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Introduction

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In the mid-2000s, when the research in this book was nearing completion, policy makers in the United States were expressing greater concern about the job market for scientists and engineers than they had since the 1950s, following the Soviet Union's 1956 launch of Sputnik. National commissions and groups issued reports about the dangers that the weakening state of science and engineering posed to the country and called for new policies to increase the supply of scientific and engineering talent by improving education from grades K through 12 to undergraduate and graduate training, and by additional funding of research and development (see appendix). The most prominent report was the National Academy of Science's *Rising Above The Gathering Storm: Energizing and Employing America for a Brighter Economic Future.* The panel that undertook this study worried that the United States was losing leadership in science and engineering and that this threatened the nation's competitiveness in the global economy and future economic well-being and national security. Concurring with these assessments, in his 2006 State of the Union Address, President Bush announced the American Competitiveness Initiative. He stressed that "for the U.S. to maintain its global economic leadership, we must ensure a continuous supply of highly trained mathematicians, scientists, engineers, technicians, and scientific support staff."

The research in this book illuminates many of the issues underlying the studies and reports summarized in the appendix and that spurred the president's initiative. It provides new information about the economics of sci-

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ence and engineering work in three broad areas: the determinants of the supply of scientists and engineers, the career patterns that they follow upon graduation, and the creation and transmission of scientific and engineering knowledge as reflected in patents, papers, and the mobility of doctorate workers between academe and industry. To do this, we used a wide variety of data sets, as indicated in table I.1. These include the National Science Foundation's (NSF's) Surveys of Earned Doctorates (which all Ph.D. recipients are encouraged to fill out prior to obtaining their degree), Sigma Xi's special survey of postdoctoral graduates, a specially constructed inventor-firm matched data set, a university productivity data set, interviews with persons involved in the scanning tunneling innovation in scientific instrumentation, and so on. Each of the chapters gives a detailed report on the particulars of the data analyzed, the methodology used, and the findings. By way of introducing the reader to what they will learn in the chapters and of delineating the links among them, we summarize the findings organized around the three main areas in the book. Then we consider how the findings illuminate some of the concerns over the science and engineering job market expressed by the various commissions and studies.

Supply of Students and Postdoctoral Fellows to Science and Engineering

1. *The supply of U.S. science and engineering students responds to fellowship support.* Between 1999 and 2005 the National Science Foundation doubled the value of its Graduate Research Fellowships (GRF), which created a pseudo-experiment to assess student responsiveness to the economic incentive of graduate fellowships. When the NSF developed the program, most of the applicants were in the physical sciences and mathematics, but as the labor market opportunities increased in other sciences and engineering, a growing proportion of applicants and GRF awardees came from life sciences, social sciences, and engineering. Similarly, in the 1950s men gained most of the awards but by 2004 women won over half of the awards, largely because the increased number of women in bachelor's degree science and engineering led to more women seeking graduate study in these fields and consequently more applying for fellowship support. Because the NSF did not increase the number of awards over time, however, the ratio of awards per B.S. graduate fell. Because NSF changed the value of awards intermittently, the value of awards relative to earnings in the economy varied over time and fell markedly in the 1990s. To reverse this, the NSF decided to increase the value of fellowships from 1999 to 2005. This produced a commensurately large increase in the number of applicants. The estimated elasticity of the applicants to stipend value over the entire history of the GRF is on the order of 0.8 to 1.0. It is more difficult to link the supply of graduate students in total in the science and engineering fields to NSF stipend policies (since only 1,000 or so are supported by these awards), so that

Table I.1 Data sets used in this volume

Name of survey	Characteristics of survey	Chapters that use survey
Survey of Earned Doctorates, annual	Annual survey of all new U.S. research doctorate graduates with questions about their educational histories, funding sources, and post-doctoral plans.	Chapter 2, degrees by national origin, field, university Chapter 4, degrees by national origin Chapter 8, firm of first job when employed in industry
Survey of Doctorate Recipients, biannual, with longitudinal component 1993–2001	National representative sample of science and engineering doctorate holders from U.S. institutions, with data on education and training, work experience, career development.	Chapter 7, job satisfaction and mismatch Chapter 4, cohort earnings and quantity data Chapter 5, longitudinal career data; publications Chapter 6, patent and articles data
Cumulative Index of NSF Fellowship Applicants and Awardees and updates, 1952–2004	Census on applicants to the Graduate Research Fellowship (GRF) with information on field, demographic characteristics, GRE scores, GPA, undergraduate college, ratings of letters of . recommendation, and review panels.	Chapter 1, effect of academic skills and personal attributes on receipt of fellowship; and of the value and number of awards on the number of applicants and measured academic quality of fellowship recipients
Sigma Xi Postdoctoral survey, 2003–2005	Multi-campus survey conducted at 47 institutions. Largest detailed survey of postdocs ever, with over 8,500 respondents.	Chapter 3, impact of compensation and organization of postdoctorate on productivity and success of the postdoctoral experience
Inventor-Firm Matched Data set:		Chapter 9, country residence of persons on patents by U.S. firms
Patent Bibliographic Data, 1969–2002	U.S. Patent and Trademark Office information on all patents.	
Proquest Digital Abstracts, 1945–2003	Data on author, title, field.	
Compact D/SEC Database, 1989–1997	Data on firms from 10-K reports.	
Standard & Poor's Guide to Stocks, Directory of Obsolete Securities	History of changes in names of firms, acquisitions, and mergers.	
Thomas Register, Megent, Corptech data	Founding year of firm.	

(*continued*)

Table I.1 (continued)

Name of survey	Characteristics of survey	Chapters that use survey
NBER Patent Citations Data, 1975–1999	All citations made in patents.	
Patent data for biotech firms and departments, Boston area		Chapter 6, network connections among inventors in both settings and within the firms and universities separately
Bioscan report on firms in existence, 1988–1998, identifying 49 firms	Data on patents by 1,115 inventors in Boston area biotech firms and 1,003 inventors in 4 Boston area universities.	
U.S. Patent and Trademark Office data		
Interviews with 150+ Probe Microscopists	Information on the development of the scanning tunneling and atomic force microscopes.	Chapter 10, history of industry and university innovation in scientific instrumentation
University-Output Data set for 102 major universities:		Chapter 11, research and teaching productivity of public and private universities
Institute for Scientific Information	Papers and citations	
NSF CASPAR database	Academic R&D, graduate students	
Integrated postsecondary education data system completions survey	University finances, degrees	
National Center for Education Statistics (NCES) faculty survey	Faculty by university	
NSF Survey of Graduate Students and Postdoctorates in Science and Engineering (GSS)	Graduate departments at U.S. higher education institutions.	Chapter 1

changes in their value can affect outcomes primarily by impacting other stipend providers as well. This appears to have occurred and there is a positive link between the NSF increase in the value of awards and first year enrollments by U.S. students in graduate studies, though with a lower estimated elasticity than that for applications for the awards (see Freeman, Chang, and Chiang, chapter 1, this volume).

2. *The supply of foreign students to U.S. science and engineering programs responds to U.S. economic and educational opportunities.* As noted earlier, an increasing proportion of U.S. Ph.D. graduates in science and engineering are foreign-born. In some fields, such as engineering and economics, on the order of two-thirds of Ph.D.s are granted to the foreign-born. The huge supply of the foreign-born to U.S. graduate programs can be attributed to three factors. The first is the extension of mass higher education throughout the world. Countries that had large increases in the number of bachelor's graduates in science and engineering have also had large increases in the number of their nationals earning Ph.D.s in the United States. The second is the greater opportunity to pursue quality graduate training in the United States than in other countries. The foreign-born Ph.D. explosion in the United States has been fueled by students from China and India, where domestic opportunities for graduate education have lagged behind the growth of undergraduate degrees. The third is the potential for working as a Ph.D. scientist or engineer in the United States with a U.S. graduate degree. As long as working in the United States is more attractive than working in one's home country, and a U.S. degree will open doors for jobs in the United States, students will flock to U.S. graduate studies. In fact, graduates from low income countries, where science and engineering pay and employment prospects are lower than in the United States, are far more likely to stay in the United States and work than students from more advanced countries, where pay and prospects are closer to those in the United States. Given that the supply of students from low income countries appears to be quite elastic with respect to opportunities to study in the United States, increased federal research funding has also contributed to the increase in the number of foreign graduate student and postdocs, since researchers fund students and postdocs to work in their labs (see Bound, Turner, and Walsh, chapter 2, this volume).

3. *The U.S. university system expanded to meet changing demand for doctorate training largely through additional places at lower quality programs.* In contrast to the trend upward in foreign-born doctorate degrees, the number of Ph.D.s granted to the U.S.-born has varied over time. It has varied with the changing number of bachelor's degrees in science and engineering and with changes in the propensity of undergraduates to go on to graduate study in response to economic opportunities. It has risen greatly for women while falling for men. In 1964, the ratio of Ph.D.s to Bachelor's degrees seven years earlier peaked at 5.6 percent, as many bachelor's grad-

uates responded to the booming job market for Ph.D. scientists and engineers and to the fellowship opportunities that followed Sputnik. The ratio then fell to 2.5 percent by 1974. While there is competition between international students and U.S.-born students within programs, the growing number of foreign-born from lower income countries has come largely in less highly ranked programs that would seem to have expanded to meet the demands of those students for U.S. graduate training. The highly elastic supply of places at lower quality programs—which increased threefold in the primary science fields in the 1960s and 1970s—argues against any important crowd-out of U.S. students in graduate programs in total (see Bound, Turner, and Walsh, chapter 2, this volume; also Freeman, Jin, and Shen 2004).

4. *Structured plans and professional opportunities at the places of work of postdoctoral students have a larger impact on their productivity and satisfaction than higher pecuniary rewards.* Postdoctoral work has become an increasingly important part of scientific careers, in part to give new Ph.D.s an apprenticeship research experience before becoming independent investigators. But the growing number of postdocs in the 1990s to mid-2000s resulted as much or more from a weak job market for new Ph.D.s as from the need for greater skill acquisition. Sluggish growth of academic positions limited full-time jobs in academe while research funding increased the demand for postdocs in labs. The growing supply of foreign-born graduates eager to get into the U.S. job market, moreover, produced a large supply of Ph.D.s for the available postdoc positions. Since many postdocs were sufficiently unhappy with their experiences, they formed the National Postdoctoral Association (http://www.nationalpostdoc.org) to lobby for better treatment in their labs. Using four measures of the success of a postdoctoral experience—the postdoc's satisfaction, their relation with their supervisor, the presence/absence of problems at the laboratory, and research productivity reflected in papers and grants—Davis (chapter 3, this volume) finds that structured oversight and creation of professional opportunities are the main factors associated with positive outcomes. Postdocs who plan their fellowship experience with their advisors, for example, have a higher submission rate of papers to journals as well as higher satisfaction. Agreements that clarify obligations for both sides are important in organizing the postdoctoral experience in a mutually advantageous way and limiting the danger that one side will opportunistically take advantage of the other.

Careers in Changing Markets

5. *Increases in the supply of foreign-born students to a field increases new doctorates and lowers the earnings of graduates, in part because the increased supply leads to more low-paying postdoctoral appointments.* The influx of

immigrant scientists and engineers has helped the United States meet changing demands for these specialists, but at the cost of reducing the earnings and employment opportunities for U.S.-born as well as other graduates in those disciplines. Between 1968 and 2000, over 200,000 foreign-born persons obtained doctorates in the United States, largely in the sciences and engineering. Many chose to stay and work in the United States. They constitute about 90 percent of all foreign-born doctorates in the country.
Using the fact that the number of immigrant doctorate students and immigrant scientists and engineers varies greatly among fields and among cohorts, Borjas (chapter 4, this volume) finds that increased numbers of foreign-born Ph.D. graduates in a cohort and field reduces earnings in the cohort and field and increases the probability of working as a postdoctoral fellow. The elasticity of annual earnings to the increase in supply is on the order of 0.3 to 0.4. About half of the impact of increased supply on earnings occurs through the increased likelihood that new graduates will end up doing postdoctorate work, whose annual earnings are markedly lower than those of otherwise comparable scientists and engineers with regular jobs. In the 1990s, native-born postdocs earned about 55 percent as much as those with regular employment.

6. *In academe, women in the physical sciences, engineering, and life sciences have similar chances of receiving tenure track jobs and promotion to tenure as men, whereas women in the social sciences and humanities have lower chances.* A rising female share of doctorates in science and engineering rises should reduce the gender gap in the number of faculty, as long as women get into tenure-track jobs and win promotions at the same rate as men. Analyzing career patterns in academe in the Survey of Doctorate Recipients files, Ginther and Kahn (chapter 5, this volume) find that in the physical sciences, engineering, and life sciences women have about the same probability of getting tenure-track jobs and being promoted as do men. By contrast, they find that women have lower promotion probabilities than men in the social sciences and humanities. Still, even in the physical sciences, engineering, and life sciences, family factors affect men and women differently. Marriage is associated with better career outcomes for men but not for women, whereas having young children is associated with poorer outcomes for women but not for men. And there remain significant differences in salaries by gender once scientists obtain tenure-track jobs, especially at the full professor rank. The problems of balancing work and family and attaining equality in pay notwithstanding, the female proportion of tenured-track faculty in the physical sciences, engineering, and life sciences has risen commensurate with the rising female proportion of doctorates in those fields.

7. *In industry, the organizational structure of research affects the research productivity of women in ways that reduce gender disparities in producing*

measurable outcomes, such as patents. The percentage of science and engineering doctorates working in industry has been growing, which places more new Ph.D.s, both female and male, in an environment in which scientific activity is organized differently than in academe. In industry, patents are more important than papers in scientific journals, and work is more likely to involve collaborative teams than in academe. The Survey of Doctorate Recipients (http://www.nsf.gov/statistics/srvydoctoratework/) indicates that between 1990 and 1995 about 40 percent of doctorate scientists in industry patented, compared to 15 percent of doctorate scientists in university. By contrast, while 67 percent of the scientists in industry published articles, 95 percent of scientists in academe did. In industry women are about as likely to patent, publish, or publish and patent as men, whereas in academe they are less likely to do so. Looking at the way academic and industrial scientists in biotechnology collaborate in patenting, Whittington (chapter 6, this volume) finds that academic patenting is linked around tenured scientists while industrial patenting is linked to wider networks of researchers. The organization of research work in industry as collaborative networks as opposed to the organization of research in academe as competing labs may fit better with the work patterns of women and help explain the differences in patenting and publishing between female and male scientists in industry relative to academe.

8. *Working in jobs unrelated or weakly related to their fields of study or doing work different from what they expected as graduate students reduces job satisfaction and earnings and raises the turnover of doctorate scientists.* Ph.D.s in science and engineering spend six to seven years studying as graduate students and many spend another three or more years employed as postdoctoral fellows before obtaining a regular job. Most want to work in the area in which they were trained, doing what they trained to do. But Bender and Heywood (chapter 7, this volume) find that in the 1990s on the order of 15 to 30 percent of doctorate scientists and engineers report a mismatch between their careers and their training: 15 percent report that they would not choose a similar field if they could start over, 20 percent report their job was not what they expected, and 30 percent reported that their job was only somewhat related (23 percent) or not related (7 percent) to their education. These mismatches are associated with large differences in earnings and job satisfaction and with greater chances of job turnover across workers and for the same worker over time.

9. *New Ph.D.s in science and engineering who choose to work in industry are less likely to stay in the state or local area in which they are trained than bachelor's or master's graduates.* Geographic entities that support graduate education in science and engineering often do so in the hope that relatively many graduates will stay in the local area and transfer the knowledge that they obtain to industry, which they hope will spur local industrial growth. Examining the placement of newly-minted science and engineering Ph.D.s who obtained first jobs in industry in 1997 to 1999, Sumell, Stephan, and

Adams (chapter 8, this volume) find that a bit over one-third stay in the same state as their doctoral institution. This rate falls far below the 60 percent or so stay rate for bachelor's or master's degree graduates in science and engineering or for graduates in law (one of the few nonscience fields for which such data is readily available). Individuals trained in top-rated departments are more likely to leave the area in which they obtained their degree than graduates in lower-rated departments. But there is huge cross-state variation in state retention and attraction of new Ph.D.s. California and New Jersey, in particular, are more likely to retain their Ph.D.s in science and engineering and to attract others than most other states. A major factor in the geographic location of Ph.D.s is the employment opportunity for graduates in a particular field in a given locality, so that industrial demand (rather than location of training) is the critical determinant of location, especially for graduates from top programs.

Creation and Use of Knowledge

10. Industry and university innovations in instrumentation create communities of producers and users that connect corporate and academic worlds in ways beyond simple commercial transactions. Scientific instruments are the physical capital in the production of knowledge. The development of a new instrument for analysis—the telescope, microscope, computers, FMRI brain scan machines—can revolutionize the way a science operates. Tracing the development of the scanning tunneling microscope (STM) developed at IBM in the 1980s into a widely used instrument in the 1990s, Mody (chapter 9, this volume) shows how corporate and university innovators formed a research and development community that made the STM and the follow-up atomic force microscope such great successes. Given differing resources and goals, the firms and universities operated differently to design STMs for different audiences. The need for tacit knowledge in producing the microscopes meant that in universities and firms graduate students and postdoctoral fellows were important in spreading STM use in scientific laboratories. The links between the industrial and academic communities led to the atomic force microscope. The implication is that having both industry and universities working in the area led to hybrid forms and innovations that might never have happened in a highly managed single institution environment.

11. Innovative U.S. firms employ researchers with foreign experience living and working overseas to tap the spread of technological knowledge around the world. As scientific and engineering activity spreads around the globe, U.S. companies who seek to stay in the forefront of technology must find ways to use overseas talent and ideas. By identifying the addresses of inventors on U.S. patents, Kim, Lee, and Marschke (chapter 10, this volume) find that U.S. pharmaceutical and semiconductor firms have relied increasingly on inventors residing overseas and appear to use them to tap into patented knowledge from those countries. From 1989 to 1997 the percentage of inventors who were foreign residents on U.S. patents increased from 14 to 30 percent in pharmaceutical firms and from 9 to 15 percent in semiconductor firms. By contrast, the percent of inventors living in the United States who had foreign patenting experience is less than 2 percent and fell over the period. The implication is that U.S. pharmaceutical and semiconductor firms employ or collaborate with researchers overseas to tap foreign talent as opposed to hiring immigrant researchers to work for them in the United States. In addition, U.S. firms tap knowledge from overseas by making use of inventions from other countries in their own inventions. In pharmaceuticals, 55 percent of patents cite at least one patent for an innovation originating outside the United States, while in semiconductors, 48 percent do so. When one inventor is or has residence in the past in a foreign country, the U.S. patent is more likely to cite patents from that country, suggesting that employing or collaborating with researchers who have research experience abroad facilitates access to overseas knowledge.

12. The level and increase of research and teaching productivity of universities differed greatly between private and public universities and among universities in each sector in the 1980s and 1990s. Universities are multiproduct institutions that produce research output (reflected in papers and citations) and teaching (reflected in undergraduate and graduate degrees). In the 1980s and 1990s when the growth of full-time faculty was less than half the rate of growth of science and engineering workers in industry, research activity grew more rapidly in leading universities than did teaching activity. Research productivity was higher in private universities than in public universities, with the gap increasing over the period. Teaching productivity was similar between private and public universities, though it increased a bit more rapidly over time in the public universities. Universities with more rapid growth of research or teaching productivity expanded less than those with less rapid growth of productivity, suggesting a possible allocative inefficiency in the higher education market. Sector aside, the analysis highlighted wide variation among universities in papers or citations per faculty and in bachelor's and graduate degrees per faculty, that implies that the United States has a highly variegated higher educational system even among top institutions (Adams and Clemmons, chapter 11, this volume).

Illuminating the Mid-2000s Concern

> Chicken Little was walking in the woods when—kerplunk—an acorn fell on her head. "Oh my goodness!" said Chicken Little. "The sky is falling! I must go and tell the king."
> –Children's fable (available from http://www.geocities.com/mjloundy)

Many of the findings summarized previously depict a science and engineering job market in the 2000s that changed greatly in the 1990s and 2000s (and in some cases earlier) compared to the market in the 1960s and 1970s. The chapters on supply show that a largely academic market dominated by native-born men changed into a market dependent greatly on international students and women, and where many doctorates came to work as postdocs in labs before obtaining regular jobs. The chapters on careers highlight science and engineering doctorates working in industry, the increased success of doctorate women in academe and industry, and the impact of the growing supply of foreign-born doctorates on the job market. They identify differences in the nature of work in industry and academe and the way this affects performance. The chapters on outcomes stress the interaction between universities and industry and the determinants of patents in industry, including the contribution of researchers overseas to U.S. patents. Overall, the volume shows the importance of both largely pecuniary/economic factors and of nonpecuniary factors and the organization of work, and the connections between industry and academe on careers and productivity in supply and demand decisions and market outcomes.

In contrast to the late 1950s, the upsurge of concern about the science and engineering job market in the mid-2000s was not sparked by a Sputnik-style signature event. The country did not face a shortage of scientists or engineers. If rapidly rising pay is the primary signal of a market shortage, the United States lacked CEOs and financiers, professional athletes, and entertainers, not scientists and engineers. As chapter 2 indicates, the earnings of doctorate scientists and engineers increased modestly—less rapidly than the earnings of college graduates in general by most accounts. The postdoctoral experiences through which many young Ph.D.s went were of mixed quality (chapter 3). A substantial number of Ph.D.s found their skills mismatched with their training, producing job dissatisfaction (chapter 7). Employment in science and engineering grew at an annual rate of 3.2 percent from the 1990s to 2004, far above the rate of growth of the work force (Freeman 2006b, exhibit 3), with foreign-born graduates of U.S. institutions contributing greatly to this increase (chapter 4).

A cynic might view the burst of concern about the need for more scientists and engineers in the appendix to be a replay of the late-1980s bogus claims that the United States had a shortage of scientists and engineers (Weinstein 1998). At that time the leadership of NSF proclaimed that the country faced an impending shortage of some 675,000 scientists and engineers. It based these claims on extrapolations that were not based on any remotely plausible assessment of the labor market. When the scientific community learned what had happened, there were angry articles and editorials in *Science* and *Nature.* The next director of the NSF apologized for the claims.[1] The top officials seemingly proclaimed a shortage to induce

1. "[The NSF scarcity study] went on to project the Ph.D. replacement needs would double between the years 1988 and 2006. Based on a number of assumptions, these data were pretty widely interpreted as predictions of a shortage, while there was really no basis to predict a shortage." (NSF Director Neal Lane, Congressional Testimony, July 13, 1995).

more young Americans into science and engineering to lower the cost of scientists and engineers to large firms.

There is undoubtedly some self-interest in the expressed concerns about the state of the science and engineering job market in the mid-2000s. The high tech firms who benefit from an ample supply of scientists and engineers were in the lead proclaiming a problem. The senior scientists who employ graduate students and postdocs in their laboratories were members of the various commissions. And the major research universities that would benefit from increased funding for R&D and graduate science education were also in the forefront of discussion. But the reports listed in the appendix are not based on misleading projections of the supply-demand balance for scientists and engineers or on claims of an impending shortage. Most of the reports recognize that scientific careers are less attractive to young Americans than they were in earlier decades. Still, they see problems that can be solved only with an infusion of more talent into science and engineering. Their analyses are based, as best we can tell, on a subtler picture of the role of science and engineering in the economy and in national security than the clear and compelling post-Sputnik shortages or the late 1980s erroneous forecasts—a picture that this volume illuminates.

One reason the blue-ribbon commissions and panels worried about the market for scientists and engineers in the mid-2000s is that various metrics show the United States losing its dominance in science and engineering. The U.S. shares of world R&D, papers and citations in scientific journals, science and engineering graduates and workers, are all falling (Freeman 2006a). This is a near-inevitable trend. With 5 percent of the world's population, the United States cannot maintain the 35 to 45 percent of science and engineering activity that it had at the end of the twentieth century, at least as long as other countries also invest in the modern knowledge economy, as they have done. The European Union has rebuilt and expanded its university system. In 2003 it graduated 56 percent more Ph.D.s in science and engineering than the United States and is on track to graduate twice as many Ph.D.s in the fields as the United States in 2010. The major Asian countries—China, India, Japan, Korea, Taiwan—also expanded their university system to graduate more S&E Ph.D.s in the early 2000s than the United States. By 2010 China will by itself graduate more Ph.D.s in science and engineering than the United States. Like the rest of economic and social life, science and engineering have become increasingly global. But as indicated in chapter 10's evidence on the contribution of foreign residents to the patents of U.S. firms, the knowledge created by foreign resident scientists and engineers can be used by American firms and inventors to help make technological advances. And the increased number of science and engineering bachelor's graduates overseas is also likely to mean a continued sizable flow of international students into the United States for graduate study. Whether Ph.D.s trained overseas will be as willing to come to the

United States for work as U.S.-trained Ph.D.s are willing to move from the state in which they earned their degree to other parts of the United States (chapter 8) is, however, a matter which our data do not address.

Some of the commissions and study groups fear that as other countries become more competitive in knowledge production and its application to the economy, the United States will lose comparative advantage in some high-tech sectors and thus gain less from exporting high-tech products. But greater competition should not translate into a fall in the average American's living standard. There are advantages to increased science and engineering activity around the world that will in the long run benefit virtually everyone. A scientific advance in China, Germany, Brazil, wherever, adds to the stock of knowledge that allows firms to create new products or to reduce the price of existing products. It will benefit consumers regardless of where the ideas are generated or the product is made. Increased knowledge offers the best opportunity for solving the great problems of climate change, global warming, energy efficiency, and disease that affect all people around the world. And the United States has some distinct advantages in turning knowledge into innovation—the close links between universities and business (described in chapter 9 for the development of probe microscopy), and in the flow of Ph.D.s into industrial jobs (examined in chapter 8). The collaborative organization of industry research and development may be more suitable for the rising supply of women Ph.D. scientists and engineers than the academic tournament style model of research.

The experience of the late 1990s/early 2000s shows, moreover, that simply increasing R&D spending does not improve the job market for scientists and engineers. Between 1998 and 2003 the U.S. government doubled spending on the National Institute of Health (NIH), but this did not create a boom in the job market for bioscientists. Most of the research awards went to senior scientists, who hired graduate students and newly minted Ph.D.s from the United States and overseas to work as postdocs in their labs. The chances that a young scientist would gain a grant on their own fell to negligible proportions. And with universities hiring few new tenured faculty, the chances for postdocs to move into independent research positions dropped as well. When NIH spending leveled off in the mid-1990s, it was a hard landing for senior scientists, who had greater difficulty than in the past funding their research projects, for postdoctorate fellows who worked in the labs, and for universities who had built up research facilities. The analysis in chapter 3 on the organization of the postdoctoral experience, in chapter 6 on network collaborations in industry and academic research, and in chapter 7 on mismatch bring to the fore the importance of the organization of work in creating a market that makes best use of talent.

Going beyond economic issues, some of the commission reports were especially concerned about the number of U.S. citizens in the nation's science and engineering workforce, particularly in areas where the government hires only citizens, such as the National Security Agency. The huge change in the demographic composition of the U.S. graduate student and doctorate graduate population in science and engineering analyzed in chapters 2 and 4 underlie these concerns. Foreign-born students accounted for slightly over half of U.S. Ph.D. graduates in science and engineering in 2003, which is more than double the proportion in 1966. If, for some reason, the United States became a less attractive place to work for foreign-born scientists and engineers, the United States could indeed face a supply-side problem. The analysis in chapter 1 shows that if the United States wants to increase the supply of citizens in science and engineering, it can do so by offering higher valued or more fellowships for graduate study.

All told, the concerns expressed by the blue-chip commissions and study groups go far beyond special pleading by the scientific-education establishment. The concerns are based on interpretations of how science and the economy interconnect, of how globalization of science affects economic performance, and how the job market for scientists and engineers operates, all of which this book illuminates in various ways. The more knowledge we have on these issues the better will we be able to assess the concerns and proposed policies to deal with them. At the same time, as with any research, the volume raises new questions about the economics of the science and engineering workforce and the ways to organize their activities to stimulate innovation and economic growth, which the chapter authors lay out. From the data sets that we analyzed and others there is more to learn about this important job market and the work of scientists and engineers in increasing the stock of useful knowledge and innovation and economic growth.

Appendix

Concern about the Science and Engineering Workforce, circa mid-2000s

We must "enhance the science-technology enterprise so the U.S. can compete, prosper, and be secure." National Academy of Sciences (NAS) (2007)

The Department of Defense and the defense industry are "having difficulty attracting and retaining the best and brightest students to the science and engineering disciplines relevant to maintaining current and future strategic strike capabilities." U.S. Department of Defense (2006)

"To maintain our leadership amidst intensifying global economic competition, we must make the best use of talented and innovative individuals, including scientists, engineers, linguists, and cultural experts. . . . The nation must cultivate young talent and orient national economic, political, and educational systems to offer the greatest opportunities to the most gifted American and international students." American Association of Universities (2006)

"If trends in U.S. research and education continue, our nation will squander its economic leadership, and the result will be a lower standard of living for the American people." National Summit on Competitiveness (2005)

"Together, we must ensure that U.S. students and workers have the grounding in math and science that they need to succeed and that mathematicians, scientists and engineers do not become an endangered species in the United States." Business Roundtable (2005)

"It is essential that we act now; otherwise our global leadership will dwindle, and the talent pool required to support our high-tech economy will evaporate. . . . [n]ot only do our economy and quality of life depend critically on a vibrant R&D enterprise, but so too do our national and homeland security. . . . [a] robust educational system to support and train the best U.S. scientists and engineers and to attract outstanding students from other nations is essential for producing a world-class workforce and enabling the R&D enterprise it underpins." Task Force on the future of American Innovation (2005)

There is "a shortage of U.S. citizen scientists to work in sensitive national security programs." Lewis (2005)

"The message is clear. Today's relentless search for global talent will reduce our national capacity to innovate unless we develop a science and engineering workforce that is second to none." Building Engineering and Science Talent 2004

"The United States is facing a crisis in science and engineering talent and expertise . . . For the United States to remain competitive in a vibrant global innovative and research environment, it must . . . attract, educate, recruit, and retain the best S&E workers. Assuring that the nation has the number and quality of scientists and engineers is a national imperative upon which the nation's security and prosperity rests entirely." Jackson (2003).

"The Federal Government and its agencies must step forward to ensure the adequacy of the U.S. science and engineering workforce. All stakeholders must mobilize and initiate efforts that increase the number of U.S. citizens pursuing science and engineering studies and careers." National Science Board (2003)

"The inadequacies of our systems of research and education pose a greater threat to U.S. national security over the next quarter century than any potential conventional war that we might imagine." Hart-Rudman Commission on National Security (2001)

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