Session I

SUPPLY OF SCIENTISTS AND ENGINEERS

THE HUMAN RESOURCE BASE FOR SCIENTIFIC AND TECHNICAL ACTIVITY IN THE UNITED STATES

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Introduction

The importance of science and technology in fostering growth and well-being is generally unchallenged as a proposition. Equally unchallenged is the critical role played by the human resources devoted to this activity. Although equipment and facilities are important ingredients, working scientists and engineers, technicians and other support staff are its heart and soul.

Recent patterns of degree production and projected demographic and economic trends have given rise in many countries to concerns about whether we will be able to meet future needs for these critical, highly-skilled workers, particularly in academia. The purpose of this paper is to review briefly the major issues associated with this concern in the United States. These include:

- the adequacy of the human resource base for meeting critical national needs as they are reflected in the demands of academia, industry and government for scientists and engineers;
- the adequacy of mechanisms for altering the size and structure of this talent pool in response to shifts in national priorities;
- the adequacy of the resource base allocated to the production of the mathematics and science skills embodied in the entire population.

Each of these issues will be discussed briefly below.

The adequacy of the science and engineering talent pool for meeting critical national needs is not easily assessed. A major reason for this difficulty is that adequacy must be addressed in both quantitative and qualitative terms. The conventional measure of inadequacy (conventional, that is, to students of labor markets) is unfilled vacancies. These vacancies imply that employers are unable to attract a sufficient number of qualified applicants for their available science and engineering job openings at prevailing wages.

The absence of such vacancies do not necessarily mean that the supply of scientific and technical talent is adequate. When confronted with such vacancies employers may choose to lower their recruiting standards in order

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*Executive Director, Office of Scientific and Engineering Personnel, U.S. National Research Council to fill their positions. In such circumstances a "qualitative" shortage could exist even though there were no unfilled job vacancies.

The Current Situation

At the current time, relatively few industrial employers report difficulties in meeting their staffing requirements for scientists and engineers, although spot shortages seem to exist in some fields of engineering (i.e., aeronautical, electrical, and electronics). In general, the reported recruiting difficulties center on experienced scientists and engineers. Recruiting new graduates does not appear to be as much of a problem. Conditions of shortage (i.e., an inability to find qualified applicants for job openings) were more widespread in the late 1970s and early 1980s. In the fall of 1986 about 28 percent of industrial employers responding to an NSF survey reported difficulties recruiting in at least one field of science or engineering, down from the more than one-half who reported such difficulties in the early 1980s. Thus, it appears that the current industrial labor market for scientists and engineers has moved closer to a situation of balance. A major factor underlying this change was the deep recession experienced by the U.S. economy in the early 1980s and the sluggish economic recovery that followed.

Although the United States appears to be meeting its current quantitative needs for scientists and engineers, there is concern that it may be paying significant, but hidden, costs for achieving this goal in the form of a lower quality workforce of scientists and engineers. A recent study of engineering labor markets found, for example, that about one-half of the engineering job openings that were generated in the 1972-86 time period were filled from sources other than new engineering graduates. The major sources other than new degree recipients included degree recipients in closely-related fields and foreign-born engineers. [National Research Council, 1988b.] The potential costs of meeting industrial needs for scientific and engineering talent from these other sources of supply is that they may provide workers who are either less productive than degreed engineers or they may be more costly because they require additional training to make them as effective as degreed engineers [Fechter and Tuckman, 1989].

In academia, the problem appears to be centered in a small number of quantitative fields (engineering, physics, mathematics, computer sciences and economics). These fields are characterized by the high proportion of foreign students in their graduate programs and on their faculties. [Chart 1.] The origins of these recruiting problems seem to lie in the very lucrative industrial job opportunities open to American students who complete their bachelor's degrees in these fields (especially in engineering positions).

Although these foreign graduate students and faculty members make a significant contribution to our academic research enterprise, their prominence evokes a number of concerns [National Research Council, 1988 a; Finn, 1989] including:

- their teaching effectiveness (arising from possible language difficulties and/or cultural differences);
- constraints on their utilization in certain types of work (e.g., work requiring security clearances);
- the effect of their presence in the scientific and engineering work force on market variables that would otherwise send signals of shortage to American students considering their career options.

The concern of policy makers has not been focused on the strong presence of foreign students and faculty members; rather, it has centered on the failure of American students to pursue careers that require the doctorate and, among these students, the shrinking share that opt for academic careers. The number of American citizens and permanent residents who earned doctorates in natural sciences and engineering was 9,724 in 1987, roughly 3.3 percent of the doctorates employed in these fields that year. This percentage has been trending downward steadily since 1973, when it was approximately 7.0 percent. [Chart 2.] Assuming that losses due to deaths and retirements average around two percent per year, the current rate of degree production in these fields would not permit the doctorate work force to grow by more than one percent per year, less than one-half the growth rate experienced by this workforce since 1973 [Finn, 1989]. The earlier growth was supported increasingly by employment of new degree recipients who were foreign nationals on temporary visas. These foreign nationals accounted for roughly one-sixth of the estimated employment growth in 1973; they accounted for almost two-thirds of the estimated growth in 1987.

If these trends in degree production continue, future growth in doctorate employment in these fields will be slower and will be fueled almost entirely by foreign nationals on temporary visas. The consequences of these trends are already visible in engineering, where more than one-half of the faculty below the age of 35 are either foreign or naturalized Americans.

The data on engineering faculty highlight another concern; that an increasing share of these new degree recipients are finding employment in non-academic positions [National Research Council, 1989]. The major factor underlying this trend is the growing prominence of industry as an employer of doctorates. It is not certain, however, whether this represents a fundamental and permanent change in the skill requirements of industry or a temporary shift in industrial demands arising from the recent dearth of employment opportunities for these doctorates in academia, their traditional primary employer. If it represents the former, then academia will be facing increased competition in recruiting these new doctorates in the future, when its demand is expected to increase dramatically.

The Future

As noted earlier, current patterns of degree production and expected demographic and economic patterns are giving rise to widespread concerns about the ability to supply the scientific and engineering talent that will be required to meet national needs as we enter the twenty-first century. The specific source of concern centers on current trends in degree production, which augur a future in which new degrees in science and engineering fields will not grow, while at the same demand in the form of job openings will be increasing dramatically.

Assessment of future degree production is difficult because this degree production reflects a complex process involving demographic factors and career choice behavior. Future bachelor's degree production depends on:

- the pool from which new degree recipients can be drawn; and
- the proportion of that pool who acquired degrees in these fields.

The latter proportion, in turn, reflects a number of behavioral variables:

- the fraction of that pool who completed high school;
- the proportion of these high school graduates who continued their schooling at the undergraduate level;
- the proportion of undergraduates who majored in science and engineering; and
- the proportion of science and engineering majors who completed training for bachelor's degrees in these fields.

Future doctorate degree production is also affected by:

- the fraction of bachelor's degree recipients in these fields who continued their training at the graduate level; and
- the fraction of these graduate students who completed the requirements for the doctorate degree in these fields.

Recent trends in these variables do not indicate strong future growth in degree production at either the bachelor's or the doctor's degree level. The pool from which these degree recipients can be drawn – typically defined operationally as 22 year olds for the baccalaureate and 30 year olds for the doctorate – has already been born. Thus projections of the size of this pool can be made with considerable certainty. These pools are expected to decline significantly over the next 5-10 years.

Evidence based on past relationships between the size of these pools and degree production suggest that this decline will be more of a potential constraint on growth for baccalaureates than it will be for doctorates. The number of baccalaureates in natural sciences and engineering per one hundred 22 year olds has been relatively stable over a long period of time, hovering around 4.0 [Chart 3]. This suggests that the other variables affecting bachelor's degree production have either been very flat or have operated to offset each other. In recent years, however, the ratio of bachelor's degrees in these fields to the pool of 22 year olds has displayed a distinct upward trend, rising to 5.0. This upward trend has permitted the number of bachelors degrees in these fields to remain relatively stable despite the decline that has begun to occur in the 22 year old population. Given that this ratio is at an all-time high, it is not obvious that this trend can continue. If it does not, then bachelor's degree production in these fields can be expected to fall.

We are on less solid ground when it comes to forecasting values of the other, nondemograpic variables. One indicator, however, the percent of undergraduate freshmen who plan to acquire degrees in these fields, does not provide much cause for optimism for the years beyond 1986. This percentage has been declining for natural science and engineering fields since 1982.

The relationship between the number of doctorates in natural science and engineering fields and the number of 30 year olds in the population is considerably looser. The number of doctorates has fallen in times when the number of 30 year olds has been rising and the number of doctorates has risen in times when the number of thirty year olds has been falling. This suggests that future doctorate production in these fields may not be as inexorably linked to population trend as it appears to be for the bachelor's degrees. Part of the reason for this may be that doctorate production constitutes a substantially smaller share of the pool from which these degrees are typically drawn than is the case for bachelor's degree production. Thus, relatively small absolute changes in this ratio may offset the effects of the expected decline in the 30 year old population.

At the same time as the supply of new degree recipients is expected to grow more slowly (or to shrink), the demand, approximated by job openings, is expected to grow. In part, this growth will be fueled by increased replacement demand as larger numbers of the current scientific and engineering workforce approach retirement age. In engineering, for example, the death and retirement rate is expected to increase by one full percentage point [National Research Council, 1988 b]. In part, this growth will occur as a result of projected new demand for these skills. Jobs for scientists and engineers are projected to increase by roughly 40 percent between 1986 and the year 2000 [U.S. Department of Labor, 1988].

Coping With the Future

Although it is not possible to generate forecasts of future supply/demand condition with a tolerable degree of certainty, prudent policy would suggest preparing for a contingency in which demand growth will not be matched by comparable growth in new degree production. Under these circumstances, policy concerns center on measures to increase the pool from which new degree recipients can be drawn and/or to increase the share of this pool opting for degrees in science and engineering.

In attempting to increase the pool, policy makers have been devoting a considerable amount of attention to two areas: raising the yield from underrepresented groups – women and members of non-Asian race/ethnic minority – and increasing the mathematics and science content of precollege school curricula. The former area is particularly important because demographic projections indicate that these underrepresented groups will constitute an increasing ratio of the pool. Thus the decline in degree production may exceed that which can be expected purely on the basis of future numbers in the pool unless improvements can be made in the proportions of these groups who opt for, and successfully complete, degrees in science and engineering.

Accomplishment of this task will require policies that result in better training in math and science at the precollege level (especially for minorities), improved counselling and mentoring, and less social stereotyping of these groups in ways that discourage them from considering degrees in these fields.

Increasing the amount and quality of the mathematics and science coursework taken by students prior to their graduation from high school will clearly increase the pool of all students, regardless of whether they are members of underrepresented groups, with the requisite minimum training in these disciplines for the successful pursuit of degrees in these fields at the undergraduate level. Concern about the adequacy of math and science training at the precollege level goes beyond the perceived need to increase the pool from which new scientists and engineers can be drawn, however. There is widespread belief that these skills will become increasingly necessary to becoming a productive member of a more technologically oriented work force, regardless of whether one becomes a scientist or an engineer.

In attempting to increase the share of the pool that will opt for careers in science and engineering, policy makers have been concentrating on various mechanisms for providing financial support to students – particularly at the graduate level – in the form of fellowships. The cost of acquiring a doctorate in these fields (including the earning foregone while in graduate school) is considered a significant barrier to the pursuit of this degree because of: (1) the substantial amount of time required to complete the degree (currently ranging from six to eight years in these fields); and (2) the lucrative earnings available to students who enter the work force with a bachelor's degree in these fields (currently as high as $ 30,000 per year for engineering graduates) [National Science Board, 1987].

Failure to achieve these goals will mean continued reliance on the other major sources of supply – foreign students and Americans with degrees in closely related fields. For several reasons, this is not considered to be a desirable outcome. First, there is concern about the reliability of the foreign sources of supply, which could dwindle as a result of political instability or improved employment opportunities for scientists and engineers abroad.

Second, as mentioned earlier, there are concerns about the qualitative implications of increased or continued reliance on these sources of supply. Given these concerns, one can expect to see continued strong emphasis placed on measures to increase the number of American students who opt for careers in science and engineering fields.

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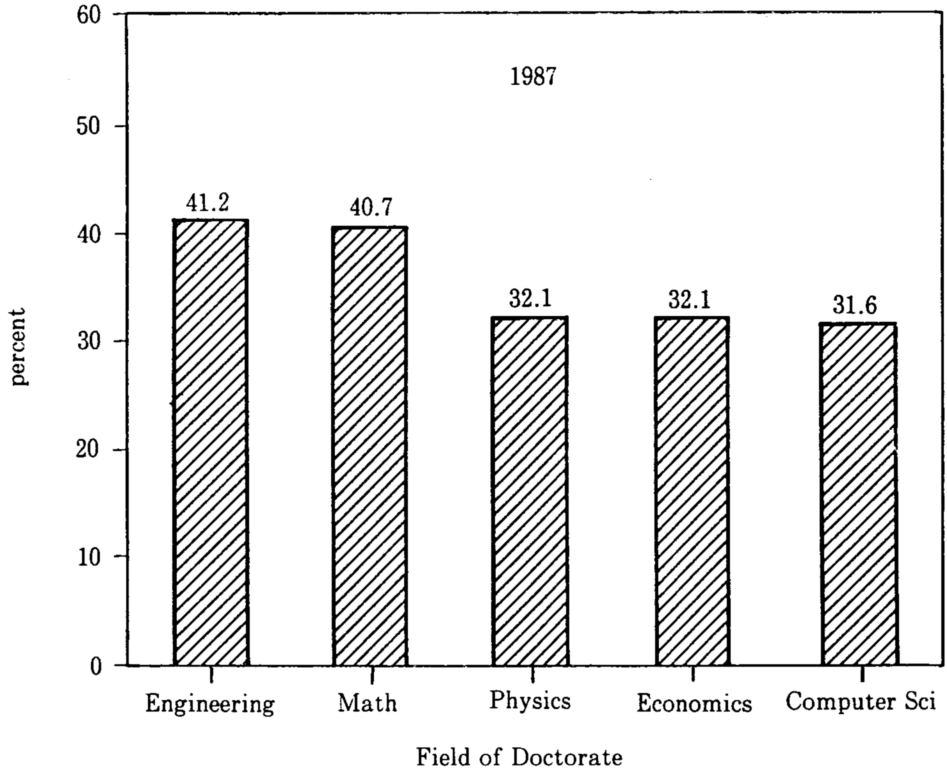
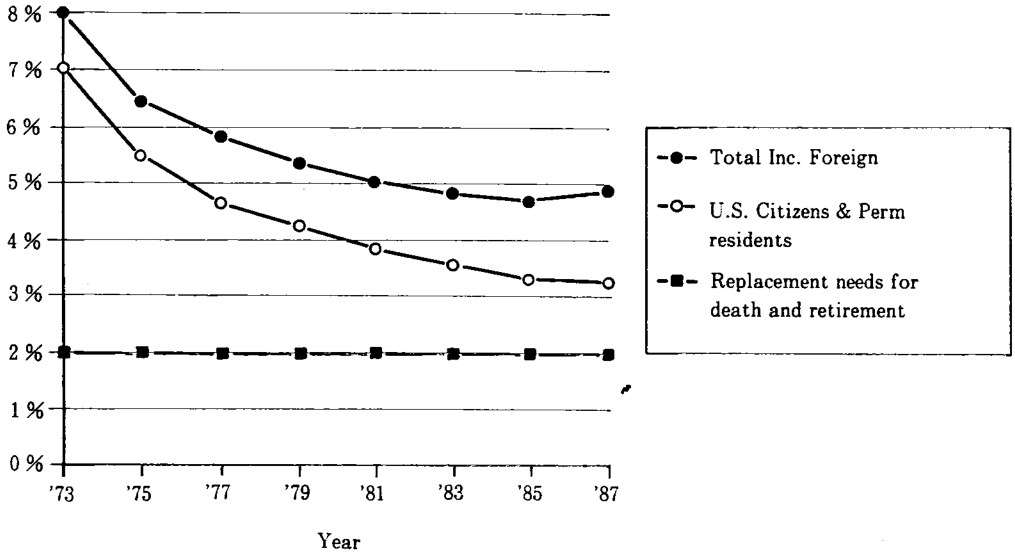
Chart 1. Proportion of Doctorate Recipients Who Were Temporary Visa-holders



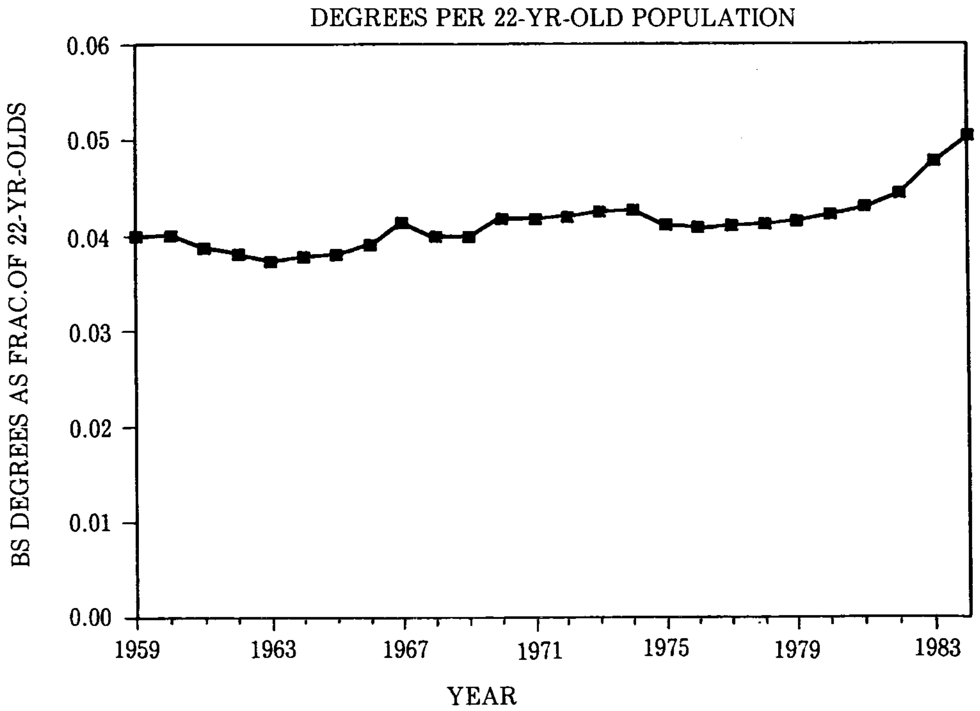
Source: National Research Council.

Chart 2. New Doctorates as a Percentage of Total Employment of Doctoral Scientists and Engineers, 1973-1987



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

Chart 3. Bachelor's Degrees per 22-year-old Population



Source: The Science and Engineering Pipeline
National Science Foundation, PRA Report 87-2, April 1987.

RESEARCH CONSEQUENCES OF AN AGING U.S. SCIENTIFIC COMMUNITY

Paula E. Stephan*

Introduction

The American scientific community is aging and will continue to age in the near future as the large group of Ph.D. scientists educated during the 1960s moves through the latter stages of their careers. The cause of the aging is due in large part to the significant decline in demand for scientists in the U.S. that began in the late 1960s and early 70s. This decline was occasioned by a decrease in funding for research and augmented by the fact that by the late 1970s the baby boomers were no longer of college age. Moreover, at approximately the same time, mandatory retirement laws changed, giving sci entists the option to extend their careers by four to five years. Concurrently, the demand for the occupations of medicine and law increased. As a consequence the supply of young scientists declined and some question if the pool that remained drawn to science was as talented and motivated as the group that entered science in the 1950s and early 1960s.

The magnitude of this aging can be appreciated by comparing age distributions between 1975 and 1985 for scientists employed in research and development and in teaching. In the research and development sector in 1975 over a third of all scientists were under 35 while just 9 percent were over 55. Now, less than 25 percent are under 35 and over 13 percent are over 55. Moreover, the age distribution has picked up a substantial middle age bulge that, unless hiring increases substantially in the near future, will take twenty more years to work its way through. In the teaching sector the story is similar but more extreme. Here, in 1975 24 percent were under 35, 14 percent over 55. Today, the youngest category figure has shrunk to 9 percent while the over 55 category has increased to almost 25 percent. And, here too there is a middle-age bulge that will take twenty or so years to reach retirement, as reported in National Science Foundation [1988].

Reasons for an Age-Research Relationship

The realization that the scientific community is aging has spurred

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renewed interest in the relationship between age and scientific performance, particularity since this aging comes at a time when the leadership role of the United States in science and technology is being challenged. Is the older U.S. scientific community of the 1980s less productive than a younger community was a decade or two earlier and will the still older community of the 1990s be even less productive?

A popular belief held by scientists and the lay public alike is that science is a young person's game. Examples easily come to mind illustrating this notion. Darwin was 29 when he developed the concept of natural selection, Einstein 28 when he formulated the theory of relativity, Newton 24 when he began his work on universal gravitation, calculus and the theory of colors, and Gaus 18 when he developed the method of least-squares.

Psychologists, sociologists, and economists offer different explanations for the hypothesized age-productivity relationship. Psychologists, for example, focus on changes that occur within an individual over the career that make the individual less likely to produce research as one's career progresses. Factors that are given special attention include the realization in mid-career that one may not be the great researcher that was hoped for earlier in the career and the sense of overload reported by some in mid-career that leads to a cutting back in the area of research. Sociologists, who see the quest for reputation as the motivating force behind research activity, argue that through the processes of cumulative advantage and reinforcement, recognition and resources are given to those with a proven track record while those who have not enjoyed previous success find research resources and recognition elusive. Consequently, as scientists age and their careers unfold, some continue to be productive, while others become discouraged and discontinue their research efforts. Economists see the finiteness of life as providing sufficient reason for a decline in the age-research productivity profile. In economic terms, scientists produce research because of the expected financial rewards associated with the activity. As the scientist ages and the future becomes shorter, the present value of these rewards declines and the scientist has less incentive to engage in research.

Evidence Concerning the Relationship Between Publishing and Age

We recently completed a study designed to examine the question of whether age is significantly related to research activity as reported in Stephan and Levin [1987]. The measure of research activity used for the study was number of articles authored in a two year period. In an effort to make adjustments for the quality of the article and the number of authors, four measures of publishing activity were created. Four fields of science were studied: biochemistry, physics, earth science and plant and animal physiology. Data for the study were taken from the Survey of the Doctorate, administered biennially by the National Research Council. The study includes articles written during the period 1974 to 1981. Scientists were included in the study if they were working full time in the field regardless of sector of employment. Here, results are presented for all employment sectors aggregated together. In the larger study, the analysis is disaggregated by employment sector as well as subfield of employment.

For Ph.D. physicists, we find that the number of articles declines with age regardless of how published articles are measured. There is no indication, as suggested by other researchers, that productivity peaks in the middle of the career. (See, for example, Cole [1979] and Bayer and Dutton [1977]) The decline is significant and of relatively large magnitude. For example, while 53 percent of all Ph.D. physicists under 35 publish, only 39 percent of those 50-54 engage in research while 24 percent of those over 50 publish. In terms of straight article counts, the under 35 year old physicist writes 2.14 articles a year compared to about 1.7 for those in mid-career, 1.06 for those in their late fifties and .72 for those over 60. On the other hand, it should be pointed out that while the relationships found are statistically significant, the overall explanatory power of age is low. For the four fields studied, the adjusted R-squares vary from just under one percent to four percent. While these are extremely low, it must be recognized that in analyzing micro level data economists and sociologists generally find R-squares that are no greater than 8 percent in regressions that include many explanatory variables.

Substantially similar results are found for earth scientists. Regardless of measure, publishing activity declines with age throughout the career, never experiencing a mid-career peak. Those in mid-career write about two-thirds as many articles a year as those under 35 while those over 55 write less than 50 percent of what their younger peers write and the oldest group writes at best a quarter of what the youngest group does. As in the case of physicists, however, the overall explanatory power of age is low.

Due to resource constraints, only two measures of output were computed for the fields of biochemistry and physiology. In these fields, the results are somewhat different. Here output increases early in the career, reaching a peak among those between 35-44 and declines thereafter. The decline, however, is not as extreme as in the case of physicists and earth science. For example, in biochemistry, those over 60 produce about 55 percent of what their most productive mid-career peers produce and in physiology the comparable measure is just slightly lower. As in physics, however, age is found to explain only a very small amount of the variation about the mean that exists in publishing.

Implications of the Study

These results suggest that an older group of scientists is less productive than a younger group was a decade or two earlier. In biochemistry and physiology the conclusion is tempered for the movement by the fact that the age-distribution of scientists in the field is skewed towards middle-age, the precise group that is the most productive. No such temporary consolation, however, exists in physics and earth science where the mid-career group is consistently found to be less productive than their younger colleagues.

According to the Alan Fechter paper in this volume, "The Human Resource Base for Scientific and Technical Activity in the United States" the supply of new degree recipients is expected to grow more slowly in the future or to shrink. Therefore, the American scientific community will continue to age throughout the 1990s as the larger group of scientists hired in the late 1950s and early to mid-1960s complete their careers. The results suggest that the productivity of the American scientific community will decline as a consequence of this aging effect. Thus, the U.S. must be concerned not only with having an adequate number of scientists but with the more important issue of whether the scientists that it does have are as productive as they could be if the field of science had not grown in such a sporadic fashion.

Are the Effects Really Due to Age?

The validity of this conclusion depends upon whether the aging affects that we observe in the data are really due to age or due instead to what could be called cohort effects. The question is raised since the conclusions are down from a cross-sectional analysis of the data. Consequently, older scientists in the data base are drawn from earlier cohorts, younger scientists from later cohorts. As a result, there is the possibility that it is not age that makes older scientists in the data base less productive and youth that makes younger ones more productive but instead some type of competitive edge that the newer cohorts enjoy compared to the older cohorts. For example, if knowledge in science progresses over time, newer cohorts have a knowledge edge and consequently are more productive than their peers who come from earlier cohorts and must deal with the threat of obsolescence.

Investigating whether such cohort effects exist, and whether the aging effects reported are due to such cohort effects, requires tracking the publishing activity of scientists from different cohorts over time. In our study, we have but six years of data, and therefore a fairly short "window" for performing such analysis. What we find, however, when we examine the scientists over the six year period is that there is little indication to suggest that the newer cohorts are more productive. Indeed, in physics, earth science and physiology there is no indication at all that the newer cohorts are more productive, and some indication that to the extent a competitive edge exists it belongs to earlier cohorts. Thus, the aging effects found, at least in three of the fields, are not the result of cohort effects but can be considered "pure" aging effects.

One can only speculate as to why the later cohorts may not have a competitive edge. One reason is that knowledge in science does not always advance smoothly. Indeed, in some instances science takes false moves, only to return to theories formulated at an earlier stage. Thus, the latest educated need not necessarily be the best educated. This appears to have been the case in particle physics, where there is evidence that the cohort educated when field theory was strong, have had a competitive advantage compared to those educated five to ten years later.

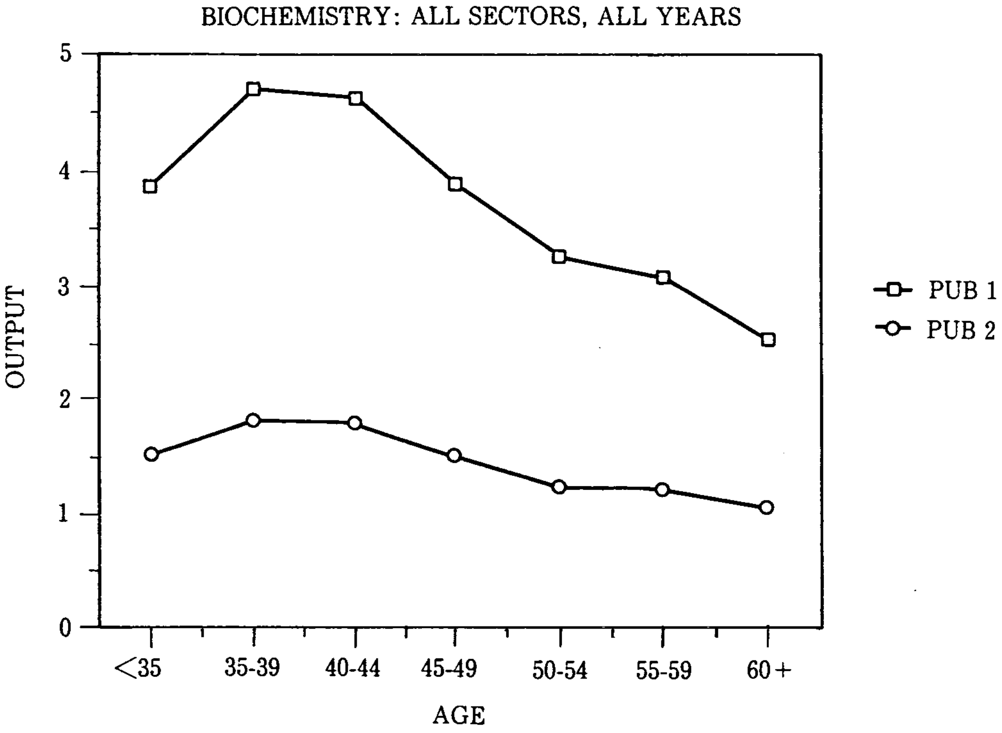
There is another explanation, however, as to why later cohorts proved to be no more productive than earlier cohorts. During the 1960s science grew very rapidly. It is possible that scientists obtaining doctorates during this period were not, on average, as talented or motivated as scientists coming from earlier cohorts which represent a smaller, more elite portion of the population. Thus, even if the more recent cohort has a knowledge edge, a talent deficit may make them no more productive than their peers.

Concluding Comments

The question posed initially was whether the productivity of the American scientific community is adversely affected by the fact that it is older. The results of our study reveal that scientists, on average, tend to publish less as they age, particularly after mid-carrer. Given the prospect that the U.S. scientific community will continue to age for at least the next 15 years, the study leads to the conclusion that U.S. scientists on average will be less productive in the foreseeable future than they are now. Moreover, for the most part, the results also suggest the presence of cohort effects in the sense that the latest educated are not necessarily more productive than earlier cohorts. This leads us to the conclusion that the older generation of scientists who came from earlier cohorts would have been even less productive were it not for the fact that some of the negative aging effects have been mitigated by positive cohort effects. Thus, the findings suggest a further decline in productivity through the 1990s as science becomes increasingly dominated by older persons who come from relatively less productive cohorts. Perhaps this is one reason why the leadership role of the United States in science and technology is being challenged.

Some consolation can, of course, be taken in the knowledge that while a statistically significant age-publishing relationship exists, the variable age does not explain a great deal of the variation in the publishing patterns that exist among scientists. Stated differently, while age affects scientific productivity, many other variables are at play (such as the availability of resources) which can be manipulated by policy makers in an effort to off-set the aging effects noted. On the other hand, there is another more speculative basis for anticipating that productivity may be depressed in science in the U.S. for the next ten to fifteen years as the scientific community continues to age... , a factor which is somewhat immune to policy intervention. This factor focuses on the relationship of age to the production of revolutionary ideas in science.

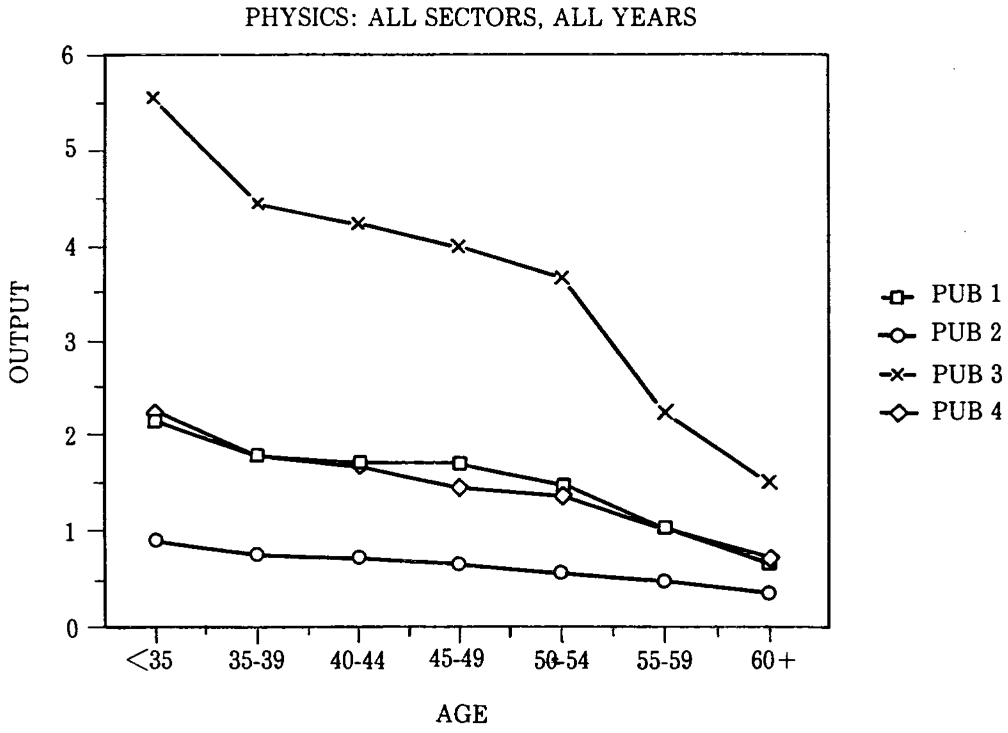
Although the process by which science advances is controversial, there is agreement that from time to time leaps or revolutions in theory occur. The larger question then is how an older scientific community affects the prospects that these leaps or revolutions occur. The age structure of a scientific community not only has an impact on the ability of innovative work to be produced, to be accepted. Production may be affected since older scientists, though still somewhat productive, may produce what one physicist calls back-water research that does little to further the frontiers of science. Acceptance may be affected if older scientists, steeped in their own perspective, are resistant to change. In concluding, one cannot help but be reminded of Max Planck's famous statement that "a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it," as quoted in Barber [1962].



PUB1 measures straight counts of articies, PUB2 measures counts adjusted for number of co-authors.

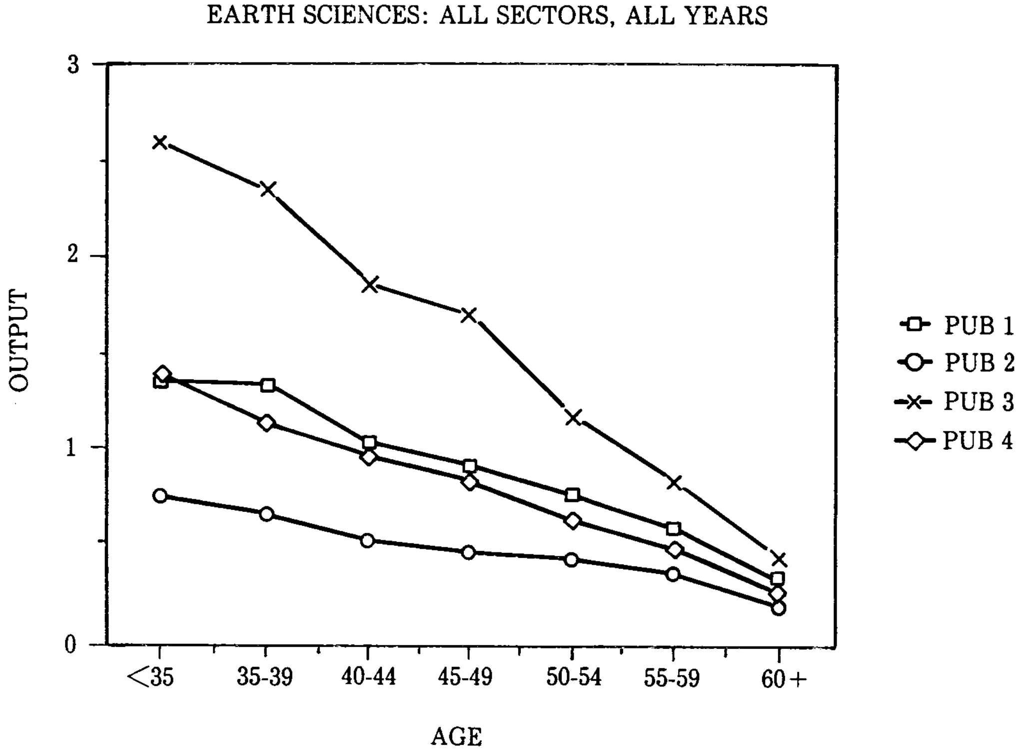
Source: Stephan and Levin, Chapter VII.

Figure 1



PUB1 measures straight counts of articies, PUB2 measures counts adjusted for number of co-authors, PUB3 adjusts for quality, by controlling for the impact of the journal and PUB4 adjusts for both co-authorship and impact.
Source: Stephan and Levin, Chapter VII.

Figure 2



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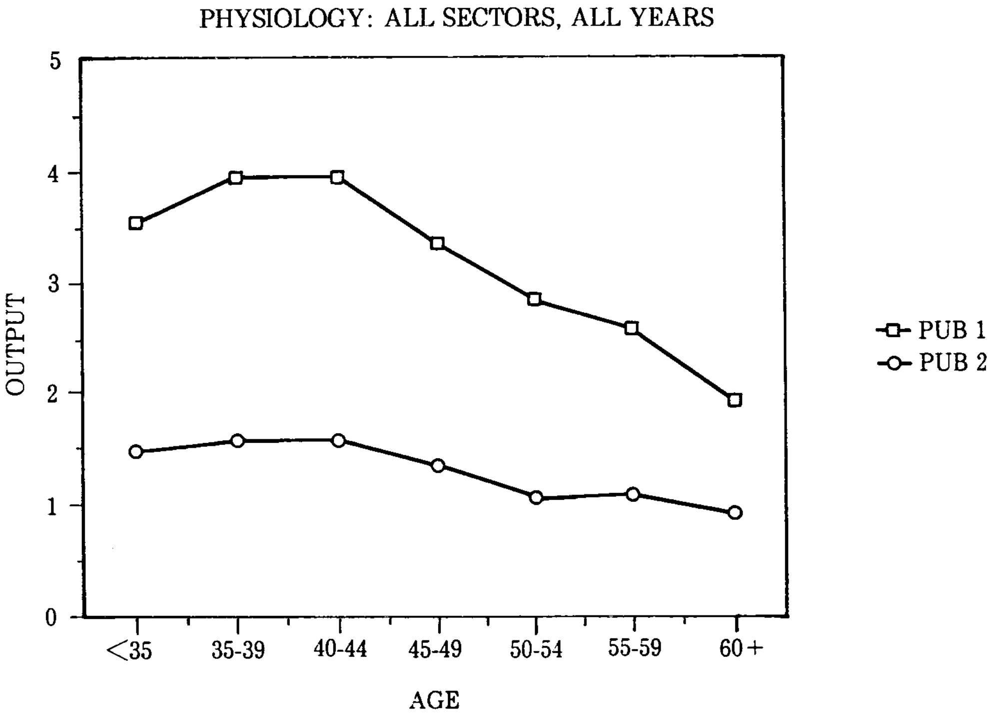
Source: Stephan and Levin, Chapter VII.

Figure 3



PUB1 measures straight counts of articies, PUB2 measures counts adjusted for number of co-authors.
Source: Stephan and Levin, Chapter VII.

Figure 4

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SUPPLY AND DEMAND OF SCIENTISTS AND ENGINEERS

Yde J. van der Meulen*

Introduction

In reviewing the status of our knowledge and discussing issues related to the adequacy, qualitatively as well as quantitatively, of the supply of scientists and engineers, I will focus very much on the graduate supply, in particular doctoral degree holders, in the 1990's. Also, in the following notes the words "scientists" and "scientific" refer first and foremost to the physical sciences and to mathematics and computer science. And, given the affiliation with a large industrial company, my point of view is an industrial one.

However, before considering the supply, first a few comments about the nature of the industrial demand:

It is sometimes assumed that PhDs find, or should find, their future in a traditional academic career and that industrial and other employment can be a buffer for absorbing a surplus, but does not have as fundamental a need for PhDs as universities do for faculty positions. In other words, that the industrial demand for PhDs, if necessary, could be quite flexible and cut back at will. This was perhaps true in some scientific disciplines long ago, but it certainly is not true in the current day and age. Industrial corporations employ many PhDs, not because they constituted an academic surplus at the time they were recruited, but because they have the highest potential and ability to advance science and technology in an industrial setting. Doctoral scientists and engineers have become a key ingredient of modern industrial activity, numbering, for example, well over one thousand in IBM's Research Division alone. This is the essence of the demand, and it is not surprising that industrial employment of scientists and engineers at all levels of education has increased as society has grown more technology-dependent and technology-driven since 1945.

Until recently, industrial employment employment for PhDs spanned the full spectrum from pure research to very applied development. In addition, we now see manufacturing change its complexity and importance, becoming much more engineering oriented, and we may expect the industrial demand for highly-trained scientists and engineers to increase in that area as well. For example, just last month it was reported that NeXT, Steven Jobs' new

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*Manager, Laboratory Administration and Planning, IBM firm, attracted a cadre of PhD experts to optimize certain factory operations.

Flexibility in the industrial demand does exist in another sense: The likelihood of rather substantial changes in the kind of work done over the duration of the career of an industrial scientist is high. In addition, many industrial activities require a multidisciplinary approach. This puts a premium on the recruitment of people whose professional interests range beyond their own specialty and, in turn, can make it possible to recruit for general excellence, rather than exact specialty.

But is it truly essential that industry recruit and employ PhDs, or could it do equally well by using lesser educated people and training them further, recognizing full well that such continuing employee learning is needed to avoid obsolescence, regardless of degree level?

The answer is that the advantages are real, because there is a difference between training and education. The years spent in graduate study at premier universities are very important and effectively open up the mind in a way that is not easily achieved otherwise and they can be a lasting stimulant for scientific and technological endeavors. For example, studies in IBM have shown the technical productivity of a PhD engineer or scientist to be on average several times larger than of MS graduates, as measured by inventions or by technical awards received. The difference with BS graduates was found to be larger, yet. These studies were based on a substantial technical population. If repeated elsewhere, in a different setting, similar studies would probably show similar results. There is literally direct leverage in employing PhDs, irrespective of the fact that their salaries and benefits will be higher.

Current reality confirms the theory: Industry competes vigorously to recruit PhDs and in doing so certainly impacts the ability of universities to replace or add to their faculty. And, the availability of industrial positions must be one of the reasons that in the early 80's roughly 60 percent of the foreign students remained in the U.S. after obtaining their doctorates.

Extrapolated to a wider domain, it has to be expected that the national economy will benefit if a sufficiently large stream of PhD level scientists and engineers is offered and accepts career opportunities in the private sector. But more importantly, shortages of PhD scientists and engineers have a long-term effect on industrial competence and international competitive positions. And, while there may be ups and downs in the demand depending on such factors as the state of the national economy and the level of defense R&D spending, the long-term employment trend for people in engineering and the hard sciences can be expected to continue on its upward slope of the past decades, if the supply if there to meet the demand. That may indeed be the most important question.

Supply Trends at the PhD Level

In some sense, the supply of PhD level scientists is equivalent to the small pinnacle of a large pyramid, whose base was built a long time before the top could be completed and which has successively smaller layers. But there is an enormous difference: Once begun, there was a strong interest in seeing the pyramid completed, to put the last blocks at the top in place. And unlike the educational process the whole construction took place under the same management. Perhaps a food chain analogy is even more appropriate. Graduate education is equivalent to the top of the food chain and many events can stimulate or disturb the eventual inputs to the graduate education process, causing feast or famine at the top.

In the U.S. a number of factors are operative that can significantly shrink the numbers of native science and engineering PhDs in the 1990's. Such a decrease is not a new phenomenon. Fur U.S. citizens and permanent residents the numbers showed an almost continuously downward trend throughout the 1970's, falling by about 42% from 1971 to 1980, and stabilized since then, rising by about 4%. However, the small rise in the 1980's can be fully accounted for by the increase in doctorates awarded to women in these categories. What is of greatest concern is that a further decrease in supply in the 1990's may well take place at a time of increase in the demand. As the growth in the base population slows, replacement needs from deaths and retirements cannot be expected to remain at the relatively low, historic level of 2%, especially in the aging academic work force.

There are several factors that are militating for the decrease and give reason for serious concern for the high-tech industry. First of all, the cohort size is shrinking for those in their twenties, reflecting lower post-1964 birth rates. Thirty years of age is often seen as the age at which a PhD is obtained and this particular cohort will shrink by 13% from 1989 to 2000. Secondly, within the cohorts, the fraction of white males, who traditionally have opted for careers in science and and engineering at a higher than average rate, is falling. Finally, the relative interest in science and engineering majors at the undergraduate level is shrinking. Surveys of incoming freshmen regarding their intended major have been carried out since 1966 by the American Council on Education. Their surveys have shown a strong correlation with later reality. From 1982 to 1987, the percentage of freshmen listing engineering as their intended major dropped from twelve to eight, those listing computer science dropped from almost nine to less than three percent. Some, but by no means all, of this decrease reflects already the shift in cohort composition and a greater representation in these cohorts by minority groups. Disconcerting is that the female interest in engineering is no longer increasing, because women represent the group with the highest numerical potential for this field. Such numbers lead us to expect that the fraction of BS degrees in natural sciences and engineering will retreat shortly from its historic high of 5% in the early 1980's. And, career choices now being made by incoming freshmen will in turn be felt at the graduate level in the mid-1990's.

What then should be done to keep the supply of science and engineering PhDs at a level commensurate with demand? Several suggestions have been made. Among these are proposals to increase the number and level of federal stipends to U.S. graduate students in the sciences and engineering. This appears to be an action that could yield positive results in the near future. But more can be done, short term as well as long term. Among graduating high school students, U.S. colleges and universities make substantial efforts – some would indeed say excessive efforts – to recruit undergraduate students, but this effort is not repeated four years later, when career choices are made by graduating college seniors. While industrial and other employers and professional schools (medical, law, etc.) make concerted efforts to recruit among these students, graduate science and engineering departments do not. Again, such efforts could have immediate results. Long-term, the issues are much more fundamental and require focus on the pre-college education in mathematics and science. However, because of the long lead times such efforts will not yield results at the doctorate level in this century.

Beyond the efforts that are immediately relevant to the educational process itself are issues that have to do with the esteem in which scientists and engineers are held. It is worth noting that in the 1960's nuclear physicists were among the most-admired professionals and that the number of PhD degrees awarded in nuclear physics peaked in 1972 at 195, but than started a long downhill trend to only 37 in 1982. To attract more of the best and the brightest to one's profession, it helps to highlight the achievements of the current practitioners and to appropriately honor the best among them. Industry does some of this, professional societies also do, and so does the government: The National Medal of Science and the National Medal of Technology are examples. But more must be done. If scientists and engineers get blame when things go wrong, they should also get credit for their considerable achievements. That does not happen automatically.

Foreign Participation and Immigration

A growing presence of foreign students on temporary visas in U.S. graduate schools helped cushion somewhat the decrease in doctoral degrees in physical sciences and engineering awarded in the 1970's. During that time period total numbers fell from 8685 in 1971 to 5962 in 1980, a decrease of 31%, as compared to the 42% drop for U.S. citizens and permanent residents (see above). And, when between 1980 and 1986 the total number of PhD degrees awarded rose by 1633, or 27%, foreign students accounted for more than 2/3 of this increase and U.S. women for the balance. The number of these students doubled from the mid-1970's to the mid-1980's when they received 40 % of the doctoral degrees. However, in engineering they now actually receive a majority of the doctoral degrees and occupy half the entry level faculty positions. Although student visas are temporary, it has been estimated that 60% are able to secure employment in the U.S. after graduation. There is some uncertainty how many of these positions are permanent and how many people return to their country of origin at a later time. These are striking numbers amply deserving further analysis and comment.

Over the past decade, the increase in foreign graduate students and doctorate recipients has been fueled very much by students from China (including Taiwan), Korea, the Middle East and Africa in engineering, and from those countries and regions plus Europe in the physical sciences. Groups that have maintained a substantial presence over this time include students from India. Relative and absolute fluctuations have been substantial for some countries. The number of students is leveling off at this time, but the number of degree recipients will continue to rise for at least another three to five years. Even so, the total number of doctorates awarded will be lower in 1990 than it was in 1970.

Much has been written about the effect that foreign graduates, most of whom actually become U.S. citizens as soon as possible, have on the U.S. labor market, where they are at this time employed in more than proportionate numbers by universities. Little, however, is understood about the continuity of the supply, both in terms of the students arriving and the graduates staying. These processes are not solely influenced by U.S. policy. As countries around the Pacific Rim industrialize the opportunities at home for graduates must be increasing, witness also the number of Taiwanese and Korean leaders educated in the U.S. Clearly, for countries such as the PRC a primary objective must be to see their students return home. On balance then, there is no great sense of security that the availability of foreign graduates will continue to increase in the 1990s as the number of U.S. citizens graduating decreases further.

The U.S. is not alone in its needs for scientists and engineers. Elsewhere in the Western world the native supply can be equally insufficient. To give just one example: The Swiss chemical industry, an important pillar of economic activity in its home country, hired 1200 chemists in the past five years of whom no less than 49% were foreigners. We may expect that labor markets for highly-trained personnel will increasingly become global, on one hand because industrial activity in many cases now has reached a global scale and on the other hand because the political framework makes such movement possible.

Conclusions

The evolution towards a society that strongly depends on science and technology in many of its products and services has created a multitude of career opportunities for PhD level scientists and engineers. As that process continues in the 1990's, it can with reasonable certainty be expected that the U.S. educational pipeline in an increasing number of technical disciplines will not yield sufficient professionals to fill available positions in education, government and industry in the U.S. Experience over the past decade has shown that such shortages can be alleviated by admitting students from abroad to U.S. graduate schools of sciences and engineering. It is not certain that this source of supply will continue to be dependable, a well as expandable, because a number of different factors are outside U.S. control. Alternate means to encourage U.S. students to continue their studies in science and engineering at the graduate level, both in the immediate future and over a longer period of time, should be explored vigorously. For the short term, this requires a proactive policy by graduate departments, initiating or expanding efforts to attract graduating seniors and to keep these students after they obtain their masters degree. Long range, improving pre-college science and mathematics education is of key importance. Such an improvement could of course benefit all students, not only those chosing technical careers.

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WOMEN IN SCIENCE AND ENGINEERING

Carole Ganz-Brown *

History of Participation of Women in Science and Engineering

In his public speeches, the Director of NSF several times emphasized the need to attract women into scientific careers – a need heightened by the concern over severe human resource shortages in science and engineering. These words and this assessment could very well apply to Erich Bloch, current Director of the NSF. He has both in word and program initiatives enthusiastically supported the role of women in stengthening the science and engineering workforce of the United States. Rather, however, these are the words of Alan Waterman, first Director of the Foundation (1951-1963).

Over the last two decades, growth in the employment of women scientists and engineers has been quite substantial. In 1974, of the nearly 2 million persons in the science and engineering population, about 9 percent (185,000) were women. Of these, only 7600 were in engineering fields. The social sciences had the largest number of women (56,000) followed by the life sciences (34,100). Most important, almost half of these female scientists and engineers were NOT in the labor force in 1974, that is, they were not employed and were not seeking employment. Thus, only about 6 percent of the employed scientists and engineers were women.

This compares with a 40 percent representation in the total civilian workforce, and 40 percent representation in the professional and technical worker force. Professional and technical workers include occupations such as accountant, lawyer, nurse, physician and teacher. In 1970 (the most recent year for which comparable data are available), the proportions of all lawyers who were women was 5 percent, and the proportion of all physicians who were women was 9 percent. For 1974, these professions were relatively similar to that of women scientists and engineers (6 percent).

The proportion of women employed in the various science and engineering fields varied widely. Women were more highly represented among psychologists, mathematical scientists and computer specialists, and had a lower representation among engineers and environmental and physical scientists. Overall, women represented less than 1 percent of the

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engineers. They, however, represented 14 percent of all scientists. This, in contrast, to women comprising only 8 percent of the scientist labor force in 1968.

Changes between the mid-seventies and the mid-eighties were also substantial. In 1986, about 700,000 women scientists and engineers were employed in the United States. This represented 15 percent of all scientists and engineers, up from 9 percent in 1976. Women continued to account for a much larger share of employment in science than in engineering. In 1986, while more than 25 percent of the scientist labor force was female, 4 percent of engineers were women. Women continued to be highly represented in psychology (42 percent of all psychologists in 1986), and have a lower representation in the physical and environmental sciences (13 percent of physical and environmental scientists).

Significant changes in the field distribution of women did occur after the mid-1970s, most notably for computer specialists, engineers and social scientists. The fastest growing field for both men and women was computer specialties, but up at annual rates of 23 percent for women, as compared to 15 percent for men. Between 1976 and 1986, employment of women computer specialists increased more than sixfold (from 21,000 to 128,000). By 1986, 24 percent of women scientists and engineers were computer specialists, up from 12 percent in 1976.

The number of women in engineering quadrupled, growing at an average annual rate of almost 16 percent per year.. The proportion of women in science and engineering who are engineers rose from 11 percent to almost 18 percent, over the approximately 10 year period.

The number of women enrolling in and graduating from U.S. engineering schools increased substantially. In 1983, women represented approximately one fifth of the beginning engineering students in the United States, as compared with about 5 percent in the early 1970s. Today, high school guidance counselors are much more likely to suggest an engineering career for a female student. The most popular career guidance instrument – the Strong-Campbell Interest Inventory – now includes among its career scales both male and female engineer scales. In addition, many colleges and universities sponsor programs to recruit talented female high school students for engineering careers.

During the 1976-86 period, employment of women in the social sciences increased by 65 percent; this was much less than the overall growth of women in science and engineering fields. As a result, the proportion who were social scientists declined from 31 percent to 18 percent.

In 1970, women accounted for only about 14 percent of all doctorates awarded; by 1986, they earned about 35 percent. Employment of doctoral women more than tripled between 1973 and 1985. The fields with the greatest relative growth of women doctorate holders were engineering – in which employment of women increased from 100 in 1973 to 1500 in 1985 – and computer specialties – in which employment increased from 100 to 1600 during the same period.

Despite the rapid growth in these fields, only about 5 to 6 percent of the women holding doctorates were computer specialists or engineers in 1985. More than 80 percent of the increase in the employment of women doctoral scientists and engineers took place in three fields – life sciences, social sciences, and psychology. The field distribution of women with doctorates, therefore, did not change greatly over this period. Women were somewhat more likely to be social scientists or computer specialists and less likely to be mathematical or physicial scientists in 1985 than in 1973.

Problems

Although there has been dramatic growth in the employment of women scientists and engineers, they remain underrepresented in the science and engineering workforce. Women now constitute over one half of overall U.S. employment, represent about 25 percent of lawyers graduated, and about 25 percent of doctors graduated in the United States.

Women scientists and engineers are still more likely than men to be both unemployed and underemployed. The unemployment rate for women scientists and engineers in 1986 (2.7 percent) was double the rate for men (1.3 percent). Women were also about three times as likely as men to report they were underemployed (6 percent versus 2 percent); that is, working part-time when full-time work is preferred, or working involuntarily in a non-science or engineering job.

Regardless of field, women scientists and engineers are less likely than men to be employed in industry or in the Federal Government. They are, however, more likely than men to work in State and local governments, non-profit organizations, and academic institutions. Because of the more rapid increase in the employment of women, they are generally younger than their male colleagues and have fewer years of professional experience. In 1986, about three-fifths of the women and one-fourth of the men reported fewer than 10 years of professional experience.

Years of experience may affect several labor market variables. For example, women scientists and engineers in industry are less likely than men to hold management positions; in academia, they are less likely than men to hold tenure or be in tenure-track positions. However, women hold assistant professorships and nonfaculty positions more than twice as often as men – this is about the same proportion as in 1977.

Women scientists and engineers also report salaries below those for men, with the smallest difference among those with less than ten years' experience. In fact, the average salaries earned by new science and engineering graduates are now about the same for both sexes in all fields. The lower average salaries of women scientists and engineers with more than 10 years' work experience presumably reflect few opportunities for advancement.

Future Demand for Scientists and Engineers

For 1986, there appears to be a rough balance between supply and demand for scientists and engineers. However, this balance between supply and demand for science and engineering personnel has been accomplished through means other than new science and engineering graduates with fully appropriate training in their fields. Substantial occupational mobility and increasing reliance on foreign-origin personnel (native-born U.S. citizens declined from 90 percent of the science and engineering labor force in 1972 to 83 percent in 1982) have been largely responsible for the supply demand equilibrium in U.S. science and engineering human resources.

Looking ahead to the year 2000, high-technology industry growth and the increasing use of high-technology goods and services in the economy as a whole will lead to increased demand for scientists and engineers in U.S. industry.

College and university faculty are expected to decline overall in the 1990s, in response to an expected decrease in total college enrollments, stemming from a drop in the traditional college age population. On the other hand, engineering faculty shortages have been persistent, primarily because of a notable drop (compared to the 1970s) in the number of American citizens who obtained. Ph.D.s in engineering, and an increasing proportion of Ph.D. engineers opting for employment in industry.

Overall demand for scientists and engineers is projected to increase substantially between 1986 and 2000, rising by approximately 36 percent, compared to 19 percent for all occupations. However, this growth will vary substantially among fields. Computer specialists are expected to experience the largest employment increase. Engineering employment is expected to increase 32 percent between 1986 and 2000. Among science occupations, employment of mathematical scientists is projected to grow by 29 percent.

Several forces will hinder workforce ability to meet these demand increases for scientists and engineers over the next decade. The smaller birth rates of the early 1970s will definitely reduce the size of the traditional college age population, and could possibly reduce college enrollment. The proportion in the college age population of women (and minorities) has been and is expected to grow. In addition, the first waves of the baby boom population that entered the labor force in the 1960s will begin to retire.

"These changes sharply increase the importance of attracting women and minorities to the sciences and engineering. Accomplishing that end is no longer just an equity issue. It is a nationally compelling goal." These are the words of Erich Bloch.

Efforts to Increase the Participation of Women in Science and Engineering

The factors that cause a young person to choose a career in science and engineering are not well-known. But in the course of the educational process, there are several key points at which students make decisions that build their eligibility for inclusion in science and engineering programs or limit their options.

The drain of women from the science and engineering pool is dramatic, with the sharpest decline occurring during the sophomore year in high school. Although they begin with a similar population base, only 9 percent of women continue to express an interest in science and mathematics, as opposed to about one third of men.

This is why "retention programs" that work to maintain student interest in science, mathematics, and engineering courses at critical decision making points can make a major difference. A major NSF strategy with respect to human resource development is to attack these critical points in the science and engineering pipeline. The NSF FY 1989 budget provides a 23 percent increase for education and human resources and a 32 percent increase for precollege education alone. In fact, since 1984, that part of the NSF budget has doubled at the same time that the total Foundation budget increased by less than half.

It must be noted, however, that the Foundation is a small player with a small part of the Federal budget in the enormous human resources area. NSF represents 3 percent of the Federal R&D budget, and 10 percent of the budget of the Department of Education.

In addition to its overall efforts in the human resource area, the Foundation has a number of programs to broaden the participation of women in the sciences and engineering using both established and less traditional approaches.

Women scientists and engineers are eligible to apply for standard research grants in all of the Foundation's programs, and are encouraged to do so. Research Initiation Awards provide support for women who have not previously received Federal research funds. Research Planning Grants are limited in amount and duration to help women develop competitive research programs (including women who are returning to research after a career interruption). Career Advancement Awards enable women to increase their research productivity. Visiting Professorships for Women enable experienced women scientists and engineers to undertake advanced research and teaching at host institutions where they can also provide guidance and encouragement to other women seeking to pursue research careers.

NSF is also looking for new ways to encourage women to stay in science and engineering. The problems women face in entering and advancing in the sciences and engineering mirror the difficulties they encounter in the labor force generally. But some of the unique difficulties women face in entering science and engineering have been singled out. Some scholars point to the lack of training in mathematics as a major component contributing to the underemployment of women in scientific and engineering fields.

Others emphasize that women and men may occupy the same college classrooms and have the same teachers but have vastly different educational experiences insofar as academia is largely a "male milieu". Some scholars speculate that the growing numbers of foreign teaching assistants and assistant professors in the sciences and engineering may provide a disincentive to female students. Many of these teachers come from societies that still prescribe vastly different roles for men and women.

There is no single or simple remedy for these problem. The Foundation continues to assume a strong leadership role in enhancing the visibility of accomplished women scientists and engineers and in promoting a more hospitable educational environment for women students and researchers in science and engineering. NSF also continues to exploit data bases and encourage longitudinal research on the processes of educational and career development. With clarification of the process of career choice and achievement, the Foundation should be in a better position to target specific interventions.

Finally, some scholars have encouraged the use of historical role models in textbooks and awareness programs to increase the participation of women in science. The discovery of DNA provides a clear example, especially since Crick and Watson are almost household names. The story of Rosalind Franklin's research on DNA, as told by James Watson and (at much greater length, and more sympathetically) by Anne Sayre is a particularly educational example of tedious, painstaking work by a women leading to a major discovery by men. Even if Franklin had lived long enough to win a share of the Nobel Prize, it would still be likely that Watson and Crick would be known as the discovers of the double helix structure. This, notwithstanding Watson's admission that Franklin's photograph, probably obtained without her knowledge or permission, was the crucial piece of evidence.

Concluding Remarks

To acknowledge the past achievements of women in science more visably, and to encourage new contributions by women are challenges both Japan and the United States face for the future. Our cooperation in science and technology would benefit from more acknowledgement of this, and more visible incorporation of this challenge into our international programs.

NOTES

1. This paper represents the views of the author, and not an official NSF position.
2. Alan Waterman's remarks are documented in J. Merton England, *A Patron for Pure Science: The National Science Foundation's Formative Years, 1945 – 57*, National Science Foundation, Washington, D.C., 1982.
3. Quantitative information on women's participation in the labor force used in this paper are based on the series (1972 – 1987), *Science and Engineering Indicators*, National Science Foundation, Washington, D.C. Also used was *Women and Minorities in Science and Engineering*, NSF, January 1988.
4. The quoted words of Erich Bloch are from his "Remarks Before the Federal Task Force on Women, Minorities and Handicapped in Science and Technology," Washington, D.C., December 12, 1988.
5. Research related to the unique difficulties faced by women entering science and engineering is summarized in the paper, "Women as a Human Resource," Phyllis Moen, Sociology Program, Division of Social and Economic Science, National Science Foundation, Washington, D.C., December 14, 1988.
6. Stephen Brush has written extensively about the historical role of women in science. See Stephen G. Brush, "Women in Science", *The Physics Teacher*, January 1985.
7. The accounts of the discoveries of the double helix referred to in the paper are: James D. Watson, *The Double Helix*, Atheneum Publishers, New York, 1968 and Anne Sayre, *Rosalind Franklin and DNA,* Norton & Company, New York, 1975.
8. Discussions with NSF staff Joseph Danik, Director, Division of Research Initiation and Improvement; Gretchen Klein, Program Director, Visiting Professorships for Women Program, and Michael Crowley, Study Director, S&T Personnel Characteristics Studies contributed to the paper. The author extends her appreciation.

SOME ANALYSIS ON RECENT CHANGES IN JAPANESE SUPPLY AND EMPLOYMENT PATTERNS OF ENGINEERS

Fumio Kodama(*) (**)

Introduction

Major changes are occurring in Japanese supply and employment patterns of scientists and engineers. In this paper, we will first describe these changes in both graduation and employment patterns. Then, a more detailed survey will identify differences between graduates of major universities and the average, as well as differences by engineering sub-disciplines. Finally, we will try to analyze why this is occurring and give some thought to these changes, in order to set the agenda for discussion and further investigation in science policy research.

1. Japanese Supply Patterns of Scientists and Engineers

The major characteristics of the supply pattern of scientists and engineers in Japan are: the relatively large number of engineers compared with that of scientists; and a heavy orientation of students toward bachelor degrees in both the sciences and engineering, as shown in Tables 1 and 2. In 1988, we produced seventy-six thousand engineering bachelors, while we produced thirteen thousand science bachelors. Therefore, the engineer/scientist ratio was 5.7:1.0, as far as the production of bachelors was concerned.

As far as the graduate education of engineers is concerned, we produced 11 thousand masters, and 721 PhDs in 1988. Thus, the ratio of bachelors/masters/PhDs is 100:15:1. On the other hand, graduate schools in science produced 2.3 thousand masters, and 589 PhDs. Thus, the ratio of bachelors/masters/PhDs is 100:18:4. Therefore, in terms of the tendency to proceed further with higher education, there is no major difference up to the master degree between engineers and scientists. However, when it comes to the PhD level, the probability of the science bachelor entering the PhD course is four times as high as that of engineering bachelors.

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Table 1. Number of Engineering Graduates.

year	Bachelor	Master	P.h.D.
1965	30,121 (89)	1,666 (61)	170 (88)
1975	65,422 (83)	6,060 (83)	570 (31)
1980	73,508 (85)	7,135 (88)	657 (66)
1985	71,396 (83)	8,628 (89)	552 (74)
1986	73,316 (82)	9,620 (88)	588 (68)
1987	75,843 (82)	10,413 (88)	638 (64)
1988	76,362 (81)	11,129 (88)	721 (68)

( ): employment ratio (%)

NOTE 1: PhD. graduates refers to those who (1) have complete the required period of academic residence; (2) have met the required academic units; and (3) have been judged as having met the required level of academic standards as determined by a dessertation or final examination evaluation. However, one may be considered a PhD graduate if only conditions (1) and (2) have been met.

NOTE 2: The employed includes those (1) whose employment conditions include receiving salary, wage, compensation or other forms of employment related constant income; or (2) who are selfemployed. However, "household assistants" are considered unemployed.

SOURCR: Ministry of Education, Science and Culture: Report of Basic Survey on Schools.

Table 2. Number of Science Graduates.

year	Bachelor	Master	P.h.D.
1965	4,748 (74)	786 (35)	238 (70)
1975	9,504 (67)	1,382 (45)	494 (23)
1980	11,554 (66)	1,649 (49)	589 (44)
1985	12,698 (69)	1,992 (61)	610 (47)
1986	12,814 (69)	2,019 (61)	564 (53)
1987	13,389 (69)	2,213 (59)	605 (47)
1988	13,385 (69)	2,377 (61)	589 (50)

( ): employment ratio (%)

SOURCE: Ministry of Education, Science and Culture: Report of Basic Survey on School.

As far as the growth rate in the supply of science and engineering graduates is concerned, we experienced large increases in both categories, and at all levels of education, from 1965 to 1975. In the case of engineers, the supply of bachelors more than doubled, and more than tripled in masters and PhDs. Since 1975, however, the growth rates have slowed in bachelors and PhDs: we odserved a fairly modest increase in bachelors and a very small increase in PhDs. But masters continue to increase. In the case of engineers, the ratio of 1988/1975 is 1.17 at bachelors, 1.84 at masters, and 1.26 at PhDs. In the case of scientists, the ratio is 1.41 at bachelors, 1.72 at masters, and 1.19 at PhDs.

The large increase in the period 1965-1975 is an obvious reflection of the rapid growth of the Japanese economy. The continued increase of masters after 1975 reflects the shift of the Japanese industrial structure from low-technology to high-technology areas. However, we can not observe any influence of this shift on the increase of PhDs, as far as formal education is concerned.

The relatively small number of PhDs and its modest increase are explained by two factors. One is that employers prefer masters to PhDs, because they think masters are more flexible in adapting to their needs. The other is the strong inclination of those students in PhD courses to take academic jobs. This situation is reflected by the highest figure in the employment ratio of masters and lowest figure of PhDs: 88 percent of engineering masters are employed, while only 68 percent of engineering PhDs and 50 percent of science PhDs are employed.

2. Employment Patterns of Scientists and Engineers

As can be observed in every advanced country, the shift of national economic activity into service industries is progressing in Japan as well. The employment patterns of scientists and engineers are following this change in the national economy. The long term trend in the employment of engineering bachelors is shown in Table 3. In order to determine the influence of this shift on the employment pattern of engineers, certain sub-categories such as manufacturing industries, professional services industries, and the finance/insurance sector are presented in this table. Professional services industries include computer software companies, consulting companies, and real estate businesses.

The total employment of engineering bachelors increased by 14 percent from 1975 to 1988; those employed by manufacturing industries increased by 18 percent in the same period. However, employment by the professional services industries increased by as much as 185 percent and that by the finance/insurance sector increased by 86 percent.

Table 3. Long Term Trend in Employment Pattern of Engineering Bachelors.

year	total of employed	employed by manufacturing industries		employed by professional services industries		employed by the finance/insurance sector	
	A	B	(B/A)	C	(C/A)	D	(D/A)
1965	26,698	17,656	(66)	278	(1.0)	94	(0.4)
1975	54,234	27,848	(51)	3,109	(5.7)	641	(1.2)
1980	62,131	31,473	(51)	4,575	(7.4)	457	(1.5)
1985	59,216	35,373	(60)	6,333	(10.7)	454	(0.8)
1986	60,279	35,916	(60)	7,703	(12.8)	367	(0.6)
1987	61,883	36,197	(58)	8,219	(13.2)	586	(0.9)
1988	61,822	32,829	(53)	8,847	(14.3)	1,193	(1.9)

( ): the percentage in total employed.
SOURCE: Ministry of Education, Science and Culture: Report of Basic Survey on Schools.

About half of the engineering bachelors who joined the work force in 1988 were employed by manufacturing industries, although 66 percent of them were employed by manufacturing industries in 1965. We experienced a drastic decrease in the late 1970s: the percentage reached as low as 45 percent in 1979. This was due to the general economic recession caused by the oil crisis which every advanced country more or less experienced. However, we experienced a drop in absolute numbers in 1988: a decrease by more than 3000 bachelors from the previous year. It was the first time that the number and the percentage dropped drastically under conditions of good economic growth. Therefore, this drop has profound causes and implications.

On the other hand, professional service industries are employing as many as 15 percent of all engineering bachelors employed, although it comprised only one percent of them in 1965 and 6 percent in 1975. A steady increase in the percentage is observed ever since 1965. We can interpret this increase as a natural reflection of the shift of the national economy towards the service sector.

The most recent phenomenon is the drastic increase in employment by the finance/insurance sector: employment more than double in 1988 from the previous year. Although the level still remained as low as 2 percent and there was an increase at that level before 1980, job assignments for engineering bachelors changed in an essential way: in the past, they were employed as specialists involved with installation of computers, but they are now being employed as generalists with chances to be promoted to corporate managers.

3. Sample Survey in Major Universities

In order to find out whether there is any difference between graduates of major universities and the average (depicted in Table 3) and differences among various scientific disciplines, NISTEP (National Institute of Science and Technology Policy) conducted a detailed survey of 62 departments in 10 major universities : 6 national universities and 4 private ones; 637 science graduates and 3747 engineering graduates [1]. Some results are shown in Table 4.

Table 4. The Recent Trends of Employment Patterns of Engineering Bachelors in Major Universities.

year	total of employed	employed by manufacturing industries	employed by professional services industry	employed by the finance/insurance sector
	A	B (B/A)	C (C/A)	D (D/A)
1986	2,533	1,914 (76)	210 (8.3)	38 (1.5)
1987	2,555	1,849 (72)	287 (11.2)	55 (2.2)
1988	2,458	1,614 (66)	288 (11.7)	119 (4.8)

SOURCR: C. Nishigata, A. Nakanishi, Y. Hirano, A Survey of Employment Trends of Science and Engineering Graduates, NISTEP Report No.1, National Institute of Science and Technology Policy, Science and Technology Agency, June 1989.

As far as the differences in employment by manufacturing industries, the tendency to be employed by manufacturing industries is stronger in the major universities than on average: 66 percent of bachelors from the major universities are employed by manufacturing industries, while only 53 percent of them are employed by manufacturing industries on average. However, the changes in the last three years are more dramatic in major universities than on average: the percentage decreased by 10 percentage points from 76 to 66 in major universities, while it decreased by 7 percentage point from 60 to 53 on average.

As far as employment by professional services industries, there is no major differences between them: 12 percent in major universities and 14.5 percent on average. Therefore, the shift of employment into professional services industries is a general and overall trend, and it will be a long-lasting phenomenon. However, we can say, students in major universities are a little bit less inclined than on average to take a job in professional services industries.

A big difference can be found in employment in the finance/insurance sector. The ratio grows as high as 4.8 percent in major universities, while it remains only 1.9 percent on average. The increase in the last three years is more dramatic in major universities than on average: it increased more than three times in major universities from 1.5% to 4.8%, while the average ratio doubled from 0.8% to 1.9%. Therefore, it can be assumed that larger finance/insurance institutions who can employ bachelors of science and engineering are targeting their recruitment towards major universities, and those students in major universities are more interested in being employed by the finance/insurance sector.

4. Differences among Engineering Disciplines

The sample survey by NISTEP disaggregates engineering disciplines into four categories: applied mathematics; mechanical engineering; electrical/electronics engineering; and metallurgical/chemical engineering. Therefore, we can investigate disciplinary differences in employment patterns.

As far as employment by manufacturing industries (Table 5) is concerned, it has begun to play a minor part in applied mathematics, although it retains a majority position in the other three hardware-related disciplines.

Among these three disciplines, the employment ratio by manufacturing industries is highest in mechanical engineering at 71 percent and lowest in electrical/ electronics engineering at 61 percent. However, as far as time trends are concerned, we can observe an overall and constant decline in the ratios throughout all the disciplines. Moreover, it is noteworthy that the difference in ratios between bachelors and masters has lessened: the differences are reduced to within the range of 5 percent in 1988, from 20 percent in 1986.

In employment of bachelors by professional services industries (Table 6), there is not very much difference among disciplines, with an exception in applied mathematics where the sample is small.

Table 5. Disciplinary Differences in Employment Ratio by Manufacturing Industries.

year	applied mathematics	mechanical engineering	electrical／electronics engineering	metallurgy／chemical engineering
1986	54 (72)	80 (89)	71 (73)	76 (95)
1987	47 (73)	77 (76)	66 (67)	74 (90)
1988	45 (50)	71 (75)	61 (61)	65 (69)

( ): the ratios of masters.
SOURCR: C. Nishigata, A. Nakanishi, Y. Hirano, A Survey of Employment Trends of Science and Engineering Graduates, NISTEP Report No.1, National Institute of Science and Technology Policy, Science and Technology Agency, June 1989.

Table 6. Disciplinary Differences in Employment Ratios by Professional Services Industries.

year	applied mathematics	mechanical engineering	electrical／electronics engineering	metallurgy／chemical engineering
1986	14 (13)	8 (4)	9 (7)	9 (2)
1987	22 (8)	10 (6)	13 (10)	11 (2)
1988	8 (27)	11 (6)	14 (9)	10 (7)

( ): the ratios of masters.
SOURCR: C. Nishigata, A. Nakanishi, Y. Hirano, A Survey of Employment Trends of Science and Engineering Graduates, NISTEP Report No.1, National Institute of Science and Technology Policy, Science and Technology Agency, June 1989.

All the figures in the table are more or less in the range of 15 to 20 percent: it is highest in metallurgical／chemical engineering and lowest in mechanical engineering. However, the ratios are increasing gradually and steadily in all the disciplines and in both bachelors and masters. As far as masters are concerned, drastic increases are observed in applied mathematics and metallurgical/chemical engineering. The ratio has risen up to as high as 30 percent in applied mathematics.

In employment by the finance/insurance sector (Table 7), marked disciplinary differences can be found. In applied mathematics, the ratio surpassed a quarter, i.e. 26.5 percent, although this is not surprising considering the specific nature of this discipline. However, even in the hardware-related disciplines, we can observe fairly large increases in the ratios.

Table 7. Disciplinary Differences in Employment Ratios by the Finance/Insurance Sector.

year	applied mathematics	mechanical engineering	electrical/ electronics engineering	metallurgy/ chemical engineering
1986	16.0 (0.0)	1.5 (0.0)	0.9 (0.7)	1.1 (0.0)
1987	16.7 (2.7)	1.7 (0.3)	1.5 (0.6)	2.9 (1.0)
1988	26.5 (2.3)	4.3 (1.5)	2.6 (1.6)	7.0 (2.5)

( ): the ratios of masters.
SOURCR: C. Nishigata, A. Nakanishi, Y. Hirano, A Survey of Employment Trends of Science and Engineering Graduates, NISTEP Report No.1, National Institute of Science and Technology Policy, Science and Technology Agency, June 1989.

For metallurgical/chemical engineering, the ratio reached as high as 7 percent, while the ratio is as low as 2.6 percent in electrical/electronics engineering, and is 4.3 percent in mechanical engineering. Therefore, we can say that employment by the finance/insurance sector is not associated with the specific nature of the disciplines. A more plausible hypothesis might be: the more saturated demand in manufacturing sectors for a discipline and the less attractive a discipline to able engineering students, the more probable students choose employment in the finance/insurance sector. This phenomenon is a good evidence that engineering bachelors are being employed as generalists, as described above. As far as masters are concerned, however, the ratios still remain lower than 2.5 percent. But a steady increase can be observed in all disciplines.

5. Some Analysis of Changes in Supply and Employment Patterns

5-1. Another Japanese Miracle?

It is well known world-wide that: the Japanese economy grew very rapidly; industrial R&D activities grew at a rate higher than the economy as a whole; and Japanese exports shifted towards higher value added products. Also it became clear that Japanese competitiveness was in high technology products, as reported in [2]. These phenomena have been called an "economic miracle" by Western scholars. However, it is stressed, as Table 1 shows, that the increase in engineering PhDs was very marginal. Therefore, it looks as if the Japanese economic miracle was accomplished without enhancement of educational level in the higher educational sector. So, this might be termed "another miracle" or a "puzzle appearing in higher education".

First of all, let us formulate this puzzle. As far as the enhancement in the level of engineering education is concerned, the ratios of students proceeding to advanced programs of engineering education are shown in Table 8.

Table 8. Proceeding Probabilities to Higher Engineering Program.

year	masters／bachelors	PhDs／masters
1965	9.5	32.8
1975	10.1	11.3
1980	9.8	7.8
1985	13.9	8.3
1986	14.3	9.3
1987	15.1	8.4
1988	16.1	8.9

unit: percentage.
SOURCE: Ministry of Education, Science and Culture: Report of Basic Survey on Schools.

As shown in the table, the probability that bachelors proceed to masters increased rapidly: the probability is currently 16 percent, compared to 10 percent in 1965. On the other hand, the probability that masters proceed to PhDs decreased drastically in the last decade: it is now only 9 percent, while it was 33 percent in 1965. These two probabilities behaved in quite opposite directions. Therefore, it may be safe to assume that the masters program is the optimum level of engineering education through the experiences of achieving the economic miracle.

The situation in PhD programs is much worse than it appears. According to Japanese statistics, graduation from PhD programs does not necessarily mean that students received PhD degrees. Many graduates from PhD programs leave these programs without receiving the PhD degree. In Table 9, the ratio of graduates without the PhD degrees to total number of graduates from PhD programs is shown in parenthesis, together with the number of graduates.

Table 9. Number of Engineering PhD Graduates and the Percentage of those without Degree.

year	total	national university	private university
1975	570 (39)	479 (37)	64 (42)
1980	657 (44)	504 (41)	130 (55)
1985	552 (35)	427 (32)	111 (50)
1986	588 (31)	484 (30)	91 (37)
1987	638 (32)	520 (30)	101 (45)
1988	721 (28)	611 (24)	103 (53)

( ): the percentage of graduation without degree.
NOTE: Because of a small number of PhDs produced by Public Universities, figures do not add to total shown.
SOURCE: Ministry of Education, Science and Culture, Report of Basic Survey on Schools.

About 30 percent of PhD students are leaving the program without a degree, although the situation has improved in recent years. In 1980, as many as 44 percent of PhD students left the program without a degree. Although some improvements can be observed in the national universities which retain a dominant position as far as the supply of PhDs is concerned, graduation without a degree is the norm in private universities: 53 percent of the graduates are without PhD degrees. There is no improvement visible in this case, and in fact the situation has deteriorated over the last three years.

The answer to this puzzle might be found in the system which is called "dissertation doctors." In Japan, there are two ways to earn a PhD. One is the ordinary case where a student does course-work and fulfills the requirements imposed by a university. The other is where an applicant submits a dissertation paper to the university and the university accepts it. Many researchers in industry get degrees through the latter method. That is, researchers working for companies write papers based on their company work. In Table 10, the number of PhDs granted by dissertation is shown together with that by course-work. In 1986, approximately 1000 PhDs were granted through a dissertation, while 500 PhDs were earned through course-work. In other words, the "dissertation doctor" appears the major route to a PhD in Japan.

Table 10. Number of Engineering PhDs Granted.

year	by course-work	by dissertation	total	
	A	B	A + B	B／(A+B)
1960	72	6	78	8
1961	69	17	86	20
1962	84	54	138	39
1963	94	116	210	55
1970	425	428	853	50
1980	523	663	1,186	56
1981	541	695	1,236	56
1982	506	772	1,278	60
1983	489	801	1,290	62
1984	447	844	1,291	65
1985	480	924	1,404	66
1986	505	988	1,493	66

SOURCE: Ministry of Education, Science and Culture, University Periodical.

As early as 1963, the number of PhDs granted through dissertations surpassed those granted by course work. Until 1982, the number of dissertation doctors stayed more or less equivalent to the number of course-work doctors. However, the number of dissertation doctors began to increase rapidly after 1983, while that of course-work doctors decreased slightly. Therefore, the dissertation doctor has become the dominant mode of granting PhDs in the field of engineering, since almost two-thirds of engineering PhDs are granted through dissertation. As many as 66 percent of Japanese PhDs were granted by the dissertation doctor system in 1986.

Therefore, it is necessary to include dissertation doctors in Japanese statistics about the production of PhDs. For 1986/1970, the ratio is 2.31 in dissertation doctors, while the corresponding figure is 1.19 in course-work doctors. Thus, for 1986/1970, the ratio is 1.75, as far as the total number of PhDs granted is concerned. Therefore, we can conclude that the increase in the rate of PhDs is more or less equivalent to that of masters. It is obviously far more than that of bachelors degrees.

5-2. Are we losing or gaining precious talents?

One of the obvious reasons for the major changes in the employment patterns of scientists and engineers derives from changes in the demand structure in the last few years. As can be seen in Table 11, employment by the tertiary sector doubled from 1965, while that in the secondary sector increased only 1.3 times.

Table 11. Number of Employees by Sectors.

year	primary industry	secondary industry	tertiary industry
1965	63 (2)	1,266 (46)	1,455 (52)
1975	46 (1)	1,530 (42)	2,069 (57)
1980	45 (1)	1,572 (40)	2,352 (59)
1985	43 (1)	1,655 (38)	2,607 (61)
1986	44 (1)	1,652 (38)	2,675 (61)
1987	44 (1)	1,635 (37)	2,744 (62)

unit: ten thousands,
( ): the composition ratio.
SOURCE: compiled by NISTEP from The Labor Force Survey, Statistics Bureau, Management and Coordination Agency.

In terms of share, the secondary sector decreased from 46 to 37, while the tertiary sector increased from 52 to 62. Since demand in the job market reflects net increases in employment opportunity, it is reasonable to suppose that university graduates are being absorbed by the tertiary sector.

It is hard to deny that the absolute and relative increase in the employment of scientists and engineers by the finance/insurance sector is related to the widening gap in income between employees of manufacturing industries and those of the finance/insurance sector, as illustrated in Table 12.

Table 12. Income Gap between Manufacturing and Finance/Insurance at the Age of 35.

year	manufacturing		finance/insurance		ratios	
	salary A	annual income B	salary C	annual income D	(C/A)	(D/B)
1976	219.6	3838.5	253.3	4903.6	115.3	127.7
1980	261.6	4568.3	320.6	5983.8	122.6	131.0
1985	291.8	5052.6	373.9	7039.6	128.1	139.3
1986	292.5	5092.7	393.3	7427.3	134.5	145.8
1987	300.5	---	393.0	----	130.8	---

unit: thousand yen.
SOURCE: compiled by NISTEP from Basic Survey on Wage Structure, Ministry of Labor.

In Japan, the pay schedule is more or less determined by the employee's age. At the age of 35, university graduates in the finance/insurance sector are paid 30 percent higher than those in manufacturing industries in terms of salary. When it comes to comparison of annual income, which includes both salary and bonus, the gap is widened to 45 percent. In 1976, these differences were 15 percent and 27 percent respectively. Therefore, the gap almost doubled in the last ten years.

Moreover, the gap between the two pay schedules is also widening. In 1976, the gap peaked at the age of 52 in both absolute and relative terms: the difference was as much as 2.7 million yen and it amounted to 37 percent of annual income in manufacturing industries. In 1986, however, it peaked at the age of 43 in absolute terms: the difference is 2.7 million yen. It peaked at the age of 35 in relative terms: the difference amounted to 46 percent of annual income in manufacturing industries. In other words, the gap is widening and becoming effective earlier in the careers of scientists and engineers.

As to the drastic and seemingly long lasting increases in the employment of engineering graduates by the finance／insurance sector, we can formulate the problem as follows: are we losing precious talent to sectors outside manufacturing or is the country as a whole gaining talent in the light of the economic structural changes in which service sectors are becoming the leading sectors?

Obviously, manufacturing is losing a lot of the talent it definitely needs. However, it is not the most rapidly growing sector nor is it the most profitable. The finance／insurance sector shows the most growth and further will be more internationalized.

Moreover, the finance／insurance sector is totally different from before, mainly because of technological innovations produced by the manufacturing sectors. In other words, jobs in this sector have drastically changed: they are now thinking about optimal ways of operating the system; and they are talking about the development of new products in financial markets. It might not be so different from what the manufacturing sectors search for in terms of efficient factory operation and of innovating new products, as far as the way of problem-solving and the kinds of talents needed are concerned.

An analysis of Japanese history of leading industries tells us about the following interaction between recruitment of S／E bachelors and the internationalization of these industries: whenever an industry is going to grow and internationalize, young science／engineering talents are mobilized and push the internationalization forward. This pattern of interaction can be found in the textile industry, the shipbuilding industry, trading companies, and the automobile industry. Why will this not happen in the finance／ insurance sector?

5-3. Who is adjusting, professors or students?

As we described above, both the economic structure and the employment patterns of science and engineering graduates have changed drastically. Then, the last question to be addressed is whether university education has responded to this change. Since the economic structural changes and the changes in employment patterns have something to do with the emergence of information technology, the establishment of information science departments is chosen as an indicator of the responsiveness of university education, as shown in Table 13.

The educational capacity of information science can be measured by the number of students who can be enrolled in departments of information science. The capacity was 4485 students in 1986, and it comprised only 5.3 percent of the total capacity of education in science and engineering. National universities provided a capacity of 2760 students, a figure which

Table 13. Capacity of Enrollment in Information Sciences Departments.

year	total	national & public universities	private universities
1965	380 (0.9)	280 (1.6)	100 (0.4)
1970	917 (1.6)	557 (2.4)	360 (1.1)
1975	2,074 (3.1)	1,284 (5.1)	790 (2.0)
1980	2,801 (3.7)	1,701 (6.1)	1,100 (2.4)
1981	2,841 (3.7)	1,701 (6.1)	1,140 (2.4)
1982	2,841 (3.7)	1,701 (6.1)	1,140 (2.4)
1983	3,150 (4.0)	2,010 (7.1)	1,140 (2.4)
1984	3,390 (4.4)	2,170 (7.7)	1,220 (2.5)
1985	4,335 (5.5)	2,655 (9.1)	1,680 (3.5)
1986	4,485 (5.3)	2,805 (8.9)	1,680 (3.2)

( ): the ratio to total capacity of S/E.
SOURCE: compiled by Nishigata from Handbook of Universities, Ministry of Education, Science and Culture.

comprises about 9 percent of the total capacity of national universities in science and engineering. Private universities provided a capacity of 1680, or 3.2 percent of the total capacity of private universities.

The statistics presented above indicate that universities are not responding to the changing demands for university graduates, and show how the rigid departmentalization of universities, contributes. Moreover, the organization of a university is hard to change, without a net increase of faculty. This is partly because of the life long employment system of faculties, and the inbreeding of teaching staffs within departments, which prevails in the Japanese university. Therefore, as far as the original question of adjustment is concerned, the obvious answer is that students are adjusting to the changing needs of the economy.

However, there is an alternative way to solve the problem. Although the number of departments of information science is far below those required by the job market, this subject is being taught within the organizational framework of existing hardware-related departments. This might have been a very positive arrangement in a time when the application of computer technology was limited to industrial products such as the N.C. machine tools. In order to produce effective computer control programs, the programmer has to know how the machine tool is operated and manufactured. In other words, the question can be raised: which pattern would be better; mechanical engineers who learn computer programming by themselves to produce control programs for machine tools; or computer experts performing these tasks with the help of machine tool designers?

Although this arrangement might be applicable to the manufacturing sector, we do not know yet if it is true outside the manufacturing sector. Then, we have to ask about the essence of an engineering education. One of the possible answers is that an engineering education more or less centers around teaching students how to integrate all available knowledge for specific purposes. This types of training can be transferred across sectorial borders. If that is the case, the best method of teaching integration might be to teach it in the framework of the hardware, because teaching materials have been more accumulated, there exists a lot of experience, it is visible, and it is easier to understand.

Concluding Remarks

I would like to conclude this paper with several critical questions. These questions have to be answered before we make drastic policy decisions which might change the existing structure of the Japanese university system, as far as the supply of scientists and engineers is concerned.

Concerning the drastic increase in dissertation doctors vis-a-vis course-work doctors, one might interpret this phenomenon as a reflection of the inability of the university to attract young researchers, in terms of the teaching capability and of the quality of research facilities. An alternative interpretation is that this might be the method of producing engineering PhDs in the age of high technology, because the speed of innovation is so fast that knowledge accumulated in the university becomes obsolete too soon. A more essential reason might be that this is the only available and efficient method by which young researchers in the field of engineering have an opportunity to tackle real problems.

If the latter is the case, the Japanese system of dissertation doctors will become the standard method of raising the engineering PhDs. However, even if it is a good method as far as education is concerned, the problem of research is different. What will become of research in the university without PhD students? The university will not be able to function as a research center of excellence.

As far as the recent increases in the employment of science and engineering bachelors by the finance/insurance sector, a basic question is: Is the prosperity in the finance/insurance sector possible without an equivalent prosperity in manufacturing? Even if it is possible, is it healthy from the viewpoint of the national economy?

Its effect might be more than just removing precious talent from the limited pool of the able young population. One of science policy reserches on the interaction between financial markets and technical innovation reveals the following [3] : the efficient and perfect operation in financial markets discourages technology development, because the objects of investment are biased towards shortterm profits, and the perfect information about the present situation displaces risk-taking efforts and business operation in uncertain environments such as technology developments. At least so far, the Japanese investment patterns in high technology industries has not been guided by the principle of the rate of return [4].

As far as the critical question about the organizational rigidity of the university in establishing new departments, we can formulate the problem as follows: When a new discipline such as information science appears, should we teach this subject in the existing framework of departments or should we establish a new and independent department? Which is more effective and efficient? What are the limitations of the former method when the new discipline is progresses further?

Some past Japanese experience seems to bear on this limitation. The computer programs, developed by hardware engineers who acquired programming skills through self-teaching might work efficiently when use is limited to internal purposes, or when the program is built into the hardware. However, hardware producers find it difficult to bring their programs into the market as a commercial product to be used for more general purposes.

As to teaching a new discipline such as information science within the framework of existing departments, those faculty members who are teaching information science in these departments are, in many cases, people who have never had an opportunity to receive formal education in information science, because of the inbreeding of faculties within individual departments. This method might have to end when information science progresses further and unique expertise becomes indispensable.

In conclusion, we need more systematic investigation of these critical questions. Without careful study and deeper understanding of these problems, it is difficult and sometimes dangerous to implement drastic changes which might affect the whole structure of the existing engineering educational system developed through a long history of trial and error.

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THE SUPPLY OF SCIENTISTS AND ENGINEERS IN JAPAN

Sogo Okamura *

1. Introduction

Japan's educational system was reformed to the linear 6-3-3-4 school system after World War II. The expansion and popularization of higher education have been brought about by economic development, and given the Japanese people greater opportunity to go to universities. The increase in the number of students in institutions of higher education leads to elevation of Japan's intellectual level. Moreover the percentage of engineering students in Japanese universities is much higher than that in other countries, because the faculty of engineering has occupied a central place within the higher education since as far back as 1870, when the Japanese government launched a modern educational system. This contributed to training the required human resources for industry.

Recently, Japanese industry has made remarkable gains, proving its ability to adapt to changing demands and to make the most of opportunities in the world market. It is recognized in Japan that Japan was very successful in the past in utilizing the results of basic research carried out abroad, and in effectively executing applied research and development that led to useful new products. Although there are some excellent results of basic research achieved by Japanese scientists, these are not enough, and much more effort should be made to accelerate basic research activities in the future. In order to do so, development of young researchers is the most important problem. Intensive discussions have been held in the Science Council of Monbusho (Ministry of Education, Science and Culture) for developing human resources in research. In order to obtain source material for discussion, Monbusho conducted a survey to forecast the future demand for researchers.

2. Forecast of the Demand for Researchers

Demand for researchers consists of the following two kinds:

(1) Demand for substitution: demand for substituting researchers who are leaving the research profession by retirement, death, etc.; and

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(2) New Demand: demand caused by the expansion of the research enterprise, etc.

In order to estimate the demand for substitution and the new demand, the following methods are used:

Table 1. shows the ratios of researchers who have left the research profession to researchers in age groups, and the distribution of employment of researchers by age group. Assuming these ratios do not change in the future, the number of researchers who will leave the research profession in a specific year can be calculated. Multiplying this number by the age distribution of employment, the substitution demand for researchers in the next year is estimated. As for the new demand, the following two cases (Case A and Case B) are assumed;

Case A

Universities: Monbusho has a plan for the future of higher education, taking into account future demographic change. New demand for researchers is assumed to be equal to the increase of academic staff in the Monbusho plan.

National and Public Research Laboratories: *Report on the Survey of Research and Development* shows almost no growth of researchers in this sector up to the year 2000.

Industry: The gross national product and the number of researchers in industry are assumed to be correlated in the future. New demand for researchers is estimated, assuming a growth rate of GNP of 3 % up to the year 2,000.

Case B

Universities: In addition to the new demand in Case A, the effect of some expansion in university research institutes is considered.

National and Public Research Laboratories: The estimation is made by the same method used for researchers in industry in Case A.

Industry: The same as in Case A.

Estimated results in numbers of researchers are shown in Table 2. From these results, it is shown that from 1982 to 2000 the total number of researchers will increase about 180,000 to 200,000, which corresponds to about a 50% increase. The increase of researchers in industry is especially remarkable.

The estimated number of researchers necessary to meet the demand per year is shown in Table 3. The demand for researchers increases gradually up to the year 2000, and new demand is roughly equal to substitution demand.

The age distribution of researchers in universities is estimated, and the results are shown in Fig. 1 and in Table 4. It is clearly shown that, unless counter-measures are taken, the average age of university researchers becomes very old.

3. Measures for the Development of Researchers

In order to develop human resources for research, the following measures are necessary:

1) Strengthening and improving graduate schools;
2) Improving the fellowship system;
3) Strengthening international exchange of young researchers;
4) Encouraging the mobility of scientists and engineers; and
5) Improving the research environment in universities and research laboratories.

Table 1

Ratio of Withdrawal from Research and Age Distribution of Employment of Researcher

age			under24	25~29	30~34	35~39	40~44	45~49	50~54	55~59	above60
University and College	University	WD	9.2%	11.0	8.3	4.8	2.5	1.3	0.8	1.2	11.7
		ADE	5.7%	35.3	38.8	10.2	2.6	1.7	1.4	2.0	2.3
	Junior College	WD	11.4%	10.6	3.3	1.9	1.9	1.4	1.7	2.5	10.7
		ADE	11.6%	19.0	19.9	9.3	8.4	5.4	5.3	7.0	14.1
National or Public Research Laboratory		WD	0.0%	0.0	1.7	1.9	1.6	1.8	1.7	15.2	77.0
		ADE	62.2%	18.8	9.5	9.5	0.0	0.0	0.0	0.0	0.0
Industry		WD	0.1%	0.1	1.6	2.0	1.0	1.9	1.6	14.6	51.3
		ADE	87.0%	6.6	3.2	3.2	0.0	0.0	0.0	0.0	0.0

WD: Ratio of withdrawal from research
ADE: Age distribution of employment of researcher

Table 2
Forecast of Number of Researchers

Case A

(unit: 10,000)

Year	Ⓐ 1982	Ⓑ 2000	Ⓑ／Ⓐ	Ⓑ－Ⓐ
Total	39.1	57.1	1.46	18.0
Universities	12.4	14.1	1.15	1.8
National & Public Research Laboratories	3.9	4.0	1.02	0.08
Industries	22.8	38.9	1.71	16.1

Case B

(unit: 10,000)

Year	Ⓐ 1982	Ⓑ 2000	Ⓑ／Ⓐ	Ⓑ－Ⓐ
Total	39.1	59.6	1.52	20.4
Universities	12.4	15.7	1.26	3.2
National & Public Research Laboratories	3.9	5.0	1.26	1.0
Industries	22.8	38.9	1.71	16.1

Table 3
Forecast of Demand for Researcher per Year

Case A

(Unit: Person)

	1986-1990 Average	1996-2000 Average	1983-2000 Average
Total	23,400	26,000	24,200
Universities	8,400	7,200	7,900
National & Public Research Laboratories	1,500	1,500	1,500
Industries	13,500	17,300	14,900

Case B

(Unit: Person)

	1986-1990 Average	1996-2000 Average	1983-2000 Average
Total	25,100	28,200	26,100
Universities	9,600	8,800	9,100
National & Public Research Laboratories	2,000	2,100	2,100
Industries	13,500	17,300	14,900

Fig. 1 Age Distribution of University Researchers (Case A)

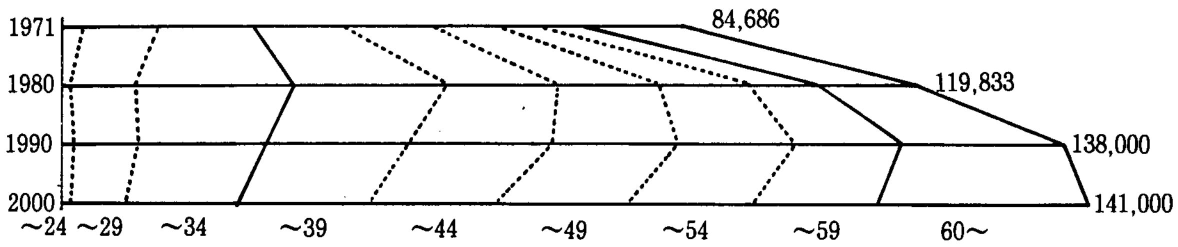

Table 4 Forecast of Number of Researchers under 34 and above 60 years

		1971	1980	1990	2000
under 34	Number of Researchers	27,195	32,238	28,400	25,000
	Percentage	32.1	26.9	21.0	18.0
above 60	Number of Researchers	12,955	14,335	21,700	27,900
	Percentage	15.3	12.0	16.0	20.0

JAPAN SOCIETY FOR THE PROMOTION OF SCIENCE FELLOWSHIPS FOR GRADUATE EDUCATION IN JAPAN

Fuminori Sakai *

Introduction

The Japan Society for the Promotion of Science (JSPS) is a quasi-governmental body under the jurisdiction of the Ministry of Education, Science and Culture (Monbusho). Originally set up in 1932 and reorganized in 1967, JSPS operates various programs to promote scientific activities in Japan, including research fellowships and international exchanges, with funding provided primarily by Monbusho. This paper discusses two JSPS fellowship programs – one for Japanese researchers and one for foreign researchers.

JSPS fellowships for Junior Researchers

This fellowship program was initiated with the general purpose of contributing to training and securing excellent young researchers, who, rich in originality, are able to assume the responsibility for the future development of Japan's scientific research. For this purpose, this program accepts excellent postdoctoral researchers (PD) or graduate students at the doctoral level (DC) as "special researchers" for a term of two years and provides them with research fellowships. Postdoctorals who are employed cannot apply for this program, and if a grantee finds employment, he has to withdraw from this program.

Through this fellowship program, JSPS offers to selected young researchers opportunities to exclusively engage in research activities at the initial stage of their academic careers, with research subjects and research environments of their own choice.

The fellowship award is 222,000 yen per month for PD and 128,000 yen for DC researchers respectively and all the PD and DC researchers are provided with research grants-in-aid from the Ministry of Education, Science and Culture (Monbusho) amounting up to 1,200,000 yen per year.

The term of the fellowship is two years, and the total number of grantees is calculated annually from the year's budget for the program and then allocated to each field of research in proportion to the number of applicants by field.

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The fellowship award for PD researchers is determined so as to be somewhat similar to the wages which research professionals in the same career receive at research institutes or university laboratories.

This program was started in 1985, and the number of applicants has remained at a constant level of about 1500 for the last five years. Of these applicants, 40 to 50 per cent have been accepted by the program.

A follow-up survey of the 1985 special researchers, which was conducted two years after the end of their term, made it clear that nearly 90% had obtained employment as researchers at universities or other research institutes. Some difference was noticed according to research fields, but the general tendency was almost the same.

A similar fellowship program is being conducted in the field of cancer research with a fellowship term of three years and the annual awards numbering ten.

Postdoctoral Fellowships for Foreign Researchers

In order to accomplish one of the purposes of JSPS "to promote international cooperation in science", the JSPS Postdoctoral Fellowship Program for Foreign Researchers was established in 1988. It aims at providing selected young foreign researchers from Australia, Belgium, Canada, Finland, France, West Germany, Italy, the Netherlands, New Zealand, Sweden, the United Kingdom and the United States of America with opportunities to pursue collaborative research with counterpart Japanese researchers at Japanese universities, thereby helping to further the studies of individual foreign researchers while advancing scientific research in each country. Candidates for the Fellowship must hold citizenship in the countries mentioned above, hold a doctorate, and be not more than 35 years of age at the commencement of the Fellowship. Fellowships are awarded for 12 months. The total number of Fellowships for FY 1989 is 130 from the 12 countries.

JSPS will provide Fellows with the following support:

1) Roundtrip ticket;
2) Monthly stipend of ¥270,000;
3) Settling-in allowance of ¥200,000;
4) Monthly housing not to exceed ¥100,000; and
5) Language-training allowance not to exceed ¥500,000;

Further, fellows shall be eligible to apply for Research-Grants up to ¥1,200,000.

There are two alternative selection procedures:

A) Through the recommendation of the nominating authority in the applicant's home country, or

B) Through direct selection by JSPS of applications from Japanese researchers wishing to host a Foreign Research Fellow.

In the United States, the nominating authorities are the National Science Foundation and the National Institutes of Health.

Traditionally, postgraduate education has not been as strongly emphasized in Japan as in the United States and most of Europe. Today, however, Japan would like to see more students enrolled in graduate education. The JSPS programs described in this paper are major steps in that direction.