Issue Paper

RAND Science and Technology

Is There a Shortage of Scientists and Engineers?

How Would We Know?

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This paper's objectives are:

- To clarify the concepts of "shortage" and "low production" in the context of scientists and engineers
- To suggest answers to the questions in the paper's title
- To point toward strategies for addressing science and engineering (S&E) workforce shortages.

WHAT WOULD A "SHORTAGE" OF SCIENTISTS AND ENGINEERS LOOK LIKE?

Over the last half-century, numerous alarms have sounded about looming shortages of scientists and engineers in the United States. What is meant by "shortage" has not always been clear. Further, the population under discussion, the scientists and engineers themselves, has not always shared the perspective of those sounding the alarm. Regardless, the implications of a shortage of skills critical to U.S. growth, competitiveness, and security are significant. So are the implications of the continuing low entry of female and minority students into many S&E fields. These implications justify closer examination of the nature and sources of the over- or underproduction of scientists and engineers. Improved understanding of the definition and nature of the problem can point toward relevant data and useful questions.

As a starting point, consider the different circumstances in which the production of any good or service, new S&E PhDs being one, might be called "low":

1. If production is lower than in the recent past (steel is a recent example)
2. If competitors' share of total production is growing (electronic component manufacturing, shoe manufacture, and oil production are increasingly foreign)
3. If production is lower than what the people doing the producing would like (automobiles)
4. If less is produced than the nation is deemed to need (well-trained K-12 teachers)
5. If production is not meeting market demand, as indicated by a rising price (nurses, Washington, DC, area housing).

Each of these concepts of "shortage" may be a cause for concern. The pain of steel workers and their communi-

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ties is real when production falls and plants close (concept #1). The nation's concern about reliance on Mideast oil is justified (concept #2). And so forth. However, one of these five concepts of "shortage" is fundamentally different from the others in a manner crucial for the question at hand. Only the fifth concept integrally embodies a corrective mechanism that solves the problem, i.e., that induces increased production of its own accord.

To see this, consider the S&E workforce. If production of scientists and engineers is insufficient to meet market demand—that is, if each new crop of American scientists and engineers is too small to fill the growing number of jobs offered by academic, industrial, and government employers—then salary offers will tend to increase and unemployment or underemployment of the S&E workforce will tend to diminish. As young people observe this tightening labor market and consider lifetime employment prospects along with the many other factors influencing their career choice, some of them will opt for S&E, rather than for clinical medicine, law, business, or another profession. As these people complete their education and join the workforce, total production of scientists and engineers will accelerate. The shortage will diminish.[1]

To the extent that production is "low" in any sense other than this fifth sense, production will tend to stay low. For example, the fact that competing countries are manufacturing more electronic components while America produces less (concept #2) may constitute a "shortage" of American-produced components. But there is nothing about this kind of shortage that will induce American companies to reverse the move offshore.

Indeed, in whichever other respect there is a "shortage," policy actions to relieve it will be effective to the extent that they operate to increase demand for the good or service (concept #5). Policy can also induce increased production by lowering the costs of production, regardless of the manner of shortage that exists.

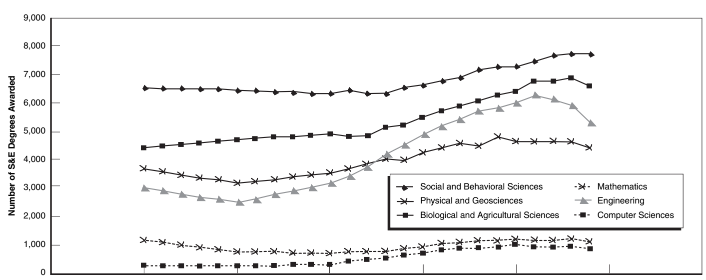
IS THERE A SHORTAGE OF SCIENTISTS AND ENGINEERS?

Diverse data from the National Science Foundation, the RAND RaDiUS database, the U.S. Census Bureau, the U.S. Bureau of Labor Statistics, the National Research Council, and scientific associations can characterize the production of S&E PhDs, indicate the respects in which such production may be low, and point to causes of observed patterns. Accordingly, we briefly focus such data on the five different concepts of "shortage," indicating the particular respects in which the production of S&E PhDs indeed appears to be low. This overview points to the fifth concept, unsatisfied demand, as the key both to understanding and to correcting whatever shortages are thought to exist according to the other concepts.

Unfortunately, the uneven detail, varying definitions, and inconsistent time periods in the available data make possible only the teasing out of "stylized facts"—hypotheses awaiting empirical testing.[2] That data more recent than 1999 or 2000 are generally not yet published is especially unfortunate, as the S&E workforce situation has arguably changed significantly since then. Hence, we conclude this analysis not with positions or solutions but more modestly with four possible strategies for increasing the production of S&E PhDs in whatever fields might be deemed low, by whatever criteria.

To begin, consider whether the United States is experiencing a shortage of S&E PhDs in either of the first two senses—decreased production or gains by competitors. Figure 1 shows that the number of PhDs awarded by American institutions in each major area of science and engineering has been increasing, beginning in the 1980s.[3] These gains were interrupted in the late 1990s, an interruption that has apparently continued in some fields, although confirming data are not yet published. Hence, at least until very recently, American PhD production has not been declining in the broad S&E fields, so there is little or no shortage in the first sense.

PhD AWARDS GENERALLY ROSE FOR 15 YEARS, THEN LEVELED OFF OR FELL



Sources: *Science and Engineering Doctorate Awards* (2000); Salsberg and Forte (2000); American Bar Association (2002).

Figure 1. S&E PhD Degrees Awarded by Broad Field, 1975–1999

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[1]Indeed, considerable statistical evidence supports the proposition that the number of students in different fields and, later, in different occupations, responds to changes in earnings across the different fields. See, for example, Berger (1988). Among the considerations that underlie career choice—no doubt including the excitement and satisfaction of a career in science—is the opportunity or lack of one to get a good job and make a good living.

[2]Measures of statistical significance are omitted. Putting the patterns and hypotheses identified in this paper to test will require them.

[3]Our focus on the PhD and corresponding international doctorates as measures of the S&E workforce oversimplifies the complex and changing nature of the S&E enterprise in some respects. In engineering, for example, the terminal degree for private sector employment is more frequently the MS or BS. More broadly, technically trained recipients of bachelor and associate degrees arguably form an increasingly important part of the S&E workforce. We emphasize the PhD because, in these aggregated data, it seems the best overall indicator of the size of the S&E workforce and because it is most often emphasized in discussions of the issues.

What about the second concept of shortage—competitors gaining ground? Figure 2 shows that S&E doctorate production increased in many other "competitor" countries during the 1980s, as in the United States, but the numerical increase in the United States has been larger.

FOREIGN S&E DOCTORATES HAVE ALSO INCREASED, BUT NOT BY AS MUCH

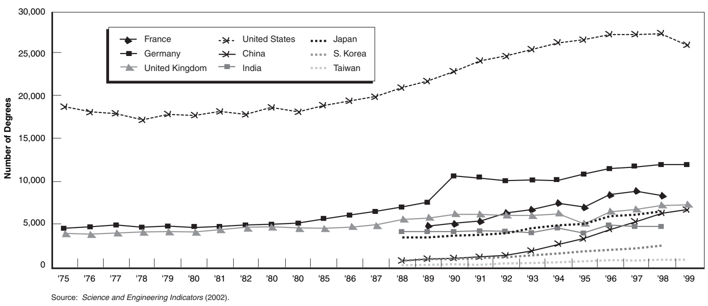

Figure 2. S&E Doctorates Awarded in Nine Countries, Varying Years 1975–1999

From two other perspectives, however, the situation vis-à-vis our "competitors" does not appear so sanguine. Figure 3 reports the ratio of S&E first-degree holders to the total population of 24-year-olds in selected industrial countries in 1975 and 1999. Think of the height of each column as representing the probability that a representative young person will complete an S&E degree. That probability for American youth grew from 0.04 in 1975 to 0.06 in 1999, a notable increase corresponding to the numerical growth evident in the first two figures.

A YOUNG ADULT'S PROBABLITY OF GETTING AN S&E DEGREE HAS RISEN MUCH LESS IN THE UNITED STATES THAN ABROAD

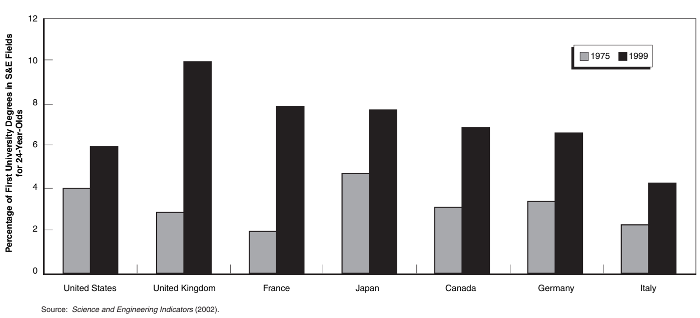

Figure 3. Ratio of Natural Science and Engineering First University Degrees Awarded to 24-Year-Old Population, by Country, 1975 and 1999

In 1975, this probability in America was exceeded only in Japan, among the countries shown. After 1975, however, the picture is radically different. Each of the other six countries has experienced a much larger increase, measured in either absolute or percentage terms.[4] Although the young-adult populations in these countries are growing less rapidly than ours (not shown), the proportion of their young people opting for university degrees in science and engineering is rising faster.

Figure 4 examines from another angle the question of whether our "competitors'" relative percentage of S&E workforce is increasing. Here, doctorate recipients from American institutions are divided into U.S. citizens and non-citizens.[5] The latter's share has grown rapidly indeed, from 23% of the total in 1980 to 42% in 1994. Even with the subsequent decline in non-citizen degree awards,[6] this longer-term rise, combined with the increasing propensity of students abroad to enter S&E fields (Figure 3), buttresses the case that the American S&E workforce is low in the sense that our "competitors'" relative percentage is increasing, as in concept two above.[7]

NON-CITIZENS HAVE RECEIVED AN INCREASING SHARE OF AMERICAN S&E AND HEALTH DOCTORATES

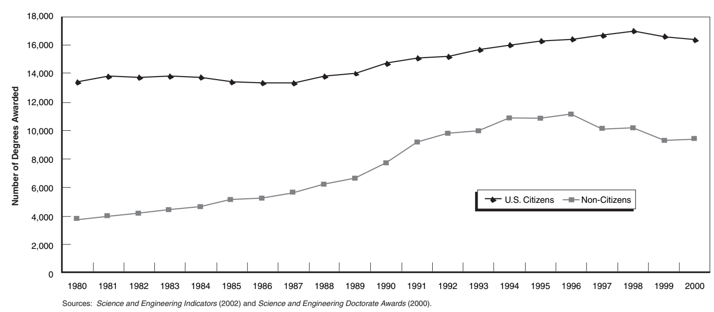

Figure 4. S&E and Health Doctorates Earned by U.S. Citizens and Non-Citizens, 1980–2000

Consideration of the third and fourth concepts of "shortage" is best deferred until we have taken up the fifth and last concept: Is growth of the S&E workforce insufficient to satisfy market demand? If such growth is insufficient, that is, if the numbers of American scientists and engineers are too few to fill the new jobs offered by academic, industrial, and government employers, then employers will be bidding to fill their empty positions. Job openings, lab facilities, salaries, advancement opportunities, and other components of career satisfaction will be on the rise, while unemployment and underemployment[8] will be falling.

[4]Other countries can be seen in the source table to have experienced even larger increases, notably Mexico and Spain.

[5]The underlying data for this figure include MDs. Permanent residents are counted with non-citizens.

[6]Since September 2001, the number of foreign students enrolled in graduate S&E programs in the United States has apparently decreased even more markedly.

[7]Of course, many foreign recipients of U.S. degrees choose to remain and work here.

[8]Prevalence of postdoctoral appointments, particularly successive appointments, might be considered an indicator of underemployment.

Alternatively, if the rewards of other careers—perhaps clinical medicine, law, or business—are higher and are growing relative to S&E, and if it is instead the costs of training for a job that are growing for S&E, then there is no shortage of scientists and engineers in this important fifth sense. Indeed, in this latter case, the "shortages" that others discern may well look more like discouraging surpluses to young people considering career choice.

Is there in fact an unsatisfied demand for scientists and engineers in the American job market? Available data are sketchy but they are consistent. We consider two indicators of S&E career opportunities: earnings and unemployment. Where data allow, we compare these opportunities and costs to those facing budding holders of professional degrees—MDs, DDSs, DVMs, JDs, and MBAs. These comparisons are instructive to the extent that bright, ambitious students inclined toward science and engineering consider a range of challenging alternatives in making their career decisions.

Figure 5 compares an estimate of annualized earnings for PhDs (all PhDs are included in this measure, not just S&E)[9] with earnings of professional degree holders (those listed just above).[10] Professional degree holders earn more at nearly every age and considerably more over an entire career, as measured by the summed difference between the lines. This is no surprise.

For the purpose of our analysis here, we would be better served had these earnings estimates been calculated separately for the S&E workforce and repeated for a decade or so earlier. This comparison would reveal whether the professional degree premium is falling, that is, whether the relative attractiveness of an S&E career is rising, indicating a shortage in that crucial fifth sense. Alas, this measure is not yet available separately for S&E or for earlier periods. Still, the data at hand give no indication of the kind of earnings premiums for scientists and engineers that would signal the existence of a shortage.

PROFESSIONAL DEGREE HOLDERS MAY EARN CONSIDERABLY MORE OVER THEIR LIFETIMES THAN PhDs

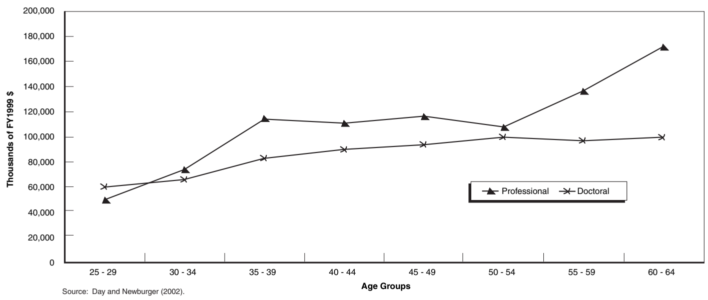

Figure 5. Annual Earnings Trajectories for Advanced Degree Holders by Age, 1997–1999 Period

Unemployment rates are another indicator of market conditions. Rates that are falling or lower than in alternative occupations also suggest shortages in the fifth sense—unsatisfied demand. Unemployment rates are available and plotted in Figure 6 for chemists, recent mathematics PhDs, and recent biomedical PhDs and MDs.[11] Although not fully comparable in population or time period, these three rates, when compared to the overall U.S. unemployment rate, suggest a general increase or leveling in the 1990s, while the general unemployment rate was falling substantially. Rising unemployment in one sector, while the overall economy is doing well, is a strong indicator of developing surpluses of workers, not shortages.

SOME S&E PhD UNEMPLOYMENT RATES HAVE RISEN, WHILE THE GENERAL U.S. RATE HAS FALLEN

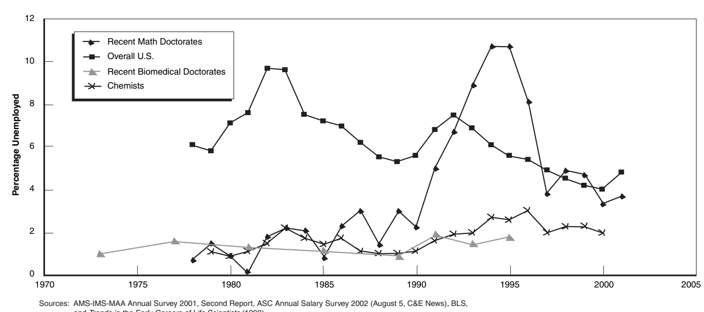

Figure 6. Unemployment Rates of the United States and Selected S&E Fields

Hence, neither earnings patterns nor unemployment patterns indicate an S&E shortage in the data we are able to find. Altogether, the data in Figures 5 and 6 do not portray the kind of vigorous employment and earnings prospects that would be expected to draw increasing numbers of bright and informed young people into S&E fields.

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[9]These highly aggregated data cannot reveal salary trends for just the S&E workforce, much less for particular disciplines and subdisciplines that may have experienced unusual salary growth or decline. For comparison purposes, about 60 percent of PhD degree holders were in S&E fields in the period covered by these data.

[10]Called by the Census Bureau "synthetic estimate of work life earnings," this measure calculates for the 1997–1999 period the annual earnings of persons in each indicated age range. A young person today might interpret the lines connecting these age points as the expected career profile of annual earnings on into her future. That interpretation requires several strong assumptions. An alternative measure of the career earnings profile would report annual earnings of the same group of people as they age over the years. As those data must necessarily refer entirely to the past, even to the deep past when the group of people was young, they also are a flawed proxy for looking at the future. However, lacking real data about the future, people and organizations use information about the past and present to make decisions, including career decisions.

[11]The American Mathematical Society and American Chemical Association publish more extensive data (including unemployment rates) on their members than are available for most other S&E communities.

We return now to the third concept of shortage: Is production lower than the people doing the "producing"—in this case the young people making career choices—would like? More young people today may arguably enjoy doing science or engineering than actually plan to prepare for such careers. Instead they may choose a professional degree, but only reluctantly. In a market economy, even one characterized by rigidities, regulations and unequal opportunity, qualified people tend toward career paths whose rewards and satisfactions are becoming more attractive and/or whose preparatory costs are becoming less onerous.

We have seen that broad fields of science and engineering do not appear particularly attractive from the earnings and unemployment perspective. What about the cost side? Figure 7 points to a sobering part of the answer. The average time from bachelor degree to PhD in the life sciences has increased by two full years since 1970.

PhD PROGRAMS HAVE LENGTHENED SUBSTANTIALLY

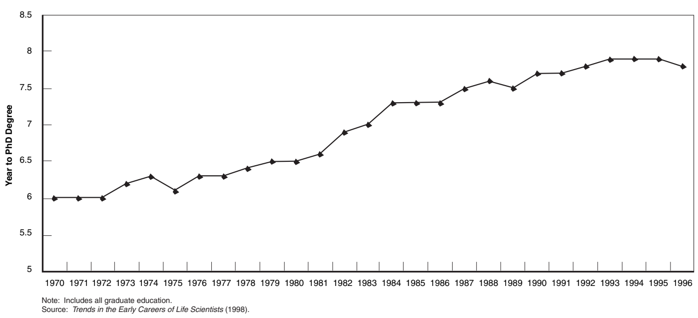

Figure 7. Average Registered Time to PhD in the Biomedical Life Sciences (Post-Baccalaureate Study)

Professional associations in several other scientific fields informally confirm similar increases. If, as is likely, the variance in time-to-degree has increased along with the mean, then prospective life scientists face not only more years out of the labor market but also more uncertainty about the number of years to attain their degree. Complaints about perceived subjectivity and arbitrariness of the postgraduate process—its length and the prospects of eventual completion—are also not infrequent.

All this might not matter so much if the brightest young people lacked alternative training and career paths. But consider the paths to the MD, DD, DVM, JD, and MBA. The number of years to degree has stayed absolutely constant in these programs for decades,[12] and the prospects for successful completion, once begun, remain high. Have the amount and complexity of material to be mastered expanded so much more in biology or mathematics than in medicine, law, or finance? This would seem hard to argue. Then why does it take longer to attain the credentials to begin one's career in most of the sciences but not in the professions?

Finally, what about the fourth concept of shortage, unmet national needs? Will particular subfields of science or engineering soon become critical, perhaps for national security, health care, feeding the world, or national competitiveness? Perhaps some fields are already critical but without the corresponding inducements that attract qualified young people. Where would these inducements come from?

POSSIBLE STRATEGIES FOR ADDRESSING S&E WORKFORCE SHORTAGES

We have seen that the production of American scientists and engineers is low neither in the sense that it has fallen over some years from previous heights nor in the sense that employers are driving S&E earnings up and unemployment rates down in a scramble to hire more scientists and engineers. However, in another sense of shortage—that of competitive foreign gains—American production does appear low.

Whether from unmet national needs, foreign competition, or any other source, a perceived shortage of U.S. S&E talent must be expressed in terms that motivate young people, or the shortage will persist. If such perceived shortages do emerge, the story loosely told by these data points toward four general strategies to relieve them. Two of these strategies involve government actions to increase the returns and rewards to be expected from a career in science. The other two strategies—somewhat less amenable to direct government policy—would reduce the costs of preparing for such a career. A fifth strategy points to gaps in the data relating to S&E workforce that need to be addressed to enable a more informed discussion of the issues outlined in this paper.

1. **Steadily and predictably increase federal research obligations for the S&E fields of concern.** This strategy, though not easy, is straightforward. There is nothing so directly under the control of the federal government as its budget, and probably little that has so direct an effect on the attractiveness of an S&E career. Federal grants, contracts, and other S&E expenditures are an important component of fellowship support, job opportunities, lab facilities, and salary growth. Figure 8 shows that federal obligations for total research, in constant dollars, have increased more than fivefold since 1970 in some fields but hardly at all in others. The substantial growth in federal support for the biological sciences seen in Figure 8 is likely a major reason for the corresponding growth in biologi-

[12] Flexible training alternatives that can extend time to degree have arisen in each of these fields, but these are optional, serving to increase the attractiveness.

cal science PhDs seen in Figure 1. If national needs now (also) point in other directions, substantial and predictable federal budget enhancements in those directions can be expected to call forth the same kind of response on the part of young people (or midcareer people) contemplating their careers.

However, growth in PhD production without corresponding growth in available jobs for PhDs may cause more harm than good. There is evidence that this has occurred in the past. Anecdotal evidence suggests recent widespread underemployment of some biology specialties, indicating possible "overshooting"—too many new PhDs to satisfy the demand. Goldman and Massy (2000), in particular, argue that funding increases naturally lead to greater increases in PhD production than PhD employment, without specific policy interventions. Romer (2000) calls for a system of portable national fellowships as a means of increasing funding for S&E while allowing market forces a role in matching supply and demand.

FEDERAL S&E RESEARCH BUDGETS HAVE INCREASED MUCH MORE FOR SOME FIELDS THAN OTHERS

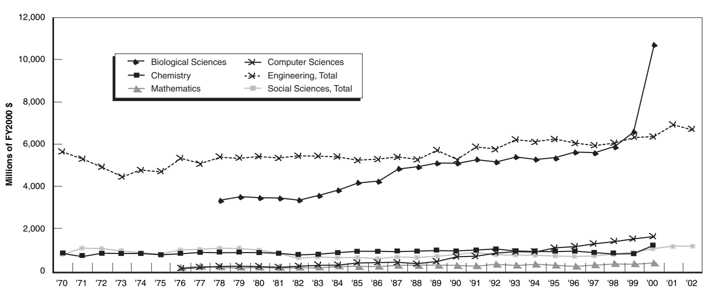

Figure 8. Federal Obligations for Total Research, by Field of Science and Engineering, FY 1970–2002

2. **Increase incentives for private investment and hiring in the priority fields of S&E.** This strategy, while less straightforward, falls also in the federal bailiwick. Subsidies, patent and intellectual property protection, and regulatory changes can be effective tools for encouraging private investment and jobs in industries that employ particular types of scientists and engineers. Often, job creation is a byproduct of policies directed toward some other goal, but job growth in particular professions could just as well be the explicit policy target. In either case, people's career decisions might be expected to respond. Although not primarily driven by federal policy, the boom in computer science and engineering degrees during the 1990s was fueled by rapidly increasing private sector demand.
3. **Adopt the "professional school model" for S&E PhD programs.** This strategy aims to reduce the early costs and uncertainties of training for an S&E career rather than increasing later career rewards. The adoption of this strategy by academe, even any resolve toward attempting it, seems remote. Still, more young people might select these S&E doctoral programs over professional schools if the years to S&E PhD completion were rolled back to, say, 1970 levels, if this term were predictable and uniform, and if the subjective and arbitrary aspects of the PhD path were curtailed.
4. **Introduce two new professional doctoral degree programs for science and engineering built on the MD model.** This fourth strategy would also reduce training costs and uncertainties, specifically for those whose career goals focus on professional practice rather than cutting-edge research. Graduates would have a firm grounding in a broad set of skills, understand how their skills fit in with other skill sets, and be able to keep up with the cutting edge. These new programs would feature a structured curriculum with well-defined completion criteria and a definite term, perhaps of four years. Their faculty would be practitioners with other sources of income, as in medical schools. The rapid growth of industrial parks, corporate-like technical centers, and corporate partnerships would facilitate this arrangement. As with existing professional degree programs, students would not normally rely on grants and fellowships but would instead look to substantially higher lifetime earnings to pay their own way. The attractiveness of this strategy depends partly on whether the current employment of S&E PhDs could be partly satisfied instead by holders of these new professional doctoral degrees.
5. **Expand the range and improve the timeliness of S&E workforce data.** To know whether shortages of scientists and engineers are in fact developing and whether strategies to encourage their production are succeeding, specific additional data should be collected. In addition, a subset of indicators could be developed to provide early warning some two years or more before full data become available.

Logic as well as repeated experience counsels caution in pursuing these strategies, particularly the first two. Young peoples' career decisions do not shift instantaneously when the relative attractiveness of their various choices begins to change. Having begun to shift, their choices do not then emerge in the employment market for as long as their educational training takes. Hence, government actions to increase opportunities and earnings in one field must be sustained for many years or else they do more damage than good. To see this, consider that such a policy must be sustained for substantially longer than the lag between the policy's initiation and the labor market entry of the last new group of graduate scientists and engineers. In this last group are the first high school students who jumped (and were encouraged to jump) in the newly favored direction. Hence, 8–10 years is the absolute minimum period of sustained government investment before those young people who responded can begin to reap the reward, much less begin to repay their investment. Policy that cannot be sustained for more than a decade will therefore be destabilizing and harmful to bright young peoples' careers and lives, to the extent that they and their advisors trusted the policy.

These important caveats notwithstanding, sustained strategic movement in any of these first four directions could reduce the costs and uncertainties of postgraduate S&E training and increase the job opportunities, earnings, and satisfaction of graduates, whether in priority fields of science and engineering or across the spectrum. In response, the young people who are bright enough to drive 21st-century American science and engineering (but also bright enough to work its clinics, courts, and businesses) would increasingly do so.

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