of scientific and technical personnel and the performance of an expanding array of research tasks. The challenges were dramatic, and the universities responded to them with vigor, imagination and intelligence.

The challenges of the 1980's will be less dramatic, but no less real. The need for the next two decades will be to maintain a vigorous and effective academic research enterprise under conditions of limited growth that threaten to reduce the vitality of academic science and to interrupt the critical continuity of the research tradition in our major research universities.

In the last analysis, the challenge of maintaining flexibility and vitality under conditions of limited growth will have to be met by the universities and colleges themselves -- and ultimately by individual academic scientists and engineers. They will need to take for themselves the principal actions needed to maintain vitality in the university research enterprise. What federal policy can do is to support temporary programs which will help universities and colleges during a fifteen to twenty year transition period during which it will be difficult for them to hire normal numbers of the highest quality young faculty. These federal programs can only succeed if the universities themselves are committed to maintaining their own vitality.

The Committee on Continuity in Academic Research Performance recommends that:

A Research Excellence Awards Program should be instituted by the National Science Foundation. These awards will be given to the most promising young scientists and the most effective and innovative established scientists. The partial salary support received by the awardees can then free university funds to hire new faculty in anticipation of future retirements and other openings, thereby helping ensure an adequate flow of new scientists and engineers into academic life while permitting the universities to accomplish a smoother transition to a balanced faculty age distribution in fields where this distribution is presently skewed. The Research Excellence Awards program should be operational in 1981 and, based on current projections, the last 5-year award would be necessary in the early 1990's. The total program cost is estimated to be $381 million in 1979 dollars assuming a 20 year period of operation. The program, as we have designed it, is directed to the NSF, but we strongly urge that other federal agencies which support significant amounts of research consider developing parallel programs in the areas they support, or that they consider participating with NSF in providing financial support for an expanded version of the REA program.

The program we have proposed is modest in scope and cost. It is not designed to try to reproduce the growth atmosphere of the 60's, but instead to help academic science to adapt with maximum effectiveness to the conditions of reduced growth of the 80's and 90's. Undoubtedly, the universities themselves, as well as government and private agencies concerned with research, will need to take further actions to help in this process of adaptation. We believe that the Research Excellence Awards Program can serve ultimately as a central component in an interacting group of programs sponsored by numerous government and private agencies, all of which will need to be strengthened and made more innovative if the challenge sketched in this report is to be met.

This program is in no way a full scale response to the problems posed for all of higher education and for society as a whole by the demographic roller-coaster this country is riding in the last third of the twentieth century. We recognize that many of these problems lie beyond our scope, although we have tried to comment briefly in chapter VI on the importance of additional methods of maintaining vitality for established scientists, the possible effects of projected demographic changes on colleges and universities other than the major research producers, and the need for improved data and monitoring of the Ph.D. labor force.

We believe that our program of Research Excellence Awards will, if instituted, enhance the vitality of academic research, and hence improve the performance of the entire U.S. research and development system during the coming decades. The program will help to ensure a steady flow of new faculty into research producing colleges and universities, and thereby foster innovation in research activities, encourage the dissemination of new techniques and ideas across departments, and increase the flexibility of departments in responding to shifting curricular and research interests. An adequate flow of new faculty will also help to preserve a desirable continuity across generations in the performance of research functions and in the training of later generations of scientists and engineers, fostering a generational interplay which we believe works to sustain valuable research traditions and to integrate new scientists into the social structure of their disciplines.

We have, in the course of this committee's work, thought long and hard about what makes the scientific process work in our respective disciplines, and how age structures and faculty flows bear on those workings. We know how much there is still to learn about these questions. But we are convinced that the threat to the system posed by the constricted flow of new faculty is real. It is affecting some fields now and it is likely to be felt soon in others. We urge the prompt enactment of the recommended program.

APPENDICES

LIST OF APPENDICES

APPENDIX A

LETTER SENT TO PROFESSIONAL SOCIETIES AND CORPORATIONS

LIST OF PROFESSIONAL SOCIETIES AND CORPORATIONS RESPONDING TO LETTER

NATIONAL RESEARCH COUNCIL
COMMISSION ON HUMAN RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

April 30, 1979

FOR PRESIDENTS OF PROFESSIONAL SOCIETIES
AND INDUSTRY REPRESENTATIVES

Dear :

I write to you in my capacity as chairman of the Committee on Continuity in Academic Research Performance which has been appointed within the National Research Council to study the future demand for young researchers in science and engineering. The committee has been asked by the National Science Foundation to assess the future demand for young investigators in each field and to recommend programs that may be needed to ensure the continuing vitality of research in our academic institutions. The study is to be completed by August 31, 1979 so that the Foundation can consider recommendations as a part of planning for 1981.

Our committee requests your help in this study. As an initial step, we will examine forecasts of demand for scientists and engineers during the period from now until the year 2000. Many of these forecasts ignore important differences among scientific fields. Therefore we are turning to you for any information that you can provide regarding the demand in your particular field.

In making this request, we wish to emphasize the need for quantitative information that may serve as a basis for prediction. It would be most helpful if you could direct us to any sources of such data that may exist in your discipline or provide us with any reports that your office may have available. The names of individuals who have conducted investigations in this area or to whom we could usefully address our inquiries, and references for any other reports of which you are aware, would also be appreciated.

We also invite your views on the role of young investigators in academic research in your field and would appreciate your addressing the following questions:

1. What are the unique contributions of young investigators? Does this suggest that there is a "proper proportion" of young investigators in your field?

2. On what evidence do you base your conclusions?

3. What are the implications of present trends, possibly including a steady aging of the faculty, for the productivity and vitality of research in your field?

Any information that you can provide pertinent to these questions would be greatly appreciated.

Since our committee must draft its preliminary report by June, we would like to receive your reply by mid-May. Thank you very much for your cooperation in this matter. We look forward to hearing from you soon.

Sincerely yours,

Robert M. Bock
Chairman
Committee on Continuity in Academic Research Performance

LIST OF PROFESSIONAL SOCIETIES AND CORPORATIONS RESPONDING TO LETTER

American Association for the Advancement of Science

American Economic Association

American Federation of Information Processing Societies, Inc.

American Geological Institute

American Geophysical Union

American Institute of Aeronautics and Astronautics

American Institute of Chemical Engineers

American Institute of Industrial Engineers, Inc.

American Mathematical Society

American Physical Society

American Physiological Society

American Psychological Association

American Society of Biological Chemists, Inc.

American Society of Civil Engineers

American Society for Engineering Education

American Society of Mechanical Engineers

American Sociological Association

Association of American Universities

Council of Graduate Schools in the United States

Engineers Joint Council

Federation of American Societies for Experimental Biology

Ford Motor Company

General Electric Company, Research and Development Center

Honeywell, Inc.

Princeton University Office of Research and Project Administration

Social Science Research Council

Xerox Corporation, Corporate Research

APPENDIX B

AGENDA OF WORKSHOP FOR SPECIALISTS IN FORECASTS OF DEMAND FOR SCIENTISTS AND ENGINEERS AND LIST OF ATTENDEES

REVIEW OF PROJECTIONS OF DEMAND FOR PH.D. SCIENTISTS AND ENGINEERS, BY DONALD HERNANDEZ

NATIONAL RESEARCH COUNCIL
COMMISSION ON HUMAN RESOURCES
2101 Constitution Avenue Washington, D. C. 20418

COMMITTEE ON FUTURE DEMAND FOR YOUNG INVESTIGATORS
IN SCIENCE AND ENGINEERING

WORKSHOP OF SPECIALISTS IN FORECASTS OF DEMAND
FOR SCIENTISTS AND ENGINEERS

APRIL 30 - MAY 1, 1979

Joseph Henry Building, Room 200A
21st and Pennsylvania Avenue, N.W.
Washington, D.C.

Chairman: Frederick E. Balderston

TENTATIVE AGENDA

April 30, 9:00 a.m. - 12:30 p.m.

Papers to be reviewed: Ph.D. Manpower: Employment Demand and Supply 1972-1985, Bureau of Labor Statistics, 1975

Oversupply of Ph.D.'s to Continue Through 1985, Bureau of Labor Statistics, 1978

The Overeducated American and other studies, Richard Freeman

Reviewers: Neal Rosenthal, David W. Breneman

Discussants: Robert McGinnis, Roy Radner

April 30, 1:30 p.m. - 5:00 p.m.

Papers to be reviewed: Personnel Needs and Training for Biomedical and Behavioral Research, National Research Council

Supply and Demand for Biomedical Manpower: 1977 Survey. Preliminary Report, Westat, Inc.

Supply and Demand for Physicists, Lee Grodzins

Reviewers: Allen Singer, William Morsch, Lee Grodzins

Discussants: Stephen P. Dresch

The National Research Council is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering to serve government and other organizations

May 1, 9:00 a.m. - 12:30 p.m.

Papers to be reviewed: Projections of the Supply and Utilization of Science and Engineering Doctorates, 1982 and 1987, National Science Foundation

Preserving a Lost Generation: Policies to Assure a Steady Flow of Young Scholars Until the Year 2000, Carnegie Council of Policy Studies in Higher Education

Projections of Educational Statistics to 1985-1986, National Center for Education Statistics

Reviewers: Charles Falk, Charlotte Kuh, Rolf Wulfsberg

Discussants: Joseph Froomkin, Richard D. Anderson

May 1, 1:30 p.m. - 4:00 p.m.

Summary of Workshop Proceedings - by Frederick E. Balderston, Chairman

General Discussion

NATIONAL RESEARCH COUNCIL

COMMISSION ON HUMAN RESOURCES

Workshop of Specialists in Forecasts of
Demand for Scientists and Engineers

April 30-May 1, 1979

LISTS OF PARTICIPANTS

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Joseph Froomkin
Joseph Froomkin, Incorporated

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Association of American Universities

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A REVIEW OF PROJECTIONS OF DEMAND FOR PH.D. SCIENTISTS AND ENGINEERS

Donald J. Hernandez

This appendix provides a description and evaluation of the studies examined at the Workshop for Specialists in Forecasts of Demand for Scientists and Engineers convened by the committee.

The forecasts and projections that were presented and reviewed at this workshop may be distinguished along three broad criteria. First, some forecasts concern the future demand for scientists and engineers, others concern both demand and supply. Second, some forecasts consider all science and engineering fields in the aggregate, others are field-specific. Third, the forecasts vary in the degree to which demographic and economic factors are incorporated into the analysis. This report is organized in terms of these three criteria.

Aggregate Science and Engineering Demand

The aggregate demand for new doctorates in science and engineering (S/E) was forecast in five of the studies reviewed. These analyses were conducted by Roy Radner and Charlotte V. Kuh (Radner and Kuh, 1978; Kuh and Radner, 1979), Richard B. Freeman (1976), the National Science Foundation (1979), the Bureau of Labor Statistics (BLS 1975; Braddock 1978), and the National Center for Education Statistics (1978). For each study the major assumptions, methods, and results are discussed. Simultaneously, the likely accuracy of each forecast or projection is evaluated through an assessment of the validity of crucial assumptions, and through comparisons with the remaining forecasts.

Radner and Kuh

The Radner and Kuh analysis builds directly on the classic work of Allan M. Cartter (1976), Ph.D.'s and the Academic Labor Market. Both studies concern the demand for new doctoral faculty in academia, which is the setting in which the majority of scientists and engineers pursue their work, and which is also the setting in which the majority of basic research is conducted. In both studies the future demand for new doctoral faculty depends primarily on projected college enrollments, and enrollment changes through time. Enrollments in turn vary mainly in response to the changing size of the college age population. Radner and Kuh adopt additional assumptions directly from Cartter. These are the constant proportion of the prime college age population that is enrolled in college, the constant faculty/student ratio, and the constant ratio of Ph.D.'s to total faculty. Changing attrition rates for junior and senior faculty are employed as assumptions, but rates of promotion to tenure are considered to be dependent on market conditions and the academic age of the faculty member. Formally, the model used in deriving the Radner and Kuh forecast is a Markov model with non-stationary transition probabilities. All the Radner and Kuh forecast results refer to 4-year colleges and universities.

In a paper prepared for the forecasting workshop (Kuh and Radner, 1979), Kuh and Radner extended the results of their earlier paper (Radner and Kuh, 1978) by employing more recent data and by making estimates specifically for science and engineering faculty. The science and engineering estimates were obtained by scaling the time path of total faculty demand to the present size of science and engineering faculties, rather than by making independent forecasts of science and engineering enrollment and faculty size. The paper prepared for the workshop also compares their results to the National Science Foundation projection results.

The Radner and Kuh forecast indicates that the annual demand for new science and engineering doctorates in 4-year colleges and universities will drop by about 46% between 1978 and 1985, will rise to roughly its former level by 1989, but then will fall precipitously by 1991 to 35% of the 1978 level (Kuh and Radner, 1979).

Insofar as young scholars and/or continuity in the age structure of scientists and engineers are necessary to the health and productivity of science, the Radner and Kuh forecasts imply a potentially sharp reduction in the vitality of science in the U.S. during the next decade.

Perhaps the most important potential limitation of the Radner and Kuh forecasts is the method of projecting college enrollments. The forecast assumes that fluctuations in enrollments are determined primarily by fluctuations in the size of the college age population. But another potentially important determinant of enrollments is the demand for college graduates resulting from change and/or growth in the national economy.

<u>Freeman</u>

The forecast developed by Freeman rests on assumptions regarding both the changing size of the college age population and the economically generated demand for college graduates. These are translated into projected college enrollment levels, which are in turn translated into the demand for college and university teachers.

The model Freeman employs to forecast college enrollments is a recursive adjustment model in which the supply of freshman males in any year depends on the population of 18 and 19 year old men, on the difference between college starting salaries and the average annual earnings of all full-time workers, and on the number of freshmen during the previous year. Moreover, the number of bachelor's degrees awarded depends on the number of freshmen both four years earlier and five years earlier. Finally, the starting college salaries in any year depend on the number of bachelor's degrees awarded the year before, on the demand for college graduates (calculated by taking a fixed-weight index of employment in 46 industries), on the average annual earnings of all full-time workers, and on the starting college graduate salaries the year before. In sum the model for projecting the number of college entrants depends on both the size of the college age population and various measures of economic demand.1/ Feedback mechanisms are assumed in the recursive model, and it is assumed that major increases in governmental R & D spending and major changes in the structure of the economy are unlikely.

On the basis of this model, Freeman draws the following conclusions regarding college enrollments, and hence the market demand for new Ph.D.'s. "The proportion of young men choosing college will stabilize in the mid-1970's, after having fallen from the peak of the late 1960's, and rise in the 1980's in response to the market upturn. Because the population of college age will be small in the 1980's, however, total enrollments will still drop, which will act to depress the market for Ph.D. and master's graduates until the late 1980's (1987)."

1/ See Smith and Welch (1979) for a review of Freeman's work which suggests that care be exercised in interpreting the role of economic variables in the model forecasting college enrollments.

In other words, taking into account both demographic changes in the size of the college age population and the interaction between college enrollments and various economic trends, Freeman draws essentially the same conclusions as those of Radner and Kuh. The annual demand for new Ph.D.'s to teach in colleges and universities will deteriorate during the 1980's. Unfortunately for present purposes, Freeman does not provide numerical estimates, the magnitude of which might be compared to the estimates developed by Radner and Kuh. The overall nature of the trends in the two sets of estimates do, however, correspond. Since somewhat different modeling procedures were employed in developing these estimates, this correspondence may be seen as providing evidence that the projected trends will materialize, unless major economic changes and/or new government policies intervene.

National Science Foundation

The NSF's forecasts differ from the preceding forecasts in three notable respects. First, the NSF forecasts the demand for S/E doctorates, rather than all doctorates. Second, the NSF develops separate forecasts for each of the broad fields within S/E, and combines the results to obtain an aggregate forecast. Third, the NSF forecasts the demand for S/E doctorates in higher education and in other sectors of the economy, rather than in the higher education sector alone.

In projecting the demand for new Ph.D. faculty the NSF takes into account the effect of college enrollments as measured by projected baccalaureate degrees. The attrition of current faculty through death and retirement is also incorporated into the projection procedures. In order to forecast the total demand for college faculty, the NSF regresses full-time academic staff on various measures of baccalaureates awarded to provide an estimate of the historical relationships among the variables. This historical model is then applied, assuming the upward trend in the number of bachelor's degrees awarded between 1965 and 1976 will continue through 1987, at one-half the pre-1976 rate. The resulting estimate of total demand for faculty is then combined with the assumptions noted above to forecast the future demand for new Ph.D.'s and the future age distribution of the faculty in higher education.

Radner and Kuh assume that the declining number of people in the prime college age population will generate substantial declines in enrollment, which in turn will produce a sharp drop in the demand for new Ph.D. faculty. Freeman, taking account of both the declining number of people in the college age population and the likely effect of economic trends, similarly concludes that college enrollments and the demand for new Ph.D. faculty will fall. The NSF, however, assumes that the number of bachelor's degrees (and presumably total college enrollments) will continue to rise (though more slowly) despite the demographically generated decline in the prime college age population.

In a special study prepared for the forecasting workshop, NSF provided rough calculations of the implications of their overall model of faculty demand for the proportion of recent Ph.D.'s on S/E faculties. Despite their greater optimism about enrollments (as well as about the faculty-student ratio and the proportion of Ph.D.'s on faculties), NSF concurs with Radner and Kuh in forecasting significant aging of faculties by 1987. Quantitatively, however, they project a somewhat smaller decline in the proportion of young faculty than Radner and Kuh and Freeman expect. Radner and Kuh project that the proportion of young faculty will decline by about 33%, and, while Freeman does not make a numerical forecast, his approach would likely lead to a projected drop about that large. The NSF, in contrast, forecasts a 20% decline.

It appears that the situation as forecast by Radner and Kuh and as forecast by Freeman is more likely than the situation as forecast by the NSF. The NSF simply assumes continued increases in college enrollments, while Radner and Kuh derive college enrollment forecasts from demographic changes which we know will occur, and Freeman derives his forecasts from these demographic changes in conjunction with the potential effect of continuing economic trends.

There are additional differences between the NSF model and the Radner and Kuh model. These involve differences in definitions, data, and underlying parameters. In the paper Kuh and Radner (1979) wrote for the forecasting workshop, they developed three additional forecasts with their general model. One was based on the Commission on Human Resources data base, and two employed the NSF's data. The three forecasts varied little in their assumptions, except that one of the NSF-based forecasts took as given the implicit linear changes in the faculty stocks projected by the NSF for 1977, 1982, and 1987.

A comparison of the new Radner and Kuh forecast based on CHR data with one of the new NSF forecasts confirms that the major difference between the original NSF model and the Radner and Kuh models is that the NSF assumes enrollments will increase linearly (with corresponding changes in the demand for faculty), while the Radner and Kuh model allows enrollments to respond to demographics. A further comparison of this new Radner and Kuh forecast with the other new NSF forecast shows that when the NSF model is altered to allow enrollments to respond to demographics, the time trend of new faculty hires from the NSF model parallels, though generally at a higher level, the time trend of new faculty hires of the Radner and Kuh model.

The comparative assessment of the assumptions and results of the models and forecasts discussed to this point suggests that a major decline in the hiring of new faculty and a consequent discontinuity in the age distribution of faculty will emerge within the next decade.

Bureau of Labor Statistics

The BLS projects the demand for Ph.D.'s by field for academic and various non-academic settings. Overall, the BLS data indicate that the percentage of Ph.D.'s employed in educational institutions will decline from 72.6% in 1972 to 65.7% in 1985. This shifting distribution of Ph.D. employment is projected to occur through growth in all sectors with the non-academic sector growing more rapidly.

Two somewhat independent methods are employed in developing these projections. Non-academic demand is projected by applying trends in the distribution of Ph.D.'s relative to total workers in specific occupations to the BLS occupational projections derived from its basic projection model of the U.S. economy. Academic demand for Ph.D.'s, on the other hand, was projected primarily on the basis of NCES projections of degrees granted. The degrees-granted projections are combined with assumptions regarding the future pupil-faculty ratio, the future doctorate-faculty ratio, and death and retirement rates, to obtain the projected demand for new Ph.D.'s in academia.

Because the projected academic demand for Ph.D.'s rests primarily on NCES projections of college degrees granted, the demand projections are evaluated concurrently with the NCES projections below. At this point suffice it to note that the BLS demand projections for 1985 fall within 1% of the NSF projections for 1987, and the field-specific demand projections of the BLS lie within 10% of the NSF projections for all fields except mathematics where the difference is about 25%. Some of these rather modest differences may, of course, be due to differences in definition.

National Center for Education Statistics

The NCES projections are derived annually through 1986-1987 and pertain to full- and part-time faculty in all institutions of higher education, including 2-year institutions. Although these projections refer to all faculty, whether or not they have earned the Ph.D., they can be translated into the demand for Ph.D. faculty by applying doctorate-faculty ratios, as was done by the BLS.

The NCES faculty projections depend to some extent on attrition rates, but primarily on projections of total enrollments in institutions of higher education. (The degrees-granted projections used by the BLS are derived by the NCES by calculating the degrees granted as a percentage of the enrolled college population by age and sex. These percentages are then applied to the enrollment projections to estimate future degrees granted. Since the projected number of degrees is closely related to the projected number of students enrolled, comments on enrollment projections are applicable to the degree projections. Hence, the conclusions derived for the NCES projections also apply to the BLS projections which depend heavily on the NCES degree projections.)

College enrollments are projected by the NCES with three alternative assumptions regarding age-specific enrollment rates. The low assumption is that the average age-specific enrollment rates for 1975-76 will continue without change. The high assumption is that the rates will rise along their 1966-76 trend through 1986. The intermediate assumption lies midway between the low and high assumptions. These assumptions regarding the trend in age-specific enrollments are crucial in determining the projected enrollment levels because of the way in which they mesh with demographic trends in the age structure of the population. Between 1966 and 1976 there was a rapid rise in the age-specific enrollment rates of the population beyond the prime college ages. The NCES projections assume that the relatively high 1976 level will be maintained or will increase at 50% to 100% of the 1966-76 pace.

When these assumptions are combined with the fact that the children of the baby boom will be aging beyond the prime college ages to produce sharp increases in the size of the older population, the result is that the NCES projections imply substantial increases in college enrollments between now and 1987.

These projected increases depend on specific sorts of enrollments, however. The rising age-specific enrollment rates of the older population between 1966 and 1976 occurred in large part through rapid rises in the proportion of older people who attended 2-year colleges, and through rapid rises in the proportion of older people who were part-time students. In other words, the NCES total enrollment projections are particularly sensitive to potential (assumed) changes in the number of part-time students and to potential (assumed) changes in the enrollment in 2-year institutions.

Hence, if part-time students were ignored, the NCES projections imply that college enrollments would change little or would decline somewhat by 1986. Moreover, if only 4-year institutions are considered, full-time attendance would drop by between 634,000 and 765,000 between 1977 and 1986, and total attendance would also drop by between 11,000 and 841,000. On the other hand, total enrollment in 2-year institutions is projected by the NCES to increase by between one-half million and three million with most of the increase occurring in part-time attendance.

The NCES assumptions that produce the increase in part-time enrollments and the increase in 2-year college enrollments are, however, of questionable validity. For example, Cartter (1976, 61) states, "(t)his observer is skeptical about the projected continued relative growth in 2-year college enrollments. During a period of rapid growth it was logical to assume an expanding market share for the public community colleges. However, as enrollments begin to contract it seems unlikely that the 2-year college will be almost immune from this trend." If Cartter is correct, then the validity of the central NCES assumption is in doubt, as are the projected values that follow from it.

In addition, projections of the demand for new Ph.D. faculty that depend primarily on enrollment projections that, in turn, depend primarily on substantial increases in projected enrollments for 2-year institutions appear to be of limited usefulness in the context of assessing implications for research vitality because the Ph.D.'s who are hired at 2-year colleges engage in little basic research.

Finally, as noted above, the BLS demand projections depend on the NCES projections of degrees awarded. Because the projected number of degrees awarded depends on NCES projected enrollments, the BLS projections are subject to the same limitations as the NCES projections.

This interpretation is supported by the close correspondence of the BLS and the NSF demand projections, because, although on different grounds, it was argued above that the NSF projections also tend to exaggerate faculty demand. Since the BLS demand projections are based on enrollment projections that appear to exaggerate future enrollments, the BLS demand projections may also exaggerate future faculty demand. In short, the evaluations of the relative quality of the five sets of faculty demand projections presented here provide an internally consistent assessment of the forecasts.

In sum this evaluation suggests that the demand for new S/E faculty in colleges and universities will fall sharply between roughly 1980 and 1990. For purposes of projecting demands for faculty at 4-year colleges and universities, the two best estimates of the magnitude of the drop are those derived by Radner and Kuh from CHR data and those derived by Radner and Kuh using data that was also employed by the NSF. As noted above, these two sets of projections follow roughly the same time trend lines, but at different levels of magnitude. Both projections imply a relative decline in the hiring of new S/E doctorates of 45-50% between 1978 and 1984 or 1985, followed by a rise in 1989 to roughly the 1978 level, followed by a more precipitous descent by 1991 to only 24-35% of the 1978 level. Not until 1996 or 1997 is the 1978 level achieved again.

Aggregate Science and Engineering Supply

Turning to the issue of supply, two of the studies reviewed at the workshop develop projections of the future supply of new and total S/E Ph.D.'s. The projections were developed by the National Center for Education Statistics (1978) and the National Science Foundation (1979). The Bureau of Labor Statistics (BLS, 1975; Braddock, 1978) reports projections, in somewhat different form, provided by the NCES.

National Center for Education Statistics

The NCES projections of new doctor's degrees for 1976-77 through 1986-87 are derived by taking into consideration two major factors. The first factor is the projected population representative of the age distributions of degree recipients, by sex. The second factor is the percentage of that population projected to earn doctorates. The latter factor is crucial in determining the magnitude of the projected number of new doctorates. Three projections are developed. The first projection assumes that the relevant population during the entire projection period will earn doctorates at the same rate that the relevant population earned doctorates in 1975-76. The second projection assumes that the 1960-61 through 1975-76 trend in the percentage earning doctorates will continue. The intermediate projection is the average of the other two projections. For men the percentage earning doctorates decreased between 1960-61 and 1975-76. Hence, the intermediate projection assumes that over the projection period the percentage of the relevant age groups of men earning doctorates will decline at half the 1960-61 to 1975-76 rate. (For women, the percentage earning doctorates is projected to increase.)

At least for men (who constitute the majority of doctorates) the intermediate assumption may produce an estimate of the supply of new doctorates that is too high, because it fails to take into consideration the possible market response of potential Ph.D.'s to the sharp decline in the demand for new Ph.D.'s in academia, which was implied by the projections of demand discussed above. In fact the intermediate projection assumes instead that at least for men the 1960-61 to 1975-76 rate of decline in the percent earning Ph.D.'s will slacken, rather than increase. But if the analysis of the demand for new Ph.D.'s above is correct it seems likely that the supply of new Ph.D.'s will slacken more than is suggested by the intermediate NCES projection of supply. In other words, if potential Ph.D.'s respond to the likely drop in demand, the supply of Ph.D.'s may be substantially less than that projected by the NCES.

National Science Foundation

In projecting the total supply of S/E doctorates in 1982 and 1987 the NSF takes into consideration the attrition (death, retirement, or voluntary withdrawal from employment) of existing Ph.D.'s, as well as inter-field mobility, immigration and emigration. In addition, the number of new Ph.D.'s is projected. The supply of new Ph.D.'s is projected using assumptions regarding the percentage of baccalaureates entering graduate school, and the percent of graduate school enrollees earning doctorates. Market forces are assumed to affect these percentages. Specifically, the demand for Ph.D.'s is used in projecting the percent of baccalaureates enrolling in graduate school and the percent of enrollees earning doctorates. Because the NSF supply projections take into consideration the operation of market forces, they may provide a more realistic estimate of the future supply situation than do the NCES projections which do not take the likely market response of potential Ph.D.'s into consideration.

However, underlying the projection procedure are the basic assumptions concerning the number of baccalaureates in future years. The baccalaureate projections used are those developed by the NSF and reviewed above in the section concerning the demand for Ph.D.'s. As discussed above, the projection of the number of baccalaureates suffers the limitation that it assumes that the number of bachelor's degrees awarded during the projection period will continue to grow at one-half the pre-1976 rate, despite the impending drop in the prime college age population. If, as was argued above, the failure to take into account this demographic fact produces bachelor's degree projections that are too high, then the Ph.D. projections that depend on them will also be too high, and consequently the supply of Ph.D.'s is overestimated.

In sum both the NCES and the NSF projections apparently overestimate the future supply of S/E Ph.D.'s. A comparison of the NCES and (and BLS) results to the NSF results shows that they all imply roughly the same future supply of S/E Ph.D.'s. Apparently, then, the limitations of each projection are such that they produce roughly the same magnitude of overestimates of future supply of Ph.D.'s for S/E in the aggregate.

The Aggregate Supply-Demand Balance

One important question regarding the overall supply and demand of S/E Ph.D.'s remains. Will the supply exceed, equal, or fall short of the demand?2/ This analysis of the relative validity of the demand projections suggested that the demand, at least in academia, will fall sharply during the next decade. Unfortunately, the studies that derived this result do not also project the future supply of doctorates in S/E. Instead, only the NCES (1978), the BLS (BLS, 1975; Braddock, 1978), and the NSF (1979) produced or reported projections of both supply and demand. It was argued above, however, that the demand projections of the NCES, the BLS, and the NSF are probably too high, mainly because underlying assumptions regarding future college enrollments are probably too high. It was also argued, though, that the supply projections of the NCES, the BLS, and the NSF are probably too high.

It should be noted that, although all the forecasts apparently suffer an upward bias, the source of the biases in both the NSF demand projections and the NSF supply projections is the same. Hence, in a comparison of the demand and supply projections of the NSF, because the effect of these biases may be roughly the same in each projection, the difference between the supply and demand projections may accurately reflect the actual future difference. Moreover, the NSF supply projections take account of the operation

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2/ The NSF study compares numbers of S/E Ph.D.'s to "science and engineering utilization " of Ph.D.'s. The BLS projection compares the projected production of new S/E Ph.D.'s to the projected growth of "traditional employment" for Ph.D.'s in science and engineering. There is controversy about whether production of Ph.D.'s in excess of the number of traditional jobs for such persons necessarily implies that more Ph.D.'s are being produced than is socially desirable, since it may be that the "excess" Ph.D.'s will make good use of their skills and training in "non-traditional" employments. In this appendix, we follow the terminology of the studies under review. BLS refers to Ph.D.'s in non-traditional employment as "underemployed"; NSF refers to the same category as "non S/E utilization."

of market forces in the Ph.D. production process, adding realism to the supply projections that is absent from the NCES and BLS projections. The NCES and BLS supply and demand projections apparently suffer upward biases, and these biases act to cancel each other to at least some extent. Hence, the difference between the demand and supply projections of NCES and of the BLS may also reflect the actual future difference fairly well. If so, the supply of new S/E Ph.D.'s may exceed the demand for new Ph.D.'s by about 25% (NSF projection) and as much as 40% (BLS projection). In other words, about 25% but perhaps as much as 40% of the new S/E Ph.D.'s between 1976 or 1977 and 1985 or 1987 may be unable to enter positions that allow them to exercise the skills and knowledge reflected in their S/E doctoral training.

Analyses for Specific Fields

Of course specific fields may vary greatly from the general trend. Attention turns to the broad fields within science and engineering.

Biomedical/Life Sciences Demand and Supply

Four sets of projections of the demand and supply of biomedical/life sciences personnel were presented at the forecasting workshop. These projections were developed by the Bureau of Labor Statistics (BLS, 1975; Braddock, 1978), the National Science Foundation, the National Research Council through its Committee on a Study of National Needs for Biomedical and Behavioral Research Personnel (National Research Council, 1978), and Westat, Inc. (1978) under a contract from the National Institutes of Health.

The projections prepared by the BLS for the biomedical/life sciences were developed with essentially the same proecedures that were used in preparing the overall S/E projections discussed above. One assumption not noted above is that these field-specific projections are derived from the NCES projections of degrees "based on the assumption that the percentage distribution of degrees by field will continue the 1960-61 trends through 1986-87." Because the procedures used are identical, the assessment of the BLS estimates presented above applies to the field-specific projections as well. The above assessment suggested that projections of the demand for faculty may be too large, but that projections of the supply of new Ph.D.'s may also be too large. It is possible then that the differences between the projected supply and demand may be roughly accurate. The results of the BLS study indicate that between 1976 and 1985 from 31% to 48% of the new biomedical/life sciences Ph.D.'s will not be employed in positions requiring the level of expertise they have obtained, that is, demand will fall short of supply.

The same may be said of the NSF projections. The overall estimates of the future supply and demand for S/E Ph.D.'s were developed by summing the field-specific estimates which were derived by the methods outlined above. Hence, the discussion for S/E in general applies to the life science projections, that is, both the projected demand and the projected supply of life scientists are too large. Nonetheless it may be that these upward biases are of similar magnitude. If so the difference between the demand and supply projections are roughly accurate. The results of the NSF study indicate that by 1987 16% of the total supply of life science doctorates will not find employment suited to their educational attainments. This is compared to an estimate for the total life science doctorate labor force derived by the BLS of 20% in 1985.

Since the difference between the demand and supply estimates of th NSF for the total life science labor force is less than the corresponding BLS estimate, it is reasonable to assume that the NSF estimate for new life science Ph.D.'s (it cannot be calculated directly from information in the NSF report) is about one-fifth less than the BLS estimate. If so, the NSF estimates imply that between 25% and 38% of the new life science doctorates between 1977 and 1987 will be underemployed.

The third set of projections of the demand/supply situation for life scientists was conducted by the National Research Council. The NRC study projects the likely demand for bioscientists mainly on the basis of R & D expenditures and bioscience enrollments in colleges and universities. In each case a range of assumptions was employed to derive a range of estimates for 1977-1983. The assumptions regarding enrollments ranged from a low of 0% growth, to 2% annual growth, to a high of 5% annual growth. This is compared to a growth rate from 1961 to 1975 of almost 7% per year, which was slightly above the 6% rate for total enrollments in colleges and universities. The NRC report considers the 2% growth rate most likely. Although college enrollments may fall substantially during the next decade, for the 1977-1983 period covered by these projections enrollments are unlikely to fall much due to demographics and 0% growth is probably a reasonable lower limit.

Life science R & D expenditures in colleges and universities were also projected with high, medium, and low assumptions. The medium assumption was derived by extrapolating the slower rate of growth in R & D that began in 1968. Without further information on future government actions this is the most reasonable assumption. The preceding assumptions were combined with faculty-student ratios and estimates of faculty attrition to derive academic demand for bioscientists. Furthermore, the NRC assumed that the annual number of new positions in government and industry was likely to continue unchanged.

The NRC study did not formally derive a projection of the likely number of new Ph.D.'s in the life sciences but simply noted that the number of new doctorates per year had remained fairly constant at about 3,200 per year between 1972 and 1977, with a slight dip in 1977. For purposes of comparison the NRC assumed this trend would continue unchanged.

The projections derived on the basis of the medium assumptions imply that 34% of the new life science doctorates emerging during the projection period will not be able to find permanent employment traditionally requiring their level and field of training. This corresponds closely to the estimates implicit in the NSF projections and is within the range of the BLS estimates. All these estimates imply that a substantial surplus of life science doctorates will be created during the next few years.

Two additional comments on the NRC study should be made. If potential Ph.D.'s respond to this potential market situation by not earning their degrees, the surplus would be reduced. On the other hand, if the demand for new doctorates in academia is less than implied by a 2% growth in enrollments, then the surplus would be larger than projected. In any case, it seems unlikely that the demand for doctorates will expand rapidly enough and/or that the supply of new doctorates will fall quickly enough to avert underemployment for a substantial portion of new life science Ph.D.'s.

The final study of biomedical manpower was conducted by Westat, Inc. under contract with the NIH. The aim of this study is somewhat different from those above. Instead of attempting to project supply and demand over an extended period based on the preceding period, this is a cross-sectional study referring to one point in time which attempts to determine whether in 1977 there was a surplus or shortage of new non-clinical biomedical doctorates. The results of this study contradict those of the preceding studies by suggesting that there exists a shortage, rather than a surplus, of new biomedical Ph.D.'s. There is reason to doubt these conclusions, however. The study is based on a sample survey and re-survey of organizations that train bioscientists, organizations that employ bioscientists, and persons who were likely to complete their Ph.D. or postdoctoral training by October, 1977.

In April, 1977, questionnaires were sent to employers asking their expectations regarding openings. The follow-up questionnaire mailed in October, 1977, asked whether or not the positions had been filled, and if not why not.

Similarly a questionnaire was sent to identify people who had or were expected to finish their doctorate or postdoctoral work prior to October, 1977. A follow-up questionnaire was sent to determine whether the identified people had finished their Ph.D.'s and postdoctorates, and if so, what their job status was.

The inference that there is a shortage of non-clinical biomedical doctorates was drawn by comparing the number of unfilled vacancies in October to the number of program completers who were still seeking positions in October. The number of unfilled positions for which suitable candidates had not been found was estimated to be 1,560, while the number of completers still seeking positions was estimated at 476. The difference between the two is the inferred shortage of non-clinical biomedical scientists.

It appears likely, however, that the apparent shortage is not an actual shortage but results instead from the way in which postdoctorate studies are treated by Westat and from some peculiarities of interpretation.

First, there is a question regarding the number of vacant positions. It seems likely that at any given time a certain number of vacancies will exist due to market friction, that is, given the amount of time it takes to fill a position with a suitable candidate (perhaps an average of 3-4 months of search and decision-making time) it seems likely that at any particular time some, perhaps substantial, number of positions will be unfilled. In fact, 20% of the positions that were vacant due to a failure to find a suitable candidate were first reported in October, suggesting that they had been available for only a short time. Since the time for filling the positions was so short, it seems likely that the short search time rather than the unavailability of suitable candidates _per se_ provides the reason that the positions were unfilled in October. If so, the number of positions that were truly vacant after a reasonable search period should be estimated at 20% less than the Westat estimate of 1,560. The more reasonable estimate would be 1,248 positions.

The second potential problem with the Westat study is the treatment of postdoctoral positions. Postdoctoral positions are interpreted as representing part of the demand for biomedical scientists, in spite of the fact that they are usually relatively temporary positions (1 to 3 years) that are designed as an extension of the educational process. It may be more reasonable, then, to treat postdoctoral positions as an extension of graduate training rather than as positions equivalent to assistant professorships or other permanent positions. If this reasoning is sound, postdoctoral positions should be eliminated from the Westat estimate of the number of positions that had not been filled for lack of a suitable candidate. A total of 584 such postdoctoral positions were included in the original estimate. If we reduce this by 20% (under the assumption that 20% of these positions also appeared too recently for a complete search to have been performed), the figure is 467. If this figure is subtracted form the 1,248 positions estimated above, the number of postions that had not been filled due to lack of a suitable candidate is reduced to 781.

Questions of interpretation also arise regarding the estimated number of young bioscientists who can be considered to be seeking or in need of a permanent position commensurate with their educational attainments. The questions revolve around the definition of postdoctoral enrollments, the definition of non-research positions held by research scientists, and the interpretation of the failure of some people who expected to complete Ph.D.'s or postdoctorates by October to actually complete when they expected.

Beginning with the issue of non-completers, Westat simply assumes that these people should not be considered part of the pool of people who are looking for positions. This is formally true, since these people have not completed their Ph.D. or their postdoctoral work, but it may be that if the job market does not appear promising to those finishing their Ph.D.'s or postdoctoral training, then some of them might postpone completing their studies for, say, a year with the hope that the job market will improve in another year. The number of people involved might be substantial. Of the 5,062 people who expected to complete their Ph.D. by October, 1,576 or 31% failed to do so. While this may reflect poor foresight on the part of the Ph.D. candidates, the percentage is so large that some of it may be due to a poor market situation. If only 10% of those who expected but failed to complete their Ph.D. in October did so because of a poor job market, then the number of people who would have wanted a position in October, but had in this sense given up by postponing completion of the degree, would be 157 people. If this is added to the 476 seekers estimated by Westat the total desiring employment would be increased to 633.

The same argument might be applied to those who expected but failed to complete their postdoctoral training. Of the 2,606 people who expected to complete such training, 703 or 27% failed to do so. Again, some may postpone completion with the hope of an improving job market the following year. If 10% of those who expected but failed to complete their postdoctoral training fall into this category, then the total number desiring employment, but unable to find it would be increased by 70 to 703.

Another area of ambiguity concerns completers who entered positions that were not research positions. Westat apparently views such people as part of the natural loss of highly trained researchers to non-research activities. It is conceivable, however, that some of the ocmpleters entered such positions because they could not find the sort of research positions they desired, i.e., they gave up the search and settled for non-research positions. Three hundred thirty two or 11% of those leaving non-clinical doctorate programs entered such non-research positions, and 378 or 23% of those completing postdoctoral programs entered non-research positions. If it is assumed that 10% of those entering non-research positions were forced to do so because of a lack of research positions, the number is 71 people, which if added to the preceding estimate implies that 774 biomedical scientists would have been unable to find employment within their competencies by October, 1977, if they had continued looking.

Finally, to extend this sort of reasoning a bit further, Westat assumes that all the people who enter postdoctoral positions do so because they desire further training, and not because it provides them with a holding pattern from which to wait for improved job prospects. But one might alternatively assume that postdoctoral positions act as a holding station for Ph.D.'s who cannot find other suitable emplyment. If so, some proportion of the 1,416 Ph.D.'s who finished non-clinical doctoral programs and who entered postdoctorates should be considered part of the October, 1977 Ph.D.'s who would be seeking employment in more permanent positions that were unavailable. If 10% of these new doctorates are in such a situation the total number of job seekers would be estimated at 916, while if 50% of these doctorates are in such a situation the estimated total job seekers should be placed at 1,482.

One indicator that suggests that this interpretation of the postdoctoral pool is appropriate is the fact that 308 Ph.D.'s who had been in postdoctoral programs at the beginning of the study had decided to re-enroll in the same or another postdoctoral program by October, 1977. This represents 13% of all new enrollees in postdoctoral programs.

It also represents 19% of all Ph.D.'s who completed postdoctoral programs during the period. In other words one out of every five Ph.D.'s who completed a postdoctoral program decided not to pursue a more permanent position, but rather to pursue further postdoctoral training. One might ask whether this sort of process would be operating if there were a severe shortage of young bioscientists in comparison to available positions. If this instead reflects a surplus of Ph.D.'s, the number of doctorates seeking permanent positions should be boosted above the preceding estimate of 1,482.

Finally, one additional fact suggests that postdoctoral training is actually a holding station for Ph.D.'s who cannot find permanent positions. Taken at face value, the flows into and out of postdoctoral training programs that are reflected in the Westat data imply that postdoctoral enrollments grew by 791 people during the study period (an earlier Westat paper implies a growth of 310 people, and the NRC study indicates postdoctoral growth of 497 between 1976 and 1977). The question arises, if there is indeed a severe shortage of biomedical scientists, why is the number of postdoctoral students growing so rapidly? With a strong demand for bioscientists one might expect them to be drawn into the presumably more lucrative, desirable, and permanent positions. The substantial increase in postdoctoral appointments suggests, on the other hand, that more permanent positions are simply not available for all who desire them. If so, the estimated number of Ph.D.'s in the biomedical sciences who would seek employemnt, if they believed they might find it, would be boosted considerably above the preceding estimate of 1,482.

In light of this analysis, two alternative, contradictory interpretations of the Westat data are possible. First, as in the Westat study it may be assumed that postdoctoral positions should be considered primarily as a genuine part of the demand for bioscientists, and Ph.D.'s in postdoctoral positions should be considered to be employed, and not part of a surplus labor force. Under this interpretation, the shortage of bioscientists is 1,560 - 476 = 1,084 positions as of October, 1977.

On the other hand, if postdoctoral positions are viewed as a refuge for Ph.D.'s who can't find suitable employment, if non-completers are at least partly viewed as not completing because suitable employment is not availabe, if those entering non-research positions are viewed as doing so partly due to a lack of suitable employment, and if some unfilled positions are viewed as inevitable market friction, then the Westat data imply a substantial surplus of bioscientists as of October, 1977, with perhaps 781 unfilled positions and at least 1,482 Ph.D.'s who are looking or would be looking for such positions if they believed them to be available. According to this interpretation, the apparent shortage of bioscientists is instead a surplus of postdoctoral positions combined with a hesitancy by near Ph.D.'s to complete their degree because of a lack of permanent positions and with the movement of substantial numbers of bioscientists away from the kind of research activities for which they are trained.

The Westat data in and of themselves cannot resolve these different interpretations. Instead, sources of outside information must be sought. The three studies by the BLS, and NSF and the NRC are of course available, and on the basis of time series data, they conclude that the demand for new life science doctorates is substantially below the supply. The concurrence of the conclusions of these three studies on the basis of extended time series data suggests that the interpretation of the Westat data proposed here is more appropriate than that provided by Westat.

Physical Sciences Demand and Supply

Three sets of projections of demand and supply for physical scientists were presented at the forecasting workshop. These were developed by the Bureau of Labor Statistics, the National Science Foundation, and Lee Grodzins (1979a,b,c) of the Massachusetts Institute of Technology. The BLS projections include overall estimates for the physical sciences and separate estimates for physics and chemistry. The NSF projections are for the physical sciences in their entirety (including chemistry, earth science, physics, geology, meteorology, astronomy, metallurgy, geophysics, and pharmaceutical chemistry). The Grodzins projections are for traditional physics and astronomy.

The BLS projections for the physical sciences and physics and chemistry were prepared with the procedures discussed in earlier sections. Hence, the above assessment applies, that is, both the demand and supply estimates are probably too large, but the difference between them may be reasonable. The BLS projections suggest that 10% of all doctoral physical scientists, 7% of chemists and 30% of physicists will not find traditional employment by 1985.

Similarly, the NSF projections for the physical sciences use the procedures outlined and discussed above. The comments on the NSF work presented above apply here, that is, both supply and demand may be overestimated but the difference between the two may be reasonable. The NSF study estimates that 9% of the total labor force of doctoral physical scientists will not be employed in positions traditionally held by such people in 1987. This is quite close to the BLS projection of 10% in 1985.

The final projections for the physical sciences, prepared by Grodzins (1979a,b,c), are concerned only with physicists and astronomers. To calculate the future demand for these physical scientists Grodzins takes into consideration death, retirement, migration out of physics for the current labor force, and the upgrading of positions, and assumes a modest growth rate of 1% per year in demand. On the supply side, Grodzins assumes constancy in baccalaureate production and in the ratio of baccalaureates to Ph.D's. He also considers immigration and emigration, and mobility in and out of the field. The results of the analysis imply that about 20% of the new Ph.D.'s in physics and astronomy will not find positions suited to their education.

This 20% estimate is much less than the BLS estimate of 51% to 113%. The difference lies in the fact that Grodzins projects a somewhat greater supply than the BLS and considerably more demand than the BLS. From the information provided at the forecasting workshop it would be difficult to reconcile these two sets of projections which differ considerably not only in the results but also in the procedures employed and perhaps in definitions employed as well. Although the magnitudes involved in the two estimates differ considerably, it is noteworthy that both projections imply that new Ph.D.'s will face a severe shortage of appropriate positions at least until the mid-1980's, and that both suggest the demand in academia will fall far below the supply through the 1980's.

Engineering Demand and Supply

Two sets of projections of the demand and supply for doctoral engineers were presented at the forecasting workshop. These were prepared by the BLS and the NSF. As with other BLS field-specific projections discussed above, projections for engineering probably overestimate both supply and demand to some extent. The NSF projections for engineers are different from those developed for other disciplines, however, in that engineering baccalaureates are projected using a market related method that allows the number of degrees to respond to the demand for baccalaureate engineers. The importance of market forces in determining the supply of baccalaureate engineers implies that the NSF model is probably more adequate than the BLS model in describing engineering demand and supply.

Unlike the preceding field-specific cases, the results obtained by the BLS and the NSF are contradictory. The BLS data suggest that the situation for engineering Ph.D.'s will shift from an 11% surplus of doctoral engineers in 1976 to a shortage of 9% in 1985. On the other hand, the NSF projects that the 6% surplus of doctoral engineers in 1977 will rise to a 19% surplus by 1987. In reconciling these differences, it may be noted that Freeman reports a set of projections developed at MIT which imply that first year engineering enrollments will fall substantially between 1978 and 1984. This might be expected to produce declines in the hiring of doctoral engineers as college faculty with a slight lag. These market related data were developed at the MIT Center for Policy Alternatives, as were the degree projections employed by the NSF as inputs to its projections. Because the NSF projections incorporate market forces as described above, they may be more adequate than the BLS projections which do not consider the action of the market on academia. If so, it seems reasonable to conclude that there will be at least a slight and perhaps a substantial surplus of doctoral engineers by the mid-1980's. Nonetheless, because the market for Ph.D. engineers is so volatile and so heavily influenced by non-academic demands which are very difficult to project, forecasts of the market for engineers are probably even more uncertain than those for other fields.

Mathematics Demand and Supply

Two of the studies reviewed in the forecasting workshop developed projections of the demand and supply of doctoral mathematicians. The Bureau of Labor Statistics projections depend on the procedures described above. Hence, the preceding general assessment applies to mathematics as well. The BLS projections indicate that by 1985 30% of the doctoral mathematics labor force will not be found in employment traditional to this group. This is compared to 25% in 1976. Moreover, the BLS projections imply that between 42% and 88% of the new mathematics doctorates between 1976 and 1985 will not be in traditional employment by 1985.

The other projection for mathematics was developed by the NSF. The procedures used are the same as those described earlier, except that the total number of Ph.D.'s on mathematics faculties is assumed to remain roughly unchanged. The results obtained by the NSF are broadly similar to those of the BLS, though the magnitudes are different. The NSF projections indicate that underemployment of doctoral mathematicians will rise from 6% in 1977 to 21% in 1987.

Despite the differences in the magnitudes of the estimates, both indicate a substantial difference between the demand and supply of doctoral mathematicians during the next few years with demand falling far short of supply.

Social Sciences Demand and Supply

The Bureau of Labor Statistics, the National Science Foundation, and the National Research Council have developed projections of the demand and supply of social scientists.

The BLS projections were derived with procedures identical to those described above, and conclusions drawn above apply here as well. The BLS projections imply that by 1985 the level of underemployment of doctoral social scientists will rise to 27% compared to 12% in 1976. The projected situation for new social science doctorates between 1976 and 1985 is that by 1985 between 41% and 54% will be underemployed.

The projection procedures of the NSF for the social sciences are similar to those for other fields except that total social science faculty size is assumed constant. According to the NSF projections the percentage of underemployed social science doctorates will rise from 13% in 1977 to 19% in 1987. As was the case for mathematics, the magnitude of the shortfall in demand projected by the NSF is less than that projected by the BLS but the trends are similar.

The final projections for the social sciences were derived by the NRC's Committee on a Study of National Needs for Biomedical and Behavioral Research Personnel. The NRC derives a series of projections on the basis of a range for each major assumption. The growth rate of undergraduate enrollments is assumed to be 0%, 2.0%, or 3.5%. A range of assumptions for faculty/student ratios is also used. Under the medium set of assumptions, and further assuming that non-clinical Ph.D. production in the social sciences will remain constant, the NRC projects that between 1976 and 1983 the percentage of new doctorates who will be underemployed is about 33%. Although the caveats discussed with regard to the NRC projections for the life sciences apply here as well, it is notable that, although the magnitude of the shortfall in the demand for social scientists in the NRC projections is less than in the BLS projections, the BLS, NSF, and NRC projections all depict the same general trend, substantial underemployment of doctoral social scientists.

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APPENDIX C

REVIEW OF THE LITERATURE ON THE RELATIONSHIP BETWEEN AGE AND SCIENTIFIC PRODUCTIVITY, BY BARBARA F. RESKIN

A REVIEW OF THE LITERATURE ON THE RELATIONSHIP BETWEEN AGE AND SCIENTIFIC PRODUCTIVITY

Barbara F. Reskin

For almost half a century students of science have been interested in whether scientists' age affects the quality or quantitiy of their scientific contributions. Because almost all of the empirical studies of this question have been flawed methodologically, unequivocal evidence on the existence, strength and form of the relationship between age and scientific productivity is still lacking. In this review several methodological problems that vitiate most of the work on the impact of age on scientists' productivity are discussed. Some general findings on the relationship between age and scientific productivity based on data that are aggregated across scientific disciplines are then summarized and several possible theoretical models of the form of the relationship are presented. Finally, results for several scientific disciplines are reviewed, and some tentative conclusions are presented regarding the probable impact of scientists' age on their scientific productivity.

Early work by Lehman (1936, 1944, 1953) supported the commonly held belief that scientific performance declines as scientists age. However, Lehman's work has been criticized on methodological grounds (Dennis, 1956a, 1956b, 1956c, 1966; Cole, 1979). Rather than comparing the proportions of scientists in each of his age groups who made important discoveries to see whether they diminish over time, Lehman asked what proportion of important discoveries was made by scientists of different ages. Thus he implicitly and erroneously assumed an equal proportion of scientists in each age group. In fact, the growth of science over the last two centuries means that scientists are disproportionately young, so proportionately more discoveries should be made by young scientists even if age has no effect. A second problem with Lehman's work is the effect of life span on the distribution of the achievements of scientists at various ages. Accomplishments by scientists who die young are necessarily made by young scientists. Had they survived, some of them probably would have produced additional important work at older ages as well. Thus, if all scientists were equally long-lived, Lehman would presumably have observed more scientific achievements by older scientists.

Several other methodological problems characterize most empirical work in this area. First, many studies used measures of association that assume a linear relationship when in fact evidence indicates that the relationship is non-linear. Second, most studies have considered only the bivariate relationship between age and productivity, ignoring other variables (e.g., organizational context) that undoubtedly affect the form of the relationship. Discipline is often ignored, and recent research by Bayer and Dutton (1977 -- reviewed below) demonstrates the existence of disciplinary differences. Third, in the absence of true longitudinal data, distinguishing between age and generation (cohort) effects is problematic, since both could produce the same pattern of declining productivity among older cohorts of scientists.

Fourth, difficulties involved in measuring scientific performance are often ignored. Neither of the most common measures -- recent article and citation counts -- may wholly capture the phenomenon of interest. On the one hand, article production may decline over time as scientists change their publication patterns without any decline in the quality of their scientific contributions. Citation counts, on the other hand, presumably reflect both the calibre of scientists' work and their professional visibility, which is partly a function of non-performance-related factors such as the prestige of their academic department. Other measures of scientific performance such as lifetime contributions are more seriously flawed. Bayer and Dutton (1977) show the dependence of age-performance curves on the criterion selected.

Fifth, many studies of the relationship between age and scientific performance fail to assess the amount of variance in productivity that is uniquely attributable to age. Where this is reported, age accounts for an inconsequential proportion of the variation in productivity. Although this can be due to misspecification of the prediction model (either improper specification of the form of the relationship or failure to include all appropriate predictors), more likely it reflects the unimportance of age relative to other factors (such as the calibre of scientists' training, their propensity to publish, their early research experience, their place of employment, and the availability of resources and rewards for research; Reskin, 1977, 1978) that affect whether or not scientists continue to carry out and publish research as they age.

Finally, the generalizability of even the most robust findings is dubious, in view of the omitted intervening variables that might account for any association between age and productivity. If, for example, older scientists publish less because they are disproportionately recruited for administrative responsibilities, as the number of older scientists increases, a smaller proportion of them would be subject to competing administrative obligations, and the association would be attenuated. Taking into account primary activity during the period performance is observed is obviously essential.

Studies Based on Aggregated Data

In their study of doctoral scientists employed in research and development laboratories, Pelz and Andrews (1966, rev. ed. 1976) found two peaks in several measures of scientific performance (including "scientific contributions" and published and unpublished papers), although the slump occurred earlier for those in research (45-49) than in development (ages 50-54). The authors believed that motivational changes were more likely to be responsible for the mid-career slump than the assumption of admininstrative responsibilities. Elsewhere in the study they showed that at least moderate administrative loads did not interfere with scientists' output.

Blackburn, Beyhmer, and Hall (1978) examined the association among Ph.D. holders who were faculty members at 4-year colleges and universities. Among those in high-prestige institutions, they observed the "spurt-obsolescence" pattern (Bayer and Dutton, 1977) -- a bimodal "saddle-shaped" curve which Lehman also reported much earlier. Productivity was highest for scientists in their late 30's and late 40's, with a slump in the intervening years. However, the bimodal pattern did not occur among scientists at lower-prestige institutions.

Although this review excludes studies restricted to eminent scientists (e.g., Roe, 1965), data Zuckerman (1977) presents on age-specific annual productivity rates for Nobel Laureates and a matched sample of non-Laureates are of interest. Both groups showed the bimodal pattern described above, although the peaks for the Laureates are a half a decade later than those for the members of the matched sample (and, of course, the Laureates outproduced the matched sample at every age).

Models of the Relationship between Age and Productivity

Perhaps the most sophisticated research on the relationship between age and scientific performance is that of Bayer and Dutton (1977). It uses 1972-73 American Council on Education data for over 5,000 doctoral teaching faculty from seven scientific fields to assess six alternate models of the relationship for eight measures of productivity: recent articles, lifetime articles, books, number of works cited in the 1973 Science Citation Index, pure research orientation, time spent in research, number of journal subscriptions, and time spent consulting. Reasoning that the linear model might misspecify and hence underestimate the strength of the actual relationship, the authors test the linear model and five alternative models for goodness of fit to the data. The six models which are shown in Figure 1 are:

1. linear or cumulative growth: $Y = a + bX$ (where Y equals the productivity measure and X equals age);

2. declining rate of increase, which reflects the "aging" hypothesis that performance tapers off over time, such that $Y = a + b \log X$;

3. leveling out function, which also reflects the "aging" hypothesis, but with a plateauing effect of age such that $Y = a - b\,(1/X)$;

4. obsolescence function, a parabolic function in which performance peaks and then declines, either because scientists lose

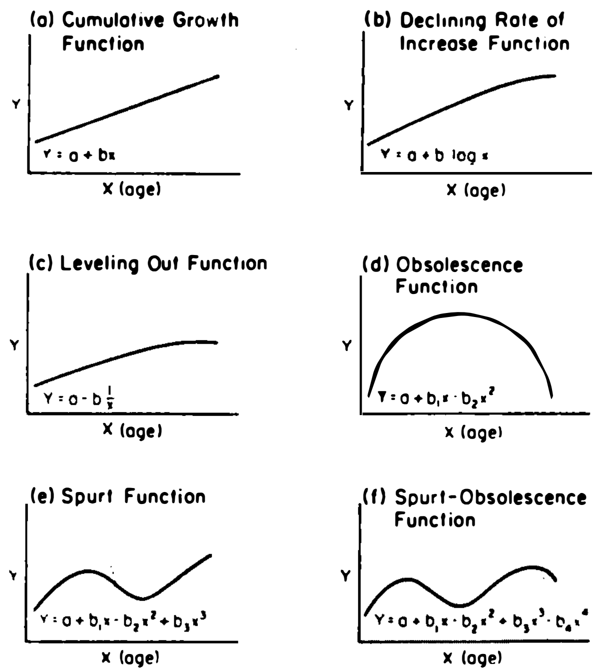

Fig. C1. Alternative Models of Aging Functions.

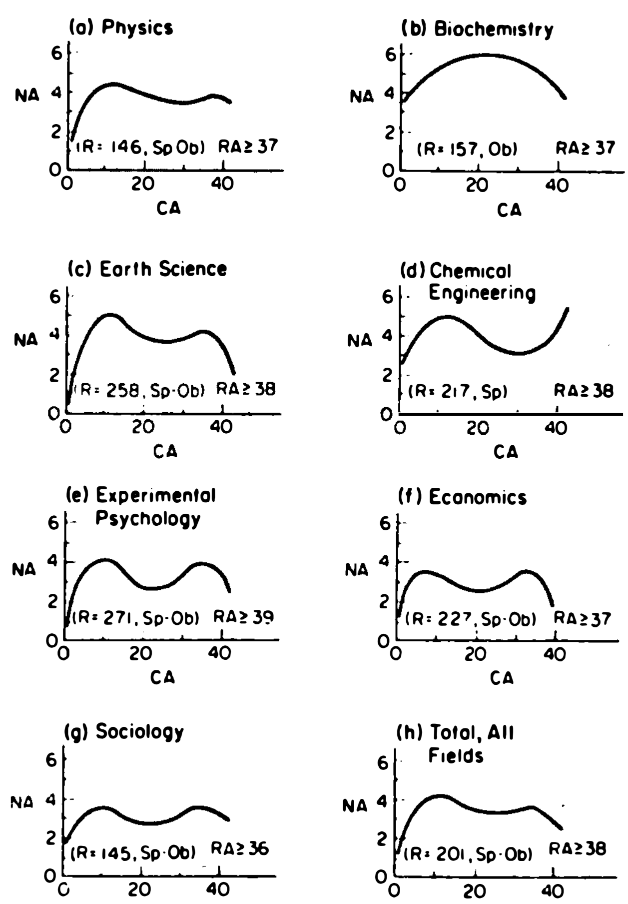

Fig. C2. Plots of Best-Fit Model of Career Age with Number of Published Articles in Last Two years, by Field. NA is number of articles published in last two years, CA is career age, and RA is career age at which retirement is expected (from Table 1).

SOURCE: Bayer and Dutton, 1977, pp. 262, 273, Figures 1 and 2.

their "vigor" or because the declining returns to performance reduce scientists' incentive to do research. Here,

$Y = a + b_1X - b_2X^2$;

5. spurt function, a bimodal distribution that overlays the expected effects of the academic reward system on the direct aging effects to yield two peaks -- one during the early creative years and a second ten to fifteen years later. Here,

$Y = a + b_1X - b_2X^2 + b_3X^3$;

6. spurt-obsolescence function bimodal distribution in which the second peak is followed by a decline in performance, such that

$Y = a + b_1X - b_2X^2 + b_3X^3 - b_4X^4$.

Although the authors present analyses for both aggregated data for all seven fields as well as data disaggregated by field, for none of their eight productivity measures did the same model provide the best fit for each of the seven fields. Hence, generalizing from the results for one discipline to another may often be inappropriate.

The Relationship between Age and Productivity within Selected Disciplines

There are several reasons to expect field differences in the relationship between age and scientific productivity. Fields differ in the length of doctoral training and hence in the age at which students typically complete their Ph.D.'s, they differ in the extent to which research is a collaborative enterprise, in journal acceptance rates and publication time, and in the form in which publications typically appear. They also differ in their degree of codification (Zuckerman and Merton, 1972, p. 303), that is, the extent to which empirical knowledge is consolidated into succinct theoretical formulations or the degree to which practitioners share consensus on what the important questions are and how they can be solved. Zuckerman and Merton hypothesize that the degree of codification in a field should affect the ease with which young scientists learn research questions and appropriate techniques and hence the extent to which they do not need long experience to become competent practitioners.1/ Finally, fields differ in the extent to which techniques learned in graduate school are subject to technological obsolescence.

Physics

Bayer and Dutton (1977) report a weak spurt-obsolescence pattern for recent publications among a sample of Ph.D. holding college and university teaching faculty (see Figure 2) with age accounting for less than 2% of the variance in recent output. On a sample of physicists from Ph.D. granting departments, Cole's (1979) results from a study of academic scientists in six fields employed in Ph.D. granting institutions show an obsolescence pattern among the physicists with mean article productivity peaking between the ages of 40 and 44, and then declining steadily to 55% of its peak level among older cohorts.

Physicists' mean number of citations did not show the same obsolescence pattern. Rather thay were about equally high -- about three per year -- for physicists aged 35 to 39 and those over 60,

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1/ Cole (1979) points out that codification should also affect the extent to which there is consensus in a field on what findings are important and that significant discoveries can be readily identified as such, but although this may affect the relationship between age and professional recognition, it should not influence the relationship between age and productivity.

but less than half as high for physicists between 45 and 49, thus displaying a spurt pattern.

Differences in the results for article productivity in the compositions of the two samples might account for the discrepancy for physicists nearing the end of their careers, since the less productive older scientists in Bayer and Dutton's more heterogeneous sample might have been more likely to abandon teaching and research positions earlier than more productive researchers. If so, those faculty remaining would show an apparent upsurge toward the ends of their careers. As Bayer and Dutton showed, the patterns for articles and citations typically differ.

Allison and Stewart's (1974) aggregate analysis of data for faculty at Ph.D. granting departments showed increasing inequality in the distribution of scientific productivity among older cohorts of physicists. This is consistent with sociologists of science (Cole and Cole, 1973) "accumulative-advantage" hypothesis that holds that maintaining scientists' productivity over time is primarily a function of the availability of resources and other professional rewards which themselves are more unequaly distributed as cohorts age.

Astronomy

As part of a larger study on peer review, the National Science Board (1977) identified 85 significant advances ("innovations") made by four disciplines during the past 20 years (as judged by non-random samples of scientists selected from the four fields). In addition to exploring funding patterns that led to the innovative work, they considered the characteristics of the investigators credited with the work. Of the 21 innovators in astronomy, 52% were under 35 years old, although in 1973 only 32% of doctoral astronomers were under 35. While the proportions are not strictly comparable since the 52% refers to the investigators' age at the time the innovation was made (up to 20 years earlier), the bias is a conservative one because fields have been growing younger rather than older for most of this period. This finding and those for the other three fields (chemistry, earth sciences, and mathematics) reported below lend some support for the belief that the most creative work is done disproportionately by young scientists.

Mathematics

Stern's (1978) analysis of data on 43 distributed university-based mathematicians and of mathematicians elected to the National Academy of Sciences showed a spurt function among the university mathematicians, with the peaks for both single- and co-authored papers between the ages of 35 and 39 and after age 60, and the nadir between 45 and 49. Analysis of citations showed a spurt-obsolescence function, with declines for mathematicians between 45 and 49 and over 60. She suggests that administrative obligations that scientists assume in their 40's may account for their productivity slump during that period.

Cole's (1979) analysis of longitudinal data for a 25-year period for about 500 university mathematicians who received their Ph.D.'s in the late 1940's showed a slight spurt-obsolescence pattern, with peaks 5-10 and 15-20 years after the Ph.D., although Cole concluded that "productivity does not differ significantly with age." He found that the proportion who published at least one paper and received at least two citations over each 5-year period was quite stable over the 25 years (14%-17%), while the proportion who published nothing increased over time from 38% to 61%. Hence, correlations between the number of publications in various 5-year periods were moderate, ranging from 0.6 to 0.8, depending on the amount of intervening time. Analysis of ages at which mathematicians published papers that elicited at least five citations suggests that the ability to produce highly cited work, while uncommon among sample members, was probably unrelated to age, although the data for university mathematicians who are over 60 are not reliable.

A study of scientific innovations conducted by the National Science Board (1977), on the other hand, showed that 55% of 18 "innovations" in mathematics over a 20-year period were by scientists under 35, a group that included only 39% of all mathematicians. This finding offers some support for the widely held belief that the creative work in mathematics is done disproportionately by younger scientists.

Consistent with their hypothesis that productivity is closely tied to the scientific reward structure, which itself generates increasing inequality over time, Allison and Stewart (1974) found increasing inequality in article productivity among older cohorts of mathematicians.

Chemistry

Cole's (1979) data showed an obsolescence pattern in mean article productivity with peak productivity between the ages of 40 and 49. Mean number of citations showed a spurt pattern: chemists in their early forties and over fifty received the most citations (an average of at least one a year) while those 35 to 39 and 45 to

49 received less than 0.7 citations on the average. The National Science Board (1977) study of innovations found that young chemists made a disproportionate number of the 17 innovations judges reported in the field of chemistry over the past 20 years (53% compared to their representation as 33% of practitioners).

Allison and Stewart (1974) observed the same pattern of increasing inequality among their synthetic cohorts of chemists that they found for physicists and mathematicians.

Chemical engineering

Unlike most of the disciplines they examined, the relationship between age and article production in Bayer and Dutton's (1977) sample of chemical engineers was of the spurt form, peaking about ten years after the Ph.D. and at the end of the career (see Figure 3). However, age accounted for only 4% of the variance in productivity.

Biochemistry

The biochemistry faculty Bayer and Dutton (1977) studied were the only group whose publication patterns showed a simple obsolescence curve, consistent with a deleterious effect of aging on productivity. Their peak was slightly later than that for the other six disciplines, occurring at about the middle of the career (see Figure 2). However, age was a poor predictor of article productivity (R = -0.157), accounting for only 2% of the variance.

Biology

No individual-level analyses on the relationship between age and productivity among biologists could be located. The pattern for biologists in Allison and Stewart's (1974) aggregate-level analysis differed from those for physics, chemistry, and mathematics, in that it showed only a very slight increase in article inequality as the synthetic cohorts "aged." The authors suggest that this may be due to lower consensus among biologists on important research questions and poorer communication among practitioners, which could inhibit an efficient allocation of rewards according to merit, so that scientists best able to convert resources into future performance do not accumulate them.

Earth sciences

The age-productivity association among the earth scientists Bayer and Dutton (1977) studied was of the spurt-obsolescence form, with the first peak slightly more pronounced than the second (see Figure 2). The data fit the curve better for earth scientists than for most of the other fields they examined; but age still accounted for only 7% of the variance in article productivity. The National Science Board study of innovations mentioned above found that young researchers were overrepresented among those who had made important innovations in the earth sciences. Although researchers under age 35 constituted only one-quarter of the discipline, they were credited for 37% of the innovations.

Geology

According to Cole (1979), both the mean numbers of articles and citations of geologists showed an obsolescence curve. Both peaked for geologists between 40 and 44 years old, and declined sharply after age 50.

Psychology

The psychologists whom Cole (1979) studied showed a similar pattern to that of the geologists, except that the peak productivity period began earlier, extending from ages 35 to 45. On the other hand, the experimental psychologists in the Bayer and Dutton (1977) study showed a spurt-obsolescence pattern for articles published in the past two years, with a fairly strong decline among those who had had their Ph.D.'s about twenty to twenty-five years (see Figure 2). The difference in specialty distributions or institutional locations of members of the two samples could account for the discrepancy in their results.

Economics

The results for Bayer and Dutton's (1977) economists were quite similar to those for the experimental psychologists, except that the first peak appeared among slightly younger scientists and the length of time between the two peaks was correspondingly greater (see Figure 2). The data for the experimental psychologists fit the curve marginally better than did those for the economists (R's = 0.271 and 0.277, respectively). Thus, in neither field did age account for more than 7% of the variance.

Sociology

The curve for the sociologists Bayer and Dutton (1977) analyzed was the flattest and yielded the poorest fit to the data. Nevertheless, the data suggest a slight spurt-obsolescence pattern (see Figure 2). Cole's (1979) results, on the other hand, showed an obsolescence function for both articles and citations -- as did almost all of his disciplines -- with peaks between the ages of 45 and 49. Again, the greater heterogeneity of Bayer and Dutton's

(1977) sample may account for the discrepancy if less productive researchers tended to retire earlier than more productive individuals.

Clemente and Sturgis's (1974) study of sociologists reported a very weak negative relationship between age and article counts, but the obvious misspecification of the form of the relationship renders this result of little value.

Conclusions

Some regularities across disciplines occurred in the discipline-specific analyses. First, in no case did productivity show a simple negative relationship with age, and in almost all cases the simple linear model of cumulative growth was inadequate. The failure of the "declining" and "levelling out" models to fit the data well is inconsistent with the existence of simple aging effects, and it seems safe to rule out the hypothesis that increased age necessarily leads to lower productivity. Second, the results broken down by discipline suggest that linear models are inadequate to describe the relationship between age and at least certain measures of scientific performance. This is not to say that articles (or citations) do not decline among older scientists at certain ages. The spurt-obsolescence model offered the best fit for most fields (but in biochemistry the obsolescence model was superior, and the spurt model fit the data for chemical engineering better than the alternatives assessed -- see Figure 2). Among the groups studied the first of the two peaks tended to occur about ten years after the Ph.D. and the second as scientists neared retirement age. These patterns are consistent with market effects or selective attrition, where scientists whose productivity does not recover from a mid-career slump tend to shift into non-research positions or to retire early (although early retirements are uncommon among doctoral scientists). Bayer and Dutton (1977) concluded that market, generational, and selective attrition effects on performance may all be overlaid with any effects of aging.

Finally, regardless of their form, any simple effects of aging appear to be small. Although Cole did not provide information on the strength of the associations for the data he examined, the non-linear models Bayer and Dutton assessed never accounted for more than 7% of the total variance in productivity and usually explained substantially less. Moreover, the small zero-order effects of age would presumably be further attenuated in more properly specified models that included demonstrated determinants of productivity such as primary activity, institutional setting, and research resources, which are usually correlated with age. Multivariate analyses for specific scientific disciplines that permit non-linear effects of age are necessary to learn whether age *per se* has any independent effect on scientists' performance.

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APPENDIX D

A STEADY-STATE MODEL OF FACULTY AGE DISTRIBUTION

A STEADY-STATE MODEL OF FACULTY AGE DISTRIBUTION

Faculty flow models have become an increasingly widespread tool in analysis and planning for the higher education sector. Such models analyze the size and composition of faculties as they evolve over time on the basis of simplified assumptions about rates at which faculty members with particular characteristics enter into, are promoted within, and leave the academic sector or some part of it. Such models have been developed for the analysis of individual institutions (Hopkins, 1974; Hopkins and Bienenstock 1975; and references cited therein), of individual academic disciplines (Grodzins, 1979b; Hansen, 1979a) and of academia as a whole (Cartter, 1976; Patton, 1979a, chapter 5).

One application of such models of faculty flow is the analysis of "steady-state" age distribution and faculty composition. A "steady-state" for a model of faculty flow is defined as a situation in which the total size and composition of the faculty remain constant over time. In such a steady-state, the total number of faculty entering the system equals the number leaving; and the number entering any particular subgroup (e.g., non-tenured faculty, faculty aged 60 and above) will equal the number leaving that subgroup. In general, there will exist one steady-state faculty composition corresponding to any given set of assumptions about rates of flow of faculty into and out of the various subgroups defined within the model.

Such steady-state analyses are, of course, a theoretical approximation. Actual faculty composition will, at most, approach its steady-state values and fluctuate about them -- until the conditions change. However, steady-state analyses have proved useful as an analytical tool because they permit a particularly simple way of analyzing the relationships among the various parameters that bear on faculty flows and age distributions. They can show, for example, how sensitive the rate of hiring of new faculty is to changes in promotion policies or retirement policy (Hopkins, 1974). Also, in conditions where it is reasonable to assume no growth in overall faculty size, the parameters of a steady-state model provide a useful benchmark for comparison to actual conditions. The steady-state results show rates of hiring of new faculty, proportions of young faculty, and the like, which are sustainable in the long run without changing the size of the faculty. This appendix presents a simplified illustrative steady-state model, describes the more complex model underlying the steady-state model employed in the text, and analyzes critically the assumptions underlying that model.

A Simplified Illustrative Model

To illustrate the principles involved, it is useful to examine briefly a highly simplified example of such a steady-state solution to a faculty flow model. Suppose all faculty in some discipline and set of institutions enter the system at age 30, that half reach tenure after five years and half leave at that point1/, and that those who receive tenure stay until age 65, when they retire. Death and other sources of attrition (other than failure to be promoted) are ignored.

1/ The "system" here is best conceived as some subset of all colleges and universities -- e.g., the Ph.D. granting institution. Individuals leaving that subset of institutions may achieve tenure elsewhere in academia.

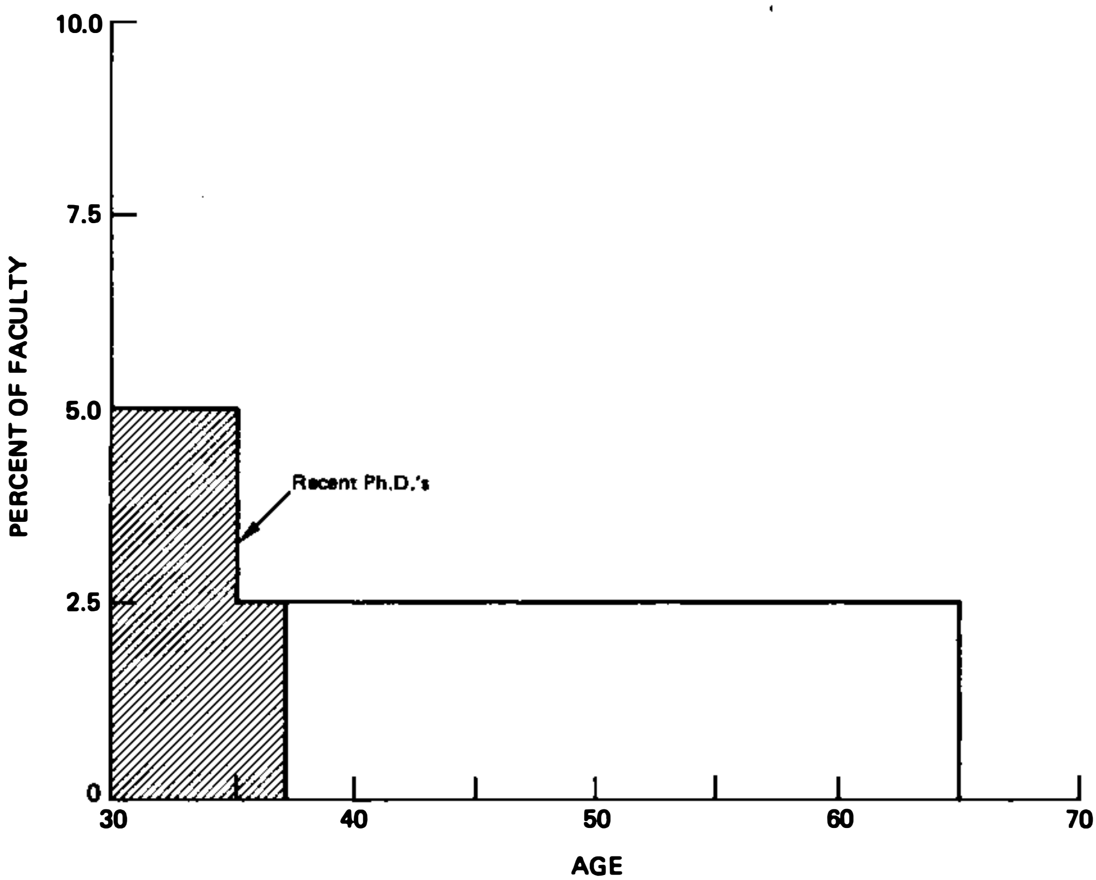

FIGURE D-1 Age Profile for Simplified Model of Steady-State Faculty Flow

Under these assumptions, the age profile of the steady-state distribution will appear as in Figure D-1, with twice as many persons at each age between 30 and 35 as at each age between 36 and 65. This is so because from each entering cohort of 30-year-olds, half will leave after five years, and the other half will stay for thirty years more. Since in the steady-state, the size of the entering cohort is the same from year to year, the age profile will have the simple shape shown in the figure.

The relevant parameters of this simple model are readily calculated. Suppose, for example, that 1000 faculty enter the system each year. Total faculty size will then be 1000 times 5 plus 500 times 30, or 20,000. Annual new hires will be 5% of the total faculty, and retirements will be 2.5% of the faculty. Six thousand of the 20,000 faculty will be within seven years of the Ph.D., so that the percentage of faculty who are "young" is 30%.

Such a model, while plainly oversimple, is suggestive of rates of faculty flow which are sustainable in the long run with a constant faculty. To make the model more realistic, it is necessary to employ more realistic assumptions about the age distribution of new entrants, the influence of death and other sources of attrition, and other factors.

The Steady-State Model Employed in the Text

The steady-state calculations reported in the text are based on a model which is intended to represent faculty flows at Ph.D. granting institutions. The steady-state model can be thought of as applying to science and engineering faculty as a whole at this set of institutions, or to faculty in particular scientific fields. Some relevant differences between fields are noted in the section on "Discussion of Model Assumptions" below.

The assumptions of the model are as follows:

1. There is a constant number of new entrants into non-tenured positions each year.

2. The number and age distribution of new entrants to tenured positions (other than those appointed from non-tenured positions) is the same as the number and age distribution of tenured faculty leaving academia for reasons other than death and retirement. (Analytically, this is equivalent to assuming that there is no net change at the tenured level other than through death and retirement.)

3. The age distribution of new non-tenured entrants to academic positions is assumed to be the same as that of the 1978 cohort of Ph.D.'s in science and engineering who planned to take academic positions (including postdoctoral fellowships) in Ph.D. granting institutions. The data, which were obtained from the NRC's Survey of Earned Doctorates, are reported in Table D-1. (Note: Ph.D.'s of age X at the time of the survey were assumed to be of age X + 1 during their first year of service.)

4. Age-specific death rates for the entire U.S. population in 1975 apply to all members of the system. These death rates are given in National Center for Health Statistics (1975).

5. Half of each cohort receive tenure after five years. The other half leave the system after five years.

Since in the steady-state every cohort of new entrants has the same size and composition, a steady-state faculty age profile based on these assumptions is readily obtained by tracing out the experience over time of a typical cohort of new entrants. Table D-2 describes the steady-state age distribution that results from these

Table D-1

AGE DISTRIBUTION OF NEW PH.D.'S PLANNING ACADEMIC EMPLOYMENT a/
IN PH.D. GRANTING INSTITUTIONS, 1978

Age b/	New Ph.D.'s	Age b/	New Ph.D.'s
25	13	50	8
26	50	51	9
27	213	52	14
28	539	53	3
29	736	54	3
30	665	55	6
31	557	56	5
32	511	57	1
33	418	58	2
34	280	59	1
35	191	60	1
36	177	61	0
37	130	62	1
38	99	63	0
39	64	64	1
40	52	65 and above	0
41	29		
42	25		
43	25		
44	21		
45	17		
46	17		
47	15		
48	9		
49	16		

a/ Includes individuals planning postdoctoral appointments.

b/ It was assumed that persons of age X at time of response to the survey were of age X + 1 at time of employment.

SOURCE: NRC, Survey of Earned Doctorates

Table D-2

AGE PROFILE FOR STEADY-STATE MODEL OF DOCTORAL FACULTY AT PH.D. GRANTING INSTITUTIONS

a) Percent Distribution of Doctoral Faculty by Chronological Age

Age	Percent of Faculty	Age	Percent of Faculty
25	0.01	45	2.70
26	0.07	46	2.70
27	0.31	47	2.69
28	0.92	48	2.67
29	1.75	49	2.66
30	2.50	50	2.65
31	3.10	51	2.63
32	3.55	52	2.62
33	3.72	53	2.60
34	3.61	54	2.57
35	3.45	55	2.55
36	3.33	56	2.52
37	3.19	57	2.49
38	3.06	58	2.46
39	2.96	59	2.43
40	2.91	60	2.39
41	2.84	61	2.35
42	2.78	62	2.31
43	2.75	63	2.27
44	2.73	64	2.22

b) Percent Distribution of Doctoral Faculty by Years Since Ph.D.

Age	Percent of Faculty	Age	Percent of Faculty
1	5.57	21	2.53
2	5.56	22	2.50
3	5.55	23	2.47
4	5.54	24	2.43
5	5.53	25	2.40
6	2.76	26	2.35
7	2.75	27	2.29
8	2.74	28	2.22
9	2.74	29	2.13
10	2.73	30	2.02
11	2.71	31	1.91
12	2.70	32	1.75
13	2.69	33	1.54
14	2.67	34	1.29
15	2.66	35	1.02
16	2.64	36	0.71
17	2.62	37	0.37
18	2.60	38	0.12
19	2.58	39	0.03
20	2.55	40	0.01

assumptions, characterized both by chronological age and by years since Ph.D. Thirty three percent of the faculty are within seven years of the Ph.D. Annual new hires are 5.6% of total faculty. 2.2% of the faculty retire each year and 9.2% of the faculty are older than 60.

Discussion of Model Assumptions

Modification of the model's assumptions would of course change the steady-state results. The following discussion provides justification of the assumptions made and an analysis of the sensitivity of the results to changes in key assumptions.

1. Retirement age. By 1982 all universities and colleges will be prohibited by federal law from requiring retirement before age 70. It is not clear at this point how many faculty will choose to postpone retirement to age 70 when they can. If the steady-state model is modified to assume that all faculty retire at age 70 rather than age 65 (the actual table is not shown here), which presumably overestimates the effect of the change in retirement laws, the effect on the steady-state parameters is moderate. New hires change from 5.6% to 5.0% of the faculty. The percentage of young faculty goes from 33% to 30%, and the percentage of faculty retiring each year falls from 2.2% to 1.8%. Such a modest effect of changes in retirement policy on equilibrium faculty flows has been corroborated by other studies (Hansen, 1979a; Patton, 1979a).2/

2/ The short run effect of the change in retirement laws may be more significant than the effect on the steady-state equilibrium. This is because the sudden shift to a later retirement age tends to lead to a period of several years where many of those otherwise expected to retire delay their retirement plans. In the steady-state, a constant flow of faculty will reach retirement age every year. See in particular Oi (1979).

2. Postdoctorals. The model assumes that Ph.D.'s enter faculty positions immediately upon receipt of the degree. But in some scientific fields a significant proportion of Ph.D.'s spend one or two years in postdoctoral study before assuming a faculty position. Such fields will, in the steady-state, have a lower proportion of faculty within seven years of the Ph.D. than the model in the text assumes.

The largest percentage of Ph.D.'s entering into postdoctoral study occurs in the biological sciences, where between 60% and 65% of all 1977 Ph.D.'s planned to undertake postdoctoral work (NRC, 1979, Table 7.1). If we were to assume that 60% of all the Ph.D.'s in a particular field who ultimately assume faculty positions first spend two years on a postdoctoral appointment, then the steady-state percentage of faculty within seven years of the Ph.D. in that field turns out to be 27% instead of the 33% indicated above.

3. Rates of promotion to tenure. The text model assumes that half of all faculty are promoted after five years, and that the other half leave the system. The "system" here is to be thought of as the set of Ph.D. granting institutions. It is likely that significant numbers of persons who do not achieve tenure at these institutions eventually receive tenure elsewhere in academia. Other studies have indicated that hiring rates and percentages of young faculty are particularlys nsitive to changes in promotion policy (Cartter, 1976; Hopkins, 1974). Appropriate values for promotion probabilities are difficult to determine, both because of inadequacies in the historical data, and because the promotion rate is likely to be different (presumably lower) in steady-state conditions than in the growth conditions on which historical data are based.

Cartter (1976), in modeling the probability of promotion to tenure for the entire higher education system, made the assumption that in any particular year 20% of a given cohort of entrants would achieve tenure and 12% would leave academic employment. On these assumptions 56% of any given cohort would eventually achieve tenure. Since Cartter's assumptions are intended to apply to academia as a whole, a lower promotion rate would be implied for the Ph.D. granting institutions.

Fernandez (1978) estimated promotion probabilities as a function of years of service. His estimates based on historical data imply that 81% of a particular cohort of entrants will eventually achieve tenure.3/ However, his projection analysis implies that this rate is expected to fall quite considerably as academic market conditions worsen.

To convey a sense of the sensitivity of the steady-state results to changes in rates of promotion, calculations were made on the assumptions that one-third or two-thirds of each cohort were promoted after five years, with the remainder leaving the system. If one-third instead of one-half are promoted, the percentage of faculty within seven years of the Ph.D. rises from 33% to 41% and the annual rate of new hires rises from 5.6% to 7.3%. If two-thirds are promoted, the percentage of recent Ph.D.'s on faculties falls to 29% and the rate of new hires to 4.6%.

4. Voluntary exits from tenured positions. The text model assumes that the number of people hired directly (i.e., not drawn

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3/ Based on Fernandez (1978), Table A10.

from the non-tenured faculty) into tenured positions will equal the number leaving such positions for reasons other than death or retirement. According to Cartter (1976, p. 169) this was roughly true during the 1950's. In the 1960's, Cartter estimates that there was a small net inflow to tenured positions, and that there has been some small net outflow since. He suggests that worsening employment conditions for faculty in the 1980's are likely to lead to an increase in the rate of net outflow, to approximately 1% to 1.5% of total faculty per year in the 1980's. Fernandez's analysis, which underlies the Radner/Kuh projection model, anticipates a somewhat smaller net outflow than Cartter's estimate for the 1980's.4/

Steady-state rates of hiring and percentages of young faculty are quite sensitive to the rate of inflow or outflow of tenured faculty. If 1% of the tenured faculty were to exit annually on net (rather than the assumption of no net outflow in the text) the rate of hiring of new Ph.D.'s would rise from 5.6% to 6.9%, assuming the 50% promotion rate were maintained. The percentage of faculty within seven years of the Ph.D. would rise from 33% to 41% in the steady-state.

Conclusion

The steady-state calculations reported in the text result from reasonable estimates of the parameters of a faculty flow model which would be consistent with no-growth equilibrium. The results are somewhat sensitive to assumptions about certain key parameters, but the model in the text appears to fall well within the range of

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4/ Fernandez assumes that the "tenured quit rate" will rise during the early 1980's and then decline again, as the market reaches a new equilibrium.

likely outcomes. In particular, it seems likely that 25% is a reasonable lower bound for the percentage of faculty within seven years of the Ph.D. in the steady-state, and that 33%, the figure employed in the text model, is a reasonable estimate of the likely steady-state percentage of young faculty in fields where postdoctoral appointments are not common. An annual rate of hiring of new Ph.D.'s on the order of 5% to 7% of the total faculty appears to be a sound estimate of the rate consistent with steady-state equilibrium.

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APPENDIX E

DISTRIBUTIONS OF FACULTY BY RANK IN CHEMISTRY, MATHEMATICS, PHYSICS, AND PSYCHOLOGY DEPARTMENTS

The distributions by rank of faculty in selected departments in the fields of mathematics and chemistry were developed from faculty listings in university bulletins. The universities included are the largest universities in research and development expenditures which collectively account for two-thirds of all university research and development expenditures.

The physics data are for departments at universities belonging to the Association of American Universities. They are taken from the Report to the Physics Advisory Committee of the National Science Board by the Subcommittee on Job-Related Issues (May 11, 1978).

The psychology faculty rank and tenure status distributions were provided by the American Psychological Association from their 1978-79 Survey of Graduate Departments of Psychology.

DEPARTMENTS OF CHEMISTRY

	UNIVERSITY	FULL PROF.	ASSOCIATE PROF.	ASSISTANT PROF.	INSTRUCTOR	OTHER
1.	Univ. of Wisconsin, Madison	27	10	3	-	-
2.	Mass. Inst. of Tech.	22	3	10	2	2 lec.
3.	Univ. of Calif., San Diego	12	19	6	-	-
4.	Univ. of Minnesota	26	7	2	-	-
5.	Univ. of Michigan	23	12	2	-	2 lec.
6.	Univ. of Washington	22	8	1	-	-
7.	Stanford University	15	1	5	-	1 lec.
8.	Harvard University	15	2	8	-	2 lec.
9.	Columbia University	18	1	2	-	-
10.	Cornell University	30 (no titles)	?	?	-	-
11.	Univ. of Pennsylvania	12	5	7	-	-
12.	Univ. of California, Berkeley	43	5	6	-	-
13.	Univ. of California, Los Angeles	27	8	8	-	4 lec.
14.	Johns Hopkins Univ.	10	5	5	-	-
15.	Univ. of Chicago	26	2	2	-	-
16.	Univ. of Ill., Urbana	21	11	10	-	-
17.	Univ. of Rochester	14	3	5	-	-
18.	Texas A & M Univ.	30	8	11	-	-
19.	Univ. of Texas, Austin	27	9	10	-	-
20.	Univ. of Calif., San Francisco	No Department of Chemistry				
21.	Michigan State Univ.	22	8	6	-	-
22.	Yale University	15	6	6	-	-
23.	Univ. of Calif., Davis	21	5	4	-	2 lec.
24.	New York University	13	6	2	-	-
25.	Ohio State University	Not Broken Down - "Faculty" = "37"				

DEPARTMENTS OF CHEMISTRY

	UNIVERSITY	FULL PROF.	ASSOCIATE PROF.	ASSISTANT PROF.	INSTRUCTOR	OTHER
26.	Penn. State Univ.	("Sr. Members"=31)	("Assoc. Member"=1)	-	-	-
27.	Purdue Univ. (all campuses)	28	10	7	-	-
28.	Univ. of Florida	29	9	4	-	-
29.	Washington Univ. (Mo.)	15	2	-	-	-
30.	Univ. of Arizona	20	12	2	-	1 lec.
31.	Univ. of Colorado	17	9	15	-	-
32.	Univ. of Georgia	7	11	5	-	-
33.	Univ. of Alaska	2	3	1	-	-
34.	Iowa State Univ.	26	4	3	-	-
35.	Calif. Inst. of Tech.	14	1	3	1	-
36.	Univ. of So. Calif.	18	4	7	-	-
37.	Univ. of Miami	11	8	1	-	-
38.	Univ. of Utah	18	6	2	-	Research Profs (1 Full, 1 Assoc., 3 Asst.)
39.	Rockefeller Univ.		No Department of Chemistry			
40.	Univ. of North Carolina @ Chapel Hill	24	4	7	-	-
41.	Duke University	12	6	3	-	-
42.	Colorado State Univ.	13	7	6	-	-
43.	North Carolina State Univ. @ Raleigh	17	1	4	-	-
44.	Univ. of Connecticut	18	4	-	-	-
45.	Oregon State Univ.	21	8	2	-	-
46.	Univ. of Hawaii (Manoa)	14	5	2	-	-
47.	Univ. of Missouri @ Columbia	12	7	-	-	-
48.	Louisiana State Univ. System	21	8	2	-	-
49.	Georgia Inst. of Tech.	16	10	1	-	1 lec.
50.	Case Western Reserve University	19	4	1	2	-

DEPARTMENTS OF CHEMISTRY

	UNIVERSITY	FULL PROF.	ASSOCIATE PROF.	ASSISTANT PROF.	INSTRUCTOR	OTHER
51.	Yeshiva University	5	2	-	-	-
52.	Univ. of Maryland @ College Park	20	12	5	-	-
53.	Northwestern Univ.	18	4	7	-	5 lec.
54.	Rutgers University	20	6	6	-	-
55.	Univ. of Texas, CC,MDA,Ti.	No courses in chemistry offered (Biology only)				
56.	University of Iowa	12	8	2	-	-
57.	Univ. of Pittsburgh	18	11	5	-	-
58.	Univ. of Cincinnati	11	7	2	-	-
59.	Princeton University	10	2	5	1	2 lec.
	TOTALS	1,028	340	231	6	27

Figures obtained from university catalogs
Dates are the same as shown for mathematical departments

DEPARTMENTS OF MATHEMATICS

	UNIVERSITY	DATE	FULL PROF.	ASSOC. PROF.	ASST. PROF.	INSTRUC.	OTHER
1.	Univ. of Wisconsin, Madison	78-79	67	2	2	-	-
2.	Mass. Inst. of Tech.	77-78	38	7	6	25	2 lec.
3.	Univ. of Calif., San Diego	77-78	14	12	13	-	2 lec.
4.	Univ. of Minnesota	76-78	38	24	10	-	-
5.	Univ. of Michigan	78-79	37	17	12	-	-
6.	Univ. of Washington	78-80	32	14	13	-	-
7.	Stanford University	78-79	19	2	5	-	-
8.	Harvard University	78-79	15	-	11	-	1 preceptor
9.	Columbia University	78-79	10	-	5	-	-
10.	Cornell University	78-80	44 (no titles)	?	?	?	-
11.	Univ. of Pennsylvania	78-79	23	-	6	-	-
12.	Univ. of California, Berkeley	78-79	64	9	1	-	7 lec.
13.	Univ. of California, Los Angeles	78-79	48	9	10	-	3 lec.
14.	Johns Hopkins Univ.	78-79	8	5	4	-	-
15.	Univ. of Chicago	77-79	28	2	2	14	19 lec.
16.	Univ. of Ill., Urbana (incl. statistics)	78-80	59	33	14	-	-
17.	Univ. of Rochester	78-79	15	4	5	-	-
18.	Texas A & M Univ.	79-80	7	25	12	-	-
19.	Univ. of Texas, Austin	77-79	28	15	15	-	-
20.	Univ. of Calif., San Francisco	78-79	No Department of Mathematics				
21.	Michigan State Univ.	78-79	38	27	8	9	1 Asst. Instruc.
22.	Yale University	76-78	14	1	5	7	-
23.	Univ. of Calif., Davis	78-79	18	12	6	-	1 lec.
24.	New York University	78-79	32	4	1	5	-
25.	Ohio State University	78-79	Not Broken Down - "Faculty" = "77"				

DEPARTMENTS OF MATHEMATICS

	UNIVERSITY	DATE	FULL PROF.	ASSOC. PROF.	ASST. PROF.	INSTRUC.	OTHER
26.	Penn. State Univ.	78-79	("Sr. Members"=25)	("Assoc. Members"=18)	-	-	-
27.	Purdue Univ. (all campuses)	76-78	66	34	47	-	-
28.	Univ. of Florida	78-80	11	15	15	-	-
29.	Washington Univ. (Mo.)	78-79	13	7	1	-	-
30.	Univ. of Arizona	77-78	21	16	4	-	2 lec.
31.	Univ. of Colorado	79-80	24	16	3	1	-
32.	Univ. of Georgia	77-79	5	9	2	-	-
33.	Univ. of Alaska (incl. comp. sci.)	79-81	4	5	4	-	-
34.	Iowa State Univ.	79-81	25	17	10	6	-
35.	Calif. Inst. of Tech.	78-79	12	1	1	8	-
36.	Univ. of So. Calif.	78-79	13	5	10	-	-
37.	Univ. of Miami	77-78	10	6	7	2	-
38.	Univ. of Utah	77-79	23	5	5	12	-
39.	Rockefeller Univ.	78-79	1	1	-	-	-
40.	Univ. of North Carolina @ Chapel Hill	78-79	14	12	4	2	-
41.	Duke University	'79	8	7	7	-	-
42.	Colorado State Univ.	78-79	15	15	2	-	-
43.	North Carolina State Univ. @ Raleigh	78-80	21	15	20	-	-
44.	Univ. of Connecticut	79-80	11	12	-	-	-
45.	Oregon State Univ.	78-79	21	7	8	-	-
46.	Univ. of Hawaii (Manoa)	77-79	10	20	7	-	-
47.	Univ. of Missouri @ Columbia	78-79	10	13	4	-	-
48.	Louisiana State Univ. System	79-80	15	12	12	12	-
49.	Georgia Inst. of Tech.	78-79	10	19	17	1	2 lec.
50.	Case Western Reserve University	77-79	11	6	9	1	-

	UNIVERSITY	DATE	FULL PROF.	ASSOC. PROF.	ASST. PROF.	INSTRUC.	OTHER
51.	Yeshiva University	74-76	8	6	1	1	-
52.	Univ. of Maryland @ College Park	79-80	43	25	14	-	-
53.	Northwestern Univ.	78-79	26	10	8	-	-
54.	Rutgers University	76-77	34	21	1	-	-
55.	Univ. of Texas, CC,MDA,Ti.	No courses in mathematics offered (Biology only)					
56.	Univ. of Iowa	78-80	13	17	3	-	-
57.	Univ. of Pittsburgh (incl. statistics)	77-79	14	15	19	-	-
58.	Univ. of Cincinnati (all math sci.)	78-79	10	16	1	-	-
59.	Princeton University	78-79	23	1	11	11	-
	TOTALS		1,266	628	423	117	40

Figures obtained from university catalogs

ASSOCIATION OF AMERICAN UNIVERSITIES
PHYSICS FACULTY
1977-78

Institution	Professors	Associate Professors	Assistant Professors	Total
Brown University	32	2	2	36
California Institute of Technology	23	2	6	31
University of California, Berkeley	53	4	1	58
University of California, Los Angeles	35	5	2	42
Case Western Reserve University	19	5	2	26
Catholic University of America	7	1	2	10
University of Chicago	24	8	11	43
Clark University	2	3	1	6
University of Colorado	37	8	3	48
Columbia University	20	-	14	34
Cornell University	38	3	4	45
Duke University	11	5	6	22
Harvard University	19	4	10	33
University of Illinois, Urbana-Champaign	52	12	4	68
Indiana University	28	10	3	41
University of Iowa	14	8	1	23
Iowa State University	22	17	6	45
The Johns Hopkins University	14	-	5	19
University of Kansas	18	5	1	24
University of Maryland	57	20	15	92
Massachusetts Institute of Technology	57	15	16	88
McGill University	14	14	1	29
University of Michigan	34	10	5	49
Michigan State University	37	8	11	56
University of Minnesota	32	16	5	53
University of Missouri - Columbia	8	10	1	19
University of Nebraska	20	11	-	31
New York University	19	5	3	27
University of North Carolina at Chapel Hill	22	7	1	30
Northwestern University	24	4	4	32
Ohio State University	29	11	3	43

Institution	Professors	Associate Professors	Assistant Professors	Total
University of Oregon	15	5	1	21
University of Pennsylvania	28	7	7	42
Pennsylvania State University	23	11	6	40
University of Pittsburgh	27	14	3	44
Princeton University	22	2	21	45
Purdue University	42	14	4	60
University of Rochester	29	5	4	38
University of Southern California	12	9	7	28
Stanford University	14	1	8	23
Syracuse University	19	1	3	23
University of Texas - Austin	29	15	6	50
University of Toronto	39	16	2	57
Tulane University	5	3	2	10
Vanderbilt University	10	7	5	22
University of Virginia	19	9	3	31
University of Washington	33	7	5	45
Washington University	17	4	4	25
University of Wisconsin - Madison	39	4	2	45
Yale University	18	5	13	36
Total	1,261	372	255	1,888

Figures obtained from 1977-78 Directory of Physics and Astronomy Staff Members, American Institute of Physics.

Figures are for Physics or joint Physics/Astronomy departments.

Figures do not include emeritus faculty, research appointments, etc.

Number and Percent of Academically Ranked Full-time Faculty in
U.S. Doctoral Psychology Departments* in Public and Private Institutions:

Row Percent in Parentheses; Column Percent in Brackets

Number (Row Percent) [Column Percent]	Academic Rank: Full Professor	Associate Professor	Assistant Professor	Lecturer or Instructor	Total Faculty
Public Institutions (103 Departments)	1196 (44.0%) [77.7%]	797 (29.3%) [76.9%]	697 (25.6%) [76.9%]	31 (1.1%) [62.0%]	2721 [77.1%]
Private Institutions (46 Departments)	334 (42.7%) [21.7%]	230 (29.4%) [22.2%]	200 (25.6%) [22.1%]	18 (2.3%) [36.0%]	782 [22.1%]
Institution Unspecified (1 Department)	9 (32.1%) [0.6%]	9 (32.1%) [0.9%]	9 (32.1%) [1.0%]	1 (3.6%) [2.0%]	28 [0.8%]
All Departments (150 Departments)	1539 (43.6%)	1036 (29.3%)	906 (25.7%)	50 (1.4%)	3531

* Does not include departments of educational psychology, counseling psychology, human development or professional schools.

Source: 1978-79 Survey of Graduate Departments of Psychology, American Psychological Association/Council of Graduate Departments of Psychology

APPENDIX F

COMPARISON OF ALTERNATIVE DATA SOURCES CONCERNING PERCENTAGES OF RECENT DOCTORATES ON FACULTIES IN SCIENCE AND ENGINEERING

COMPARISON OF ALTERNATIVE DATA SOURCES CONCERNING PERCENTAGES OF RECENT DOCTORATES ON FACULTIES IN SCIENCE AND ENGINEERING

The data in Figures 3 and 4 in the text show that estimates of proportions of faculty within seven years of the Ph.D. based on ACE data are significantly lower than those based on NRC data. The following are possible reasons for differences between ACE and NRC survey data on young faculty:

1. ACE data, which were collected in May, 1978, presumably do not include those graduating in June of that year and may underestimate the number of faculty who received doctorates within the past seven years.

2. ACE data include others who received their doctorates during the 1977-78 academic year as part of the seven year cohort of "young faculty." It is unlikely that many of these individuals will have had an opportunity to obtain faculty appointments in the same academic year that they graduated. NRC data, on the other hand, include Ph.D. recipients who had graduated in the full seven year period prior to the fiscal year (1977) of the survey. This probably accounts for much of the difference between ACE and NRC percentages of young faculty.

3. ACE data describe the proportion of young faculty in academic year 1977-78, while NRC data describe the proportion in academic year 1976-77. Since the proportion of young faculty has been declining in recent years, the ACE proportion might be expected to be somewhat smaller than the NRC proportion.

4. ACE data categorize faculty members by the name of the department in which they hold their appointments. Faculty members

employed in some of the more specialized departments (e.g., molecular physics, statistics, computer sciences, applied mathematics, educational psychology, child development, counseling) are not included in the ACE data. NRC data categorize faculty members by their field of employment and include all employed in a given field, regardless of the department in which they hold their appointments. Consequently the NRC data may be expected to have a larger faculty count than the ACE data.

5. NRC data categorize faculty by academic rank and probably include some visiting professors as well as the regular tenure track faculty. ACE faculty counts are provided by the department head and probably include only regular tenure track staff members (and consequently should be somewhat smaller than NRC faculty counts).

6. Attached is a comparison of the ACE and NRC data describing full-time faculty in four selected fields. Both sets of data are restricted to full-time faculty members employed at 288 Ph.D. granting institutions. For purposes of comparison NRC data describing both six and seven year "young faculty" cohorts are provided.

-241-

Table F-1

TOTAL AND YOUNG FULL-TIME FACULTY EMPLOYED IN 288 PH.D. GRANTING INSTITUTIONS
(COMPARISON OF NRC AND ACE SURVEY RESULTS)

Field of Employment/Department a/	NRC 1977 Survey Data: Total Faculty b/ #	NRC 1977 Survey Data: FY 1970-76 Ph.D. Recipients #	%	NRC 1977 Survey Data: FY 1971-76 Ph.D. Recipients #	%	ACE 1978 Survey Data: Total Faculty c/ #	ACE 1978 Survey Data: FY 1972-78 Ph.D. Recipients #	%
Chemistry	5,104	1,194	23.4	971	19.0	3,994	690	17.3
Physics/Astronomy	4,647	966	20.8	798	17.2	3,781	488	12.9
Mathematics	7,075	2,520	35.6	2,135	30.2	4,845	1,298	26.8
Psychology	7,234	2,564	35.4	2,179	30.1	4,344	1,382	31.8
All Science and Engineering	74,591	24,682	33.1	20,746	27.8	N/A	N/A	N/A

a/ NRC survey data categorize faculty members by field of employment; ACE survey data categorize by department name. Faculty members employed in some of the more specialized departments (e.g., molecular physics, statistics, computer sciences, applied mathematics, educational psychology, child development, counseling) are not included in the ACE data.

b/ Includes all Ph.D. recipients holding full-time faculty appointments as of February 1977 except those who had doctorates after June 1976.

c/ Includes all Ph.D. recipients holding full-time faculty appointments as of May 1978.