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THE REALITY OF RELIANCE:IMMIGRATION AND TECHNOLOGY IN THE AGE OF GLOBAL COMPETITION

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In recent years, we have read and heard a great deal about America's declining competitive position. Power and leadership in the 21st century will belong to that nation which can create and maintain technological supremacy. It is the aim of this BRIEFING to examine whether the U.S. is up to this challenge. In looking for an answer, we focus on the role that foreign-born[1] scientists and engineers have played, and will continue to play, in American life. Until now, this subject has received virtually no mention in the immigration literature, but has remained the exclusive preserve of educators, scientists, and commentators. Our goal is to bridge the gap between these groups and the immigration bar.

U.S. reliance on foreign-born scientists and engineers is not limited to this or any other decade. The U.S. has been the beneficiary of the migration of an unprecedented flow of scientific giants. The influence of immigrants in science has become so pervasive that, over time, U.S. industry has become dependent on immigrants to remain technologically competitive. Unfortunately, the early 1990s were witness to global recession, severe corporate downsizing and university research faculty cuts, resulting in a number of highly skilled, highly educated scientists and engineers finding themselves unemployed for the first time in their lives.

These unemployed professionals and their representative professional organizations find themselves at odds with U.S. universities, and the research interests they serve, who realize that if they want to attract the best talent at the doctoral level, foreign nationals in science and engineering have become an absolute necessity, not merely a preference. Studies show that U.S. corporate research programs are also dependent upon foreign-born scientists and, significantly, that such dependence is growing. Fewer Americans are entering research fields as careers.

Studies have found that without the participation of foreign-born engineers and engineering students, U.S. engineering schools and industry would have to eliminate or sharply reduce teaching and research programs. These same studies also concluded that foreign-born engineers are essential in industrial research and development, particularly in those areas critical to the U.S.' international competitiveness.

There are unemployed engineers and scientists in the U.S. However, proponents of business immigration put forward the following countervailing equities: (1) future shortages of qualified U.S. workers due to lack of engineering and scientific degree production; (2) spot shortages in academia's complex technical sub fields; and (3) the inability to instantly fill these spot shortages with U.S. specialists due to training delays.

The diversity of unemployment rates within engineering and scientific sub fields and their independence from overall unemployment rates is not a concept appreciated by some U.S. legislators. A bill was introduced in the House of Representatives on May 25, 1993 that would tie the immigration rate to the national unemployment rate without regard to spot shortages in certain occupational categories. This bill does not take into account the fact that an employer's inability to hire a critical employee can lead to its inability to timely deliver a product to market. This inability to timely deliver can have a lasting impact on the competitiveness of the employer. A company's lack of competitiveness threatens the livelihood of all of its employees, not merely that of the alien in question.

The shortage/no shortage debate[2] has never focused on the worldwide nature of engineering and science collaboration and competition. Those who would prevent foreign engineers and scientists from immigrating to and working in the U.S. are ignoring the developing trends of outsourcing and globalized research and development. Outsourcing refers to the reallocation of existing tasks to overseas locations, or the decision to establish them overseas from their inception. Globalized research is the reorientation of business focus from a domestic or insular perspective to a broader international outlook. These trends make U.S. immigration laws less relevant. Foreign scientists and engineers will no longer be required to come to the U.S.; they will compete from their lower cost overseas locations, either as divisions of U.S. companies, or as foreign competition. This competition will not be affected by revisions in U.S. immigration laws. By forcing foreign scientists and engineers to remain outside the U.S., advocates of a restrictionist immigration policy facilitate the transition to outsourcing. If these foreign scientists or engineers are in the U.S., they must be paid U.S. wages; if they are located outside the U.S., they can work for whatever wage they find acceptable.

There has been much attention in the press and among the public over our perceived economic vulnerability resulting from chronic addiction to unstable sources of foreign oil. It is perhaps time now to examine whether this concern is also applicable to our reliance upon foreign-born science and engineering professionals. Concerned experts worry that the flow of foreign science and engineering students may dry up over time, thereby placing the U.S. doctoral "pipeline" in these fields in even worse shape than it now stands. Many of the host countries from which these graduate students come are now actively developing their own graduate science and engineering programs, thus making it more and more probable that in the future, they will keep their best technical minds at home for advanced study.

If we accept the possibility that foreign-born scientists and engineers might either go home in large numbers, or simply not make the trip here at all, then the question arises as to who, if anybody, will replace them. This is a question that has taken on special urgency in recent years as the full dimensions of the crisis in science and mathematics education in the U.S. have become increasingly evident. The U.S. must radically improve the scientific and mathematical preparation of its youth. Such change, however, will take at least a decade. Can we afford to risk the competitiveness of U.S. industry and the wages of American employees who depend upon this competitiveness while we wait for a new crop of American engineers and scientists to be created?

Immigration lawyers are busy people and their clients want results, not explanations or legal treatises. There is little room in the life of the immigration lawyer for philosophical discussions or abstract analysis. We make our living by solving problems. We achieve this end by interpreting statutes, challenging regulations, or presenting arguments that surmount both. Rarely do we step back from the immediate need to solve a specific problem and consider what societal forces led to the creation of those provisions that we seek to use to the advantage of our clients.

We all know about the outstanding professor/researcher classification created by the Immigration Act of 1990 (IA90 or 1990 Act).[3] Many of us have qualified our clients as priority workers under it. Yet why did Congress create this category in the first place? Does the U.S. need more scientists and engineers? If so, is there a shortage of American citizens to satisfy this rising demand? If we as a nation now depend upon foreign technological talent, what will we do if these people go home or stop coming? Who will replace them? Is there some fundamental flaw in science and mathematics education in the U.S. that will prevent our educational system from meeting this challenge? These are the questions that we felt deserved serious study and, to the extent possible, some answers.

We should know why, as a nation, we need the immigration laws that guide our actions and govern our conduct. At a time in our national history when our economic security is subject to unprecedented challenge, it is essential for us to develop an enhanced appreciation of the extent to which our society relies upon the talent and contributions of those foreign-born scientists and engineers who have made our cause their own.

A HISTORICAL OVERVIEW

The history of technical innovation and scientific discovery in the U.S. is inextricably linked to the contributions of immigrant scientists and engineers. The first large-scale U.S. factories, the textile mills of New England, were dependent upon the knowledge of machine design imported along with British workers. What the world considers "Yankee ingenuity" is often the result of newly-immigrated Yankees. In this century, the upheavals of World War II pushed many of the world's top scientists to immigrate to the U.S. These refugee scientists, arriving mostly in the 1930s and early 1940s, contributed greatly to the Allied victory in World War II and to this country's subsequent scientific successes.[4]

114 U.S. citizens have won Nobel Prizes. Of these, 36, or 32 percent, have been foreign-born. The first Nobel Prize won by an American scientist was won by an immigrant, Albert Michaelson, in 1907.[5] Born in Germany, he emigrated at an early age with his parents and became one of the giants of American physics. Other immigrant Nobel laureates include such pioneers as physicists Niels Bohr, Albert Einstein, Enrico Fermi, James Frank, Victor Hess, Wolfgang Pauli, and Otto Stern, the chemist Peter Debye, the pharmacologist Otto Loewi, and the biochemists Otto Meyerhof and C.P. Henryk Dam.[6] Among the elite of foreign-born scientists who have not won the Nobel Prize but are considered preeminent contributors to their fields are the Hungarians John von Neumann, Edward Teller, Leo Szilard, and Theodore von Karman, the latter who in 1963 was awarded the U.S.' first National Science medal. From Germany came Heinz Frankel-Conrat and Curt Stern; from Austria, Erwin Chargaff, Kurt Godel, Maurice Goldhaber, Victor Weisskopf, and Paul A. Weis; from Poland, Richard Courant, Samuel Ellenberg, Stanislaw Ulam, and Mark Kac; and from England, Freeman Dyson.[7]

From World War II until the 1970s, scientists, especially Western Europeans, could emigrate to the U.S. with relative ease.[8] Their work has made it possible for the U.S. to lead the world in jet propulsion, space flight, superconductivity, radar, nuclear energy, medicine and biochemistry, pharmaceutical development, high-energy physics, and many other fields.

Much of the heritage of the U.S. space program and ballistic missile programs can be traced directly back to Werner von Braun and the other German rocket scientists brought to the U.S. after World War II. Von Braun and his team, first at Fort Bliss, Texas, and later at Redstone Arsenal in Huntsville, Alabama, led the development of rockets of ever-increasing power, culminating in the Saturn V boosters that carried Americans to the moon. The first U.S. artificial satellite, Explorer I, was put into orbit by an Army Jupiter-C booster, a missile developed by von Braun's team.[9] Even before von Braun arrived, Hungarian Theodore von Karman was supervising a small group of Caltech students building what were to become sounding rockets.[10] These small rockets are used as a relatively inexpensive way to probe the edges of space and boost instruments past the earth's atmosphere. The rockets developed at Caltech include the WAC Corporal, one of the early workhorses of the sounding rocket fleet. Von Karman was also instrumental in the formation of the Jet Propulsion Laboratory at Caltech, the preeminent space science lab in the U.S.[11]

The Manhattan Project brought together the best physicists in the world and would not have been possible without the seminal contributions of immigrant scientists. From Leo Szilard, one of the first to conceive of atomic weapons, to Niels Bohr, who escaped from Stockholm in the belly of an RAF bomber, to Enrico Fermi, who used the money from his Nobel Prize to emigrate, to Edward Teller, one of the most controversial figures in physics, all worked either at Los Alamos or at one of the vast industrial plants spawned by the project.[12] John von Neumann, another Hungarian who was a mathematician of vast talent, put his expertise in fluid flow to use in modeling the shock waves needed to form a critical mass in a plutonium bomb.[13] Edward

Teller, who spent much of his time at Los Alamos dreaming of a hydrogen bomb, watched as a seismograph at the University of California at Berkeley registered the blast of the first hydrogen bomb in 1952.[14] Teller and Stanislaw Ulam hit upon a particular arrangement of fusion fuel elements along with an atomic bomb detonator which made these ultra-powerful weapons possible.[15] The development of smaller hydrogen bombs at both Los Alamos and at the weapons lab founded by Teller, the Lawrence Livermore National Laboratory, allowed bombs to be carried on-board ballistic missiles. Another Los Alamos alumnus, the Ukrainian-born George Kistiakowsky, later became the science advisor to President Dwight D. Eisenhower.

Hungarian immigrant John von Neumann, a vital member of the Los Alamos team, was also one of the fathers of modern computing. The first electronic computers were controlled from the outside, by switches or by moving cords and wires. Von Neumann had a better idea. He believed that a computer should be a general-purpose machine, run by internal instructions. In short, von Neumann invented software. At the Institute for Advanced Study, he constructed the first programmable computer in the boiler room. Every computer today, except for a few specialized machines, is a general purpose machine along the lines first proposed by von Neumann.[16]

Other contributions made by immigrant scientists are more obscure, known mostly within the community of scientists. Walter Baade first resolved stars in the Andromeda galaxy during World War II when the blacked-out skies above Los Angeles let him push his telescope to the limits of its power. Classified as an enemy alien, he spent long nights at the 100-inch Hooker telescope on Mt. Wilson and helped solve a long-running astronomical debate over the nature of spiral nebulae.[17]

More recently, Samuel Ting, the son of Chinese intellectuals, arrived from Taiwan with only a few dollars in his pocket. He was eventually noticed by Victor Weisskopf, who brought him to the Massachussetts Institute of Technology (MIT). In one of the cases of simultaneous discovery that are so common in science, Ting and his team at Brookhaven National Laboratories discovered an important particle, now called Psi/J, at the same time as a team at Stanford. The Psi/J provided important information for quark theory, or quantum chromodynamics. Ting, along with the American physicist Burton Richter, was awarded the Nobel Prize for Physics in 1976 for this 1974 discovery.[18]

Immigrants have been just as active in the biological sciences. In fact, the most significant biological discovery of this century, the structure of DNA, was made by a foreign scientist. In this case, however, the scientist, James Watson, was an American working in a British laboratory.[19] Watson's partner in this discovery, Francis Crick, later immigrated to the U.S. Crick was the head of the Human Genome Project, a plan to map the entire human "blueprint" for several years.

Otto Loewi, co-winner of the Nobel Prize for physiology and medicine in 1930, with English physiologist Henry Dale, studied a chemical that helps nerves pass impulses across nerve endings. Their work on nerve conduction has had far-reaching implications, from anesthetics to insecticides to nerve gases.[20]

On the cusp of physics and medicine sits nuclear magnetic resonance, now known as magnetic resonance imaging (MRI). In 1946, the Swiss-American Felix Bloch and his team developed this technique at the same time as another team under E.M. Purcell. Bloch and Purcell shared the 1952 Nobel Prize for Physics for this discovery. MRI has allowed physicians to take detailed looks at soft tissues, tissues difficult or impossible to view on an X-ray. In addition, MRI has become a multimillion-dollar industry.[21]

The success of these scientific pioneers as well as thousands of other immigrant scientists served to legitimize immigration as a recruiting strategy.[22] The U.S. has profited immensely from the discoveries and innovations of its foreign-born scientists. While we have focused on some of the larger contributions, it must be remembered that most immigrant scientists are not as visible, but are no less vital to the scientific and economic health of this nation.

The day-to-day contributions that foreign-born scientists and engineers make to high-tech research in the U.S. are undeniable. In Silicon Valley, for example, one in three engineers is foreign-born. At such prestigious research institutions as IBM's Yorktown Heights laboratory, foreign-born workers make up one in four researchers; at AT&T's Bell Laboratories, they account for as many as two in five.[23] Because they are often excluded from work on defense contracts due to their lack of U.S. citizenship, foreign-born engineers have concentrated in those emerging fields that are growing the fastest, such as personal computers, telecommunications, and the development of medical instruments.[24]

U.S. dependence on foreign-born scientists reached a peak in the 1950s while most of the U.S. enjoyed a robust economy and Cold War fears abounded. As the economy grew, academic and industrial research flourished and was well-funded.[25] The numbers of Ph.D. chemists and engineers graduating in the U.S. increased yearly, and jobs were plentiful.[26] By 1968, however, the postwar reconstruction of the German and Japanese chemical industries was virtually complete and global overcapacity forced companies to cut prices aggressively, hurting earnings and decreasing research money.[27]

To survive, companies laid off massive numbers of scientists and engineers.[28] To safeguard those employed, and in an attempt to provide an incentive for U.S. employers to hire unemployed U.S. workers rather than foreigners, the federal government adopted the current labor certification process that included prevailing wage determinations in the 1965 amendments to the McCarran-Walter Act.[29] Congress was responsive to organized labor's opposition to immigration and was reluctant to increase the labor supply in the face of chronic unemployment, which was generally at or above seven percent from 1975 through 1986.[30] Congress also acceded to organized labor's demand that the foreign students educated in the U.S. return to their native lands once their educations were complete so as not to compete with U.S.-born graduates.[31]

The prolonged U.S. economic expansion of the late 1980s, and a steadily dwindling supply of American graduate students in the sciences and engineering softened corporate resistance to hiring foreign-born scientists and engineers.[32] While jobs were plentiful, there was no outcry against U.S. dependence on foreign-born researchers and engineers. Organized labor lost much of its political influence as workers no longer looked to trade unions to provide security for their employment.[33] Opposition to hiring foreign scientists was further eroded by a study by the National Science Foundation (NSF) in 1986 that predicted a cumulative shortage of scientists and engineers of nearly 700,000 by 2006.[34] This study, which will be discussed in detail later in this BRIEFING, was used to justify increased federal investment in science education.

With the economy thriving in the late 1980s, the priority facing most of the U.S. was not how to prevent dependence on foreign brain power, but rather, how the U.S. could retain its historical technological supremacy. The 1990 Act's new priority worker classification, among other provisions, was a product of the U.S.' desire to retain global competitiveness.[35] Importing foreign technical expertise was seen as a shortcut to regaining the U.S.' historical dominance in science and engineering enjoyed in previous decades. The 1990 Act also preserved the ability of U.S. companies to bring foreign-born scientists and engineers to this country on a temporary basis if they meet the criteria established in the H-1B specialty occupation provision. H-1B temporary workers are not granted permanent residence and are only authorized to remain in the U.S. for the duration of their visas, for a maximum of six years.[36]

In addition, the 1990 Act also extended the prevailing wage requirement of labor certifications to H-1B specialty occupation workers.[37] This provision gave the state employment agencies the responsibility and power of determining the going pay rate in a particular employment field, and forbade employers from paying less than this rate to non-U.S. workers. Labor unions successfully lobbied for the inclusion of the prevailing wage requirement into the H-1B regulations to prevent what they viewed as "scab" labor. They believed that this requirement would prevent U.S. employers from indiscriminately bringing in foreign workers to undercut and undermine existing working salaries and working conditions, since it would negate any financial incentive to do so.[38] The AFL-CIO, in particular, fought for the current system of prevailing wage determinations as a means of protecting U.S. jobs.

As previously noted, the 1990 Act was followed by a global recession, cutbacks, and high unemployment, including within the science and engineering communities.[39] At the same time, the 1986 NSF study[40] predicting critical shortages of scientists and engineers continued to be circulated, further angering those U.S. scientists and engineers who now found themselves unemployed. The study was quoted and requoted in national publications, yet was based on flawed premises. The existence of this study and its subsequent rejection has given momentum to the immigration restrictionist movement. It has allowed that movement to summarily dismiss any legitimate discussion of U.S. reliance on foreign brainpower as somehow linked to a flawed study. A further example of this trend is the recently-introduced restrictionist legislation that would link the inflow of foreign scientists and engineers to the overall U.S. unemployment rate. This broad-brush approach would damage U.S. industry's ability to compete internationally.

The speed at which legislative change can take place is startling. The "labor market information" (LMI) pilot program,[41] a focus of vocal opposition by professional societies and organized labor, may be headed toward legislative extinction. Heeding the negative outcry marshalled by these groups, Labor Secretary Robert Reich has asked that the program be cancelled. On July 1, 1993, the U.S. Senate approved an immigration "technical corrections" bill that would make the LMI program discretionary rather than mandatory.[42] This amendment would probably mean that the Department of Labor (DOL) will never implement the LMI program, both because of broad opposition to its proposed rule, and because of the difficulties it has had in implementing the program so far. Some in the engineering community, sensing political vulnerability, feel that these apparent victories have given sufficient momentum to warrant attempts at more sweeping restrictionist legislation.[43]

DEPENDENCE

If the 20th century has been the American century, it is due in part to the fact that the U.S. has previously been able to defeat foreign competition, armed with cheap foreign labor, through the use of superior technology. It is not entirely coincidental that during the 1980s, the longest economic peacetime expansion in U.S. history, the number of scientists and engineers working in private industry increased at a rate almost twice that for all workers.[44]

The U.S. has been able to satisfy the rising demand for scientists and engineers only through relying on foreign students at the graduate level. Graduate students account for a tremendous percentage of overall research production in the U.S.[45] Approximately 50 percent of the full-time graduate students in science and engineering at doctorate-granting institutions are foreign students, and the percentage is much higher in certain disciplines. Every year since 1981, for example, foreign students have earned over half of the doctorates granted in U.S. engineering schools.[46] By 1983, more than 50 percent of all assistant professors under the age of 35 at U.S. engineering schools were foreign-born.[47] By 1990, foreign students earned 56 percent of the Ph.D.s in mathematics and 48 percent of the Ph.D.s in computer science.[48]

While some believe this is an issue of numbers, it is also one of quality. U.S. universities and the research interests they serve realize that they need foreign nationals in science and engineering if they want to attract the best talent at the doctoral level. Without the continued research that top-notch graduate students perform, many of whom are foreign-born, individual universities would find it difficult to qualify for the grant money upon which they depend.

Scientific Education As An Industry

Graduate education has become a major export for the U.S. Since 1960, the number of foreign students attending U.S. colleges has risen nearly eightfold.[49] U.S. engineering schools have become dependent on foreign-born graduates, not only as teachers and research assistants while they earn the Ph.D., but also as faculty and postdoctoral researchers after graduation.[50] Moreover, the academic industry relies on foreign bodies to fill seats that American students leave empty, and which if left empty, would lead to a downsizing of U.S. scientific education, reductions in its attendant infrastructure and eventually unemployment for instructors and professors.

U.S. graduate schools have, in effect, adopted a foreign policy of their own that is clearly in their short-term self interest. It permits them to maintain world-class quality standards, provides the bright young minds on whom their faculties depend for research projects, and avoids a dramatic decline in enrollment that could shrink departmental budgets and result in drastic cuts in government spending. Since the number of science and engineering Ph.D.s awarded to U.S. citizens has remained fairly stable since the early 1970s, the explosion in graduate education since that time can largely be attributed to the enormous increase in the percentage of doctorates awarded to foreign citizens.[51] Since the authors of this BRIEFING foresee a rising demand for both faculty and researchers in the 1990s and beyond, we take the position that, in the absence of a sufficient pool of qualified U.S. academicians, foreign students in science and engineering should be encouraged to undertake doctoral study in the U.S.[52]

As the proportion of foreign students in science and engineering fields has skyrocketed, the willingness of U.S. employers to become involved with their immigration status has also changed. Chemistry is a good example. Twice as many Ph.D.s in chemistry were awarded to foreign citizens on nonimmigrant visas in 1991 as in 1981.[53] In 1981, nonresident aliens earned 15 percent of all chemistry Ph.D.s. This proportion soared to 30 percent a decade later.[54] In the early 1980s, most chemical companies felt that hiring foreign scientists was difficult, lengthy and expensive. However, when these same U.S. employers could not find sufficient potential employees among the U.S. population in the mid-1980s, they found it necessary to hire foreign scientists to fill their research needs.

A Growing Appreciation Of The Quality Of Foreign-Born Scientists And Engineers

In 1985, the prevailing stereotype was that foreign chemists could function in the academic laboratory but not in applied research with commercial applications. Nevertheless, as early as 1980, chemical companies were actively recruiting foreign-born Ph.D. chemists in response to their availability and the declining number of U.S.-born Ph.D.s. By 1990, chemical companies would not only hire foreign Ph.D. scientists, but would pay for them to obtain any necessary visas.[55]

Headhunters were also forced to adapt to changing realities. In the early 1980s, for example, David A. Small, president of a Houston-based executive search firm that specialized in chemical processing industries, told Chemical Week that applications from foreign chemistry students graduating from U.S. universities were 20 percent of his business compared to only 2-3 percent in 1968.[56] Similarly, in 1964, a little less than 20 percent of engineering Ph.D.s went to foreign students;[57] by 1980, the proportion had mushroomed to over 46 percent.[58] Such a large a pool of talented engineers could not help but become more interesting to U.S. employers.

The U.S. government is in the forefront of those employers who hire foreign-born scientists on a temporary basis. The National Institutes of Health (NIH) has the largest number of foreign nationals working in its laboratories of any federal agency. Monitoring their work is the job of Dr. Philip Schambra, Director of the Fogarty International Center at NIH. On any given day, Dr. Schambra estimates that approximately 1,700 foreign-born scientists participate in NIH research, representing about one-third of the total number of scientists at the NIH laboratories.[59]

Although most are temporary employees as opposed to permanent resident workers, Dr. Schambra credits these foreign-born scientists with contributing to many of the major research advances at NIH laboratories, including the identification of the AIDS virus; the development of a diagnostic test for HIV infection; development of vaccines against rotavirus and hepatitis B; and significant discoveries on the mechanisms of cancer at the genetic level. In fact, Dr. Schambra speculates that at the most productive of NIH's scientific laboratories, approximately 43 percent of the scientific publications are co-authored by foreign-born scientists.[60] He predicts that the role of foreign nationals in industry and academia will become increasingly important in biological research.[61]

Dr. Schambra's prediction is validated by a study conducted by the National Research Council, which consulted the research and development directors of 20 major high-technology companies. The respondents indicated that their research programs were dependent upon foreign scientists, and significantly, that such dependence was growing, as fewer Americans enter research fields as careers.[62]

Similarly, in a June 1985 telephone survey of over 150 Fortune 500 firms, the NSF learned that 56 percent of those responding hired foreign-born applicants because they were the most qualified, while 35 percent cited a shortage of U.S. scientists and engineers.[63] Interestingly, those foreign scientists hired had more education than their American counterparts. Overall, about 12 percent of American scientists and engineers held the Ph.D. compared to 35 percent of foreign-born scientists.[64] Chemical companies and pharmaceutical firms were most likely to hire foreign-born scientists at the Ph.D. level, while electronics firms were most likely to hire the foreign-born baccalaureate straight out of engineering school.[65] Over 60 percent of the chemical and pharmaceutical firms, and over 50 percent of the electronics firms responding utilized, to a greater or lesser extent, foreign-born scientists and engineers in the research and development laboratories.[66]

Why are these U.S. companies so interested in foreign scientists and engineers? It is an interest born out of need and the desire to seize the competitive edge. By the mid-1980s, for example, the U.S. had fewer physicists than in 1970.[67] From the start of the 1970s to the middle of the next decade, there was an astonishing 48 percent decline in the proportion of engineering doctorates granted to U.S. citizens.[68] If it were not for foreign graduate students, there is a real question whether there would be enough instructors to teach science and engineering courses at the undergraduate level.[69]

Ten years ago, foreign graduate students were only 20 percent of the first year enrollment at MIT. By 1985, they were 40 percent and expected to constitute 50 percent or more of all graduate students at MIT by the late 1990s.[70] By the year 2000, estimates are that 50 percent of all science and engineering Ph.D. degrees awarded by U.S. universities will go to foreign graduate students.[71] Foreign-born students constitute 40-60 percent of the doctoral candidates in the emerging areas of high technology--biotechnology, computers, manufacturing technology, materials engineering, microelectronics and robotics.[72]

There is a direct connection between the U.S. storehouse of engineering expertise and its ability to maintain or recapture technological supremacy. In 1985, Dr. Simon Ramo, a co-founder of TRW, Inc., told a Congressional task force on science policy that in Japan, of every 1,000 college graduates, 40 earned degrees in engineering, compared to only seven in the U.S.[73] By the mid-1980s, the U.S. had gone from having about one-half of the engineers in the noncommunist world to only one-third. Dr. Ramo predicted that by the mid-1990s, the U.S. would have only 25 percent.[74] In Dr. Ramo's view, in 10 or 20 years, the majority of technological breakthroughs will take place elsewhere. He noted with some alarm that the U.S. Patent Office traditionally awarded very few patents to foreigners while the number of patents to American inventors increased annually. By 1983, however, foreign-origin patents comprised 42 percent of the total U.S. patents while the annual number granted to Americans had declined by over 40 percent in the previous 15 years.[75]

The impact of insufficient science and engineering manpower on research and development can also be seen in the pharmaceutical industry. In 1964, the U.S. share of worldwide research and development activities in pharmaceuticals was 65 percent. By 1978, it was only 28 percent.[76] Experts explained that significant shortages of Ph.D.s in analytical chemistry, pharmacology, animal health and agricultural medicine had all diminished the ability of the U.S. pharmaceutical industry to pursue research and development activities.[77]

Does an American presence remain on the graduate level in science and engineering at our major doctorate-granting educational institutions? In 1960, U.S. citizens earned 77 percent of the Ph.D.s in engineering. This figure had plummeted to only 44 percent by 1989. At the same time, there was a 23 percent drop in the numbers in the physical numbers of Ph.D. in the sciences earned by Americans.[78] Between 1960 and 1989, the number of doctorates awarded to non-U.S. citizens increased sevenfold.[79] Most of this growth can be attributed to the massive influx of nonimmigrant students rather than to permanent resident students. In 1989, for example, nonimmigrant temporary residents received 21 percent of all doctorates granted in the U.S.[80] In physical science fields--physics, chemistry, and mathematics--the percentage of temporary visa holders earning Ph.D.s nearly doubled from 1973-1983, with the greatest increases coming in mathematics.[81] Similar growth is evident in foreign-born engineering degree recipient rates. In 1959, for example, only 9.6 percent of engineering Ph.D.s were on temporary visas. By 1983, this proportion had mushroomed to 34.2 percent[82] and eventually reached 46.5 percent in 1989.[83]

By the mid-1980s, foreign students comprised 30-40 percent of graduate enrollment in five of the largest engineering fields--civil, chemical, electrical, industrial and mechanical.[84] Foreign graduate students earned over 60 percent of the Ph.D.s in civil engineering, industrial engineering, and mechanical engineering.[85] In fact, the only major engineering field where foreign graduate students earned under 50 percent of the Ph.D.s was nuclear engineering. Even here, they earned slightly over 49 percent.[86] The proportion of foreign doctorates in engineering at U.S. universities, on both temporary and permanent visas, more than doubled from 1960 to 1984. This increase can be attributed to nonimmigrant temporary residents, since permanent residents earning Ph.D.s in engineering have declined since the early 1970s.[87] It is sobering to realize that from 1970 to 1984, at a time when the number of 30-year-olds (the average age at which the Ph.D. is earned) in the American population rose by 65 percent, the number of engineering Ph.D.s awarded to American citizens declined by 51 percent.[88]

Findings On The Effect Foreign Scientists And Engineers Have On The U.S.

The implications of the increasing participation by foreign-born scientists and engineers in American society were sufficiently troubling to prompt the National Academy of Engineering to ask the Office of Scientific and Engineering Personnel in 1988 to undertake a preliminary study of these issues. The National Research Council created the Committee on the International Exchange and Movement of Engineers for this specific purpose. The study these groups produced remains the most comprehensive portrait of foreign engineers in American life.

The Committee found that without the participation of foreign-born engineers and engineering students, U.S. engineering schools and industry would have to significantly curtail teaching and research programs.[89] Specifically, the Committee concluded that foreign-born engineers were essential in industrial research and development, particularly in those areas critical to the U.S.' international competitiveness in selective fields such as nonlinear optics and the commercial applications of laser technologies.[90]

The National Research Council surveyed research and development (R&D) directors for 20 firms that accounted for a large percentage of the technological output of the U.S. A majority of the R&D executives who responded to the survey admitted that their particular industries were dependent upon foreign-born engineers. In several instances, foreign engineers were felt to be a critical element of the firm's research activities.[91] When asked if their business could prosper without foreign engineers, most respondents said that they could continue but would have to restrict certain areas of research or staff them with less qualified people. Other respondents noted that foreign engineers were making significant contributions to the technical quality of U.S. industrial research.[92]

For multinational and large domestic corporations, the issue of national origin was less relevant than ability, training and technical proficiency. In fact, companies such as Nestle, Mitsubishi and Imperial Chemicals considered national origin to be irrelevant, except as it affected prospects for advancement into management positions.[93] Significantly, survey respondents worried not about hiring foreign-born engineers, but about keeping them.[94] The concern was what their firms would do if a large percentage of foreign-born engineers elected to return to their homelands.[95]

Despite the growing dependence on foreign-born engineers, the time for panic is far from here. Non-Americans still accounted for only 3.5 percent of employed engineers in the U.S. in 1982, a slightly lower percentage than a decade earlier.[96] The substantive impact of foreign-born engineers becomes greater as the degree level rises. Thus, the representation of foreign engineers is more pronounced for holders of the Ph.D. than for the baccalaureate or master's degree.[97] The influence is at its apex in academia where, for example, about two-thirds of the postdoctoral candidates in engineering are not U.S. citizens.[98]

The vast majority of foreign engineers have already received their baccalaureate training in their home countries. In view of the many benefits they bring with them to this country, it was not difficult for the Committee to conclude that the continued influx of the best engineering minds from around the world to the U.S. contributed to our economic welfare and strengthened our international competitive position at a very low cost to the U.S. consumer.[99]

NO OVERALL SHORTAGE

The Argument Over Shortages

As noted earlier, there are currently unemployed American engineers and scientists. Proponents of business immigration, however, offer several reasons why business immigration should not be artificially hindered, including potential future shortages of U.S. scientists and engineers due to lack of degree production, existing spot shortages in certain subfields, and the inability of U.S. employers to instantly fill these spot shortages with qualified U.S. workers.

When one takes the time to objectively analyze the debate surrounding the alleged shortage of engineers and scientists in the U.S., it is important to acknowledge the fact that both sides of the argument have previously been misrepresented. Professional organizations and immigration restrictionists would have you believe that the U.S. is awash in foreigners who will steal away jobs from Americans by working for less pay. This position has been fueled by a recent spate of anti-immigration, anti-labor certification articles in Texas, Washington, New York and California.[100] These articles and the erroneous statistics contained within them are being used by the American Engineering Association, among others, to support a movement that seeks to amend U.S. immigration law to keep foreign-born professionals out.[101] These groups believe that with the current naggingly high unemployment rate in the U.S., any available job should go to an American regardless of skill level. Most Americans would probably agree that given the choice between two qualified applicants, an American job should go to an American worker.

On the other side of the debate, proponents of business immigration sometimes posit that the U.S. economy would be devastated if scientific and engineering immigration were curtailed. Business immigration supporters argue that due to inadequate scholastic preparation on the part of American students, the U.S. economy would fail without skilled workers from foreign lands. The truth lies somewhere between these two extremes.

The Labor Market Information Pilot Program

The 1990 Act directed the DOL to conduct the LMI pilot program to determine whether the alien labor certification process can be streamlined by supplementing the existing case-by-case process with an approach using lists of occupations in which there are labor shortages or surpluses.[102] Under the LMI program, the DOL must make a determination that surpluses or shortages exist in up to 10 defined occupational classifications.

Labor certifications would then be made "automatic" in designated states for occupations in which the DOL has identified potential shortages. The DOL's recently published proposed regulations contained only shortage occupations and included the following 10 occupational classifications: biological science; chemistry; chemical engineering; computer science; materials engineering; mechanical engineering; medical engineering; Chinese and Japanese specialty cooks; primary care physicians; and special education teachers.[103]

The intent behind the LMI program was to eliminate costly bureaucratic delays for employers who wished to hire aliens to fill positions in labor areas that were experiencing an obvious shortage of U.S. workers. The program, however, is based on extrapolations from data collected six years ago during peak employment among most science and engineering professions. As a result, it lists shortages in areas where there are no current shortages.

The implementation of the program has been widely criticized. On May 14, 1993, Robert B. Reich, U.S. Secretary of Labor, citing the adverse reaction to this program, wrote the Chairman of the Committee on the Judiciary of the U.S. House of Representatives to ask that this program be cancelled.[104] On July 1, 1993, the U.S. Senate approved a bill that would make the LMI program discretionary rather than mandatory.[105] Rep. Collin C. Peterson (D-Minn.) objected to the "hasty and questionable process" under which the LMI rule was made, stating that the rule, if adopted, would open the doors of several occupations in which U.S. workers are already fighting layoffs and poor job prospects to large numbers of foreign workers."[106] He further charged that the DOL "did not even make a prima facie case of occupational shortages."[107]

The Washington, D.C. office of the American Institute of Chemical Engineers also contests the DOL's identified occupational shortage categories. The Institute's in-house survey indicates that two percent of its members are actively seeking work, and that corporate downsizing is anticipated to add to that unemployment figure.[108] The Institute further expects that students currently studying chemical engineering will have difficulty finding jobs.[109] Betty M. Vetter, Director of the Commission on Professionals in Science & Technology, who has written a number of papers in this area, found it "astonishing" that a list of current occupational shortages was created from 1987-1988 data, when there were shortages in all the fields listed.[110] Dr. Vetter found no indication that anything had been done to update the list upon which the proposed LMI program was based.[111]

The Case Against Immigration Of Scientists And Engineers

Congressman Lamar Smith (R-Tex.) filed a complaint with the DOL challenging the Department's contention that there is a shortage of mechanical, chemical, and computer engineers. The complaint, in which Congressman Smith asks, "why should we make it easier to hire engineers from Bangladesh when so many American engineers are out of work?," best describes the position of those opposed to continued business immigration.[112] The American Society of Mechanical Engineers (ASME) joins Congressman Smith in his complaint and directly contests the findings of the DOL. The ASME complains that the DOL is proposing a rule that lists job categories as experiencing shortages in a number of states where there is a current lack of jobs for many U.S. mechanical and materials engineers, to cite an example.[113]

Representatives of the American Engineering Association claim that there is currently a "gross amount" of unemployment in the engineering industry as a whole and that lax immigration policies have allowed foreigners to take high-paying jobs in the U.S. that should have gone to Americans.[114] These most recent complaints are in reaction to the DOL's proposals surrounding the LMI program.

One should keep in mind that the professions of science and engineering have traditionally enjoyed low unemployment rates. Consequently, a moderate rise in the unemployment rate can trigger a vitriolic response from organized labor and professional societies, and generate sympathetic media attention.[115] In 1992, unemployment among engineers as a whole jumped to 3.8 percent.[116] While still low compared to the national average, this represents a 1.4 percent annual jump, the largest increase in over a decade, and is comparably far above the median and average engineering unemployment rates.

A review of the unemployment figures for engineering specialties put out by the Bureau of Labor Statistics from 1983 to 1991, the last year for which those statistics are currently available, indicates that unemployment for engineering as a whole had not exceeded three percent during that entire period.[117] The previous peak of three percent unemployment was reached in 1983 in the midst of a comprehensive nationwide recession. Unemployment for engineers as a whole reached its lowest point, 1.4 percent, during 1989[118] (it had gone as low as 1.1 percent in 1978).[119] In that year of peak employment there was no reported unemployment in mining engineering, agricultural engineering, or among marine engineers and naval architects.[120] In that same year, aerospace, metallurgical and materials, chemical, and nuclear engineering fields all reported less than one percent unemployment.[121]

Unemployment in some engineering fields follows industry trends rather than nationwide trends. In 1983, the worst year for engineering as a whole, aerospace engineers reported a 0.2 percent unemployment rate.[122] Even though the economy as a whole improved from that point on, unemployment rates among aerospace engineers grew rather than fell, with a few peaks and valleys along the way, to the 1991 rate of 2.1 percent.[123]

Unemployment in other engineering fields has varied much more erratically due to market demand. In 1983, marine engineering and naval architecture suffered through a horrific 19.5 percent unemployment rate.[124] By 1989 there was zero percent reported unemployment, i.e., total employment, among marine engineers and naval architects. Unemployment in those fields remained virtually nonexistent for the following year; however, it shot up to high unemployment, 8.8 percent, in 1991.[125]

Other engineering fields are much more stable. Chemical engineering had a median unemployment rate approaching two percent throughout 1983-1991.[126] Rates ranged from a high of 3.0 percent in 1984 to a low of 0.7 percent in 1988.[127] Electrical and electronic engineering was even more stable with its unemployment rate hovering around 1.7 percent during this time period.[128]

The diversity of unemployment rates within engineering and scientific subfields and their independence from overall unemployment rates is not a concept appreciated by Congressman Smith, who introduced a bill in the House on May 25, 1993 that would tie the immigration rate to the national unemployment rate without regard to spot shortages. This arbitrary proposal would leave American employers unable to fill an opening in a specialty in which there was no unemployment if the national unemployment figures exceeded a certain level. This, in turn, has the potential of preventing U.S. employers from filling critical skill positions on a timely basis, thereby eliminating them from the competitive marketplace.

The Institute of Electrical and Electronics Engineers (IEEE-USA's) Manpower Committee seeks a more balanced approach. The IEEE questions both the ability of industry, government or academia to measure or predict labor market demand with reliability, and the wisdom of legislation that places too much emphasis on immigration to meet the U.S.' need for better educated and more highly skilled workers.[129] IEEE has publicly taken the position that immigration should be viewed as a supplement to, not a substitute for, concerted public and private efforts to improve our nation's technological capabilities. IEEE believes that the U.S. should focus on more effective education and training at all levels as well as better management and utilization of American workers, including scientists and engineers.[130]

The IEEE's approach lacks the reactionary character evident in so many professional organizations. These reactionary organizations would do well to realize that when a Japanese, German or Korean firm is able to supply a more timely, accurate and thorough proposal, or capture a larger market share by taking advantage of free market, international brainpower, Americans of all skill levels will lose jobs. A myopic "Americans-first" approach that ignores wider consequences will create not only social injustice, but economic downfall for the U.S.

The Infamous PRA/NSF "Future Scarcities Of Scientists And Engineers" Study

In 1985, the NSF's Policy and Research Analysis Division (PRA) began a demographically based study that projected a shortfall of 692,000 bachelor's degrees in natural science and engineering by the year 2006.[131] The study was based on a simplistic premise.[132] It held that as the participation rate of 22-year-olds in natural science and engineering degree programs had been stable for a decade, and since the number of 22-year-olds in the U.S. was declining, there would eventually be a shortfall of degrees produced in the U.S.[133] The NSF study relied heavily on the assumptions that: (1) white males would remain the primary source of future scientists and engineers; (2) demand for scientists and engineers would increase dramatically in the next century; and (3) the domestic labor pool would be incapable of adapting to fill an increase in demand. It is our goal in this BRIEFING to distinguish the real U.S. dependence on foreign brainpower from the "sky is falling" scenario put forward by Peter House of the NSF, the principal author of the study.

In 1986, the NSF's director took that shortfall number to Congress and presented the "crisis" in his fiscal year 1987 budget testimony.[134] In 1987, the NSF further disseminated the "shortfall" number by publishing a draft of the study and distributing it to over 1,000 people.[135] The study had neither been peer-reviewed nor given any sort of serious methodological review before its release.[136] Because of the confusing and interchangeable use of the words "shortfall," "shortage," and "scarcity," and discussion by NSF officials of supply and demand, many members of Congress, academic institutions, the media, and the public became convinced that fewer degrees meant that a real shortage of workers was looming.[137] The perceived solution was government intervention in the form of increased financial support for science and engineering education.[138] The NSF produced and distributed at least ten other drafts of the study between

1988 and 1990, with varying numbers and years of shortfalls.[139] These drafts became known as NSF's underground literature, with different decision-makers possessing different versions of the study.[140]

The NSF ultimately settled on a constant number of 675,000 as representative of the projected shortfall, even though the years charted changed from report to report without the 675,000 number ever changing.[141] The lack of a statement of methodology, data points, lists of assumptions or bibliography contributed to the inability to verify the study.[142]

From the beginning, labor economists, including those within the NSF itself, scoffed at the methodology as seriously flawed.[143] A principal area of concern was that the study addressed only supply, and did not take into account the market's flexibility in adjusting to demand.[144] The statistical unit of the NSF found that the "stable" participation rate of youths entering the science and engineering professions was not stable at all.[145] As noted above, this study was a remarkably simple one which merely stated that as supply will remain the same, needs are assumed to increase, ergo shortage. Thus, the entire premise of the study was eradicated by its author's own colleagues within the NSF.

Through its repeated use in speeches and testimony by the NSF's director, university administrators, and members of Congress, and countless articles and news stories, the study took on a life of its own.[146] The study was referred to in Fortune magazine as late as May 1992, was cited by Sen. John C. Danforth (R-Mo.) when discussing NASA appropriations, and often permeates the discussion of future scientific needs.[147] Many people who cite articles claiming future shortages are unaware that those publications, such as Science magazine, are quoting the study on good faith, relying upon the reputation of the NSF, and are unaware of the study's extremely weak methodology. Its lack of credibility, when combined with its wide distribution, has muddied the reasoned discussion about the future of science and engineering immigration in the U.S.

The study only began to become discredited when the engineering community publicly attacked it in late 1990.[148] Alan Fechter, Executive Director of the National Research Council's Office of Scientific Engineering Personnel, reviewing the NSF study, pointed out specific deficiencies. For instance, the model used in the study only looked at university degree production in the science and engineering fields to determine supply; it did not take into account other sources of supply.[149] Mobility from closely related fields, which has traditionally been an important source of supply, was ignored.[150] Further, the study's assumption that U.S. degree production will rise slowly and then remain constant is a completely arbitrary assumption.[151] Incredibly, demand was never analyzed in this study; the PRA argued that determining demand was too conceptually complex.[152] Dr. Fechter concluded that, overall, the study was not useful for policy formation.[153]

In a published response to this criticism, the study's principal author, Peter W. House, attempted to minimize the intended significance of the PRA/NSF study, as if it had been intended only as a means of stimulating discussion.[154] Mr. House claimed the study was never meant to be a model, but merely a projection of future scarcity if the U.S. continued to produce the same number of scientific and engineering graduates as it had in the past.[155]

The confusion surrounding the study resulted in Congressional hearings to investigate the "scandal" at the NSF, with the express intention of preventing Congress from being misled as to the existence of a "crisis" ever again. Congress found that this study, and the subsequent cover-up of its flawed premise, seriously undermined the credibility of the NSF, and that the debate on future shortages was as open as ever.[156]

This, however, is not the case. As the NSF study has become discredited, it has smeared the entire shortage thesis. When presented in a balanced, academically honest, and sophisticated context, the possibility of future science and engineering shortages still retains considerable validity. Due to the now-infamous PRA/NSF study, however, those who take an expansive view toward the engineering and scientific needs of the U.S. in the next century are tarred by the NSF scandal, thus tipping the scales in favor of the immigration restrictionist.

The Difficulty Of Predicting Future Demand: Beware Of False Prophets

Since the time of the PRA/NSF study, Alan Fechter, along with Betty M. Vetter, Executive Director of the Commission on Professionals in Science and Technology, among others, have written papers explaining in detail the flaws of the NSF study and the difficulty of making predictions about future employment demands. The general consensus is that while projections can be made, no statistician, regardless of his or her educational credentials, can conclusively predict future demand for scientists and engineers. Although Congress may prefer to be told what the future holds, the most statisticians can provide are projections created through reliance on research that follows accepted methodological rules.

Technological breakthroughs, economic cycles, and changes in government policies make it impossible to predict future requirements for scientists and engineers. The changing state of technology sporadically creates great demand in distinct fields. One example would be if the cold fusion discovery in 1989 had been real.[157] Technological breakthroughs bring radical shifts in workforce compositions.[158] Software engineers existed before the advent of the personal computer (PC), but it took the introduction of the PC to create explosive growth in software engineering demand.

Another complexity is that these fields are highly sensitive to governmental changes.[159] The U.S. government funds an enormous number of scientific and engineering positions through direct grants from its various research agencies and indirectly through infrastructure and military spending. Changes in governmental policies, such as reductions in defense spending, infrastructure development programs, and huge governmental projects such as space stations and supercolliders can radically change the requirements for the science and engineering workforce.

Spot Shortages Versus Profession-Wide Shortages

Some professional organizations have recognized that in the current global marketplace there can be simultaneous surpluses and shortages among specialties and skill levels. In a paper submitted to Congress for hearings on scientific and engineering manpower, the American Association of Engineering Societies (AAES) conceded that the nation can experience simultaneous shortages of science and engineering faculty, surpluses of older workers in industry, spot shortages of new graduates in burgeoning fields, such as environmental or manufacturing engineering, concurrently with surpluses of graduates in fields of less demand. The AAES gave examples of shortages in civil and chemical engineering specialists occurring while surpluses of electrical and aerospace specialists existed. The report concluded by acknowledging that when all of these differing situations are mixed together at the aggregated, national level, it is possible for supply and demand to appear to be in balance when in fact they are not.[160]

The AAES recognizes that one of the complexities in the shortage/no shortage debate is that little if any objective data exists on the supply-demand mix for all these subsets of the technical workforce.[161] A second complexity is that the data kept by the INS and that kept by the Bureau of Labor Statistics is recorded under different categories. The INS, for example, keeps no statistics on the distinct professions of H-1B temporary workers; instead, they are lumped into one category of "Professional, Technical and Kindred Workers."

This lack of comparable data categories makes it impossible to determine what historical effect the immigration of scientists and engineers has had on the employment rate of American professionals within the same disciplines. The AAES realizes that the failure to face informational shortcomings results in confusion and heated debates on the existence or nonexistence of a shortage in which both parties may be right, but are not referring to the same categories.[162]

The cyclical nature of engineering work and the need to increase engineering staffs quickly can lead to industry's short-term reliance on qualified aliens who can go to work on relatively short notice.[163] Attempts to hire Americans in short time periods can result in an insufficient supply of qualified applicants.[164] New graduates are sometimes not qualified because universities cannot prepare them for all eventual specialized skills. Generally speaking, colleges teach broad skills which require refinement before they can be of practical use.[165] It can sometimes take new engineers as long as a year before they can "pull their own weight" on a project.[166]

One thing upon which all experts will agree is that changes in science education take years and even decades to reap results. In the interim, spot shortages of scientific and engineering talent can put U.S. industry at a significant disadvantage vis-a-vis foreign competition. What few people are willing to admit is that a U.S. employer's inability to fill a critical scientific or engineering position on a free-market, timely basis could lead to much more significant U.S. unemployment than is now the case. Those who would rather fill a critical superconductivity research or engineering position with an unqualified U.S. mechanical engineer merely because that individual is temporarily unemployed and American are putting scores of other American jobs at risk.

The Need To Make The Public Understand

Professional organizations contend that employers have contrived a shortage of U.S. workers so they can hire foreigners who are often willing to work cheaper.[167] One issue that cannot be stressed too much when educating laypersons, including journalists and members of Congress, about the current U.S. dependence on foreign brainpower is that U.S. employers are prohibited by law from paying aliens less than the prevailing wage for their area of specialty. Most people outside the immigration community are also unaware that the DOL determines the prevailing wage for the specialty for which an alien is petitioning.

It is imperative that the public be made to understand that it is much more difficult and expensive to place an alien in a U.S. job than simply to hire a qualified American. Logic dictates that given a choice between qualified applicants, U.S. employers would typically choose an American worker over an alien worker to fill a U.S. job opening. Unemployed American engineers and scientists may not have been hired for positions that were subsequently filled by labor-certified aliens because the Americans may not have possessed the specific skills necessary to fill the positions in question. It makes no sense for an American employer to hire a foreign-born scientist or engineer if qualified Americans are available. In addition to paying the prevailing wage for the position in question, the employer must pay legal fees which can run between $2,000-$5,000 per application.[168] The employer must then endure INS and DOL requirements, which add additional costs of time, money and aggravation. The only logical reason for employing a qualified alien is if an employer cannot find a qualified American in the particular job market for which it is hiring.[169]

Independent wage studies have verified what immigration experts have always known: foreignborn scientists and engineers do not work for less than their U.S.-born counterparts. "From the standpoint of policy, our most potentially controversial finding in the area of earnings is that we reject the notion that foreign scientists and engineers work for less than comparable U.S. natives,"[170] says a study prepared for the NSF by the Labor and Policy Studies Program of the Manpower, Research and Training Division of Oakridge Associated Universities. Those conducting the study reached this conclusion after taking a wage survey of over 13,000 scientists and engineers. The results were in direct contradiction to the assertions of some representatives of the engineering community that foreign scientists and engineers are paid less than their U.S. counterparts.[171]

The study examined the oft-repeated charges that salaries for U.S. engineers were depressed by the alleged willingness of foreign-born engineers to work for lower wages, and that American engineers had lost job opportunities to foreign rivals. The authors of the study found no evidence to support or sustain these accusations. Since foreign-born engineers as a group constituted only 3.5 percent of the total U.S. engineering workforce in 1982,[172] they were not displacing American engineers to any significant degree. As for salary depression, despite assertions to the contrary, there is no hard evidence that foreign-born engineers earned either more or less than their American counterparts.[173] There was some evidence to suggest that noncitizen engineers without U.S. degrees might earn less; however, this was a small group, and the earnings differential was only about three percent.[174]

Having said that, however, we must acknowledge, as did the Committee on the International Exchange and Movement of Engineers, that by their very presence, foreign-born engineers probably depressed earnings below what they would otherwise be.[175] If foreign-born engineers had been barred from the U.S. workforce in the 1980s, there would most likely have been an increase in engineering salaries above then-current levels, particularly for those American engineers with the Ph.D. In turn, this could have sparked an increase in Ph.D. enrollment.[176] The Committee also found it relevant, however, that engineering salaries were still higher than salaries in nearly all other occupations.[177] Since engineers only account for 1-2 percent of the U.S. workforce and a comparable proportion of legal immigration, restrictions on the entry of foreign engineers would have little overall impact without comprehensive restrictions on total immigration admissions.[178] Moreover, the Committee also found it reasonable to believe that the adoption of such restrictions would reduce the overall quality of the American workforce.[179]

In sum, the Committee clearly felt that any attempt to restrict the ability of American industry to recruit and retain foreign-born engineers would be contrary to our national interest and should not be adopted.[180] At a time when U.S. technical dominance was under increasing challenge, the Committee felt it more important than ever for this nation to attract and keep the best technical minds from other nations as well as to provide new incentives for U.S. students to pursue careers in science and engineering.[181]

SHORTAGE

Why We Still Need Foreign Scientists And Engineers

Economic concerns of the moment, however painful to those affected, should not obscure the extent to which the continued influx of foreign scientists and engineers may serve to strengthen the U.S.' future competitive position in the global economy. Present difficulties are not necessarily predictive of future challenges or possibilities. Foreign-born scientists and engineers continue to be an essential ingredient of our industrial and technological base.

The U.S. remains attractive to the world's best scientific and engineering minds. Our key competitors, notably Japan and Germany, have not historically welcomed large-scale importation or permanent settlement of foreign talent.[182] By inviting the best and the brightest to do their work here, U.S. employers are helping the nation reap the full benefit of its historic openness. However, they should also keep in mind that the continued infusion of talented foreign-born scientists and engineers cannot be maintained indefinitely.

The Crisis In Academia

Set against the dilemma of current engineering unemployment and the undeniable difficulties confronting talented young scientists who must struggle to launch professional careers, the rationale for a flexible and expansive immigration policy must rest on an ability by immigration advocates to make the counterintuitive argument that a generous and flexible immigration policy is also an exercise in national self-interest. To suggest, for example, that there is not now an engineering glut in some fields or certain regions, such as electrical engineers in Silicon Valley, is to deny reality. Yet realities change and tomorrow's economy may bear scant relation to today's headlines. As a nation, we must deal with contemporary problems without sacrificing our capacity to adapt if the U.S. is to remain dominant in the global economy of the 21st century.

In no area is the need for foreign talent so obvious or evident as in academia. Over 70 percent of basic research in the U.S., research that supports and makes possible commercial applications of technology, is conducted in colleges and universities.[183] That is why the issue of faculty shortages in science and engineering is, or should be, a matter of grave national concern. In 1986, for example, a Presidential panel found that 10 percent of engineering faculty positions were vacant in critical fields such as electrical engineering and computer science; indeed, some universities reported 50 percent vacancy rates in these areas.[184] While there are 14,000 full professors of engineering in the U.S., current vacancies combined with projected retirements during the 1990s prompted the Office of Technology Assessment to estimate a need to hire 3,300-5,000 new engineering Ph.D.s by the year 2005.[185]

At a 1990 Congressional hearing, Dr. Russell C. Jones, Research Professor at the University of Delaware, warned that the engineering doctoral pipeline was so empty of American students that the U.S. would be unable to replenish the technical expertise needed for research and engineering education.[186] In a 1987-1988 survey, major engineering schools reported that more than 20 percent of their engineering faculty was expected to retire over the next decade at a time when the demand for engineering graduates at the doctoral level would be increasing, particularly for U.S. citizens.[187] More of the faculty hired during the boom years of the 1960s will begin to retire in large numbers starting in the late 1990s. Testifying at a late 1990 Senate hearing, Dr. Richard Atkinson, then-President of the American Association for the Advancement of Science, warned that the replacement demand for Ph.D.s in science and engineering was expected to climb to 11,000 in academia, industry and government by the year 2010.[188]

The need to replace science and engineering faculty stands as one of the strongest arguments for a generous approach to the immigration of foreign scientists and engineers. The number of college-age Americans (18-22 years) peaked in 1982 and will not begin to recover until 1996. This means that as the demand for faculty replacement and researchers in industry and government increases, the number of Americans earning baccalaureate degrees in the sciences and engineering will decrease. In turn, this provides a shrunken base for Ph.D. production.[189] In fact, Ph.D. awards in physics, chemistry, mathematics and engineering per thousand 30-year-old American citizens, the average age at which the Ph.D. is earned, have declined steadily since 1971 with no present evidence of significant increase. It is expected that the number of 30-year-old Americans will drop by more than one million by 2005 when the need for faculty replacements in these fields will be significantly greater than it is today.[190]

There is no present need to panic. The American Society of Engineering Education reports that in 1987, only 7.2 percent of full-time faculty positions in engineering were vacant compared to a 10 percent vacancy rate in 1980. It is a tell-tale sign, however, that a full 25 percent of all reported vacancies in 1987 were in electrical/electronic engineering.[191] The problem is also evident in computer science, computer engineering, and industrial engineering, all with more than 10 percent of authorized full-time faculty slots open.[192]

Vacancies were concentrated at the assistant professor level, the faculty with the heaviest undergraduate teaching load. Here, one-sixth of all authorized engineering positions were vacant.[193] As early as 1983, more than 50 percent of new hires at the assistant professor level in engineering were foreign-born.[194] In 1986, electrical and mechanical engineering had the highest percentage of faculty nonimmigrant visas, while civil engineering boasted the most permanent resident faculty members.[195] At this same time, researchers from the Institute for International Education and Washington University in St. Louis surveyed departmental chairs and engineering faculty on the impact of so many foreign students. Significantly, they concluded that these foreign graduate students were essential to both teaching and research programs in U.S. engineering schools.[196]

The Graying Of Academia

Except for computer science, U.S. universities must deal with an aging faculty in science and engineering. How will more and better engineers be developed if there is no one to teach them? Will not a faculty shortage necessarily translate into restrictions on enrollment? Unless they deny the crisis in academia, it is incumbent upon those who advocate a more restrictive immigration policy to explain how the manifold difficulties created by such a faculty shortage will be addressed.

In turn, engineering faculty must come to terms with the possibility that the downsizing of U.S. industry may remain as a permanent fact of economic life, thus serving to limit the number of future engineers that business will need. Will this happen? Neither we, nor anyone else, really knows. If this scenario does come to pass, it will be incumbent upon those who guide U.S. engineering schools to justify the continued need for such a massive program of graduate education. Fewer students and less demand for engineers and/or scientists may mean less faculty will be needed. The casual observer who is understandably confused by seemingly conflicting predictions must understand that such informed speculations are inevitably tinged by the self-interest of those who make them. Neither immigration advocates, universities, government agencies, representatives of professional societies, nor Congress, are immune from this temptation.

The NSF estimated that over 50 percent of American doctoral scientists and engineers in 1987 were 45 years of age or older; 25 percent were 55 years of age or older.[197] The NSF projects that 25 percent of the teaching faculty in sciences and engineering will reach age 65 by 1995. From 1977-1987, there was a substantial increase in the above-54 age group in doctoral scientists and engineers coupled with a decline in the under-age-35 group from 21 percent in 1977 to 12 percent a decade later. Over this same decade, the percentage of retirees in the doctoral scientific and engineering population rose from 3.1 percent in 1977 to 4.8 percent in 1987.[198] Set against these demographic realities comes the projection by the Bureau of Labor Statistics of a 3-7 percent increase in university faculty by the year 2000. This translates into 23,000 to 62,000 new faculty members but does not include the numbers required to replace present science and engineering faculty who would retire.[199]

Over the last three decades, the U.S. has produced one million lawyers but only approximately 55,000 Ph.D. chemists.[200] Moreover, the interest among these doctoral chemists in academic careers continues to wane. In 1970, 18.5 percent of chemistry Ph.D. graduates indicated an interest in teaching positions. By 1985, that figure had dropped to only eight percent, which translates into about 147 individuals nationwide.[201] The number of American-born Ph.D. chemists is not keeping pace with our principal competition. In the mid-1990s, we will graduate an estimated 1,250 American-born Ph.D. chemists. Germany, with only one-third the population, will graduate approximately the same number of German-born Ph.D. chemists.[202] From 1970-1985, the number of foreign nationals earning Ph.D.s in chemistry at U.S. universities rose from 15 percent to 22.7 percent This figure has gone up substantially since 1985.[203]

Examining available data on both supply and demand, excluding engineering, researchers at Princeton University recently predicted a net deficit in math and physical sciences faculty that would stretch well into the initial decade of the 21st century. Due to aging in the present faculty, the study concluded that replacement needs would be substantially increased after 1995.[204] These replacement needs will rise beginning about 1996, at the same time as the college-age population bottoms out and begins to climb once again.[205]

A joint National Science Foundation/National Security Task Force on Mathematics concluded in 1990 that the demand for skilled scientists, engineers and technicians in the year 2000 would exceed the 1986 demand by 36 percent--nearly double the growth in overall employment demand.[206] At the same time, going beyond academia, the Executive Director of the Office of Scientific and Engineering Personnel for the National Research Council recently estimated that retirements in the scientific and engineering workforce as a whole would triple between 1991 and the turn of the century.[207]

Pipeline Problems And Employment Projections

To ignore the possibility of future shortages makes no more sense than to deny the reality of a present glut. What is necessary is to continuously reappraise the current level of shortage or glut in each sub-specialty to take into account market shifts and cycles. In the last decade, when positions in science and engineering were advertised, more often than not it was not Americans who responded. In 1982, the Dean of the Faculty of Arts and Sciences at the University of Pittsburgh told a House Subcommittee looking into science and engineering education and manpower that 95 percent of applications for advertised faculty vacancies came from foreign-born scientists.[208]

It is simply impossible to increase the number or quality of American engineering students while a chronic shortage of engineering faculty persists. In turn, when engineering schools are forced to limit enrollments in response to such chronic faculty shortfalls, the shortage of skilled engineers is only made worse.[209]

While unemployment projections are, of necessity, an inexact science, it is instructive to look at what the Bureau of Labor Statistics (BLS) thinks will happen in science and engineering as the 20th century draws to a close. Past BLS projections have admittedly been overly optimistic due to their 10-year cycle approach in which trends can reverse, and then reverse again. In 1970, for example, the BLS projected that there would be over 270,000 mechanical engineers in the U.S. in 10 years. In fact, there were only 232,000 mechanical engineers by 1980, a 19.3 percent difference between the BLS projection and the actual figure.[210] The BLS projected that, by 1980, there would be over 59,000 chemical engineers; once again, there were only 46,000, a 28.9 percent differential.[211] The number of civil engineers was projected to grow from approximately 180,000 to over 235,000 in 1980; here too, the actual number of civil engineers in 1980 was 22.7 percent short of the BLS projection.[212] Despite this cautionary reminder, any speculation as to whether America will continue to need foreign-born scientists and engineers must consider future employment possibilities in these disciplines. While our national policies should not be dictated solely by such projections, they should not be made in complete ignorance of them.

In April 1990, the BLS studied employment opportunities in a variety of engineering and scientific fields. The BLS found that employment prospects in engineering would continue to be good through the year 2000 because employment was expected to rise faster than the average for all professions while the number of engineering degrees was likely to fall.[213] One sign that the BLS used to support its belief that engineering graduates had good employment prospects is the fact that they received starting salaries higher than those of other graduates, and that most engineering students could choose from more than one job offer before graduation, something not true for other occupations. In fact, the BLS found that starting salaries for engineers with bachelor's degrees were significantly higher than starting salaries of college graduates in other fields.[214]

Some engineering disciplines, such as aerospace and electrical engineering, are sensitive to cutbacks in defense spending that could result in large-scale layoffs. This sensitivity has been visible in recent years, particularly in California. Reflecting this current glut, the Wall Street Journal recently reported that the number of electrical engineers employed in this country had declined some 20 percent from a 1990 peak.[215]

Nonetheless, employment in chemical engineering is expected to expand as the chemical industry increases research and development expenditures.[216] A growing population and an expanding economy will create jobs for more civil engineers who will repair or replace a decaying infrastructure and transportation system.[217] More industrial engineers will find work as businesses seek to reduce costs and increase productivity through greater automation and more efficient management.[218] Employment opportunities for mechanical engineers will grow as the demand for machinery soars and the equipment itself becomes more complex.[219]

Looking beyond engineering, the BLS found in its 1990-91 survey that employment of systems analysts was expected to grow much faster than the average for all professions through the year 2000. The demand for systems analysts was expected to climb as advances in technology created new computer applications. In addition, as the price of computer hardware and software continued to fall, small businesses would be more able to computerize their operations, further stimulating employment opportunities for systems analysts.[220]

The shortage of Ph.D.s in mathematics was expected to continue and create favorable employment opportunities. This was particularly true for doctorates in applied mathematics although even theoretical mathematicians were projected to have excellent employment opportunities for teaching and research jobs in academia.[221] Expanded research and development, particularly in pharmaceutical, biotechnology and environmental protection, were expected to lead the way in creating good jobs for chemists.[222]

Our understandable concern with current unemployment in selected engineering disciplines should not cause us to ignore the likelihood that things will get better in the future. The demand for engineers, at all degree levels, should jump by 32 percent between 1988 and 2000.[223] The BLS' Office of Employment Projection speculates that all professional specialty occupations will gain over 200,000 jobs between 1988-2000. More than 50 percent of these jobs are anticipated to be in engineering.[224] Some specializations within engineering are expected to grow faster than others. The most dramatic job growth is expected for electrical and electronic engineers, anywhere from 22-39 percent by the year 2005.[225] The demand for civil engineers is expected to rise between 1990-2005 anywhere from 19-39 percent while employment for mechanical engineers should go up from 13-29 percent over this same period.[226] Mathematicians and computer scientists are also anticipated to see tremendous growth in their fields.[227]

OUTSOURCING AND GLOBALIZED RESEARCH AND DEVELOPMENT

The Changing Nature Of The Global Market

What some participants in the shortage/no-shortage debate do not realize is that their arguments may not take into account the worldwide nature of engineering and science collaboration and competition. The focus should be international, not domestic, in scope. Those who would prevent immigrant engineers and scientists from working in the U.S. are ignoring the economic trends referred to as outsourcing and globalized research and development. Outsourcing is the sending of a portion of production abroad, including design or research development. Generally, by sending production (or a portion thereof) abroad, production costs are lowered, making the producing company more competitive in the global marketplace.

Globalization is distinct from outsourcing in that international companies draw upon all of their resources wherever they may be located for the good of the company as a whole. Global companies assume an aggressive posture when they introduce products and services into new foreign markets. They cultivate worldwide markets through the natural advantages created incident to their use of local resources, both material and human, to enhance their international competitiveness. Outsourcing, by contrast, is a policy of retrenchment that serves merely as a cost-cutting measure. Outsourcing relies upon the reduction of labor and production costs that become possible by taking advantage of wage disparities available in Third World environments.

U.S. engineers and scientists have benefited greatly from globalization, as British, Dutch, French, German, Japanese and multinational corporations of other national derivations have employed tens of thousands of U.S. engineers and scientists in the U.S. and abroad.

In any free-market system, production and market share will inevitably gravitate to the lowest-cost producers. Recognizing this fact, global companies seek the lowest cost labor to be able to lower the price of their products, increase market share, maximize production, and boost profits. This is why the U.S. clothing and footwear industries have been lost to the Far East, why American car components are made in Mexico and why bananas still come principally from Central America. These are natural economic results from the loosening of trade restrictions.

U.S. engineering and research firms have heretofore been shielded from worldwide competition because their main competitors in Europe and Japan had similar, or higher, wage costs for their scientists and engineers. Firms from scientifically emerging countries such as India, Pakistan, and Korea, as well as from former and current Communist countries such as the Soviet Union, Hungary, and the People's Republic of China (PRC), were not regarded as serious competitors to Western engineering and research firms. This lack of attention was due to worldwide perceived qualitative inadequacies. This dismissive attitude, if maintained, could prove economically fatal to U.S. scientific and engineering interests in the 1990s.

The era of Western technological dominance is dead. It may be argued that the U.S. still produces the best engineers and scientists in the world, but extraordinary numbers of these top-notch scientists and engineers who were trained in the U.S. were of foreign birth and are forced by U.S. immigration laws to return to their homelands. These returning scientists and engineers have developed institutes, trained new generations in their homelands, and are now in direct competition with U.S. firms.

Outsourcing and globalization make U.S. immigration laws less relevant. Foreign scientists and engineers will no longer be required to come to the U.S.; they will compete from their lower-cost overseas locations, either as divisions of U.S. companies, or as foreign competition. This competition will not be affected by revisions in U.S. immigration laws. Further, by forcing foreign scientists and engineers to remain outside the U.S., advocates of immigration restrictions facilitate the development of a critical mass of overseas technical talent that will only hasten the process of outsourcing. If these foreign scientists or engineers are in the U.S., they must be paid U.S. wages; if they are kept outside the U.S., they can work for whatever wage level they find acceptable.

When soliciting competitive bids for large engineering or research projects, the prestige of hiring a Western firm pales before the lower cost of non-Western engineers. Firms have determined that the quality differential is negligible to nonexistent. Companies like Conner Peripherals freely admit that the lower cost and rising competence of Asian engineers means that such companies will be forced to rely more heavily on outsourcing in the future.228 U.S. engineers and scientists who never planned to compete outside the U.S. no longer have a choice. Technology is making it as easy to confer with a colleague in Brussels, Seoul or Moscow as it is to walk down the hall to discuss the latest development.

Outsourcing

Some argue that the scientific process is by nature so interactive that colleagues must maintain physical proximity to stoke the coals of scientific development. Schlumberger, Inc., a worldwide engineering firm, does not believe in outsourcing. It is their position that the most efficient relationship between research and development communities is "by simple human contact--across the table, at the chalkboard or over a beer."[229] Schlumberger believes that "a formal video conference does not achieve this" and that "the importance of face-to-face meetings is underscored by Schlumberger's air travel expenditure of over $95 million in 1991."[230] Richard Ellis, Research Director of the Engineering Work Force Commission, points out that the tidal wave of outsourcing that has been predicted for the last eight years has never materialized.[231] Mr. Ellis feels that at the top level, research is an art form and that researchers must be together to keep their creative fires burning.[232]

However, AT&T, Corning, Sun Microsystems, United Technologies and General Atomics, among others, have found a way to keep creative fires burning with much cheaper fuel. These companies have hired the services of entire laboratories of Russian scientists.[233] AT&T has recently hired 100 specialists from the General Physics Institute in Moscow while Corning has hired 115 scientists from the Vavilov State Optical Institute and the Institute of Silicate Chemistry in St. Petersburg to work on glass materials technology.[234] These companies now have access to the most advanced technology in the world in fields like metallurgy, ceramics, and rocket propulsion systems.[235]

These U.S. companies are not planning to bring the newly hired scientists to work in the U.S.[236] To these companies, it is preferable that the scientists remain in Russia as members of ongoing research institutes.[237] In this way, the productive research environment is not disturbed, collaborative research is preserved and the cost of research is less than a tenth of what it would cost to perform in the U.S.[238] Apparently, these companies do not feel that centralized research is such a critical objective. While it is not to be suggested that all U.S. engineering and research jobs will flow to the Soviet Union, the above research arrangements exemplify the emergence of an alternative to centralized research.

The experience of Komag, Inc., reflects the economic model of production flowing to the lowest-cost producer. Komag, Inc., a maker of exotic materials used in computer storage devices, has decided to open a plant in Malaysia rather than expand its California factory, expressly because wages are lower for both professionals and production workers in Malaysia.[239] William Kaufman, Komag's Chief Financial Officer, takes the position that if demand for Komag's products were not growing, its U.S. professionals might be getting pink slips even as others are added overseas.[240] In Komag's case, the profitable overseas branch is actually subsidizing the U.S. branch and making it possible for the U.S. company to remain afloat. The extrapolation is that if Komag did not employ Malaysian engineers in Malaysia, and thus remain price-competitive in its market, Komag would lose sales that would result in the termination of the less-price-efficient American engineers.

Similarly, Intel has added an Irish engineering subsidiary to take advantage of the higher unemployment rate in Ireland.[241] The lower wage rates for the Irish engineers means that Intel's overall cost of production is less, and that it can produce products cheaper than if it were to design them solely in the U.S.[242] In this way, outsourcing presents much more danger to the employment prospects of American professionals than does immigration. The potential does exist that, over time, more and more jobs will leave the U.S. until there are not any left for U.S. engineers. However, in the short term, outsourcing can actually save some U.S. engineering jobs by keeping production costs down and maintaining a company's competitive position. Arguably, if the company employed only U.S. engineers, its production costs would be so high that it would lose sales and hence jobs for U.S. engineers.

In the U.S., the prevailing wage is enforced by the U.S. Labor Department; no foreigner can be paid less in the U.S. than his or her American counterpart. This measure is meant to prevent "scab" labor from depressing the U.S. wage rate. Governments of countries with less developed standards of living actually tout their lower wage rates as a means of promoting foreign investment and infrastructure development.

As barriers on the worldwide movement of goods are reduced, services follow. If American engineers and scientists cannot provide qualitative superiority, then their services will merely be judged according to price. Due to higher standards of living, U.S. engineers and scientists are handicapped in their price competitiveness, and may be forced to rely on overseas operations to subsidize American jobs. Thus, outsourcing may subsidize some U.S. jobs while eliminating others.

Globalization

Dr. James D. Burke, Manager of Professional Recruitment for the Rohm and Haas Research Laboratories, explains the typical internationalization of worldwide research companies. Rohm and Haas manufactures products in 22 nations, maintaining four regional research laboratories in North America, Europe, Latin America and the Pacific.[243] Rohm uses these laboratories for training customers to use the company's products, customizing products for specific uses, and providing consulting services for customers in technical areas that involve the use of the company's products.[244]

Each laboratory has been established by U.S. personnel on overseas assignments with the intention of staffing them from top to bottom with indigenous personnel so that the company can remain close to the market.[245] Historically, Rohm and Haas' research center has been located in the U.S. As the European and Japanese laboratories flourish, however, they will inevitably originate their own research projects.[246]

Dr. Alan Fechter doubts the effect on U.S. citizens of the heralded onslaught of outsourcing and globalization that is predicted for the next decade.[247] Dr. Fechter believes that since much of industry-sponsored research is market-driven, one cannot understand a market without being physically in it.[248] Dr. Fechter is probably right that outsourced products will not come to dominate the American market. However, this misses the point. The economic playing field of the 21st century will not be U.S.-dictated as in the past; it will be international in scope. For U.S. engineering and research firms to grow, they cannot be content merely to dominate the domestic market; rather, they must become competitive in the international arena. To be competitive overseas, U.S. firms must understand local market conditions just as foreign companies must understand those of the U.S. This will require an overseas presence that will call for professionals to be on location in foreign countries. As exports become increasingly important to our economy, outsourcing and globalization will serve to create U.S. jobs rather than "stealing" them away. The threat isn't really outsourcing, per se, which may in fact become an advantage in the global marketplace of the future. Rather, the danger seems to be a myopic focus on the domestic market and clinging to a passé protectionist labor policy that ignores worldwide competitive factors.

Technological Breakthroughs

The two elements previously preventing the flow of significant amounts of engineering and research activity out of the U.S. to the lowest-cost-providing companies were: (1) substantial qualitative differences, and (2) logistical impediments that made outsourcing impractical. The qualitative gap has been closed if not completely erased. "We can solve all the engineering problems we'll face on our own," says Thian Hoo Tan, the Malaysian manager of Komag's new Malaysian plant.[249] The issue of logistical impediments is being erased by either moving entire research and engineering projects overseas or through burgeoning interactive technology.

Multiple-site engineering has the same technological constraints that potential outsourcers face. Schlumberger, Inc., a global engineering firm that does not outsource, uses modern technology to link its key people regardless of their location. This technology, and subsequent advances in it, will be used by companies that have no qualms about outsourcing to link their overseas research and development sites.

The use of satellites and portable computers is an example of technology currently in use on multiple-site engineering projects that should advance tenfold in the future, be reduced in price and gain much wider industry acceptance. The SInet system has been in use for ten years.[250] SInet is a satellite and ground-based information system consisting of electronic mail and data files used for scientific computations.[251] A supercomputer in Austin is linked via other computers and satellites to personnel worldwide. The supercomputer used is a "Thinking Machine" CM5, the most powerful parallel processor in the world.[252] This technology is capable of linking multiple worldwide locations with real-time (simultaneous-interactive) video. Executives and scientists use Apple Macintosh PowerBooks_, powerful laptop computers, as portable terminals through which they are able to access the supercomputer in Austin from any telephone in the world, at any time of day or night. Through this technology, an individual can log in to the Austin supercomputer from an oil platform off the shore of Africa.[253]

This technology is now used in concurrent engineering projects. No face-to-face meetings are required among various research facilities working on the same project. Most importantly, the information is processed almost simultaneously with its transmission. Engineers and scientists are able to interact with each other across oceans rather than correspond through fax machines. This concurrent engineering makes physical presence less critical and lowers the cost factor of dispersed research. The progress to date achieved in linking up worldwide research centers could serve as a model for other international companies. When combined with interactive technologies under development, the trend toward globalization may diminish the need for foreign engineers and scientists to come to the U.S.

REVERSE BRAIN DRAIN AND THE RISKS OF DEPENDENCE

The Risks Of Dependence

In March 1990, President Bush's science adviser, Dr. D. Allan Bromley, warned against U.S. overdependence on foreign students to satisfy its future technological needs. He cautioned against assuming that foreign students will continue to remain in the U.S. in such massive numbers, or indeed to study here at all, as their own nations develop the infrastructure and incentives that only the U.S. traditionally has been able to offer them.[254] Foreign scientific and engineering graduates who may have remained in the U.S. for an extended period of time after the Ph.D. are now increasingly going home, particularly in the case of Korea, where their talents are in high demand.[255]

It is particularly in emerging fields such as nonlinear optics and laser technologies that U.S. companies have come to depend so much upon foreign engineers. At Texas Instruments, for example, 25 percent of the Ph.D.s in research laboratories are foreign-born. As of May 1991, of the 10,000 resumes in research and development that Texas Instruments received each year, only 42 percent were from U.S. citizens. At IBM, 35 percent of the Ph.D.s hired in recent years to do research and development needed a visa to come here. At Bell Laboratories, 40 percent of the Ph.D.s in research are foreign-born.[256]

Technical shortages are appearing exactly in those fields where foreign countries are beginning to mount serious drives to attract their engineering Ph.D.s back home. As technological change continues, for example, in Korea and Taiwan, the likelihood also grows that many of these students will go home.[257] What if Chinese physicists or Korean engineers go back or are prevented from coming here to study? Doubtless, new sources of foreign graduate students, perhaps in the emerging market economies of Eastern Europe, can and will be found. Even if this is the case, do such foreign graduate students form a stable basis for future research and teaching projects so integral to U.S. national economic security? If there is no present alternative to such reliance, should one be developed? Are Americans willing to pay significantly more for preparatory education in order to do so? Will any such attempt smack of intellectual nativism and trigger seriously adverse foreign policy consequences?

These and other pertinent questions must be asked, if not answered. Indeed, the increasing role of foreign students in science and engineering only serves to highlight the lack of involvement of American graduate students in these same critical areas. The 1990 graduate enrollment data at the American Institute of Physics indicated, for example, that foreign nationals comprised nearly 44 percent of the first-year graduate students in physics.[258] Everyone agrees that the quality of these new students is very high, but when nearly 50 percent of the graduate students in a particular area are foreign, some well-intentioned observers view this as a warning sign of overreliance.[259]

That these questions are now being raised with increasing insistence in the public forum suggests a level of concern that may have reached critical mass. It is inconceivable for this debate to have erupted in the vastly more confident climate of the 1950s and 1960s when the U.S. had no international economic rivals capable of mounting a sustained or serious challenge.

Then, not viewing its national self-interest at stake, U.S. policy spoke of the dangers to the developing world from an exodus of scientific and engineering talent. It is a measure of the change in national self-confidence since this halcyon era that concern over the "brain drain" abroad has now been replaced by the far more divisive and seemingly intractable issues of retention and reliance at home. As the terms of the debate have so dramatically changed, the attention paid to our immigration policies, as well as their political importance, has steadily grown to the point where immigration has now arrived center stage as a linchpin of national economic strategy. Who comes and who stays, under what terms and for how long, have suddenly been transformed into economic issues that directly affect the U.S.' competitive position in the global economy.

There are some anecdotal indications that the process of return is now well underway. Dan Hartley, president of a union representing Boeing's 28,000 professionals, reports that unlike years past when Americans would go abroad to work, an increasing number of foreign engineers now come here to learn and then return home.[260] If foreign countries begin restricting emigration of their engineers to the U.S., will we be ready to meet personnel needs in critical industries?

Almost five years ago, the National Academy of Engineering analyzed the extent to which the electronics industry in Silicon Valley relied on foreign-born engineers. At that time, 7,000 of the approximately 20,000 engineers in Silicon Valley were foreign-born and 5,000 of those immigrated here from the People's Republic of China and Taiwan.[261] Standford Penner, Chair of the National Academy study and a member of the faculty at the University of California in San Diego, warned that the supply of foreign engineering talent was not inexhaustible.[262] He made the common-sense observation that as conditions in the host countries change, the campaign to bring these engineers back to their home countries will intensify for no other reason than that the home country needs them just as much as the U.S. does.[263] Repatriation incentives, including airfares and cash, may be one reason why the NSF found that 45 percent of scientists on temporary visas left the U.S. between 1981 and 1985.[264]

Emigration: Do Foreign Scientists And Engineers Stay In The U.S.?

Most of what we know about the future intentions of science and engineering doctorates is actually limited to the immediate period of postdoctoral study. In fact, there is precious little known about what happens after the "post-doc" is over, or about those Ph.D.s who do not pursue postdoctoral studies. It is therefore somewhat misleading, and ultimately unsatisfying, to learn that about 70 percent of the physical science doctorates plan to stay in the U.S. or that 68 percent in the biological sciences plan to do so.[265] Moreover, statistical surveys of postgraduate plans can be subject to more than one interpretation. When the NSF studied science and engineering doctorates from 1960-1989, it found that on the one hand, almost 64 percent of foreign Ph.D. engineers had definite post-graduate plans in the U.S. At the same time, engineering had the highest number of Ph.D.'s with definite post-graduate plans abroad.[266] Two points seem reasonable enough to be relied upon. First, it is likely that the best students are the ones most likely to stay.[267] Second, there is simply little hard data to sustain the thesis that many foreign-born scholars go home after earning their doctorates. They may be doing so, as the anecdotal information suggests, but no one is keeping track, certainly not the NSF or the INS, the two government agencies most likely to be interested.[268]

A working paper estimating emigration of foreign-born scientists and engineers was prepared in January 1988 for the National Science Foundation and the U.S. Department of Energy by Michael Finn and Sheldon Clark. They did not address the long-term stay rate of immigrants who earned U.S. degrees, but rather sought to build on previous research by estimating emigration rates during the 1980s for experienced foreign-born scientists and engineers who worked in the U.S. in 1981 or 1982.[269]

Because they are fluent in foreign languages, foreign-born scientists and engineers are much more employable in other countries than the average U.S.-born scientist or engineer. They are also more likely to have relatives abroad. It is not uncommon to find them obligated to go home and/or experience difficulty if they choose to remain in the U.S. For these and other reasons, Finn and Clark concluded that the foreign-born scientist and engineer in the U.S. was likely to have a positive emigration rate.[270] Over the 1981-1985 period, Finn and Clark found Ph.D.s in engineering and computer science on nonimmigrant visas had an emigration rate of 45 percent, as compared to 44.4 percent for foreign-born doctorates in the physical sciences.[271] This figure is deceptively high, however, since Ph.D. emigration reflected only the activities of a small part of the total population of foreign-born scientists and engineers. In fact, 80 percent of those foreign-born workers classified by the NSF as scientists or engineers did not have Ph.D.s. The four-year emigration rate for this group from 1982-1986 was significantly lower than the Ph.D.-based estimates. Taking experienced scientists and engineers without the Ph.D., Finn and Clark found that 10.8 percent of the non-U.S. citizen engineers and 11.6 percent of the foreign scientists went home.[272]

The most important theoretical contribution that Finn and Clark made was to explain that emigration is an adjustment to immigration. Foreign-born scientists and engineers who earn degrees in the U.S. do not make an irrevocable decision to stay in the U.S. or leave after graduation. Rather, because they have personal and occupational mobility, they can, and often do, leave and then return at various points in their careers. Therefore, in all our attention to study the influx of foreign-born doctorates to the American work force, we should not lose sight of the fact that people are leaving at the same time.[273] While emigration does not drastically alter the extent to which the U.S. depends on foreign-born doctoral scientists and engineers, it is an important qualifier that must be taken into consideration.[274]

Foreign Attempts To Reverse The Brain Drain

Emigration from the U.S. in the future will intensify in response to aggressive foreign recruitment. Our competitors elsewhere realize, if we do not, that intellectual capital necessarily flows across national boundaries in a global economy where knowledge means prosperity and power. The signs of these cross-currents are already evident and can only deepen in the coming decades. The U.S. must either become intellectually self-sufficient in science and engineering, or compete for such intellectual resources on the world market where supply is limited and demand high. In an international search for technological advantage, foreign scientists and engineers need no longer remain in the U.S. Economic growth abroad, especially in Asia, has created options that previously did not exist.

Some Taiwanese engineers, for example, can now return home to work on major research projects at the Industrial Technology Research Institute in Taipei.[275] Taiwan offers to pay their airfare back, plus cash bonuses and interest-free loans. Taiwanese companies provide free housing and the National Taiwan University promises tenured, full professorships. In Korea, large private corporate conglomerates, like Lucky-Gold Star and Sansui, have been actively recruiting.[276] Private industry and some government laboratories are also trying to lure back India's specialists in computer software and biotechnology. In Sri Lanka, the government is creating projects with foreign investment and joint collaboration to persuade its citizens to return, and is also beginning to hold out the prospect of dual citizenship.[277]

Because of cultural attitudes, the Japanese have had a more difficult time attracting foreign scientific and engineering talent. This is particularly true in the case of foreign women. To compensate, Japanese businesses such as NEC have started research laboratories in the U.S. to recruit Americans and others who might not want to work in Japan.[278] Therefore, even while these recruits stay in the U.S., the technology they develop goes back to Japan. In fact, the Japanese actively recruit top students for their U.S.-based research centers, offering salaries about 15 percent above comparable American research institutes like IBM.[279] The Japanese recognize, as do the Koreans, the Taiwanese, and the Indians, that they are in a global competition for advanced scientific expertise. Ironically, precisely because America's graduate schools continue to serve as a magnet for the best students from around the world, it is here that the talent scouts have come.[280]

Economic supremacy in the 1990s and beyond will, in large measure, depend upon scientific and technical dominance. For this reason, it is the Japanese, the Chinese and the Indians who are in the ascendancy as we approach the year 2000. Japan, for example, can draw upon a larger body of research scientists and engineers than all of Western Europe combined, particularly in the commercial application of technology.[281]

Yet, the engineering supremacy of Japan may be short-lived. Today, for example, India boasts as many software programmers as Japan and Germany combined, while Korea trains more engineers than France or Britain.[282] Experts predict that in the 1990s, it will be the Chinese-speaking countries that will assert their engineering authority. China now educates more engineers annually than Germany, France and Britain combined; in terms of software programmers, it already ranks ahead of Japan. Simultaneously, other Asian nations under the economic influence of China, such as Taiwan, Singapore, Indonesia, Malaysia and Thailand, are also generating large numbers of engineers.[283] They recognize that such intensive commitment to science and engineering is the foundation of industrial and technological power in the 21st century.

We can no longer automatically assume that the best foreign students will continue to come to this country in sufficient numbers to keep us at the forefront of technological change. While the U.S. still remains the country of choice for young scientists,[284] this could change with profound consequences for our competitive position. Traditionally, for example, Taiwan was a major source for foreign students in chemistry. Today, U.S. chemistry graduate schools do not see many Taiwanese applicants.[285]

Americans must recognize that there are foreign companies that are at least the equal of their American rivals. To maintain their level of competitiveness, Taiwan and Italy, for example, reportedly lure their citizens back with promises of modern laboratory equipment and research support. In Italy, the Institute for Industrial Reconstruction, the giant state-owned industrial holding company, built a research and development facility to attract scientists to the poor Naples region.[286]

Realizing how dependent they are on foreign talent, U.S. corporate research centers hope that the best minds will continue to come, given the absence of any immediate alternative to such continued reliance.[287] Nonetheless, a sense of acute vulnerability leads some resource planners in industry to speculate that in the long run, U.S. universities may be training foreign scientists and engineers to return home and prepare their own societies to compete against us.[288]

The Korean Campaign: U.S. Science And Engineering Is No Longer The Only Game In Town

In what appears to be a successful attempt to reverse the brain drain, the Asian economic miracle, particularly in Korea, has persuaded thousands of expatriates, many of them top scientists, to go home.[289] In the case of South Korea, since 1980, approximately 20,000 expatriates have given up permanent resident status overseas.[290] In 1989, for the first time in the post-Korean war era, the number of people leaving Korea annually dropped below 30,000.[291] South Korea has created what is increasingly being called the "MIT of Korea." At the Pohang Institute of Science and Technology, or "Postech," the first privately financed research university in Korea, 87 percent of the faculty members earned doctorates at American universities. Many did postdoctoral research or taught at such prestigious universities as Harvard, MIT, Princeton, Stanford, and the University of California at Berkeley.[292]

This does not mean that Korean students still do not want to study in the U.S. or that an American degree no longer carries prestige or influence. It does, but not as much as it used to. The traditional advantage in basic science afforded by an American over a Korean degree has been narrowed as more and more Koreans find the money, facilities and technical support to build their careers at home.[293] The Pohang Iron and Steel Company, the world's fifth largest steel producer, gave Postech a $300,000,000 endowment. Both the university and the steel company have a close working relationship with the Research Institute of Industrial Science and Technology, an applied think tank next to Postech that employs half of Postech's faculty in part-time research.[294]

It is no longer necessary to come to the U.S. to pursue high-tech research now that research funding may be easier to obtain in Korea than here. In November 1989, for example, the Samsung Electronics Company opened a laboratory for developing ultra-large-scale integrated circuits. Only Japan and the U.S. lead South Korea in this strategic industry.[295] The consumer electronics divisions of several Korean conglomerates now set aside 10 percent of their sales revenue for the development of new products.[296] So ambitious has Postech become that a two-billion-electron-volt synchrotron radiation accelerator (a high-powered electron microscope that will analyze basic molecular structure) is scheduled to be operational by 1994. Pohang Iron and Steel and the South Korean government will each provide 50 percent of the accelerator's $250,000,000 cost. In terms of gross national product, Postech's leaders say the project compares to the superconducting supercollider in Texas.[297]

Persuading U.S.-trained Korean scientists and engineers to come home is an essential component of Korea's carefully calibrated attempt to break the American grip on the applications-specific integrated circuit market, one of the most lucrative aspects of the semiconductor industry.[298] Samsung Gold Star Company and Hyundai Electron Industries, both leaders in Korea's booming semiconductor industry, are headed by recent defectors from Intel Corporation, Honeywell, Inc., and Digital Equipment. The Director General of Korea's Ministry of Science and Technology frankly admits that Koreans trained in the U.S. are one of his nation's most important technological resources.[299] By some estimates, returning Koreans have helped that country reduce the U.S. lead in semiconductor technology by five years.[300] That is why Korean conglomerates such as the huge Daewoo Industrial Group began to send corporate emissaries to the U.S. during the 1980s to persuade talented Korean engineers to return home and participate in the national economic renaissance.[301]

The Korean government estimates that since 1968, over 1,200 expatriates have returned to staff government laboratories and universities, most coming since 1982.[302] Indeed, a measure of the reverse brain drain can be seen in the fact that the Pohang Institute of Science and Technology was able to hire 140 Korean faculty members in only 18 months, 120 coming from U.S. universities and laboratories.[303]

Some U.S. policy analysts worry in public that these returnees are making Korea and other Asian economies competitive to the point that a serious transfer of technology has taken place.[304] As an example, a former NASA engineer helped Daewoo build an automobile and automated diesel engine plant that began production in 1986. Consequently, Daewoo now builds its own engines and no longer has to license foreign designs.[305] A metallurgical engineer, Choi Won Jib, returned from the University of Kentucky to help the Pohang Iron and Steel Company develop a malleable steel that makes Korean automobile bodies more competitive with their U.S. counterparts. Kwon Oh Joon left a postdoctoral appointment at the University of Pittsburgh in 1986 to introduce to the Pohang Iron and Steel Company methods of reducing the carbon content in hot-rolled steel. Now Pohang sells the higher-quality steel for $400 per ton, 33 percent more than it could command before this breakthrough.[306]

U.S. industry can no longer assume that Korean graduate students in science and engineering will also stay after graduation. That is why some business executives, as early as 1989, advocated that foreign engineering and science students should be required to sign an agreement requiring them to work three to five years in the U.S. after graduation.[307]

Return And Reentry: Those Professionals Coming Are Not Necessarily Staying

The homeward migration of Asian scientific and engineering professionals is not irrevocable. Indeed, at different points in their careers, the same scientists or engineers may lecture or conduct research in Asia, the U.S., or both depending upon the needs of the moment.[308] As the developing countries expand their economy, they increase their capacity to make use of highly educated citizens, thus permitting them to retain a greater proportion of this class.

That is exactly what has happened in Taiwan. Between 1960-1979, Taiwan sent 50,000 college graduates overseas for advanced study, but only 6,000 came back.[309] Half of those who did later left again. By contrast, the recent economic boom has raised the overall return rate from about 8 percent in the 1960s and 1970s to approximately 20 percent in the mid-1980s.[310] In Singapore, to cite another example, the government accused Australia in the early 1970s of stealing Singapore's best workers. By the 1980s, however, Singapore had become a net importer of educated professionals.[311]

What has happened in Taiwan and Singapore demonstrates that a developing nation can entice highly educated labor back home as a consequence of economic growth. Advanced economies attract highly educated workers in science and engineering for three reasons: (1) their economies are large enough to afford a high level of division of labor, thus facilitating specialized research and the creation of a professional work force with a distinct identity; (2) they have accumulated scientific knowledge and the requisite social infrastructure to foster an inviting research environment; and (3) there is large-scale government funding for research and development, especially for the military that, in turn, generates new job opportunities in the private sector.[312] Korea, Taiwan, and the other rising Asian economies now have, or will soon develop, a large enough industrial base to offer their graduates appropriate opportunities at home. They will no longer be compelled to leave to remain a part of the world scientific community.

The China Question: What If This Mass Producer Of Scientific Talent Stops The Annual Exodus Of Talent?

The case of the PRC deserves special mention. By virtue of sheer numbers, the Chinese student, on all levels, has become the foreign prototype in the U.S. for science and engineering. The PRC is changing. It is the world's most populous nation whose gross domestic product could readily quadruple in the next 20 years; a nation whose banks now hold some $40 billion in hard currency, about equal to U.S. holdings; and that runs a trade surplus of about $13 billion with the U.S., second only to that of Japan.[313] The PRC's university system, however, has not kept pace and is totally unable today to support and sustain massive economic growth. There are only 1.5 million college students in the PRC, a percentage of the population smaller than America's 100 years ago. Even India, with a literacy rate only one-half that of the PRC, has four times as many university students.[314]

China's leaders realized that their economic growth could be aborted by a shortage of engineers and scientists, as well as other educated professionals. Emulating what South Korea did some 40 years ago, the PRC sought to solve its education problems by sending its best minds abroad. The question arises, however, as to how long the PRC government will permit some 40,000 students to leave each year, not knowing whether or when they will return.[315] Only 25 percent of the scholars sent abroad by the Chinese Academy of Sciences since the doors swung open in the late 1970s have returned. In April 1992, the Chinese Academy admitted that over the previous 14 years, only 3,700 of the more than 15,000 students and scholars it had allowed to study abroad had come home.[316]

PRC officials now are openly anxious over what they perceive to be a critical shortage of qualified researchers and professors in the sciences. The core of Soviet-trained professionals will retire during the decade of the 1990s without a younger generation ready to replace them.[317] As in the U.S., the cadre of scientific professionals in the PRC is an aging one. Only 20 percent of the researchers in the Chinese Academy in 1988 were between the ages of 36 and 45, as compared to 59 percent a decade earlier.[318] Ninety-six percent of university professors and 77 percent of associate professors at Chinese universities are older than 51.[319] There is reason to believe that in the near future, Chinese universities will be more reluctant to allow junior faculty to go abroad. After all, these were the most vocal supporters of the pro-democracy movement and are widely perceived to be looking for a way to avoid even tighter bureaucratic control over their research.[320]

Even at the height of Sino-Soviet collaboration in the 1950s, by way of comparison, there were never more than about 500 PRC students studying in the former Soviet Union at any one time.[321] As a result of the Tiananmen Square massacre-induced delayed return of students at foreign universities, the PRC has recently tended to permit foreign study only in select fields, decreased the quotas for undergraduate or master's-level study abroad and increased the number of older students studying for the doctorate.[322] Additionally, the PRC is now attempting to encourage students to come back by establishing post-doctorate research stations across the nation and a national service center to assist returning students.[323] There is also a tendency to send students to Europe, New Zealand, Australia, or Japan rather than to the U.S.[324] At present, and probably for the foreseeable future, the PRC's effort to restrict foreign study will not prevent growing enrollment of Chinese students at U.S. colleges and universities. Indeed, the number of such students, according to the Institute of International Education, continues to rise at a rather dramatic rate.[325]

At least in the field of chemistry, however, some corporate recruiters believe that the level of quality has fallen off somewhat in recent years. Dr. James D. Burke, Manager of Professional Recruitment at the Rohm & Haas Research Laboratories, believes that initially, the Chinese researchers were clearly superb since they were the top chemistry talent in China. Dr. Burke contends that in the aftermath of the Tiananmen Square massacre, however, the Chinese government is no longer allowing the very best people in chemistry to come out. He thinks that, right now, the Chinese chemistry Ph.D.s are on a level with the best American Ph.D.s but that in previous years they were clearly superior.[326]

Dr. Burke also concludes that the Europeans and the Japanese have essentially stopped coming for graduate chemical education, although he suggests that Japanese women may continue to come because there is very little professional opportunity for them in their own country.[327] Dr. Burke argues that it will be a long time before the PRC's economy and university system can compete with the U.S. so that the PRC government will not entirely shut off the flow of chemistry Ph.D.s, although, as noted above, he believes that the quality has already declined.[328] The question presents itself: Is the PRC government holding back its best minds to stock the teaching ranks of its universities in an effort to copy the Korean model? The

Wall Street Journal has already published examples of young Chinese professionals returning to the PRC, planning to be on the ground floor of an economic revitalization.[329]

No Key To The Executive Suite: Top Scientists And Engineers Have More Opportunity For Advancement In Their Home Countries

Recently, the director of Taiwan's science division at its Los Angeles Diplomatic Mission reported that an estimated 6,000-7,000 Taiwanese scientists and engineers had gone home over the previous three years. The vast majority were newly graduated students who, in years past, would overwhelmingly have stayed in the U.S.[330] Aerospace layoffs and rising wages in Taiwan help, in part, to explain this exodus. But that is not the whole story. Cultural bias and racial stereotypes, particularly as these factors limit management opportunities for Asian and Asian-American scientists, have also played a part.

Asians account for 24 percent of the Hughes Aircraft technical staff, according to an internal study done by UCLA professor William Ouchi; yet they are only five percent of the managers. At TRW, Asians are 20 percent of the aerospace engineering and science staff but just 11 percent of the managers.[331] Some Asian-American engineers have reportedly been denied top security clearances because they have relatives in the PRC or North Korea, thus raising questions of alleged dual loyalty and creating intense professional bitterness among those whose careers are handicapped.[332] Reportedly, U.S. aerospace firms are reluctant to allow their Asian employees, particularly recent immigrants, to become actively involved in forging business ties to Asia.[333] Consequently, there is a disproportionately high turnover of Asians as they look for management opportunities elsewhere. The concern is that top Asian graduates may not pursue aerospace careers in the U.S. and that Asian immigrants may go back to their home countries.[334] In fact, this is already happening to some extent as reflected by the example of former Asian-American TRW researcher Peter Tai and former Aerospace Corporation researcher Frank Wong who are now developing Taiwan's satellite program.[335]

When Will The Foreign Scientists Depart, Leaving U.S. Technology Crippled?

While 62 percent of those international students who earn doctorates in engineering, physics and mathematics stay in the U.S. after graduation, all but 12 percent of these do so on temporary visas.[336] Academia's current level of dependence on foreign students creates an interesting predicament. If foreign students were removed from U.S. classrooms, academia could not support itself. Serious downsizing and dislocation would result. Once the downsizing occurred, the U.S. would no longer have the infrastructure necessary to develop the scientific and engineering skills required in the 21st century. While the absolute numbers of foreign students in the U.S. continues to go up, the rate of increase is slowing. In the U.S., the annual increase has dropped to only 1.5 percent for the period 1983-1985 as contrasted to an annual increase of more than 10 percent in the previous decade.[337] Moreover, a 1986 report from the National Youth Commission for the Republic of China revealed that the largest proportion of returned students from 1971 to 1985 were engineering students as compared to any other discipline.[338]

We should be most concerned over the possible return of Asian scientists and engineers to their countries of origin. In 1989, Taiwan ranked first in total numbers of foreign Ph.D.s and supplied the most non-U.S. Ph.D.s in engineering and life sciences.[339] Taiwan also ranked second in physical sciences, right behind the PRC.[340] Korea, the second largest source of Ph.D.s overall, ranked second as a source of supply for engineering Ph.D.s.[341] India and the PRC were third and fourth, respectively.[342]

Asians accounted for more than 50 percent of all scientists and engineers immigrating to the U.S. from 1970-1985.[343] Encouraged by the abolition of national origin quotas in 1965, Asian graduate engineering students have flocked to U.S. universities in unprecedented numbers. By 1984, they earned nearly 70 percent of foreign engineering Ph.D.s.[344] The PRC has shown perhaps the most dramatic growth, more than tripling the number of Ph.D.s between 1986 and 1989.[345] Bear in mind that before the 1978 Sino-American Understanding on Educational Exchanges, the PRC only allowed its students to study languages in the U.S.[346] Because it is so relatively recent, the Chinese impact on graduate education in the sciences and engineering is doubly impressive.

As the U.S.' trading patterns have shifted away from Europe and toward Asia, the number of European students coming to study science and engineering has declined while the number of Asian students has soared in these same fields. By the mid-1980s, there were 9,000 Taiwanese students studying in the U.S. compared to 6,000 from all West European nations; 75 percent of these Taiwanese students were studying science and engineering at the graduate level.[347]

The percentage of foreign doctorate recipients in science and engineering on temporary visas who indicate that they will stay has increased from 38.5 percent in 1970 to 54 percent in 1990.[348] However, we are essentially talking about post-doctoral appointments which, by definition, soon end. Neither the NSF nor the National Research Council really knows what happens next. It is distinctly unlikely that a flood of returning scientists and engineers will soon leave U.S. industry bereft of research talent. Yet the possibility that they will eventually stop coming, or will go home, can no longer be dismissed cavalierly. Careful planning must now take place--while there is still time.

THE CRISIS IN U.S. SCIENCE AND MATH EDUCATION

Who Will Take The Place Of The Foreign Scientists And Engineers On Whom We Currently Rely?

If we accept the possibility that foreign scientists and engineers might either go home in large numbers, or simply not make the trip here at all, then the question arises as to who, if anybody, will replace them. This is a question that has taken on special urgency in recent years as the full dimensions of the crisis in science and mathematics education in the U.S. have become increasingly evident.

The U.S. system of pre-college mathematics and science education has faltered. There is no more grave threat to America's future. Our universities can neither function nor flourish in a vacuum. This does not mean that the U.S. can no longer boast of bright and inquiring minds. It does mean, however, that unless and until large numbers of Americans become scientifically literate, as a nation we will remain unable to compete in the global economy of the 21st century without the active and continuing contributions of foreign scientists and engineers. Forsaking such assistance out of a false sense of national pride, or denying the need for it, will only serve to deprive this country of a plan for the future and a policy for the present. Rather than seeking to scapegoat the foreign scientist or engineer as a despised symbol of our technological malaise, we would do well to honor them as invited guests whose shared commitment to the maintenance and restoration of American competitiveness can mirror our own.

Lower down the education ladder, indicators are more discouraging. Only about 40 percent of high school students ever take a chemistry course; no more than about 20 percent ever take physics, fewer than 10 percent take calculus in high school and 70 percent do not bother with algebra.[349] In 1992, the U.S. Department of Education's National Center for Education Statistics and the NSF asked the Educational Testing Service, a New Jersey-based educational research consultancy, to conduct an international study on the science and mathematics skills of 9- and 13-year-olds in the U.S. and several other countries.

In both mathematics and science, U.S. 13-year-olds ranked at the bottom, averaging much less than all other students except those from Ireland and Jordan in science, and only those from Jordan in mathematics. South Korea and Taiwan, by contrast, were consistently at or near first place.[350] U.S. 13-year-olds did lead the world in watching television. The number of students watching five hours or more per day here was more than twice that of the highest-ranked countries.[351] By the third grade, half of all American students don't want to take any more science; fewer than 50 percent ever take a math or science course after the 10th grade.[352]

In a landmark April 1983 open letter to the American people, the National Commission on Excellence in Education warned that the U.S.' once unchallenged dominance in science and technology was rapidly being overtaken by foreign competition. The Commission proclaimed that the educational foundations of American society were being washed away by a tide of scientific illiteracy that placed the nation's survival at risk. If a hostile foreign power had secretly schemed to impose this sorry state of affairs upon America's school children, the Commission was confident that most parents would have regarded this as a blatant act of war. Yet this is precisely what the Commission believed we had allowed to happen to ourselves.[353] According to the Labor Department, more than 50 percent of U.S. high school graduates do not have the analytical skills needed for employment. Minority groups, who by the year 2000 will constitute fully one-third of all students, are in even worse shape.[354] The National Research Council estimated that 75 percent of high school graduates would flunk out of a college freshman mathematics or engineering curricula course.[355] A 1991 study by the Council of Chief State School Officers revealed that less than 50 percent of U.S. high school graduates had taken chemistry and Algebra II, both of which are considered necessary for college courses in mathematics and science.[356]

On the average, U.S. elementary schools devote 15 minutes daily to science.[357] Almost 80 percent of elementary school teachers saved science instruction for the last period of the day.[358] In 1986, the National Science Teachers' Association conducted a study which revealed that of the nation's 24,000 high schools, almost 30 percent offered no physics courses, 17.5 percent no chemistry and 8 percent no biology.[359] In that same study, the majority of teachers on the pre-college level characterized their own preparation to teach science as adequate or minimal at best.[360] Ten years ago, science educators worried over the fact that over 50 percent of high school science classes provided no laboratory experience for students.[361] A decade later, things had only gotten worse. In 1991, less than 39 percent of junior and senior high school science classes offered any laboratory activity.[362]

Not only does the pre-college system of science and mathematics education not help, it seems to actively discourage interest in these fields. Studies reveal a persistent decline in math and science interest from high school through the Ph.D. In one study, 750,000 out of 4,000,000 high school sophomores expressed an interest in the natural sciences and engineering. By their senior year, this number had fallen to under 600,000. When they registered for college, the number was down to 340,000; by the time of college graduation only a little over 200,000 received a B.S. degree in the natural sciences and engineering. Of the 61,000 who entered graduate school, fewer than 10,000 would get the Ph.D. degree in the natural sciences and engineering.[363]

Since most elementary education majors do not take chemistry, physics, or science, whether in high school or in college, it is rather unremarkable to realize that they don't teach it very well.[364] This, in turn, serves only to discourage what little student interest has miraculously managed to survive. Perhaps that is why a national assessment of educational progress conducted in 1990 found that less than one-half of eighth-graders could tell the weight of a 30-pound object when taken to the moon after being told that the object's moon weight was 1/6 of its weight on earth.[365]

Engineers and scientists, regardless of degree level, are not instant creations or overnight wonders; they must be nurtured with great care for a long time. This is especially true for the best minds whose innovative insights create jobs and whole industries where none existed before. If the U.S. is to become and remain intellectually self-sufficient in science and engineering, it must have an educational system committed to the pursuit of technological excellence as a well-defined national priority and be capable of achieving it. Until that happens, to suggest that the U.S. suffers from an overabundance of scientific and engineering expertise, whatever its origin, is to ignore reality.

Academic Trends In Higher Education

Selection of any natural science or engineering field as a major area of study consistently declined throughout the 1980s. Interest peaked in 1982 for engineering and computer science but has dropped by 25 percent in engineering and more than two-thirds in computer science since then. Interest in science or physical science as majors has declined at a slow but steady pace for 15 years.[366] We are not only talking about the marginal students; the percentage of National Merit Scholars electing engineering majors dropped from 20 percent in 1983 to 16 percent in 1988.[367] In 1970, according to a survey by the National Science Teachers' Association, 52,400 college and university freshmen planned to major in math or statistics; this number had declined to just over 10,000 in 1980--an amazing 80 percent drop.[368] From 1970-1980 there was a 41 percent decline in the number of college and university graduates holding math degrees and a 63 percent decline in the number of physics graduates.[369]

Data on the plans of freshmen entering college in 1989 and 1990, however, suggests that this precipitous drop in the natural sciences and engineering may have bottomed out and could begin to increase in the 1990s.[370] Interest in computer science, somewhat surprisingly, has not shown similar signs of recovery.[371] While it is true that the number of students at U.S. universities earning doctorates in science and engineering rose in 1991, the absolute number of American students earning such degrees fell slightly from the previous year, although the number of women and minorities did increase. It is only because more foreign students earned Ph.D.s in science and engineering in 1991, up 37.9 percent from 22.2 percent a decade earlier, that the 1991 figures look more favorable.[372]

While demography is not destiny, the declining interest in mathematics and science is compounded by the fact that fewer American students will be making any choice whatsoever. As a segment of national population, the 18-24 year old age group will decline by roughly 20 percent between 1990-2000.[373] This means that precisely when many experienced scientists and engineers who entered the work force after Sputnik will be retiring, the replacement pool will be dramatically constricted. It is possible that to some extent, declining enrollments will shrink the need for more faculty, or that industrial reorganization will permit greater efficiencies with fewer employees. Yet it seems no less plausible to predict that both corporate and federally sponsored research and development may have to be postponed, delayed, or reduced due to a shortage of top scientists and engineers, unless the foreign pipeline remains open.

It is not only American students who are increasingly disinclined to go into science. Last year, for example, nearly 40 percent of all Japan's doctoral students in engineering came from overseas.[374] The science and technology agency in Japan predicts that by the year 2005, Japan will need 980,000 researchers but will only be able to generate 500,000. Consequently, in 1990, 15,000 of Japan's largest companies reported 18 percent of their research slots vacant.[375] As in the U.S., Japanese students are looking to make easy money elsewhere; the Japanese are reportedly turning to women for their scientists rather than attempting to increase salaries.[376] Five of Japan's largest electronic companies are unable to increase research and development spending above 1991 levels and a sixth was forced to cut back. These six companies accounted for more than 50 percent of all Japanese industrial spending on research and development in 1991. The retrenchment was most severe in the semiconductor industry.[377]

We would do well to remember that in a knowledge-based economy of global dimensions, international influence is largely a function of technological supremacy. Economists estimate that fully one-third of the gain in gross national product (GNP) from 1948-82 was attributable to an increase in the educational preparation of the American work force and that one-half of the rise in GNP resulted from technological innovation and advanced expertise.[378] If these trends falter, or even are reversed, can we realistically expect our national economy to emerge unscathed?

The collapse in pre-college science and math education is inextricably linked to instructional difficulties on the baccalaureate level. In turn, these diminish both Ph.D. production and quality among American citizens in graduate school. That is why the failure to capture young minds for science in the elementary and junior high grades makes it infinitely more difficult years later for American industry to wean itself from a dependence upon foreign scientists and engineers. The issue is not simply, or even primarily, one of numbers but of quality. Any educational system that must devote so much time, money and energy to remedial efforts will inevitably have fewer resources of all kinds to nurture the talented few. So long as U.S. graduate schools can skim off the cream of science and engineering students from around the world, thus providing the nation with an enormous intellectual subsidy, the full impact of the crisis in science and math education will not be readily apparent.

Science And Engineering Majors

Even when entering freshmen select science or math as their likely major, the impact of inadequate preparation holds them back. Kay A. Connor, undergraduate advisor to chemistry and science majors at Purdue University, analyzed the 1987 freshman class. There were 97 entering freshman chemistry majors; by the fall of 1989, only 15 were left. From 1985 to 1988, only 74 out of 379 chemistry majors stayed the course.[379] In the fall 1989 term, Connor put together a profile of incoming Purdue freshmen. Of the 95 chemistry majors, she found much to her surprise that 40 percent had to start out in remedial math, despite the fact that all of them had taken at least three semesters of algebra with high grades and most had studied at least one semester of trigonometry.[380] Despite their best intentions, the math and physics necessary to sustain a major in chemistry were simply too tough.[381]

The impact that such numbers have on the pipeline for chemistry Ph.D.'s is easy to observe. Even if attitudes of incoming freshmen could be changed and their preparation could be miraculously upgraded overnight, it would be 11 years before any impact could be felt.[382] That is why Dr. Paul D. Gassman, University of Minnesota Chemistry Professor and then-President of the American Chemical Society, said almost three years ago that it would take a minor miracle to graduate as many American Ph.D. chemists in the year 2010 as earned the degree in 1985.[383]

Lack Of Qualified Teachers

U.S. high schools are also unable to recruit adequate numbers of qualified physics and chemistry teachers. Every two years, the American Institute of Physics, with the aid of the American Association of Physics Teachers, conducts a national survey of high school physics teachers. In the 1989-90 survey, the American Institute of Physics polled high school principals about their experience recruiting physics and chemistry teachers. Fully one-third of those high schools surveyed were currently looking for such teachers and many had encountered strong problems in locating qualified candidates. One-half of these schools were looking for a physics teacher and one-third were searching for a chemistry teacher.

Some small schools reported having to drop the physics or chemistry course altogether, while in larger urban districts, the most frequent alternative was to draft an unqualified teacher and place him or her in the physics classroom.[384] In fact, almost one-third of the physics teachers who taught one or more physics classes had been drafted without adequate preparation or background.[385] Bill G. Aldridge, Executive Director of the National Science Teachers' Association, explained that contrary to what we might think, of the 8,000 high schools surveyed in 1990-1991, 80 percent of what physics teachers taught was not physics; rather, it was mostly math, business and meteorology.[386]

As in Japan, this fundamental educational breakdown is having a practical impact. The U.S. is losing ground in the global market for high-technology products. In 1988, our nation supplied 37 percent of these products for the world market, down from 40 percent 10 years earlier.[387] While we still continue to maintain a trade surplus in high technology, the 1988 balance was only one-half the 1980 surplus. While academic research and development rose during the late 1980s, it did so at a slower pace than during the first half of the decade.[388] That may be one reason why the National Science Board noted, with some degree of concern, that U.S. corporations were spending an increasing amount of corporate research and development dollars at foreign facilities.[389] Failure to reverse the continuing decline in science and technology education can only cost American jobs in the future, for it is in these areas that new job growth is most likely to occur.

The crisis in science and mathematics education in the U.S. is not simply a failure to stimulate graduate degree production. Rather, it is a lack of basic science and math literacy among all Americans, regardless of their level of education. The issue is not one of advanced degrees but an ability to endow the nation's populace with the basic skills that will permit them to compete in the next century.

Where Do We Go From Here?

Enhanced restrictions on the entry and employment of foreign scientists and engineers would seem contrary to the U.S. national interest. In the long run, it seems abundantly evident that the best scientific and engineering minds who come to this country from around the world can play a critical role in making the U.S. the leader in technology for the next century. Seizing this competitive edge will, despite current hard times, be the key to full employment in science and engineering. For that reason, experts in industry recruitment still argue that the U.S. should exploit the competitive advantage offered to it when the top brains of other countries in science and engineering come here for training and post-graduate employment.[390]

U.S. universities have been unable or unwilling to attract sufficient numbers of American graduate students to meet the demands of industry and academia for highly trained scientists and engineers. Xerox Corporation told Congress in 1987 that its need for graduate-level computer scientists far outstripped supply. Hewlett-Packard warned that both national security and America's competitive position in the global marketplace could be seriously harmed by the existing shortage of graduate electrical engineers and computer scientists.[391] So eager are the U.S.' top research universities, such as MIT and Stanford University, to entice foreign scientists to come to the U.S., that representatives from these institutions have gone to Israel in an attempt to persuade top Russian-Jewish scientists to emigrate to this country.[392] So intense has international economic competition become that in an effort to slow down the onrushing development of science and technology abroad, leading U.S. research universities suddenly find themselves under mounting pressure to limit their ties to foreign companies and strengthen the U.S. position in science and technology.[393]

As the 20th century draws to a close, U.S. universities are faced with a difficult choice. Some critics suggest that only by limiting foreign access to our universities can we hope to increase the number of American-born engineers and scientists. The experience of the 1980s, however, offers little reason to believe that vast new numbers of American students will enter these fields in the near future.

This may not be an American problem, but appears to be a character flaw of affluent societies in general. Some observers note that Europe, North America, and increasingly, Japan, tend to produce students who are reluctant to confront or endure the intellectual rigors of science and engineering in preference to what they perceive as the softer, and more attainable, pursuits of law, finance, real estate and communications. In 1991, for example, 50 percent of graduates in the computer science department at Tokyo University elected careers in such non-industrial disciplines.[394] Most European countries, including France, Britain and Italy, now generate only about one-half of the new engineers their industries require each year.[395] Consequently, it appears that for the more developed nations the best, and perhaps the only, way to amass more technically competent people is through immigration from the developing countries that still produce an excess of available scientists and engineers.[396] From this perspective, rather than trying to eliminate or choke off the flow of foreign graduate students, U.S. universities and government officials should be looking for ways to speed up the process by which foreign scientists and engineers can use their talent to enrich our national economic welfare.

CONCLUSION

The national security of the U.S. will depend as much in the 21st century upon our resources in science and engineering as upon our military strength and political leadership. For the foreseeable future, notwithstanding the economic dislocation caused by the collapse of the Soviet Empire and the end of the Cold War, the U.S. will continue to rely upon foreign scientists and engineers, especially in areas of high-technology research and academia. At the same time, we must acknowledge that American engineers and scientists do have legitimate employment concerns that must be addressed. We in the immigration bar must not only be aware of these concerns, but seek to satisfy them in a manner compatible with the best interests of our clients. Only by so doing can we hope to create an enduring national consensus for an enlightened and humane immigration policy.

In a time of widespread unemployment among certain engineering and scientific subdisciplines in select areas of the country, it becomes tempting for the press and public to point to foreign scientists and engineers as the root cause of the problem. This is unfair, but perhaps inevitable. Those who decry such tactics must adopt a counterintuitive approach that seeks to look beyond the problems of the present to the needs and opportunities of the future.

The immigration bar has not sought to build bridges to the American scientific and engineering community. Consequently, it regards us as hired guns interested only in making money and unwilling to tell or acknowledge the truth. Ours is not the popular cause in a nation that continues to be unsure of its future and itself. While the American engineering and scientific community is in a stronger political and public relations position, it too must understand that in a very real sense, the continued industrial supremacy and research capacity of this nation depends upon a steady and continued supply of foreign scientists and engineers.

Unless and until the crisis in U.S. science and engineering education is solved, or substantially ameliorated, the pipeline problems will be so severe that the U.S.' research capacity, particularly its corporate facilities, would be massively disrupted if the foreign supply of scientific talent dried up without advanced warning.

The American scientific and engineering communities cannot avoid the economic trends of the 21st century. We will witness an increasing amount of intellectual outsourcing as the revolution in research and scientific communications develops to a greater extent than any of us can dream of today. The need for physical proximity in applied research will continue to decline. Foreign engineers, particularly in India and the economies of Asia under the Chinese influence, will find themselves increasingly able to remain at home and pursue their careers. That is something for American engineers to be concerned about. These kinds of globalized developments, and the resulting cost savings open to U.S. corporations who take advantage of them, cannot be curtailed by changes in U.S. immigration law.

As the globalization of American business increases, it is likely that foreign operations will, to a large extent, subsidize the less profitable domestic ones. From this perspective, the practice of intellectual outsourcing, so feared by American engineers, may ultimately prove to be their unwitting ally in the preservation of a domestic engineering base, albeit on a reduced scale. Certainly, the market realities of applied research will never permit the total elimination of physical proximity as a necessary ingredient of collaborative research. For this reason, our immigration policies, as they affect foreign scientists and engineers, will remain relevant for a long time to come. Their importance, however, will inevitably diminish.

It is in the interest of the immigration bar to understand why American scientists and engineers are concerned, but it is in the interest of our scientific and engineering community must realize that in a global economy, the interests of all must be balanced. Nations that can do this in an efficient and compassionate manner will seize and keep the competitive edge as science and immigration learn to coexist in the age of technology.

FN 1. This BRIEFING uses the terms "foreign" and "foreign-born" interchangeably.
FN 2. The term "shortage/no shortage debate" refers to the current debate as to whether the U.S. is experiencing (or will soon experience) a shortage of qualified U.S. workers in the science and engineering professions.
FN 3. Immigration Act of 1990 (IA90 or 1990 Act), Pub. L. No. 101-649, 104 Stat. 4978 (adding or amending many sections of the INA) (signed by the President on Nov. 29, 1990).
FN 4. Burke, "Hiring the Foreign Scientist," Chemtec, Feb. 1993, at 14-18.
FN 5. I. Asimov, Asimov's New Guide to Science 384 (Basic Books 1984).
FN 6. Congressional Research Service of the Library of Congress for Task Force on Science Policy, The Nobel Prize awards in Science as a Measure of Nat'l Strength in Science, House Comm. on Science and Technology, 99th Cong., 2d Sess. (1986).
FN 7. Id.
FN 8. Burke, supra note 4.
FN 9. Wulforst, The Rocketmakers 37 (Random House 1990).
FN 10. Id. at 76.
FN 11. W. E. Burrows, Exploring Space 37 (Random House 1990).
FN 12. R. Rhodes, The Making of the Atomic Bomb (Simon & Schuster 1986).
FN 13. Id. at 479.
FN 14. Id. at 777.
FN 15. Id. at 774.
FN 16. Heppenheimer, "How Von Neumann Showed the Way," 6 American Heritage of Invention & Technology no. 2 (Fall 1990).
FN 17. Ferris, "The Red Limit," Quill, 1983, at 104.
FN 18. Riordan, The Hunting of the Quark (Simon & Schuster 1987).
FN 19. Asimov, supra note 5, at 627.
FN 20. Id. at 835.
FN 21. Id. at 560.
FN 22. Burke, supra note 4, at 14-18.
FN 23. Kotkin, "Enrolling Foreign Students Will Strengthen America's Place in the Global Economy," Chron. of Higher Educ., Feb. 24, 1993, at B1, col. 3.
FN 24. Id.
FN 25. Burke, supra note 4, at 14-18.
FN 26. Id.
FN 27. Id.
FN 28. Id.
FN 29. Id.
FN 30. Id.
FN 31. Id.
FN 32. Id.
FN 33. Id.
FN 34. Projecting Science and Eng'g Personnel Requirements for the 1990's: How Good are the Numbers: Hearing before the Subcomm. on Investigations and Oversight of the Comm. on Science, Space, and Technology, 102d Cong., 2d Sess. at 1-3 (1992) (hereinafter Science Committee hearing).

FN 35. Immigration & Nationality Act of 1952 (INA) § 203(b)(1), 8 USC § 1153 (b)(1) (added by § 121(a) of IA90).
FN 36. INA § 214(g)(4); 8 CFR § 214.2(h)(15)(ii)(B)(1).
FN 37. IA90 § 205(c)(3) (adding INA § 212(n)).
FN 38. Tai, "Prevailing Wage Has High-Tech Companies on Edge," Star Tribune, Sept. 29, 1991, at 19A.
FN 39. Burke, supra note 4, at 14-18.
FN 40. Discussed at infra notes 131-156 and accompanying text.
FN 41. See infra text accompanying notes 102-111 for a discussion of the labor market information (LMI) pilot program.
FN 42. See 70 Interpreter Releases 893, 894 (July 12, 1993).
FN 43. See, e.g., open Prodigy E-Mail letter from Seth Fellin to the membership of the American Engineering Association, June 5, 1993 (provided as Appendix A) (hereinafter Fellin letter).
FN 44. Bromley, "The Role of Human Resources in Our Nat'l Competitive Stance," 1990 Symposium on Human Resources in Science and Technology: Improving U.S. Competitiveness 5 (Washington, D.C., Mar. 15-16, 1990) (available from Comm'n on Professionals in Science and Technology, 1500 Massachussetts Avenue, N.W., Suite 831, Washington, D.C. 20005).
FN 45. Science Policy Study-Report of the White House Council Panel on the Health of U.S. Colleges and Universities: Hearing before the Task Force on Science Policy of the House Comm. on Science and Technology, 99th Cong., 2d Sess. 17 (1986) (testimony of David Packard on shortage of eng'g faculty) (hereinafter Packard testimony).
FN 46. Id. at 5-6.
FN 47. Vetter, "Foreign Citizens Among U.S. Scientists and Eng'rs," Occasional Paper No. 92-2 at 11 (Aug. 1992) (available from Comm'n on Professionals in Science and Technology, supra note 44).
FN 48. Vetter, "Supply and Demand in Science and Eng'g," Occasional Paper No. 91-4 at 5 (Jan. 1992) (available from Comm'n on Professionals in Science and Technology, supra note 44) (hereinafter Vetter, Occasional Paper No. 91-4).
FN 49. Vetter, "Foreign Citizens Among U.S. Scientists and Eng'rs," supra note 47, at 6.
FN 50. Id. at 12.
FN 51. Id. at 7.
FN 52. See infra notes 182-227 and accompanying text.
FN 53. Burke, "Foreign Scientists and Eng'rs in the Domestic Workforce," American Chemical Soc'y Workforce Rep., Dec. 1992, at 1, 3.
FN 54. Id.
FN 55. Id. at 2.
FN 56. "Wanted: U.S.-Born Graduate Students," 128 Chemical Week 44, 45 (1981).
FN 57. Id.
FN 58. Id. at 44.
FN 59. Letter from Dr. Philip E. Schambra to Gary Endelman (Dec. 22, 1992) (discussing foreign scientists at the National Institutes of Health (NIH) laboratories).
FN 60. Id.
FN 61. Id.
FN 62. Increasing U.S. Scientific Manpower: Hearing before the Subcomm. on Science, Research and Technology of the House Comm. on Science, Space and Technology, 101st Cong.,

2d Sess. 31 (1990) (testimony of Dr. Richard Atkinson on shortage of scientists).

FN 63. National Science Foundation, Science Resources Studies Highlights No. 85-336 3 (Feb. 28, 1986).
FN 64. Id.
FN 65. Id.
FN 66. Id.
FN 67. Scientists and Eng'rs: Supply and Demand: Hearing before the Task Force on Science Policy of the House Comm. on Science and Technology, 99th Cong., 1st Sess. 599 (1985) (testimony of Dr. Simon Ramo, co-founder of TRW, Inc.) (hereinafter Ramo testimony).
FN 68. Id.
FN 69. Id.
FN 70. Id. at 70-71 (testimony of Dr. Daniel Rieppner on shortage of American physicists).
FN 71. Id. at 75.
FN 72. Id. at 599 (testimony of Dr. Simon Ramo).
FN 73. Id.
FN 74. Id. at 600.
FN 75. Id.
FN 76. Id. at 378 (testimony of Dr. Ralph F. Hirschman, Senior Vice President for Chemistry, Sharp & Dohme Research Laboratories, Rahway, NJ).
FN 77. Id. at 379.
FN 78. National Research Council, Office of Scientific and Eng'g Personnel, Summary Report 1989: Doctorate Recipients from U.S. Universities 9 (1990) (hereinafter 1989 Doctorate Survey).
FN 79. Id. at 56.
FN 80. Id.
FN 81. National Research Council, Office of Scientific and Eng'g Personnel, Survey Report 1983: Doctorate Recipients from United States Universities 13 (1983).
FN 82. Id. at 11.
FN 83. 1989 Doctorate Survey, supra note 78, at 40.
FN 84. National Science Foundation, Foreign Citizens in U.S. Science and Eng'g: History, Status and Outlook 12 (1985) (hereinafter Foreign citizens outlook).
FN 85. Id. at 160.
FN 86. Id.
FN 87. Id. at 50.
FN 88. Id. at 111.
FN 89. National Research Council, Office of Scientific and Eng'g Personnel, Comm. on the Int'l Exchange and Movement of Eng'rs, Foreign and Foreign-Born Eng'rs in the U.S.: Infusing Talent, Raising Issues 3 (1988).
FN 90. Id.
FN 91. Id. at 110.
FN 92. Id.
FN 93. Id. at 112.
FN 94. Id. at 114.
FN 95. Id.

FN 96. National Research Council, Office of Scientific and Eng'g Personnel, Comm. on the Int'l Exchange and Movement of Eng'rs, Foreign and Foreign-Born Eng'rs: Infusing Talent, Raising Issues 9 (1989).
FN 97. Id. at 10.
FN 98. Id. at 1.
FN 99. Id. at 19.
FN 100. E.g., "Giving U.S. Jobs Away," Seattle Times, June 20, 1993, at 1, § A; "Letters to the Editor," Seattle Times, June 27, 1993. See also "The Ph.D.s are Here, But the Lab Isn't Hiring: Waves of Unemployment Wash Up on Science's Shores," N.Y. Times, July 18, 1993, at E3. Even a writer in the prestigious New York Times has been pulled aboard the nativist bandwagon, perhaps not consciously, and certainly not overtly, but espousing an "Americans-first" mentality. In the second-to-the-last paragraph of the above-cited article, the presence of foreign-born students is tied to the unemployment situation of U.S. scientists. The author states that potential academic lab jobs for these recently unemployed U.S. scientists are unavailable because these positions are occupied by foreigners, "some of whom benefit from Federal grants and subsidies to the Universities." This aside is tremendously misinformative and plants a false perception in the minds of the reader that tax dollars are being spent on foreign students that should rightfully go to unemployed Americans. The subsidies and grants referred to go either to the university or to the professor heading the research, not to the student. It is usually the sending country that has borne the financial burden of educating these top-notch scientific minds from abroad. The benefit derived by the foreign student is the opportunity to take part in new research and to gain valuable practical experiences. As noted earlier, however, the benefits we receive from these foreign-born researchers are far more substantial.
FN 101. See Fellin letter, supra note 43. Note that the 99 percent approval rate for labor certifications statistic that was first "created" by the Houston Chronicle and is now being recited as fact, is erroneous and extremely misleading. It does not take into account 22.5 percent of labor certification applications that were cancelled by the Texas Employment Commission, and clearly misstates the 5.2 percent denial rate. In all, 27.7 percent, or roughly one-third of all labor certifications filed in Texas from Jan. 1, 1992 through May 25, 1993, were not approved. Source: Texas Employment Commission: open records request no. 32232, May 24, 1993, requested by Gary Endelman.
FN 102. See generally 67 Interpreter Releases 1477 (Dec. 21, 1990).
FN 103. See 70 Interpreter Releases 346 (Mar. 22, 1993).
FN 104. Letter from Robert B. Reich, U.S. Secretary of Labor to Jack Brooks, Chairman of the House Committee on the Judiciary (May 14, 1993).
FN 105. See supra text accompanying notes 41-43. See also "Foreign Worker Plan Hit: U.S. Scientists Fight Easing Hiring Rules," Boston Globe, July 14, 1993, at 41; "Senate Votes to Kill Alien Hire Program: Bill Would Revise Immigration Law," Houston Chron., July 20, 1993, at B2.
FN 106. Lepkowski, "Chemical Job Surplus Alleged, Finding Riles Scientists and Congress," Chemical and Eng'g News, Apr. 26, 1993, at 6.
FN 107. Id.
FN 108. Id.
FN 109. Id.
FN 110. Id.
FN 111. Id.

FN 112. See "Foreign Labor Proposal Draws Fire: Texas Scientific Jobs in Debate," Houston Chron., May 21, 1993, at 1, § B.
FN 113. See 70 Interpreter Releases 590 (May 3, 1993).
FN 114. "Bill Would Link Immigration, Jobless Rate," Houston Chron., May 26, 1993, at B1.
FN 115. E.g., "The Ph.D.s are Here but the Lab Isn't Hiring: Waves of Unemployment Wash Up on Science's Shores," N.Y. Times, July 18, 1993, at E3. The graph from this article (provided as Appendix B) clearly illustrates that unemployment rates in these broad technical fields react independently of each other, thus supporting the proposition that shortages can exist in a narrower field contemporaneously with surpluses in the broader composite fields or in unrelated technical fields. It is also important to note, however, that unemployment among scientists and engineers is historically half to one-third the national unemployment rate.
FN 116. Labstat Series Report, Labor Force Statistics--National, Unemployment Rate: Engineers, provided by Tom Nardone, Division of Labor Force Statistics, U.S. Bureau of Labor Statistics.
FN 117. Annual Average Industry and Occupational Tables, Table 32: Employed and Experienced Unemployed Persons by Detailed Occupation and Class of Worker, provided by Tom Nardone, Division of Labor Force Statistics, U.S. Bureau of Labor Statistics.
FN 118. Id.
FN 119. Labstat Series Report, supra note 116.
FN 120. Annual Average Industry and Occupational Tables, supra note 117.
FN 121. Id.
FN 122. Id.
FN 123. Id.
FN 124. Id.
FN 125. Id.
FN 126. Id.
FN 127. Id.
FN 128. Id.
FN 129. Immigration Act of 1989: Joint Hearings before the Subcomm. on Immigration, Refugees and Int'l Law of the House Comm. of the Judiciary and the Immigration Task Force of the House Comm. on Educ. and Labor, 101st Cong., 2d Sess. 869 (1990) (statement submitted for inclusion by the Manpower Committee of the U.S. Activities Board of the Institute of Electrical and Electronic Engineers (IEEE)) (hereinafter manpower hearing).
FN 130. Id.
FN 131. Science Committee hearing, supra note 34.
FN 132. Id.
FN 133. Id.
FN 134. Id.
FN 135. Id.
FN 136. Id.
FN 137. Id.
FN 138. Id.
FN 139. Id.
FN 140. Id.
FN 141. Id.
FN 142. Id.

FN 143. Id.
FN 144. Id.
FN 145. Id.
FN 146. Id.
FN 147. Id.
FN 148. Id.
FN 149. Fechter, "Eng'g Shortages and Shortfalls: Myths and Realities," The Bridge, Fall 1990, at 16-20.
FN 150. Id.
FN 151. Id.
FN 152. Id.
FN 153. Id.
FN 154. House, "NSF Projections in Science and Eng'g," The Bridge, Fall 1990, at 21-22.
FN 155. Id.
FN 156. Science Committee hearing, supra note 34, at 1-3.
FN 157. Vetter, "Recruiting and Retaining a Diverse, Quality, Technical Workforce," Occasional Paper No. 91-1 at 1 (May 1991) (hereinafter Vetter, Occasional Paper No. 91-1) (available from Comm'n on Professionals in Science and Technology, supra note 44).
FN 158. Id.
FN 159. Id.
FN 160. Manpower hearing, supra note 129, at 1-3.
FN 161. Id.
FN 162. Id.
FN 163. "As U.S. Employers Find Some Jobs Hard to Fill, They Turn to Foreigners," Houston Chron., May 2, 1993, at B1.
FN 164. Id.
FN 165. Id.
FN 166. Id.
FN 167. Id.
FN 168. Id. (quoting Charles Foster, an immigration attorney with Tindall & Foster in Houston, Texas).
FN 169. Id.
FN 170. Finn, "Foreign National Scientists and Eng'rs in the U.S. Labor Force, 1972-1982," National Science Foundation Study at 69 (1985).
FN 171. Id.
FN 172. Id. at 52.
FN 173. Id.
FN 174. Id. at 18.
FN 175. Finn, "Foreign Eng'rs in the U.S. Labor Force," Foreign and Foreign-Born Eng'rs in the U.S.: Infusing Talent, Raising Issues 100 (1988).
FN 176. Id.
FN 177. Id.
FN 178. Id.
FN 179. Id.
FN 180. National Research Council, Transportation Research Board Circular No. 357, National Impact of Foreign-Born Eng'rs 5, 13 (Mar. 1990).

FN 181. Kuswa, "Effect of Foreign Nationals on Federally Supported Laboratories," Foreign and Foreign-Born Eng'rs: Infusing Talent, Raising Issues 133 (1980).
FN 182. Kotkin, supra note 23, at B2, col. 1.
FN 183. Packard testimony, supra note 45, at 17.
FN 184. Id. at 19.
FN 185. National Research Council, Education and Employment of Eng'rs: A Research Agenda for the 1990s 19, n.23 (1989).
FN 186. Excellence in Mathematics: Hearings on the Science and Eng'g Act of 1990 before the Subcomm. on Labor, Health and Human Services, Educ. and Related Agencies of the Senate Comm. on Labor and Human Resources, 101st Cong., 2d Sess. 36 (1990) (testimony of Prof. Russell C. Jones, Research Professor at Univ. of Delaware, on eng'g faculty shortage) (hereinafter Jones testimony).
FN 187. Id. at 38.
FN 188. Id. at 156 (testimony of Dr. Richard Atkinson on replacement demand for Ph.D.s in science and eng'g).
FN 189. Vetter, "Replacing Science and Eng'g Faculty in the 1990's," Occasional Paper No. 89-4 (1989) (available from the Comm'n on Professionals in Science and Technology, supra note 44) (hereinafter Vetter, Occasional Paper No. 89-4).
FN 190. Id. at 4.
FN 191. Id. at 6.
FN 192. Vetter, "Replacing Eng'g Faculty in the 1990's," Eng'g Educ. 540 (July/Aug. 1989).
FN 193. Id.
FN 194. Vetter, Occasional Paper No. 89-4, supra note 189, at 6.
FN 195. Vetter, supra note 192, at 541.
FN 196. Id.
FN 197. Vetter, Occasional Paper No. 89-4, supra note 189, at 8.
FN 198. Id. at 10.
FN 199. Id. at 21.
FN 200. Id.
FN 201. Id.
FN 202. Id. at 54.
FN 203. Id.
FN 204. Id. at 21.
FN 205. Id.
FN 206. Science and Technical Educ.: Hearings before the Subcomm. on Science, Research and Technology of the House Comm. on Science, Space and Technology, 101st Cong., 2d Sess. 8 (1990) (testimony of Rep. Donald Retter (R-Pa.) on eng'g/scientific shortage).
FN 207. Scientific Manpower: Hearing before the Subcomm. on Science, Research and Technology of the House Comm. on Science, Space and Technology, 102d Cong., 1st Sess. 11 (1991) (testimony of Dr. Alan E. Fechter).
FN 208. Science and Eng'g Educ. and Manpower: Hearing before the Subcomm. on Science, Research and Technology of the House Comm. on Science, Space and Technology, 97th Cong., 2d Sess. 22 (1982) (testimony of Dr. Jerome Rosenberg).
FN 209. The Nat'l Eng'g and Science Manpower Act of 1982: Hearing before the House Comm. on Science and Technology, 97th Cong., 2d. Sess. 5 (1982).

FN 210. Corey & Kasunic, "Evaluating the 1980 Projections of Occupational Employment," 105 Monthly Lab. Rev. 22, 26 (1982).
FN 211. Id.
FN 212. Id.
FN 213. U.S. Dep't of Labor, Bureau of Labor Statistics, Occupational Outlook Handbook 63 (1990).
FN 214. Id. at 64.
FN 215. Zachary, "White Collar Blues: Like Factory Workers, Professionals Face Loss of Jobs to Foreigners," Wall St. J., Mar. 17, 1993, at 1, col. 1.
FN 216. Id. at 65.
FN 217. Id. at 66.
FN 218. Id. at 67.
FN 219. Id. at 67-68.
FN 220. Id. at 78-79.
FN 221. Id. at 80.
FN 222. Id. at 91.
FN 223. Nat'l Research Council, Educ. and Employment of Eng'rs: A Research Agenda for the 1990s, 17, n. 23 (1989).
FN 224. Silvestri & Lukasiewicz, "Projections of Occupational Employment in 1988-2000," 112 Monthly Lab. Rev. 42, 44 (1989).
FN 225. Silvestri & Lukasiewicz, "Occupational Employment Projections 1990-2005," U.S. Dep't of Labor, Bureau of Labor Statistics, Outlook: 1990-2005 62, 66 (1992). This projection is in obvious conflict with the current widespread unemployment among electrical engineers.
FN 226. Id.
FN 227. Id. at 88.
FN 228. Zachary, supra note 215, at 1, col. 1.
FN 229. Address by Ian Strecker, session on "Increasing R & D Efficiency--A Business Perspective," The European Conference on Global Issues of R & D (Brussels, Belgium, Nov. 23, 1992).
FN 230. Id.
FN 231. Telephone Interview with Richard Ellis, Research Director of the Eng'g Workforce Comm. (Apr. 21, 1993).
FN 232. Id.
FN 233. Passell, "Hiring Russian Scientists: Exploitation of the Workers?" N. Y. Times, June 4, 1992, at 1, col. 1.
FN 234. Id.
FN 235. Id.
FN 236. Id.
FN 237. Id.
FN 238. Id.
FN 239. Zachary, supra note 215, at 1, col. 1.
FN 240. Id.
FN 241. Id.
FN 242. Id.
FN 243. Letter by James D. Burke, Manager of Professional Recruitment for Rohm & Haas Research Laboratories (May 11, 1993).

FN 244. Id.
FN 245. Id.
FN 246. Id.
FN 247. Telephone interview with Dr. Alan E. Fechter, Executive Director of the Nat'l Research Council's Office of Scientific and Eng'g Personnel (Apr. 14, 1993).
FN 248. Id.
FN 249. Zachary, supra note 215.
FN 250. Telephone interview with Dr. Michael Greenberg, Schlumberger Inc. (Feb. 25, 1993).
FN 251. Id.
FN 252. Id.
FN 253. Id.
FN 254. Bromley, supra note 44, at 6.
FN 255. Vetter, Occasional Paper No. 91-1, supra note 157, at 17.
FN 256. Lee, "Train 'em Here, Keep 'em Here," Forbes, May 27, 1991, at 110-11.
FN 257. Id. at 111.
FN 258. Porter, "Enrollment Trends in the Physical Sciences," 1990 Symposium on Human Resources in Science and Technology: Improving U.S. Competitiveness 81 (Washington, D.C., Mar. 15-16, 1990) (available from the Comm'n on Professionals in Science and Technology, supra note 44).
FN 259. Id.
FN 260. Zachary, supra note 215, at 1, col. 1.
FN 261. "Electronics Industry Relies on Foreign-Born Eng'rs," L. A. Times, May 17, 1988, at 4, col. 1.
FN 262. Id.
FN 263. Id.
FN 264. "Congress Told Current Immigration Law Impedes Efforts to Attract Scientists," 149 Daily Labor Rep. A-7 (Aug. 2, 1990).
FN 265. Finn, "The Role of Foreign-Born Graduates in U.S. Educ. and Indust.," 1990 Symposium on Human Resources in Science and Technology: Improving U.S. Competitiveness 89 (Washington, D.C., Mar. 15-16, 1990) (available from the Comm'n on Professionals in Science and Technology, supra note 44).
FN 266. Nat'l Science Found., Pub. No. 90-320, Science and Eng'g Doctorates: 1960-89 213 (1990).
FN 267. Finn, supra note 265, at 89.
FN 268. Letter from Eleanor Babco to Dr. Isaac Dvoretsky (Feb. 11, 1993).
FN 269. Finn & Clark, Estimating Emigration of Foreign-Born Scientists in the U.S. (Jan. 1988) (available free from Michael G. Finn, Labor and Policy Studies Program, Oak Ridge Associated Universities, Oak Ridge, TN 37831-0117).
FN 270. Id. at 2.
FN 271. Id.
FN 272. Id. at 7.
FN 273. Id. Using the 1986 Nat'l Survey of Natural and Social Scientists and Eng'rs, a post-census sample drawn from respondents to the 1980 Census long-form questionnaire, Finn and Clark excluded those above age 58 (to minimize the impact of post-retirement emigration), as well as those who earned a U.S. degree and got a job between spring 1980 and spring 1982.

Additionally, they did not count persons who came to the U.S. during this same period. Without all these exclusions, the total emigration rate would be slightly elevated.
FN 274. Lee, supra note 256, at 111.
FN 275. Id.
FN 276. Id.
FN 277. Id. at 112.
FN 278. Id.
FN 279. Id.
FN 280. Id.
FN 281. Kotkin, supra note 23, at B2, col. 2.
FN 282. Id.
FN 283. Id.
FN 284. Id.
FN 285. Pezzullo, "Imported Talent: Foreign-Born Students Tend to Stay in America--and Help Hone Its Scientific Edge," U.S. News and World Rep., Mar. 22, 1993, at 75.
FN 286. Solomon, "American Laboratories, Foreign Brains," N. Y. Times, July 19, 1987, at F8, col. 2.
FN 287. Id. at col. 5.
FN 288. Id.
FN 289. Gittelsohn, "Surging Economy Spurs Many Asians to Return Home," Chron. of Higher Educ., Nov. 15, 1989, at A45, col. 5.
FN 290. Id.
FN 291. Id. at A46, col. 5.
FN 292. Id. at A46, col. 3.
FN 293. Id.
FN 294. Id. at A46, col. 1.
FN 295. Id. at col. 3.
FN 296. Id. at col. 2.
FN 297. Id. at col. 1-2.
FN 298. Yoder, "Reverse Brain Drain Helps Asia But Robs U.S. of Scarce Talent," Wall St. J., Apr. 18, 1989, at 1, col. 6.
FN 299. Id.
FN 300. Id.
FN 301. Id.
FN 302. Id. at 20, col. 6.
FN 303. Id.
FN 304. Id.
FN 305. Id.
FN 306. Id. at 20, col. 5.
FN 307. Id.
FN 308. Ong, Cheng & Evans, "The Migration of Highly Educated Asians," Int'l Educator, Fall 1991, at 29.
FN 309. Id.
FN 310. Id.
FN 311. Id.
FN 312. Id. at 26.

FN 313. Horner, "China on the Rise," 94 Commentary 33 (Dec. 1992).
FN 314. Drucker, "China's Growth Area, the Service Sector," Wall St. J., Mar. 3, 1993, at A14, col. 3.
FN 315. Id. at col. 2.
FN 316. Driver, "China Plans Measures to Encourage Its Best and Brightest to Come Home," Chron. of Higher Educ., Apr. 8, 1992, at A44, col. 1.
FN 317. Id.
FN 318. Pedersen, "The New China Syndrome: Delayed Return as a Viable Alternative to the Brain Drain Perspective," NAFSA: Association of International Educators (NAFSA) Working Paper No. 30 at 2 (1991) (available for $4 from NAFSA, Publication Order Desk, 1875 Connecticut Ave., NW, Suite 1000, Washington, D.C. 20009-5728).
FN 319. Id.
FN 320. Id.
FN 321. Id. at 1.
FN 322. Id. at 2.
FN 323. Id.
FN 324. Id.
FN 325. Eng'g Manpower Comments, Jan.-Feb. 1992, at 30.
FN 326. Telephone interview with Dr. James D. Burke, Manager of Professional Recruitment at Rohm & Haas Research Laboratories (Mar. 8, 1993).
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