A CANARY IN THE MINESHAFT?

INTERNATIONAL GRADUATE ENROLLMENTS IN SCIENCE AND ENGINEERING

IN THE UNITED STATES

Frank D. Bean

and

Susan K. Brown

Department of Sociology

and

Center for Research on Immigration, Population and Public Policy

University of California, Irvine

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A CANARY IN THE MINESHAFT? INTERNATIONAL GRADUATE ENROLLMENTS IN SCIENCE AND ENGINEERING IN THE UNITED STATES

Technological innovation is arguably the key ingredient for achieving strong economic growth in advanced knowledge-based societies (Freeman 2005). While the specific mechanisms through which new technologies foster growth are strongly debated (Barro and Sala-i-Martin 2003; Lindert 2004), technically based inventions such as wrought iron, steam power, the generation of electricity, and the internal combustion engine have historically generated major economic expansions (Easterlin 1996; Galbraith 1995; 1997). Regardless of whether the invention of the computer and the internet ultimately rank as high in economic significance (Madrick 2002), the fact that many analysts think they will gives weight to the idea that contemporary technology plays a crucial role in international economic competitiveness. It would thus seem self-evident that national science and technology policies would seek to protect and sustain high-technology innovation and capability, for reasons of minimizing risk if nothing else. To take the vitality of technological innovation for granted or to pursue policies that are neglectful invites the possibility of long-term relative economic decline (Prestowitz 2005).

At the moment, the U.S. economy still benefits from technological pre-eminence. But this dominance may be slipping because of global trends in the spread of technology, the force of world population distribution, changes in where scientists and engineers receive graduate training, and relative declines in support for basic research. The first of these, the global diffusion of technology itself, provides a clear example of the need to rethink U.S. strategies regarding graduate education and basic research. As Thomas Friedman (2005) has so incisively noted, the installation, indeed over-installation, of fiber-optic cable around the world during the latter half of the 1990s makes high-speed, low-cost broad-band connectivity available in almost every corner of the world. This “leveling of the playing field” makes possible more than ever before the development and deployment of science and engineering talent and ideas outside the United States.

Developing adequate policies and strategies for sustaining U.S. technological innovation requires understanding the roles a number of factors have played in building U.S. strength. Five are worth noting here. One is an open and flexible immigration system that has allowed talented individuals to come to the United States to study and work. Another is a superb higher educational system that has attracted scientific and engineering (S&E) graduate students and post-doctoral scholars. Another is a high priority on basic research, as well as applied research and product development, an emphasis which has supported graduate-student and post-doctoral research programs. Another is a vital and dynamic U.S. high-tech industry that has converted innovation into useful products, thereby creating demand for highly skilled science and engineering workers. And still another has been the relative global monopoly, at least until recently, of these factors (especially S&E higher education on the one hand and investment in basic research and high-tech product development on the other).

The broad purposes of this paper are to assess inter-relationships among these factors and to gauge their relative importance for sustaining technological leadership on the part of the United States. More specifically, we seek (1) to highlight the importance of high-skilled migration, both permanent and temporary, for the vitality of the U.S. economy in general and for the high-technology science and engineering sector in particular; (2) to point out inter-dependencies between temporary high-skilled migration (involving S&E graduate students and workers on H-1B visas) and high-skilled permanent migration in order to clarify how and why U.S. immigration policy, along with other factors, carries implications for flows of foreign-born science and engineering graduate students; (3) to examine and explain patterns and trends in the application, admission and enrollment of science and engineering graduate students in the United States; and (4) to assess research and development spending, both in the United States and elsewhere, because the degree of such investment strongly affects both innovation and the likelihood that the world's extremely talented students will continue to study and relocate here. In the concluding section, we note that the growth of higher education and high-tech employment outside the United States, developments that increase world competition for top-flight students and workers (Freeman 2005), may be changing both the dynamics of high-skilled migration to the United States, including graduate-student enrollments, as well as the labor market implications of such migration.

INTERNATIONAL MIGRATION AND THE U.S. WORKFORCE

High-skilled international migrants play a prominent role in the U.S. economy. The foreign-born are just as likely as natives to complete college and more likely to hold advanced degrees, especially in the case of immigrants who have come to the country since 1990 (Hansen 1996; Martin and Midgley 2003). The importance of such immigrants for the economy cannot be captured simply by noting that 13.1 percent of the U.S. population was foreign-born in 2003. Instead, attention must be focused on the adult workforce, where an even larger percentage, 14.4, is foreign-born (U.S. Bureau of the Census 2003) and on young adult workers (those under the age of 45 and thus most likely to be involved in the newer sectors of the economy), where a still higher percentage, 17.2, is foreign-born. Even more dramatic, among highly skilled young workers (with Ph.D. degrees and working in science and engineering), the percentage is a whopping 52.0 percent (Freeman 2005). Such figures illustrate the importance of international migrants in general, and of younger, highly skilled workers in science and engineering in particular, for U.S. economic productivity and growth.

Three main flows of foreign-born persons augment the high-skilled workforce in the United States. The first consists of people who enter via the policy provisions of the regular legal immigration system, namely the employment preference categories. The second consists of temporary non-immigrants who enter with H-1B visas, which run for three years, are renewable once, and are designed for those in high-skilled specialty occupations. A third less direct augmentation consists of international students. Although not initially in the workforce, many of the entrants in this group stay in the country and ultimately contribute to the high-skilled workforce. About one-fourth of these international students are S&E graduate students (National Science Foundation 2004). Also prominent are postdoctoral scholars, many of whom, like the graduate students, stay in the country and thus also contribute to the high-skilled workforce. Even more critically, international S&E graduate students and post-doctoral scholars hold important research positions that are vital to the country's basic research effort. We show below trends in each of these flows and discuss their implications for the nation's workforce and research and development activities.

High-Skilled Legal Immigration

Before 1992, the United States gave considerably more weight to family re-unification than to employment as a basis for granting legal immigrant visas. This was evident not only in the numbers of legal permanent resident (LPR) slots granted under these alternative auspices, but also in the fact that four family-preference categories existed for obtaining legal permanent resident admissions but only two employment-preference categories. Because of concerns in the late 1980s that the U.S. economy needed more high-skilled workers, in 1990 Congress passed the Immigration Act, which President George H. Bush signed in November and which began to affect immigration statistics by fiscal year 1992. This legislation, together with the 1986 Immigration Reform and Control Act (IRCA), constituted the most far-reaching shift in the country's immigration laws since the 1965 amendments to the Immigration and Nationality Act, which abolished national origin quotas as bases for immigrant admission (Bean and Stevens 2003). The main goals of the 1990 legislation were to increase the diversity of the country's immigrants and to allow the entry of greater numbers of skilled workers (Sorensen et al. 1992).

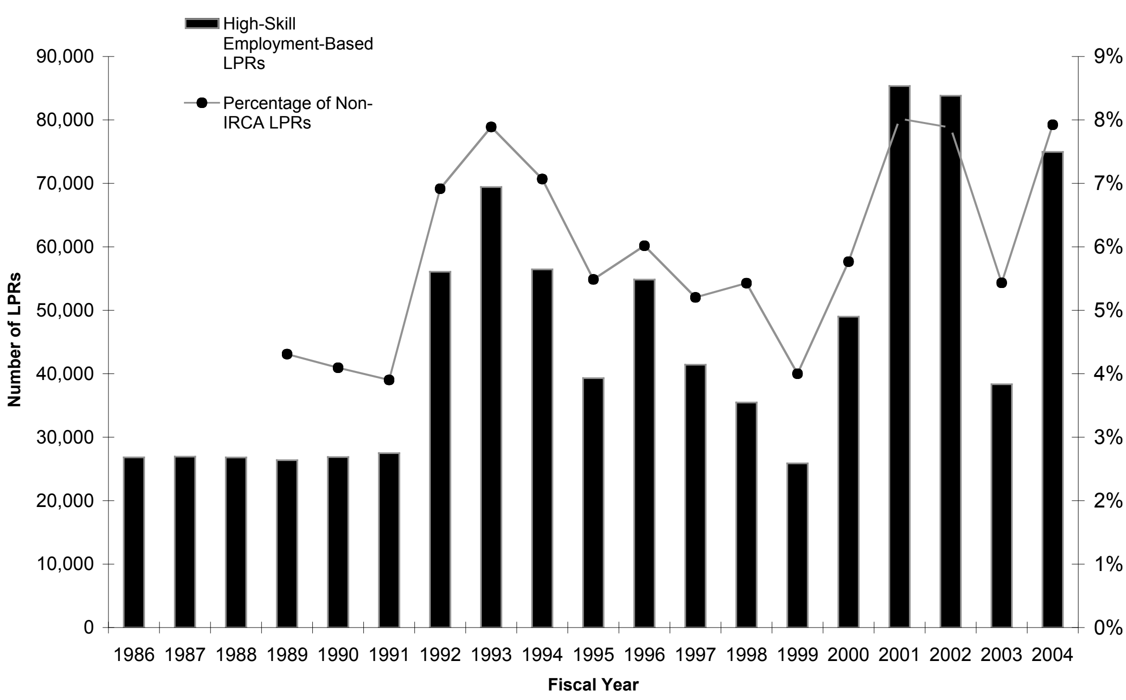
The new employment-based immigration system raised the number of slots available for workers and their families from about 56,000 to 140,000. The law arranged these visas into five categories, which are still in effect. The first consists of priority workers, or persons of extraordinary ability in the sciences and arts. The second consists of professionals with advanced degrees. The third consists of professionals who have a bachelor's degree, and also includes other skilled and some unskilled workers. The fourth consists of special immigrants, such as religious functionaries, and the fifth category consists of investors who will invest at least $1 million, or at least $500,000 in rural or high-unemployment areas. The new law thus opened the door wider to employment-based immigrants and substantially changed the composition of employment-based immigration. Under the first three employment provisions of the new law, more spots were allotted to professionals and skilled workers and fewer to unskilled workers. The latter group, now limited to 10,000, received scarcely half the number it had before 1990 (Fix and Passel 1991).

The numbers of legal permanent residencies granted to high-skilled workers (principals) in each fiscal year since 1985 are shown in Figure 1. The figures under-represent, perhaps substantially, the volume of high-skilled migration to the United States, for at least two reasons.

First, the vast majority of U.S. immigrants still enter under the family re-unification categories. Many of these immigrants have high levels of education (Sorensen et al., 1992), although these entrants do not show up in statistics about numbers of high-skilled employment immigrants. Second, the immigration statistics for high-skilled employment LPR's include the spouses and children of principals. However, in order to emphasize principals, Figure 1 excludes spouses and children, even though they constitute about half of all high-skilled LPR's over the past several years. No doubt, many of the spouses also hold advanced degrees and are themselves employed.

Figure 1

High-Skilled Employment-Based Visas, Number by Year and as a Percentage of non-IRCA Visas



Souce: Office of Immigration Statistics, Table 24 of Yearbook of Immigration Statistics: 2004 Temporary Admissions (Nonimmigrants)
http://uscis.gov/graphics/shared/statistics/yearbook/yrbk04ta.htm

By showing the overall numbers of employment-sponsored immigrants (those in the first three categories) in particular fiscal years, not the numbers of persons newly admitted to the country in those years, Figure 1 also misrepresents when the immigrants first came to the country. In fact, well over 80 percent of each of the fiscal year totals involves persons who had adjusted their statuses. In 2004, for example, 87.5 percent of the principals in the first three employment preferences and their spouses were "adjusters" rather than "new arrivals" (U.S. Citizenship and Immigration Service 2005). Most of these were changes from student or H-1B temporary worker visas (or even sometimes from unauthorized status, which itself usually results from overstaying either a student or H-1B visa). Thus, the figures for the most part involve high-skilled people who had already been in the country under student or H-1B visas. This is one of the chief reasons it is important to examine trends in all three of these kinds of admissions taken together.

Student or H-1B visas are thus perhaps the chief pathways by which high-skilled foreign-born persons enter the U.S. immigration system and ultimately gain legal permanent residency (Usdansky and Espenshade 2001). The possibility of obtaining legal permanent residency status on the basis of education and skills provides an incentive for foreign-born persons to come to the United States as graduate students and H-1B workers, illustrating what is often an interdependency between temporary and permanent forms of entry to the country. What many observers may not realize, however, is that a ceiling on permanent high-skilled slots creates a squeeze whenever greater numbers of temporary entrants seek permanent status than the ceiling can accommodate. Such squeezes are almost inevitable because in recent years Congress has been far more likely to increase temporary slots than to raise the ceiling on permanent slots (Lowell 2001).

The big upswing in the numbers of high-skilled, employment-based legal permanent residents after the 1990 Immigration Act is evident in the yearly totals in Figure 1, although levels jump around somewhat from year to year, partly because lag times in the processing of applications vary from year to year. In any event, by the 2000s, around 70,000 high-skilled principals each year were receiving employment-sponsored legal status, a figure that constituted about 8 percent of the total number of legal immigrants coming to the country outside the special legalization provisions of the 1986 Immigration Reform and Control Act (IRCA).[1] If we compare only principals, the percentage of high-skilled employment-based principals of all principals would be even higher, about 16.0 percent. And if the data were available to include in the category of high-skilled principals those family-based principals with high levels of education who are also employed, the percentage of principals with high levels of education would be greater still, perhaps reaching 20-25 percent.

The relatively high levels of high-skilled immigration during the early 2000s after the economic boom of the late 1990s reveal the sometimes problematic feature of the cap on employment-based permanent immigration (the slight fluctuations in the numbers in Figure 1 after 2000 may be more a reflection of application processing variations than of changes in either the demand for such workers or the demand for such visas among potential immigrants. The high levels thus mean that demand in those years probably continues to outstrip supply (Lowell 2001), even in a relatively stagnant economy (except perhaps in 2003, which may represent a delayed manifestation of the dampening effects of 9/11 on interest in adjusting to legal permanent resident status). But because under current law, the number of employment-based legal permanent residents cannot change, and because many high-skilled employment immigrants have previously held either student or H-1B visas, and because the latter especially is growing enormously (as we show below), the demand for high-skilled employment-based legal status appears recently to have been outrunning supply. The important point here is to note this may be troublesome in the near future, especially if the business cycle swings upward.

Temporary High-skilled Migrants

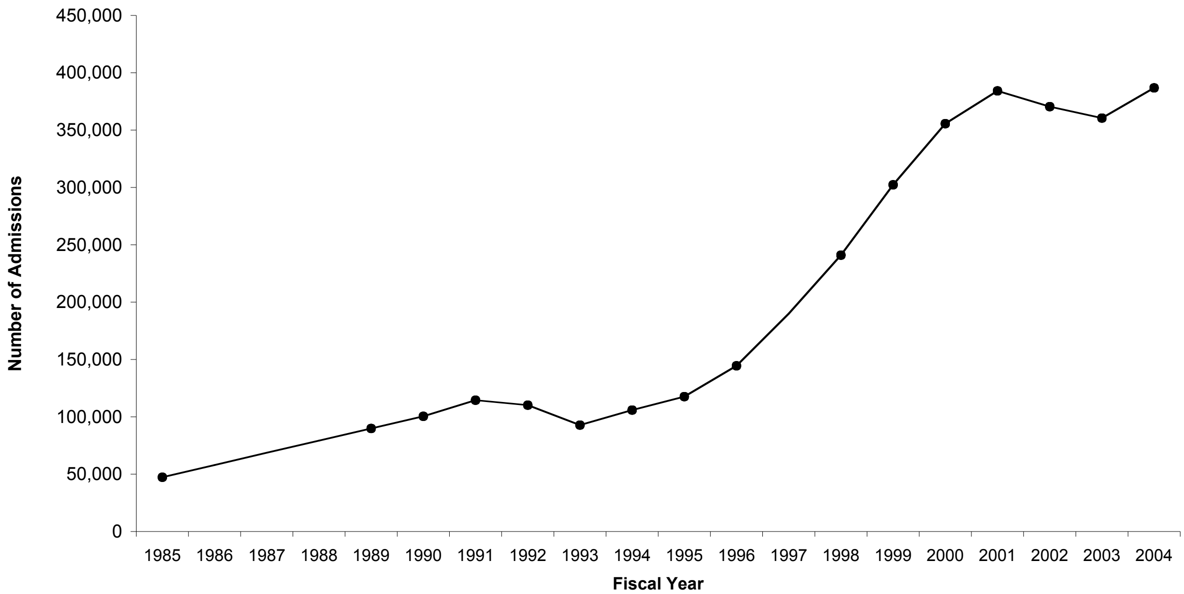
Because many of the employment-sponsored slots are granted to persons who have previously held H-1B temporary visas, it is instructive to examine trends in the numbers of such visas granted. The 1990 Immigration Act defined skills for the first time on the basis of education (Usdansky and Espenshade 2001: 34-37). In addition to increasing substantially the number of employment-based slots (allowing them to almost triple to 140,000 by 1992), and raising the number of employment-based preferences from two to five, the law introduced a special category of high skilled-temporary worker through its adoption of the H-1B visa for non-immigrants. The number of such visas was set at 65,000 annually. H-1B workers were to be paid the prevailing wage for their job and were permitted to stay three years (renewable for another three years). Also, no cap was set for their spouses and minor children, unlike the case of regular employment-based visas (Usdansky and Espenshade 2001). For example, for H-1B visas, the 65,000 ceiling applies to principals, but by the time spouses and children are included, this generates many more than 65,000 entrants, whereas the 140,000 ceiling for permanent employment visas, which includes principals and spouses and children, generates only about 70,000 principals annually. A new development as of May, 2005, is that 20,000 more H-1B visas will be issued to foreign students who completed a graduate program in the American universities (these visas will NOT be included in the 65,000 visa cap).

The impetus for the 1990 legislative changes was a growing concern during the late 1980s about looming shortages of high-skill and specialty workers, fears that were fueled by think-tank and government studies like the Hudson Institute's "Workforce 2000" report and the 1990 Report of the Council of Economic Advisors predicting that high-skilled labor squeezes were likely soon to develop (U.S. Congress 1991). In 1997, for the first time, the 65,000 ceiling on H-1B visas set in 1990 proved insufficient to meet demand. Up until then the number of such visas had not been an issue, but after that point, there were pressures to increase the ceiling. In response, Congress in 1998 raised the number to 115,000 visas for 1999 and 2000. But in fiscal year 1999 the new supply of H-1B visas still ran out by June, with the result that in October of 2000 Congress rushed to extend the limit to 195,000 for an additional three-year period.

The strong growth in the number of H-1B admissions began in the mid-1990s (Figure 2). Interestingly, its initial trend was counter-cyclical with that of high-skilled employment-sponsored immigrants. That is, as the number of H-1B admissions went up during the late 1990s, the number of high-skilled employment immigrants went down, reflecting in the early stages of the H-1B expansion a substitution of temporary workers for legal permanent resident workers (Lowell 2001). However, by the early 2000s, the rising levels of temporary H-1B workers undoubtedly were creating greater demand for legal permanent resident status as H-1B recipients confronted the expiration dates of their three-year stays. This trend is likely only to grow. Time and time again, in place after place around the world, temporary migration programs have begotten permanent migration (Cornelius, Martin and Tsuda 2003). It is thus no shock that the same pattern seems to be emerging with high-skilled migration to the United States. Current limits on high-skilled *permanent* immigration may be too low to meet the needs of the economy. If so, it would not be at all surprising to see growing *unauthorized* migration of the high-skilled in the next few years.

Figure 2

Number of H1B Admissions by Year



Source: Office of Immigration Statistics, Table 24 of Yearbook of Immigration Statistics: Nonimmigrants Admitted by Class of Admission: Selected Fiscal Years 1981-2004. http://uscis.gov/graphics/shared/statistics/yearbook/2004/table4.xls

GRADUATE-STUDENT ENROLLMENTS IN SCIENCE AND ENGINEERING

Given the importance of science and technology in the global economy and the importance of international migration among the highly skilled, trends in international enrollment of science and engineering students are of particular interest, especially since graduates who remain in the United States to work comprise a major source of high-skilled foreign-born workers. Trends in enrollments are also important because of the tightening of entry requirements for foreign-born students after 9/11and the greater subsequent difficulty in obtaining visas. We seek here to address a number of important questions about these trends. First, to what extent does the available evidence indicate that the enrollment of science and engineering graduate students in the country has recently declined? Second, to what extent does any observed decline result from science and engineering students being unable to acquire appropriate visas because security requirements were tightened in the wake of 9/11? Third, to what extent does any observed decline derive from factors other than difficulties in obtaining visas? Fourth, to what extent have changes in the enrollment of foreign and of native-born S&E graduate students tended to move counter-cyclically with one another? Or, stated differently, do native enrollments decline when foreign enrollments increase, and vice versa, suggesting competition between these groups for graduate slots? Or does the available evidence indicate other kinds of labor market forces drive trends in enrollment?

It is important to emphasize that it is difficult at this point to answer these questions definitively based on evidence obtained from analytical studies because of limited data. For example, information collected on the visa status of graduate students (even in some very rough sense) did not distinguish first-time from continuing students until 2001, meaning that only a very short time series of information about first-time enrollments is now available, even though this information is crucial for discerning the influence of current conditions on enrollment trends. Moreover, some of the relevant data are still not available for recent years. For example, even though preliminary information on applications and admissions are available for 2004 and 2005, enrollment data for 2005 are not yet available (Brown and Doulis 2005). And information on graduate international enrollments that disaggregates graduate student visa holders by gender into temporary and more permanent residents is available only up through 2003, meaning that a gender-specific time series of only two years can be examined after 9/11 (National Science Foundation 2004). Despite such limitations, it is nonetheless possible to discern important clues, both from the patterns involved in the trends and from the results of other research studies, about the forces driving recent graduate student enrollment trends. This helps to answer the above four questions, at least in a preliminary way. We address each of the four below, after first describing the changes in graduate student enrollments over the past decade or so.

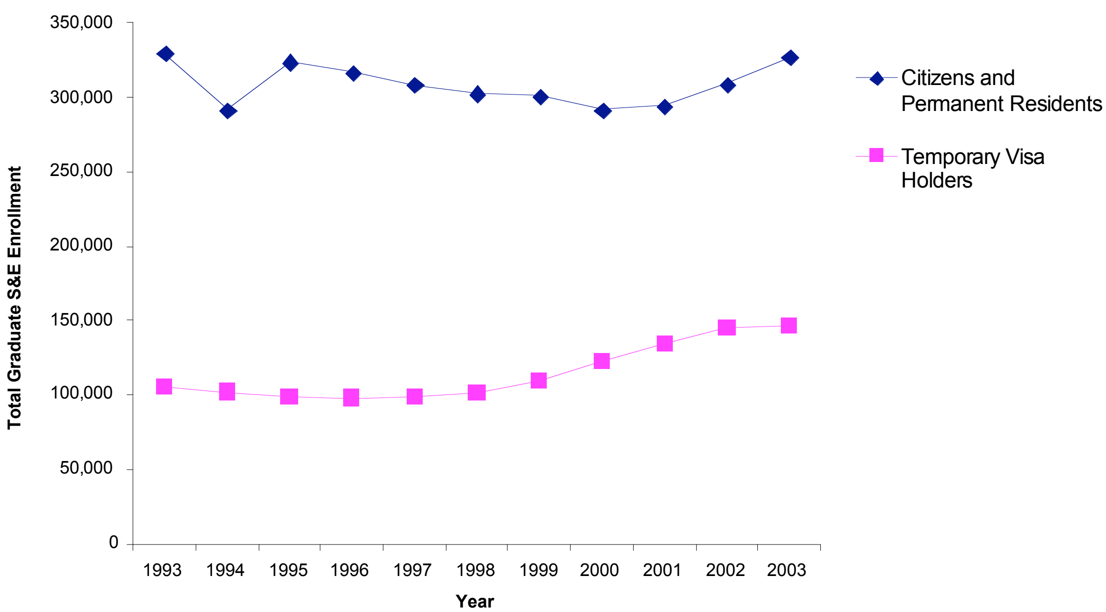
Changes in International Graduate Student Enrollments

The numbers of foreign-born students in the United States began to increase after World War II. By 1954, 34,232 (or 1.4 percent) of higher education enrollments were international students on temporary visas. This, of course is a conservative estimate of foreign-born students because immigrants who had become legal permanent residents would not be counted as international students. In short, the percentage of foreign-born enrollments was undoubtedly even higher than this figure indicates. By 2002, international enrollments had grown to 613,221 (or 4.1 percent) of the total, a conservative figure given that by the early 2000s, about 18,000 students each year were converting their status from that of student visa to legal permanent resident (U.S. Citizenship and Immigration Services 2005).

While many international undergraduate students may eventually change their status and stay in the United States, it is graduate students, especially those in science and engineering, that are immediately and more directly involved in U.S. research and development endeavors through their participation in university research projects. Figures 3 and 4 show the trends since 1992 in both total and first-year graduate student enrollments in the United States for two categories of students – citizens and permanent residents on the on hand and temporary residents on the other. 2003 is the last year as of this writing for which we have data broken down by citizenship, temporary visa status, first-time enrollment, and gender. For that year, at least 150,000 graduate students were in the country on temporary visas (an apparently unknown number of permanent residents and naturalized citizens were also here, but these two different kinds of students cannot be examined separately because the National Science Foundation's statistical reports lump these together with native citizens). Foreign-born graduate S&E enrollment has risen by about 50 percent since 1996 and continues to increase, and foreign-born science and engineering graduate students now make up almost a quarter of all foreign-born student enrollments in the United States (including undergraduate enrollments), and nearly half of all science and engineering graduate enrollments. This rise is characteristic of both men and women (Figure 5). As many observers have noted, international graduate enrollments have become an ever larger and more integral part of the nation's research and development (R&D) programs (Freeman 2005; National Research Council 2005).

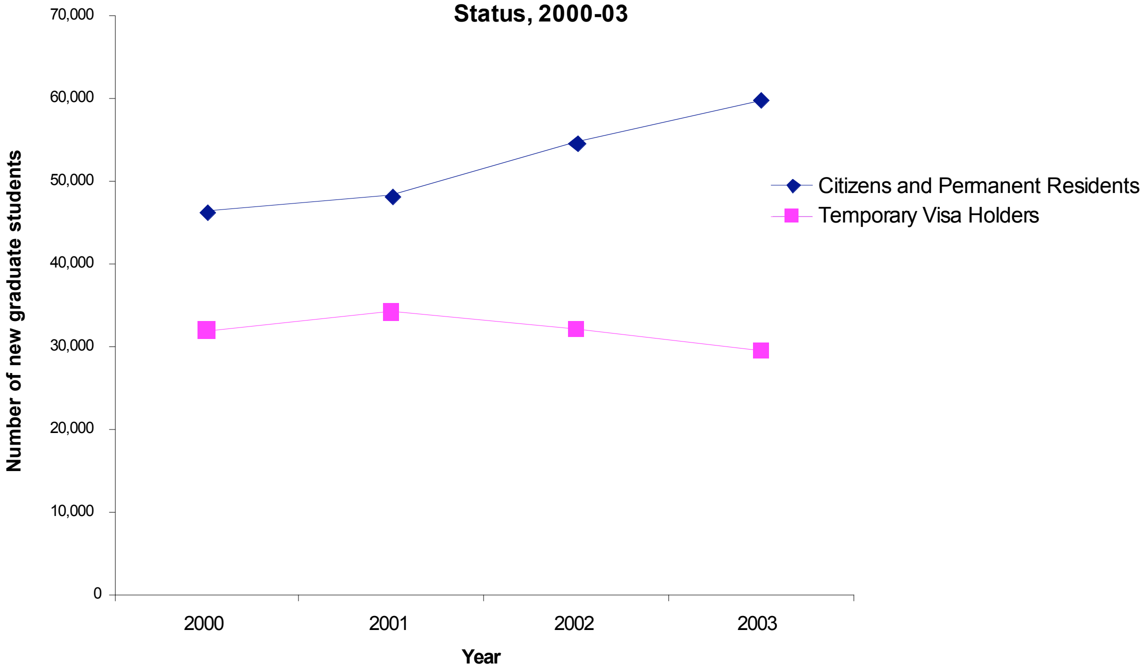
Figure 3

Graduate Enrollment in Science and Engineering, by Citizenship and Visa Status, 1993-2003



Source: National Science Foundation, Division of Science Resources Statistics, Survey of Graduate Students and Postdoctorates in Science and Engineering.

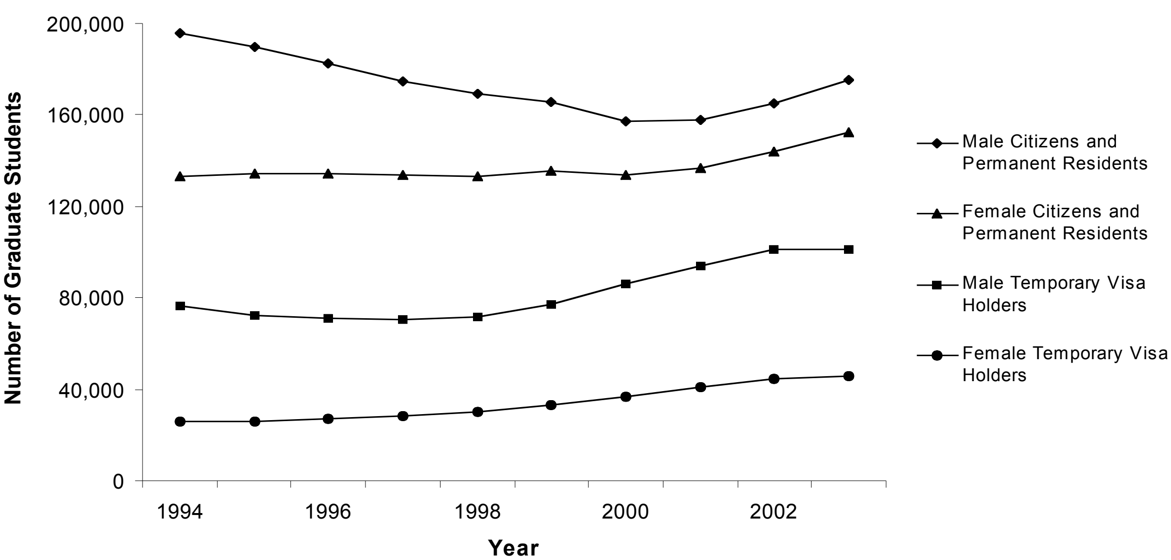
Figure 4
Enrollment of First-Time S&E Graduate Students, by Citizenship and Visa Status, 2000-03



Source: National Science Foundation, Division of Science Resources Statistics, Survey of Graduate Students and Postdoctorates in Science and Engineering.

Figure 5

Graduate S&E Enrollment by Gender, 1994-2003



Source: National Science Foundation, Division of Science Resources Statistics, Survey of Graduate Students and Postdoctorates in Science and Engineering.

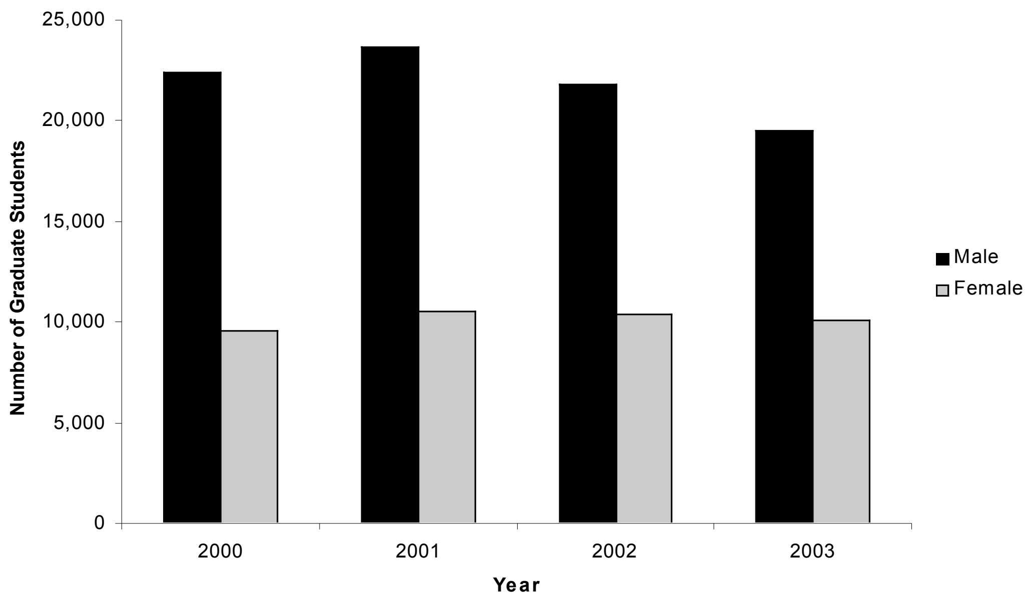
Have There Been Declines after 9/11 due to Changed Visa Review Procedures?

Since 2000, the National Science Foundation (NSF) has also been reporting information on first-time enrollments of foreign graduate students. These first-time data are more sensitive to the influence of contemporaneous events like 9/11 than total enrollments, since students already enrolled in long-term programs would be less affected by such occurrences or the policy shifts they spawn. Figure 6 shows the first-time S&E enrollments for both permanent and temporary students. The results reveal three important patterns. First, the very narrow gap in 2000 between temporary (foreign-born) and permanent/citizen (motly native-born) first-time graduate student enrollments suggests that by the end of the 1990s foreign-born graduate students constituted an even larger fraction of the total number of science and engineering enrollments (about 40 percent) than previously, demonstrating how rapidly the foreign-born have increasingly become a larger share and more integral part of S&E enrollments and R&D in the country.

Second, and most important, the results show that enrollments declined after 2001 for first-time, foreign-born graduate S&E students, showing a drop of 4,605 students, or a decline of 13.5 percent, by 2003. Third, and significantly, this decrease does not represent a broader, more general pattern since it does not characterize permanent resident/citizen (mostly native-born) first-time enrollees. In other words, the decline shows up only among foreign-born first-time enrollees, suggesting a significant negative impact from the more arduous and often intimidating visa screening after 9/11. The National Research Council (2005) recently reached this conclusion as a result of a thorough investigation of graduate enrollment trends.

Figure 6

First-Time S&E Graduate Students with Temporary Visas by Gender, 2000-2003



Source: National Science Foundation, Division of Science Resources Statistics, Survey of Graduate Students and Postdoctorates in Science and Engineering.

Although the enrollment data from the National Science Foundation (NSF) stop for now at 2003, other sources suggest that the decline in international graduate students in science and engineering continued at least through 2004. Annual percentage changes in science and engineering applications, admissions, and enrollments reported by the Council of Graduate Schools (CGS) (Brown and Syverson 2004; Brown and Doulis 2005) show overall international graduate student applications down nearly 30 percent from 2003-2004, and those for S&E international graduate students over 35 percent for the same years (Figures 7 and 8). Smaller declines occurred in admissions and enrollments. Applications for 2005, however, declined only slightly, and overall admissions and enrollments were up slightly from the previous year. However, from 2004 to 2005 small declines continued for admissions and enrollments of new international S&E graduate students.

Because most students apply to and may be admitted by more than one school, and because the least committed students may be the ones most discouraged from applying, the greater decreases in applications and admissions do not necessarily represent proportionate decreases in yield, or enrollments, as the figures in fact make clear. The National Research Council (2005) study also concluded that no clear evidence has yet emerged of a decrease in the quality of international S&E graduate students enrolling after 9/11. But as far as *overall* S&E graduate student enrollments are concerned, a decline clearly occurred post-9/11, and changes in visa review procedures seem definitely to have been responsible for a substantial portion of the drop, at least in the first two years after 2001. Moreover, the decrease has not yet bounced back to pre-9/11 levels, despite the substantial reduction in the time required to process visa applications and the lengthening of the student visa period from one to four years.

Figure 7

Changes in Applications, Admissions and Enrollment of New International Graduate Students, 2003-05

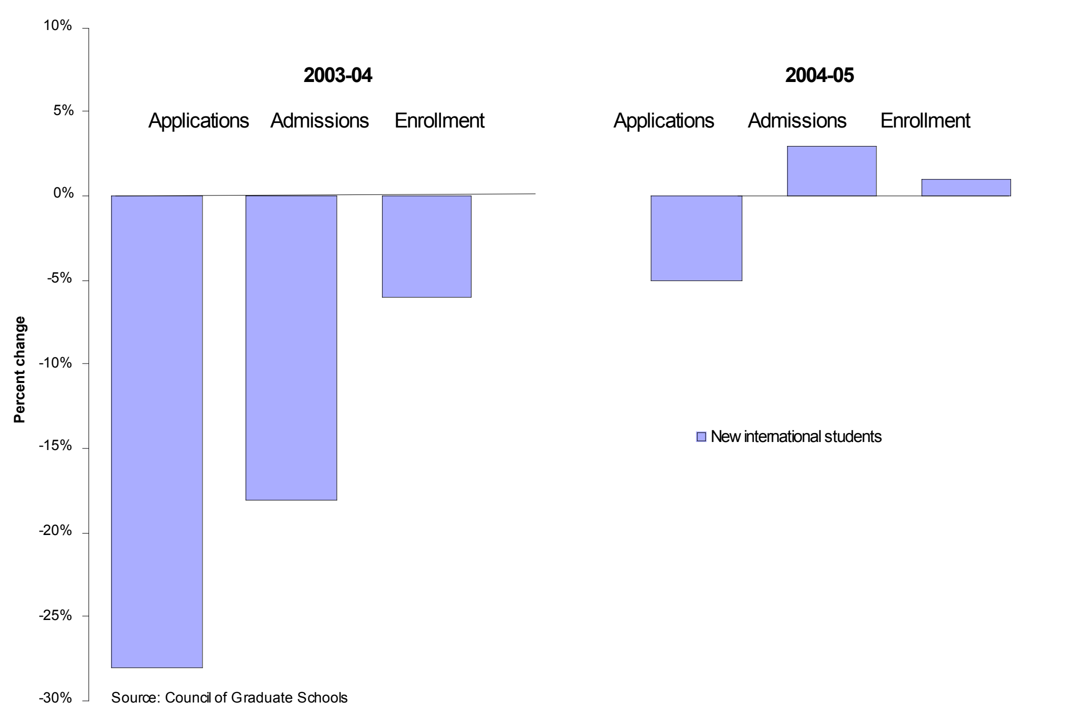
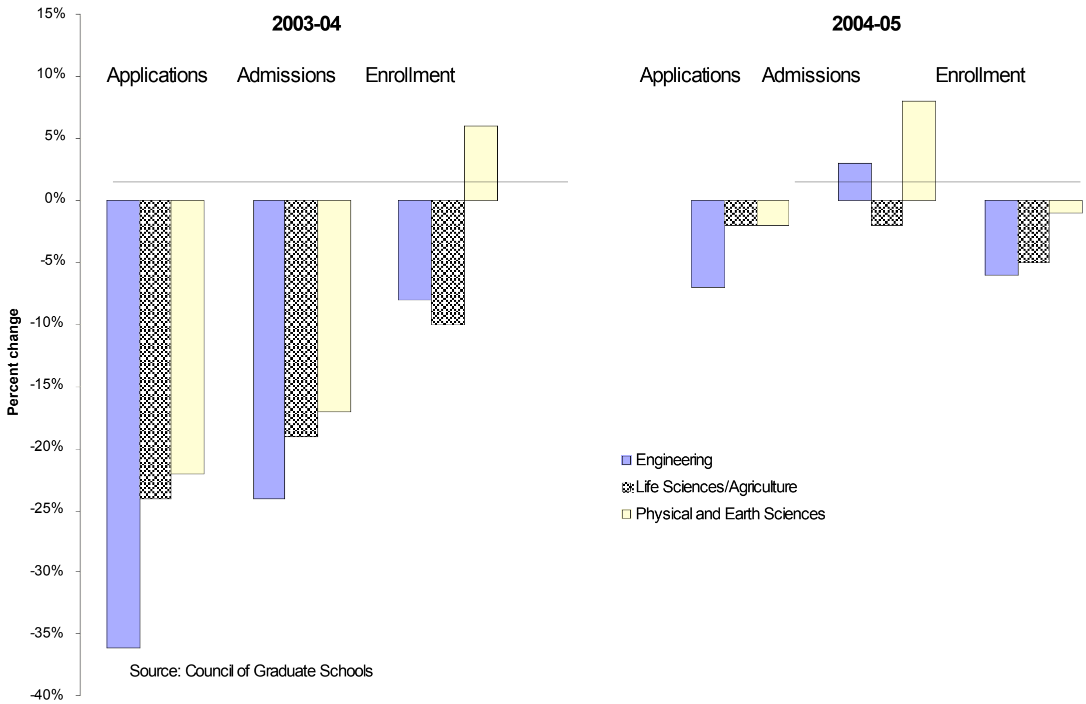


Figure 8

Changes in Applications, Admissions and Enrollment of New International Graduate Students in Science and Engineering, 2003-05



Are Other Factors also Contributing to the Decline?

Other factors thus may be contributing to the continuing retardation of foreign S&E graduate enrollments, even after the substantial improvements have taken place in the visa processing situation for international graduate students. The CGS data in Figures 7 and 8 suggest such additional forces may indeed be at work. A small decline in applications occurs from 2004 to 2005, even after the new visa processing changes were implemented. Moreover, an enrollment decline also shows up in the NSF data among foreign-born women, who had previously been moving upward in their share of first-time foreign enrollments. Also, widespread reports of recently increased opportunities for graduate S&E education in Britain, the European Economic Union (EEU), Australia, India and China suggest a greater global presence of alternatives for S&E graduate study than used to be the case (The Economist Intelligence Unit 2004).

Analysts have also noted the rise in international opportunities for graduate S&E education outside the United States started before 9/11 and has grown steadily since then (Brown and Doulis 2005). What may be new, however, is the attractiveness of these opportunities after the negative experiences many visa applicants underwent after 9/11. These may have led to the development of negative perceptions about the United States, with this in turn contributing to a boost in the demand among prospective foreign-born S&E graduate students for the pursuit of graduate studies in locales other than the United States. In short, just as other countries have started to strengthen their supply of graduate S&E educational opportunities, their attractiveness may have received an unanticipated boost from the new security practices by the United States, perhaps along with other aspects of U.S. foreign policy that have been unpopular abroad. At the moment, however, we lack clear evidence over the past two or three years that foreign-born S&E graduate students are opting in large numbers not to come to the United States, but this possibility must be given serious consideration.

Is There Evidence of Competition Between Foreign and Native S&E Graduate Students?

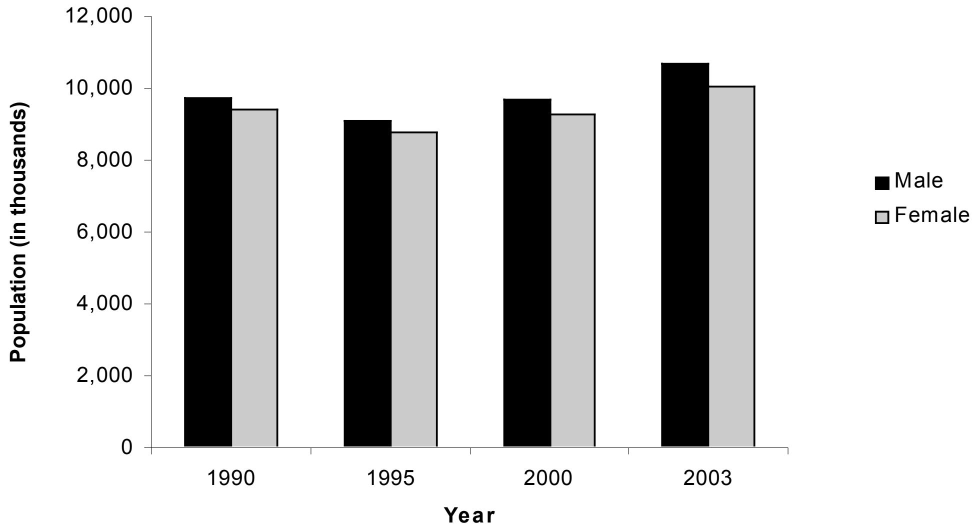
Concerns have also been expressed that natives, especially males, are increasingly less likely to enroll in science and engineering graduate programs because of increased competition from the foreign-born for research assistantships and fellowships (Borjas 2004). From 1993 to 2000 the number of U.S. citizen and permanent resident male graduate students decreased while the number of temporary international graduate student males increased (National Science Foundation 2004), as indicated by the trends shown in Figure 5. At first glance, the opposite directions of these trends would seem consistent with the possibility that foreign students may have “crowded out” natives. However, after 2000 native male enrollments rose at the same time as overall international male enrollments, a result inconsistent with the competition hypothesis. To be sure, *first-time* international male enrollments fell, but the fact that this drop owed at least in substantial measure to visa difficulties, as noted above, again does not suggest crowding effects. Rather, the results suggest the earlier enrollment decline among natives (as well as the recent increase) may have stemmed from factors other than competition from foreign students.

In fact, one factor that may help explain the recent native male upturn is growth the past few years in the size of U.S. birth cohorts becoming eligible for entry into graduate study. Figure 9 shows that, from 1995 to 2000, and then again from 2000 to 2003, increases occurred in the sizes of these age cohorts of 20-24 year olds, the primary age range for graduate school entry. This implies that recent native trends may be affected by fluctuations in cohort size related to changes in U.S. demographic factors like earlier fertility behavior, rather than merely from nativity competition. Moreover, native female enrollments held steady during the 1990s even in the face of simultaneous foreign-born female enrollment increases, a pattern again not consistent with the competition argument. Also, both foreign and native-born groups of females increased their enrollments from 2000 to 2003 (Oliver 2005), a trend that again does not suggest a crowding effect.

Beyond the influence of changes in demography, other circumstances like the strength of the S&E job market, the nature of S&E working conditions, and the relative availability of attractive alternatives (i.e., high-paying and jobs with good working conditions) also influence native graduate student enrollments. This is particularly true among native males, whose labor supply appears more sensitive to U.S. labor market conditions than that of international males.

Figure 9

US. Population Ages 20-24, 1990-2003



Source: U.S. Census Bureau, Statistical Abstract of the United States: 2004-2005; and Population Paper Listings PPL-41.

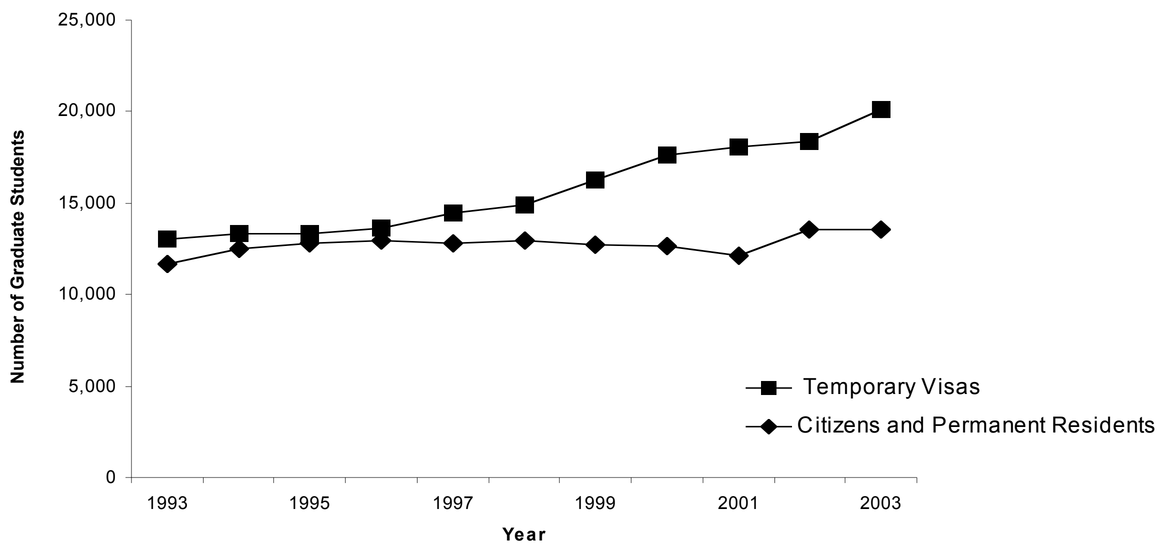
Freeman (2005) has convincingly shown that during the 1990s pay levels in S&E deteriorated even as training requirements (length of graduate study and/or post-doctoral apprenticeship) became more onerous. But the U.S. research and development community has been able to cope with this handicap by relying even more heavily on foreign-born S&E talent than before. In other words, native graduate enrollments seem likely to have declined not because research projects were competitively substituting foreign-born talent for native-born talent, but because a significant portion of the native-born talent pool pursued more attractive alternative careers.

<u>Post-doctoral Scholars</u>

If the foreign born represent a large and growing share of science and engineering enrollments in the United States, they constitute an even larger (and also increasing) share of post-doctoral students in the country. Figure 10 shows the trends since 1992 in post-doctoral enrollments. Again, the lines represent temporary (foreign) and permanent (most likely native) numbers. Even in 1993 the foreign-born occupied slightly more than half of all post-doctoral positions in science and engineering, and the gap has only widened since then, reaching nearly two-thirds of all science and engineering post-doctoral positions by 2003. Interestingly, the number of temporary visa holders has only climbed since post-9/11, possibly because many of the post-doctoral scholars were graduate students in the United States and thus already held visas. As with graduate students, the growing gap between numbers of foreign and native post-doctoral scholars seems likely to have more to do with the long periods of time many scholars have to remain in post-doctoral positions and their stagnating rates of pay, even in health-related fields (Brainard 2005).

Figure 10

Postdoctoral Scholars in Science and Engineering, 1993-2003

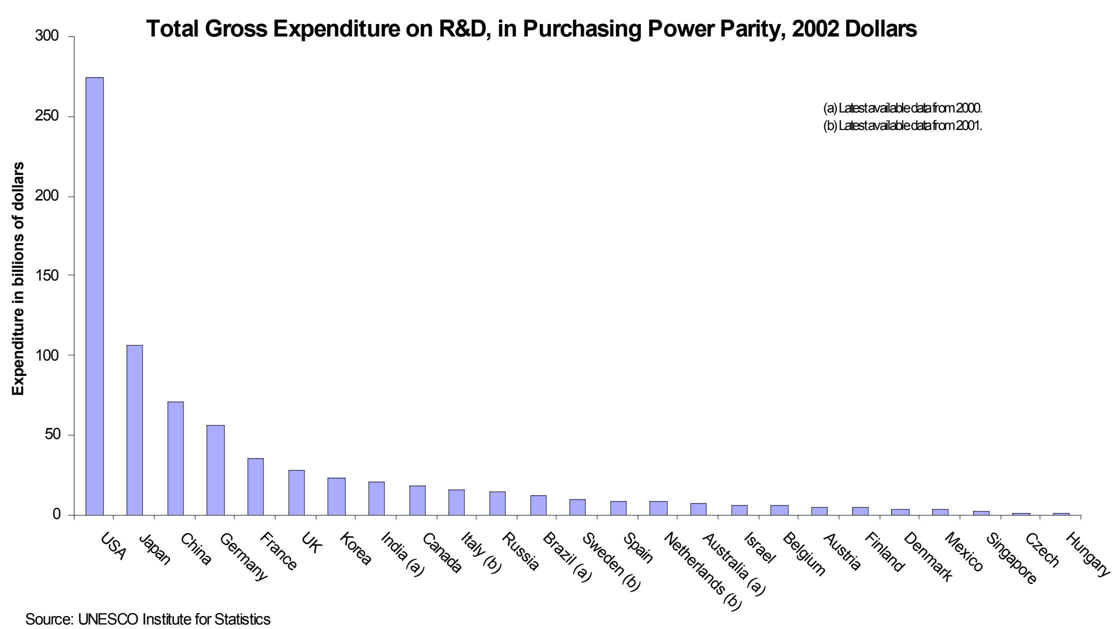


Source: National Science Foundation, Division of Science Resources Statistics, Survey of Graduate Students and Postdoctorates in Science and Engineering.

THE INVESTMENT IN RESEARCH AND DEVELOPMENT

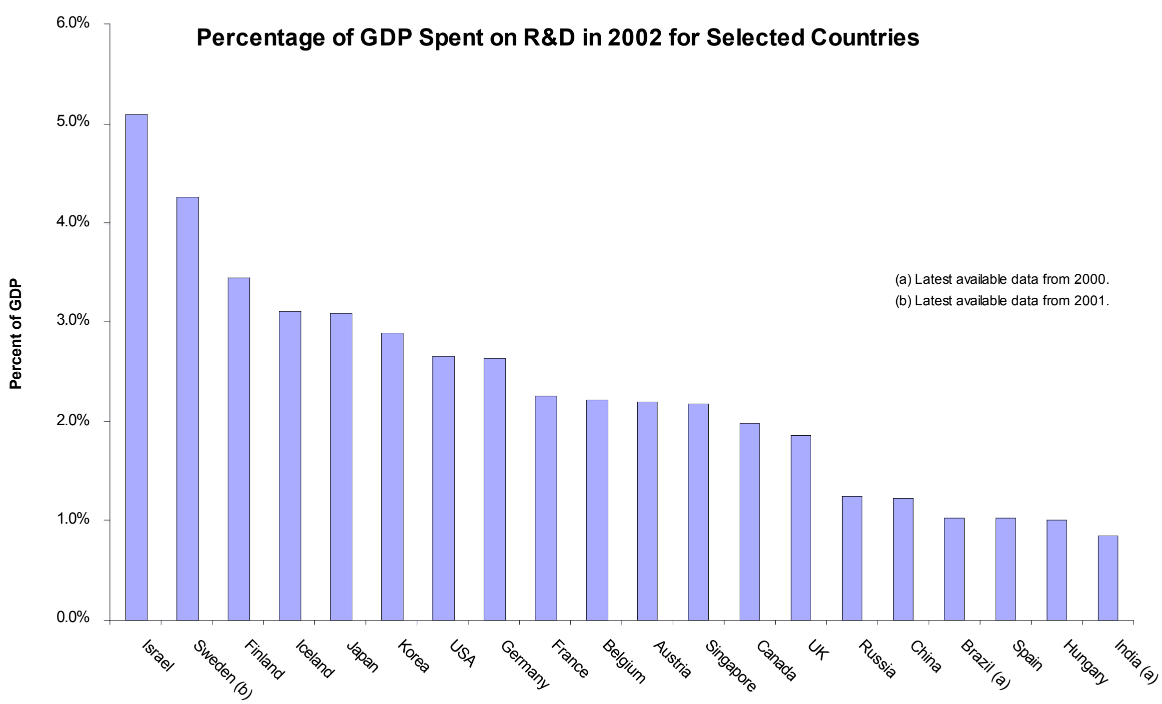
Because most of the nation's basic research is conducted in universities and because international graduate students and postdoctoral scholars constitute such a large part of science and engineering graduate enrollments and research, international students are vital to this country's research and development efforts (Fossum et al. 2004). The United States competes with other countries for top-flight talent to work on this research, and within the United States, S&E fields compete with other industries and occupations for the best students. Success in attracting both foreign and native-born talent clearly depends both on the numbers of research assistant and post-doctoral positions available and on the pay scales associated with such study and work. Since at least World War II, the United States has enjoyed a pre-eminent position in the world with respect to the total volume of spending on research and development. As Figure 11 reveals, no other country even comes close to the total gross expenditures on R&D as the United States. In 2002, the second largest expenditure (in purchasing power parity dollars) was Japan, whose level of slightly more than $100 billion was only about 40 percent of the U.S. total (UNESCO 2004).

Figure 11



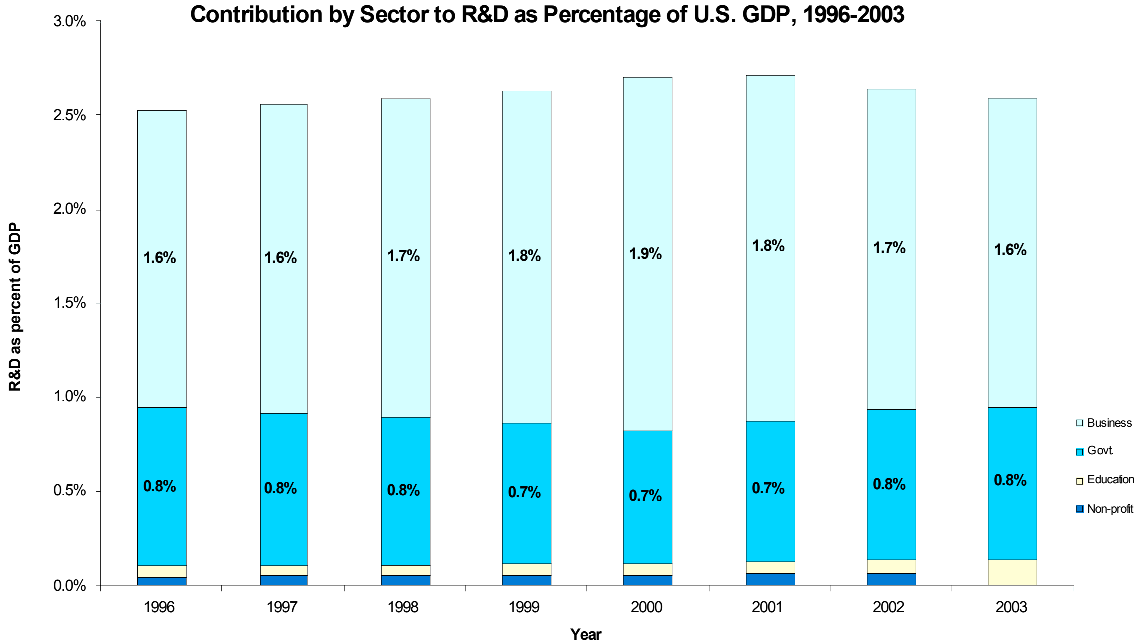
Clearly much of the U.S. superiority derives from the enormous size of the U.S. economy. However, when examined in relative terms, the United States does not fare so well. As Figure 12 reveals, when R&D investment is expressed as a percentage of gross domestic product, the United States ranks no better than 7th in the world in the priority devoted to investment in research and development. Moreover, the trend in relative investment in R&D in the country has turned downward since 2001, dropping 8.1 percent (see Figure 13). The increased emphasis given to R&D by other countries is clearly discernible in the data in Figure 14, which show increases in such relative investment since 1996. The United States has scarcely changed at all during this period, and has actually declined since 2001, with the result that the country's share of global R&D investment has fallen from 39.6 to 36.4 percent since the mid-1990s (UNESCO 2004).

Figure 12



Source: UNESCO Institute for Statistics

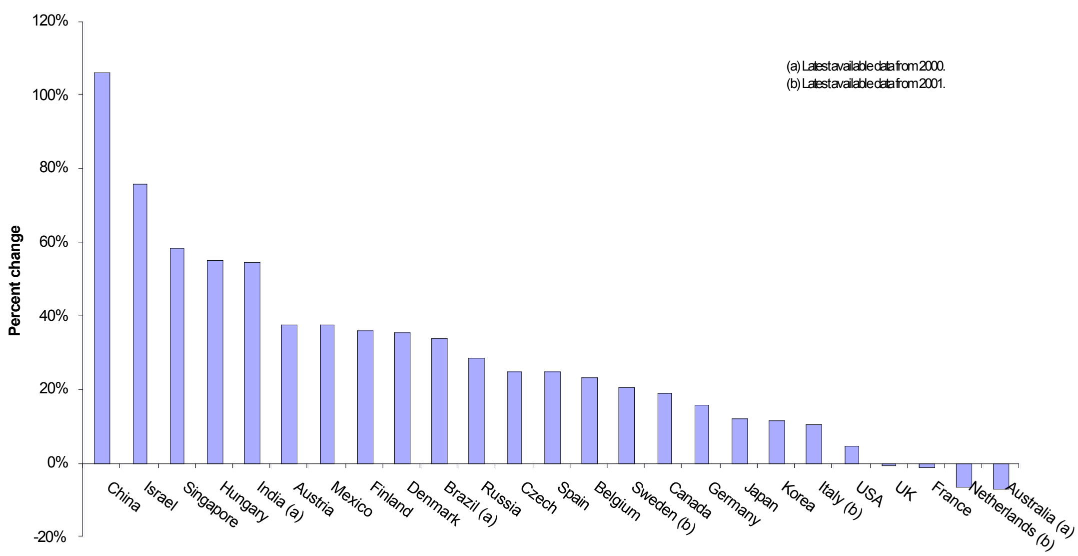
Figure 13



Source: UNESCO Institute for Statistics; Bureau of Economic Analysis, U.S. Department of Commerce

Figure 14

Change from 1996-2002 in Percent of GDP Spent on R&D, Selected Countries

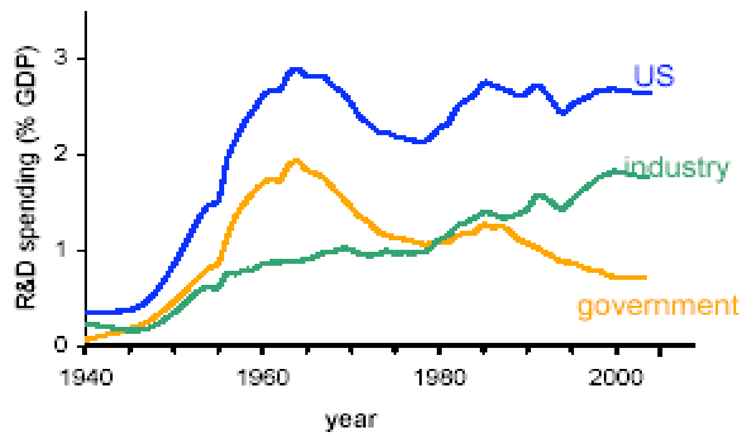


Source: UNESCO Institute for Statistics

Moreover, the effects of the decline in relative R&D spending in the United States are likely even more dramatic than the statistics suggest, for two reasons. The first is that the long-term trends are down in particular for government spending as opposed to industry spending (Figure 15). This matters because the government is much more likely than industry to support spending on basic research, the kind of investment that appears to have constituted the main well-spring of innovation in the American economy for the last sixty years (Fossum et al 2004; Freeman 2005; The Economist Intelligence Unit 2004). Industry spending is much more likely targeted at applied problems, or finding new ways better to convert innovation into viable products, rather than innovation per se (President's Council of Advisors on Science and Technology 2002). The relative decline in basic research expenditures is thus even more severe than the numbers on both research and development taken together indicate. Second, the overall relative stagnation in R&D in general, and the decline in government basic research spending in particular, would have been far worse except for major increases in life science research spending over the past ten years. Specifically, the research budgets of the National Institutes of Health approximately doubled from 1995-2004 in constant dollars (Brainard and Field 2005; Freeman 2005), a rise that serves to mask the declines and stagnation in other kinds of government basic research investment (Figure 16).

Figure 15

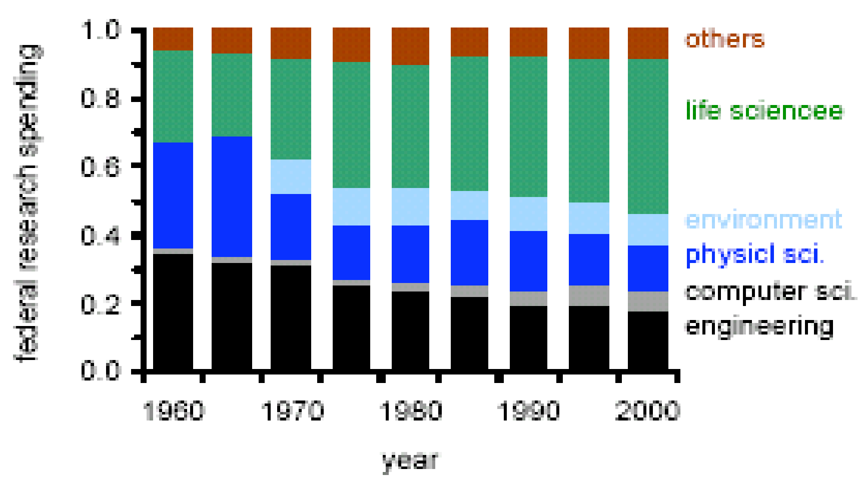
Research and Development as a Percentage of GDP by Sector in the U.S., 1940-2003



Sources: On-line supplement to Auyang, Sunny. 2004. *Engineering – an endless frontier*. Cambridge, MA: Harvard University Press. http://www.creatingtechnology.org/R&D.htm. Data from 2001-2003 from UNESCO Institute for Statistics and U.S. Department of Commerce, Bureau of Economic Analysis.

Figure 16

Federal Research Spending by Sector in U.S., 1940-2000



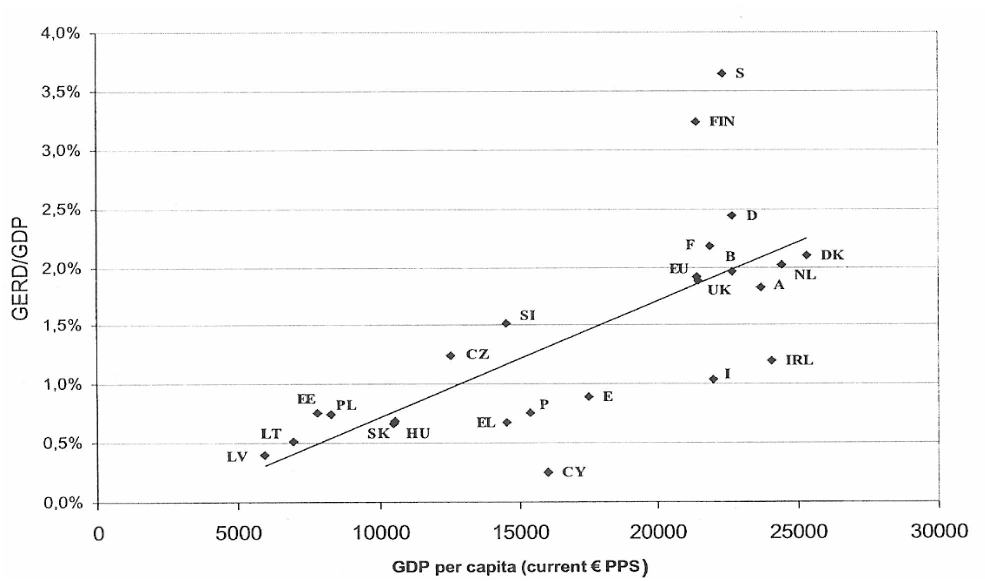
Source: On-line supplement to Auyang, Sunny. 2004. Engineering – an endless frontier. Cambridge, MA: Harvard University Press. http://www.creatingtechnology.org/R&D.htm.

The past ten years or so have thus witnessed a significant relative drop in almost all categories of U.S. investment in basic research. This decline ranges from basic defense-related spending under the auspices of DARPA (Defense Advanced Research Project Agency) to physical science, computer science and engineering basic research spending under the auspices of the NSF (Kling 2005; Fossum et al 2004; Markoff 2005). To be sure, the research budgets of the United States are still higher than those of other countries in terms of the absolute levels of dollars, but the relative priority the country has given to research and development over the past several years, and within that category to basic research in particular, is noticeably less than it was in the not too distant past.

Does investment in R&D make a difference for the economy? As Richard B. Freeman (2005: 1), the distinguished Harvard labor economist, puts it: "Leadership in science and technology gives the US its comparative advantage in the global economy. US exports are disproportionately from sectors that rely extensive on scientific and engineering workers and that embody the newest technologies. In 2003, with a massive national trade deficit, the smallest deficit relative to output was in high technology industries…. In a knowledge-based economy, leadership in science and technology contributes substantially to economic success." The relationship between science and technology leadership and economic dynamism is reflected in the positive association between per capita gross domestic product and the relative investment in research and development. This association is shown in Figure 17 for the countries of the European Economic Union. Some may think there is an ambiguity about the direction of causality in this relation, about whether it is rich countries that can afford to invest in R&D, or whether it is relatively high R&D countries that become rich. But even if it were the case that only rich countries could afford R&D, not the other way around, this would beg the question of what helps countries become rich in the first place and what now sustains high economic growth in increasingly global and ever more knowledge-based economies.

Figure 17

Federal Research Spending by Sector in U.S., 1940-2000



Source: Commission of the European Communities. 2003. "Investing in Research: An Action Plan for Europe." Commission staff working paper. Brussels. http://europa.eu.int/comm/research/era/3pct/index_en.html

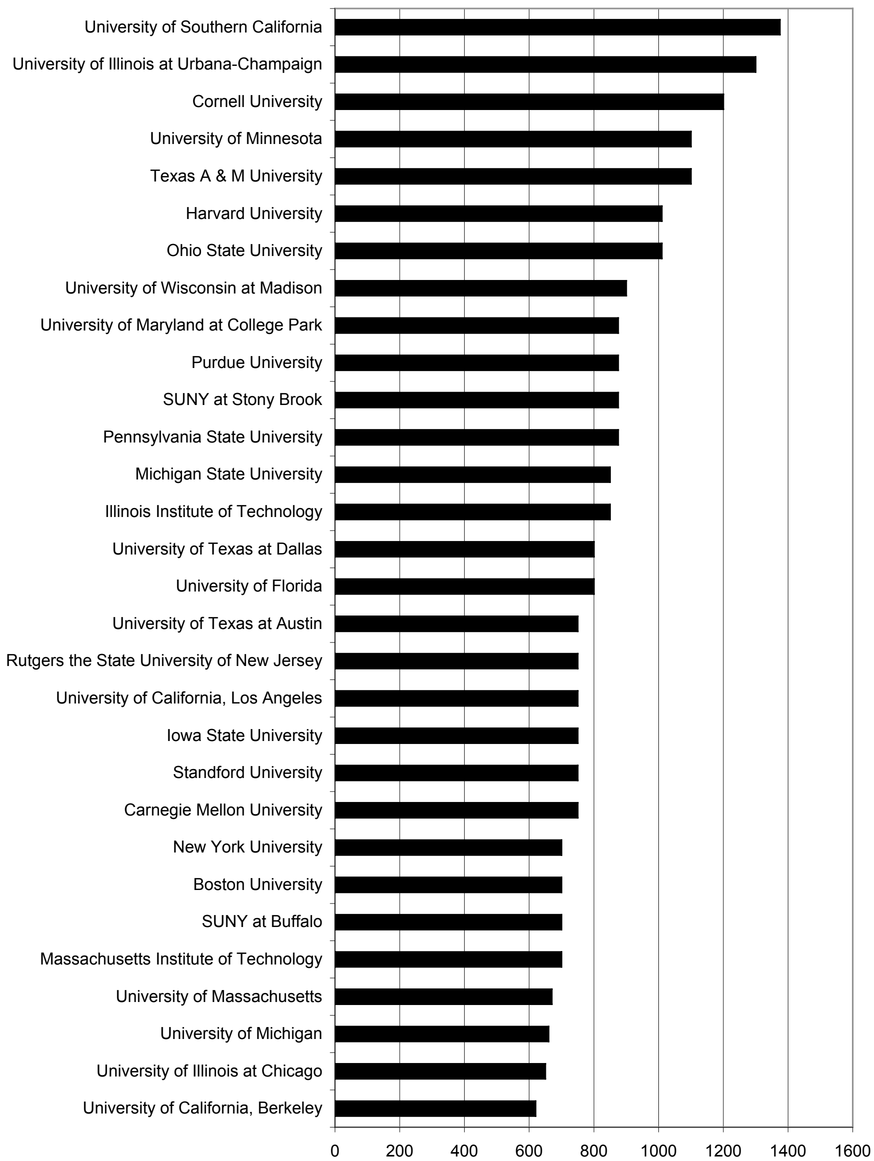
The positive implications of basic research investment for economic growth result from innovations that potentially contribute to increased productivity (Kortum 1997; Kortum and Lerner 2000; President's Council of Advisors on Science and Technology 2004). Recent research shows that the notable increase in U.S. patent applications and grants over the past 15 years was driven largely by knowledge transfers from academic science (Branstetter and Ogura 2005). In particular, most of the increase in the number of patents occurred in the bio-nexus and was found to have been generated by spill-overs from basic biological research. Interestingly, and perhaps not coincidentally, the life sciences are the one area in which major federal budget cuts for basic research have *not* been implemented in recent years, as noted above. Yet since 2003, research expenditures at even the NIH have been relatively stagnant in real dollar terms after several years of increases.

If the United States has faltered in its support for basic research funding except in the health sciences, a question arises about the degree to which the private sector has absorbed the slack. Even though increases in industrial development spending may have partially offset government cutbacks, they have not been sufficient over the past three years to cause R&D investment to rise as a percentage of GDP. This stagnation must thus be absorbed in academic science, which in engineering especially often means in public universities, whose budgets have been squeezed at the state level over the past five years even as federal research funds have fallen (Hebel 2005; Ehrenberg 2005). Most of the foreign-born science and engineering graduate students and post-docs in the country enroll in public universities (Figures 18 and 19). That the private universities do not, with three or four exceptions, meet much of the country's need for science and engineering instruction and research is striking. And, of course, even private universities depend substantially on government financing for basic research, in some ways even more than public universities (Fossum et al 2004). Further declines in the availability of basic research funds in science and engineering thus seem likely to lead to further decreases in foreign graduate students and post-doctoral scholars in S&E research in the country.

The likelihood that a drop in foreign enrollments will be made up by increases in native enrollments seems slim, given that low levels of pay, the lengthy apprenticeships of graduate students and post-docs in these fields, and the availability of attractive alternative careers discourage natives, especially males (Freeman 2005). Moreover, the increases that have occurred among natives the past three years are not likely to last given that they are probably driven more by a weak economy and by demographic change (transitory increases in cohort size) than by anything representing the beginnings of long-term upswings. And further increases in graduate S&E enrollments among women and minorities are not likely to be sufficient to compensate for even moderately large decreases in international enrollments. These factors all suggest the United States in the near future may be unable to rely as much as it has in the recent past on international graduate students and post-doctoral scholars for S&E basic research.

Figure 18

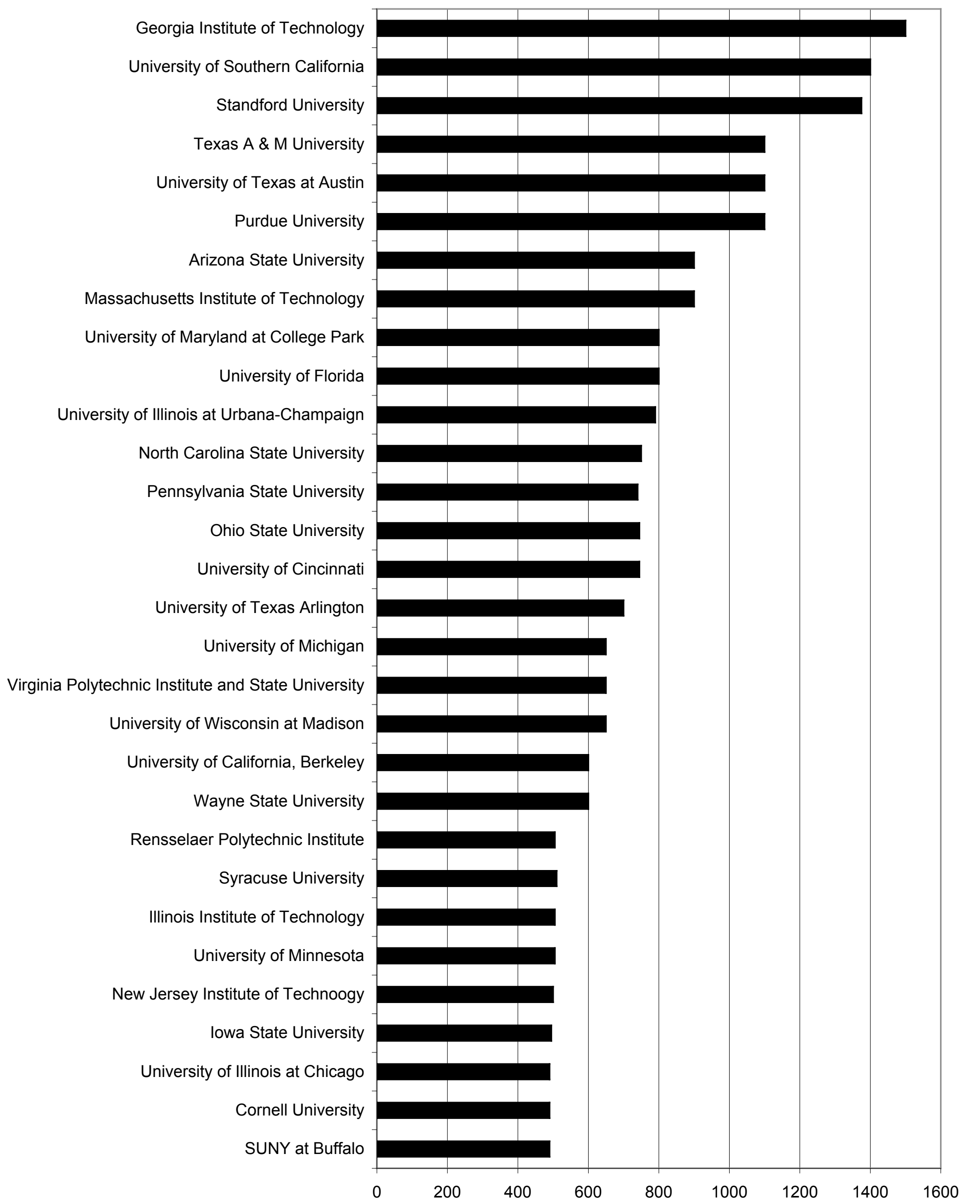
Institutions with the Largest Number of Science Graduate Students on Temporary Visas, 2001



Adapted from Figure 1-6 of Policy Implications of International Graduate Students and Postdoctoral Scholars in the United States

Figure 19

Institutions with the Largest Number of Engineering Graduate Students on Temporary Visas, 2001



Adapted from Figure 1-5 of Policy Implications of International Graduate Students and Postdoctoral Scholars in the United States

CONCLUSIONS

This paper has focused on the examination of recent trends in the enrollment of science and engineering graduate students and post-doctoral scholars in the United States. These occur in a context of a low ceiling on the numbers of legal high-skilled employment visas. Declines over the past three years in first-time graduate student enrollees appear to result substantially from changes in visa application procedures and time delays involved in security checks. However, the fact that such enrollments have not yet bounced back to their earlier levels, even though major visa processing improvements have been made, suggests that the recent enrollment decline probably does not derive from 9/11 problems alone (although some of it undoubtedly does). A portion, perhaps even a large part, may stem from recently increases in opportunities elsewhere in the world for graduate science and engineering study and employment and from the United States becoming less relatively attractive as a destination. Ironically, the changes behind such developments have occurred at about the same time as, or perhaps even a bit before, 9/11, meaning that the data emerging in the aftermath of 2001 may have obscured some of the other reasons for the drop in foreign-student involvement in the important U.S. R&D sector.

Unless decreases in graduate S&E enrollment prove short-lived, they carry enormous implications for the country's research and development programs. Some observers may be tempted to note the up-tick in native enrollments the past few years and conclude that the native upswing after 9/11 may continue and go a long way to solving any shortages that might develop in the future. This conclusion would be premature at best, because changes in native enrollments may be primarily the result of demographic changes generating growth in the size of native cohorts of 20-24 year olds and upswings in the availability of attractive employment alternatives for natives. This means the recent native increases are not permanent, because they are likely soon to turn into declines when these factors change, unless women and minorities enter science and engineering in far greater numbers than they have before. The recent drops in international enrollments, together with what are likely to be further declines in native enrollments, thus become critical concerns. Ironically, they may be exacerbated by decreases in relative U.S. spending on basic research. The United States faces the challenge, particularly in a difficult fiscal environment, of avoiding negative spirals by which declines in basic research spending beget declines in international graduate S&E enrollments, which in turn beget further declines in the country's basic research infrastructure. Clearly, such possibilities need examination with steps taken to shore up not only the country's graduate S&E enrollments, including its foreign enrollments, but also its investment in basic research (President's Council of Advisors on Science and Technology 2002).

The conclusion that buttressing the nation's basic research infrastructure requires high priority attention is reinforced by the evidence that foreign-born scientists and engineers do not appear to be crowding natives out of science and engineering activities. More likely, the native trends downward in the 1990s derived from smaller cohorts of potential students and more desirable employment alternatives, particularly for white males. Foreign students have filled the vacuum, drawn to the country by its strength in innovation and technology. But this attractiveness may now be diminished somewhat. Alternatives for graduate S&E study and R&D employment are increasingly available elsewhere and other circumstances (bad visa application experiences and distaste for U.S. policies) may have tarnished the image of the country. At the same time, the relatively poor pay and unappealing working conditions for science and engineering graduate students in the United States continue. The danger for the future is not merely that talented natives may continue to find alternative careers quite appealing, but that talented foreigners for the first time will be drawn to their own newly available alternatives elsewhere for S&E education and R&D employment. In short, neither immigrants nor natives may be very attracted to U.S. science and engineering graduate study and careers unless circumstances change. Improving basic science and engineering research funding, including taking the step of increasing pay levels for graduate students and post-doctoral scholars, might at least serve to keep these vital activities attractive to foreign students, and perhaps bring back more natives as well. If the country is to continue to lead the advanced economies of the world in the way that it has in the recent past, it’s a safe bet that either foreign or native S&E graduate students will be needed, or both.

ENDNOTE

[1] The 1986 Immigration Reform and Control Act (IRCA) included provisions allowing unauthorized migrants to legalize, that is, to become legal permanent residents, one year after obtaining temporary legal status. IRCA-based applicants for legal immigrant visas began entering the U.S. immigration system in substantial numbers starting in 1989, and their flow tapered off after 1992. We exclude IRCA immigrant visas because they came about through entirely different mechanisms than other immigrant visas.

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