Foreign Scholars in U.S. Science: Contributions and Costs

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April 2003

Prepared for the Conference "Science and the University"

Cornell Higher Education Research Institute
May 20-21, 2003

Draft

Our research on the foreign-born has been supported by the Alfred P. Sloan Foundation, the Andrew Young School of Policy Studies at Georgia State University and the graduate School at the University of Missouri-St. Louis. We thank W. Amis, M. Finn, M. Fox, J. Harrington, R. Mathless, F. Narin, D. Pendlebury, and T. Seldes for their assistance. We also thank student assistants D. Banks, A. Levin, D. Loesel, and M. Ying at the University of Missouri-St. Louis and M. Crimmins, A. Hadley, R. Hawkins, J. Keene A. Sumell at Georgia State University. We also wish to acknowledge our co-authors on the shift-share portion of this research: Anne Winkler of the University of Missouri-St. Louis and Grant Black of Georgia State University.

Section I: Introduction

The foreign-born have an exceptionally strong presence in U.S. science. They make up a large and increasing percent of the scientific workforce and an increasing percent of Ph.D. degrees in science and engineering are awarded to foreign-born students. Moreover, in recent years, U.S. scientists have increasingly published with scientists working outside the United States (Adams et al., 2002).

The presence of the foreign-born in U.S. science raises several questions. First, is the issue of security: Is the U.S. educating scientists and engineers who could use this knowledge to harm the United States and its allies? Second, is the question of contribution: Do the foreign-born and foreign-educated contribute disproportionately to U.S. science? Third, is the question of cost: Are U.S. scientists and engineers crowed out of jobs by foreign-born and foreign-educated scientists? A related cost-question is whether the presence of foreign-born scientists and engineers discourages U.S. citizens from choosing careers in science and engineering and whether this has an especially strong impact on career choices of minority students.

Here we focus on the contribution and cost questions, noting that the issue of contribution and costs is not an either or question. Rather, it resembles what economists refer to as a welfare problem, much like free-trade, where the overall economy can benefit from free trade but individuals or groups of individuals incur substantial costs. We address security issues elsewhere (Stephan et al., 2002). We leave an investigation of how the presence of the foreign-born affects career choices to others, or a later study by ourselves.

The plan of the paper is as follows: In Section II we summarize overall trends, in terms of work force and Ph.D. recipients, focusing on the changing composition of the foreign-born, as well as the changing composition of those studying on temporary visas. In Section III we address the question of contribution, examining the birth and educational origins of individuals making significant contributions to U.S. science. Section IV focuses on cost. Using a novel adaptation of the shift-share technique, we examine whether the heavy inflow of foreign talent receiving doctorates in the United States has displaced citizens from jobs in S&E, especially the choice positions within the academic sector, over the period 1979-1997. Conclusions are drawn in Section V.

Section II: The Increasing Presence of the Foreign-Born

The birth and educational origin of the U.S. scientific workforce can be examined using two related, but not strictly comparable databases. The first, known as the National Survey of College Graduates (NSCG) is based on the U.S. census and has the virtue of identifying individuals working in the U.S. but trained outside the U.S. as well as individuals trained in the U.S. The NSCG's drawback is that it is seldom fielded and thus leaves large gaps in our knowledge concerning the workforce. The second, known as the Survey of Doctorate Recipients (SDR), has the advantage of being fielded every other year. The drawback is that it only examines scientists and engineers working in the U.S. *who received their doctoral training in the U.S.*

Table 1 presents data concerning the birth and educational origins of scientists and engineers working in the United States in 1980 and 1990, using the NSCG, and thus including scientists whose doctoral training was received outside the U.S.[1] Regrettably, comparable data is not yet available for 2000. We exclude from the analysis individuals not in the labor force, individuals in the military, individuals not in the U.S. and individuals in social science occupations. We restrict our definition of highly-trained scientists to those who have a doctoral or medical degree; highly trained engineers to those who have a baccalaureate degree. We use the NSCG to determine the size of the scientific workforce in 1990 as well as in 1980. For the latter, we restrict the sample to those who immigrated or completed their highest degree before 1980.[2]

Distributions are presented in Table 1 for five fields: engineering, the physical sciences (physics and chemistry), mathematical and computer sciences, the earth and environmental sciences and the life sciences. We see that 18.3% of the highly-skilled scientists in the U.S. in 1980 were foreign-born. The percent was highest among physical scientists (20.4%) and lowest among life scientists (15.4%). By 1990 the proportion foreign-born had increased to 24.7%. More than one in four physical scientists and math

[1] The NSCG was fielded in 1993 and collected information on the education and labor market experiences of college educated individuals identified in the 1990 U.S. Decennial Census. Table 1 is drawn from Stephan and Levin (2001).

[2] We could have used the 1982 Postcensal Survey (1982 Survey of Natural and Social Scientists and Engineers) for the 1980 estimates. We chose not to do so, however, because the NSCG was a superior survey, having supplemented the mail-only questionnaire with telephone interviews and intensive follow-ups to non-respondents.

and computer scientists working in the U.S. had been born abroad; for life scientists the proportion had increased from approximately one in seven to one in five. The proportion of engineers who are foreign-born is substantially smaller than that of highly trained scientists. In 1980 approximately 14% were foreign-born; this had crept up to about 16% by 1990.

The disparate rates of growth in the native and foreign-born components of the scientific labor force can be seen from Figure 1. In computer sciences the rate of growth of the foreign-born was more than twice that of native-born; in the life sciences it approximated being twice as great. Only in earth and environmental sciences has the rate of growth been about the same.

Many immigrants come to the U.S. to receive training and subsequently stay to work (Ries & Thurgood, 1991; M. Finn, 1995). Some come prior to receiving their undergraduate degrees, others afterwards. Of the former, many immigrated with their families when they were children. A striking feature of Table 1 is the large number who come to the U.S. after receiving their doctoral training. In all but mathematics and computer science more than one out of ten individuals in the U.S. scientific workforce in 1990 received their doctoral training abroad.[3]

Table 2 takes a longer, albeit it edited view of the presence of the foreign-born in the workforce, using the SDR. We see over the period 1973-1997 that the number of U.S. trained doctoral scientists and engineers living in the U.S. who were citizens (either native-born or naturalized) at the time their degree was awarded increased almost three-fold; those who held temporary or permanent visas at the time the degree was received increased eight-fold. Thus, while fewer than one in ten U.S. doctoral-trained scientists working in the U.S. in the early 1970s were not citizens at the time their degree was awarded, by 1997 more than one in five were not citizens. The citizen-non-citizen growth differential is most striking in the mathematical/computer sciences, followed by engineering and earth/environmental sciences. In the former, the number of citizens grew almost three-fold while the number of non-citizens grew thirteen-fold; in the latter two,

[3] In recent years, many of the foreign-doctoral recipients working in the U.S. initially came to the U.S. to take a postdoctoral position. It should also be noted that some of those who have foreign doctoral degrees are U.S. citizens who go abroad for training. This is most common in the earth and environmental sciences.

citizen growth was more than two-fold while non-citizen growth was more than nine-fold.

One reason that there is such an increased presence of the foreign-born in U.S. science stems from the increased proportion of U.S. Ph.D. students who are non-citizens at the time they receive their Ph.D. degree. This is seen in Figure 2, which demonstrates how the composition by citizenship has changed among degree recipients during the period 1981-1999. Data come from the Survey of Earned Doctorates (SED), a census of all doctoral recipients in the United States. The survey is administered by Science Resources Statistics, National Science Foundation.

Figure 2 documents the dramatic increase in the number of Ph.D. recipients holding temporary visas during the period 1981-1992, followed by a decline during the next seven years. While in 1981 fewer than 2,500 Ph.D. recipients in S&E held temporary visas (20% of all those receiving Ph.D.s in S&E), by 1992 the number stood at close to 7,000 (38.4% of all doctoral degrees awarded in S&E that year). By 1999 the number had decreased by approximately 1,000, with temporary-visa recipients receiving slightly more than 32% of all Ph.D.s awarded in S&E that year. The decrease is undoubtedly related to the passage of the Chinese Student Protection Act of 1992, which permitted Chinese nationals temporarily residing in the U.S. to switch to permanent-resident status.

The growth in temporary residents has been especially dramatic in the fields of the biological and agricultural sciences and math and computer sciences. In the biological and agricultural sciences the percent of temporary residents receiving Ph.D.s more than doubled during the period 1981-1992, going from approximately 13% to almost 28%. It then fell slightly to approximately 26% by 1999. In math and computer sciences the percent increased from 23.5% in 1981 to 46% in 1991 and stood at 39% in 1999. The change in composition has been less dramatic in engineering but the proportion of doctorate recipients who are temporary residents in this field is substantial, hitting a high of 50.5% in 1991 and closing the decade at 39.6%.

Section III: The Question of Contribution[4]

We examine whether the foreign-born and foreign-educated contribute disproportionately to U.S. science by testing whether the foreign-born and foreign-educated are disproportionately represented among individuals making exceptional contributions to science and engineering (S&E) in the United States. There are several reasons why the foreign-born may disproportionately contribute. First, and depending upon immigration law in effect at the time of entry, a work permit can require an employer declaration that the scientist is especially talented. Second, given the personal sacrifices immigration requires, immigrant scientists are likely to be highly motivated. Third, foreign-born scientists and engineers who come to the U.S. to receive training, especially at the doctoral or postdoctoral level, are typically among the most able of their contemporaries. Often they have passed through several screens: they have been educated at the best institutions in their countries, withstanding intense competition for the limited number of slots available, and they have competed with the best applications from many countries, including those from the U.S., before being selected for further training in the U.S. (Rao, 1995; Bhagwati and Rao, 1996). Finally, there is some evidence that suggests that the average quality of U.S.-born individuals choosing to get doctorates in S&E declined during the 1960s, 1970s and 1980s (Stephan and Levin, 1992). This was brought about by a phenomenal growth that occurred in Ph.D. production in the 1960s and early 1970s, which arguably diluted the talent pool in science, followed by a brain drain as bright students sought more lucrative careers in business, law and medicine.

Here we draw on a study that we did in the mid-1990s to address the issue of contribution.[5] We are currently updating this study and will make these findings concerning contribution available as soon as possible.

We use six different indicators of exceptional work in S&E to test the hypothesis of disproportional contribution: individuals elected to the National Academy of Sciences (NAS) and or/National Academy of Engineering (NAE), authors of citation classics, authors of hot papers, the 250 most-cited authors, authors of highly cited patents, and

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[4] This section draws heavily on Stephan and Levin (2001).
[5] For a detailed discussion, see Stephan and Levin (2001).

scientists who have played a key role in launching biotechnology firms. We do not claim that this list is exhaustive, merely illustrative.

Members of the NAS and NAE are elected in recognition of their distinguished and continuing contributions to knowledge. We included 1,554 members of the NAS and 1,706 members of the NAE in the study.[6] Citation classics are journal articles that, according to the Institute of Scientific Information (ISI) which published them biweekly in *Current Contents*, have a "lasting effect on the whole of science."[7] We chose the 138 papers declared classics by ISI during the period June 1992 to June 1993 in the areas of life sciences; agriculture, biology, and environmental sciences; physical, chemical and earth sciences; and clinical medicine.[8] Authors of citation classics were considered to have made a significant contribution to science in the U.S. if the author was working in the U.S. at the time the article was published. This resulted in the identification of 62 first authors (54 unique) and 135 non-first authors (127 unique).

Each issue of *Science Watch*, also published by ISI, contains a list of the ten most cited or "hot papers" in chemistry and physics or medicine and biology. The selection is based on the number of times a paper has been cited by other authors in a given period, usually the two-month period eight weeks prior to the cover date. We chose the 251 papers declared "hot" between January 1991 and April 1993. Again, an author was considered to have made a significant contribution to U.S. science if the author was working in the U.S. at the time the article was published. This resulted in the identification of 170 first authors (161 unique) and 786 non-first authors (686 unique).

Both citation classics and hot papers identify articles that have made or are making a significant contribution to the knowledge base. From time to time ISI also focuses on authors as opposed to articles, preparing lists of the "most-cited scientists."

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[6] From the 2075 NAS members in 1994, we excluded foreign associates without a U.S. address, Public Welfare Medallists (who are honorary members), members of the psychology and social science sections, and 20 for whom no section was specified. From the 1,781 members of the NAE as of June 30 1995, we excluded foreign associates without a U.S. address.

[7] ISI discontinued the practice of declaring Citation Classics in the late 1990s.

[8] We excluded papers published before 1970 because of the difficult in obtaining biographical information for authors.

From the list of 250 most cited authors during the years 1981 to 1990, we studied 183 authors who were based in the U.S.[9]

The last two criteria that we used focus on technology transfer. We studied authors of highly-cited patents (the top 3.5% over the period 1980-1991) in the field of "medical devices and diagnostics."[10] We chose medical devices because of the strong consensus that patents play a key role in this area. Two hundred and six (178 unique) U.S.-based scientists were identified. Finally, we identified the scientific founders and chairs of scientific advisory boards of biotechnology firms making an initial public offering (IPO) during the period March 1990 to November 1992.[11] Ninety-eight founders and chairs (97 unique) were identified from the prospectuses of 40 firms. Altogether, the study group consisted of 4,746 scientists and engineers.

Place of birth and educational origin of each scientist and engineer, as well as the date of birth and date of degree(s) were obtained from various scientific organizations and directories. For scientists involved with biotech firms, we used the company's prospectus. Addresses were sought for the 1050 scientists and engineers for whom biographical data could not be obtained from public sources. The response rate was 64.8%.[12] Overall, essential biographical data (such as country of birth) was ascertained for 89.3% of the study group.

We adopt an agnostic approach, despite our priors, and use a two-tail test. For each of the six indicators, we determined whether the observed frequency by birth (or educational) origin was significantly different than the frequency one would expect given the composition of the scientific labor force in the U.S. in either 1980 or 1990 (see Table 1). To do so, we used a non-parametric "goodness of fit test," computing the chi-square statistic. In cases where the chi-square statistic was inapplicable because of small cell

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[9] David Pendlebury of ISI provided the list. In preparing this list, some heavily-cited authors with common last names were omitted because ISI could not accurately determine attribution.

[10] The list was prepared by Francis Narin of CHI, using the database created by CHI Research, Inc. Research suggests that citations to patents (the citations that appear on the front page of a patent under 'references cited') can be used as an index of the importance of a given patent. See, for example, Trajtenberg (1990), Albert, Avery, Narin, McAllister (1991) and Hall, Jaffe and Trajtenberg (2001).

[11] Individuals were assumed to be scientists if they held either the Ph.D. or M.D. degree. Audretsch and Stephan (1996) examine the various roles that scientists play with start-up firms in biotechnology.

[12] The response rate was 54.5% for the entire sample; 64.8% for deliverable surveys. A review of the names of the non-deliverables suggests that a disproportionate number may have been foreign-born. For the non-respondents, there does not appear to be a birth-origin bias.

size, a two-tailed binomial test was applied.[13] We use the 1980 benchmark for the underlying composition of the scientific workforce for individuals elected to NAS or NAE, most-cited authors, authors of citation classics, and founders/chairs of biotechnology companies, because each of these indicators was based on a list of scientific accomplishments that began before that date. The remaining indicators used a 1990 benchmark.

Engineers elected to the NAE. Table 3 provides summary data concerning the birth and educational origins of engineers elected to the NAE by section. Overall, we see that the proportion of foreign-born engineers among this elite group is 19.2 percent and is significantly different than the underlying benchmark population (13.9 percent) at the P=0.01 level or less. Members of the NAE are also more likely to be educated abroad than is the underlying population (10.7% vs. 7.4%). The results and level of significance vary somewhat by field both for birth origin and educational origin, especially in the case of civil engineering where neither proportion is significantly different from the benchmark population. The engineering section with by far the largest proportion born and educated abroad is mechanical.

Scientists making exceptional contributions to the life sciences.[14] Table 4 displays data for scientists making exceptional contributions in the life sciences. Included are separate indicators for first and non-first authors of citation classics and hot papers, members in NAS sections in the life sciences, and a category called "outstanding" authors, which combines the most-cited with the first authors of citation classics. We find that all indicators benchmarked by the 1980 composition of the scientific labor force are statistically significant at the P=0.10 level or less, with several at the P=0.01 level or less. Nearly three out of ten of the 'outstanding' authors are foreign-born compared to a population percentage of 15.4. The proportion foreign-born among first and non-first authors of hot papers is not, however, significantly different that the proportion found for life scientists in the 1990 benchmark population.

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[13] The chi-square statistic is inapplicable when the expected frequency in any cell is less than 5 and there are just two categories in the classification of the data. In such cases, the binomial test is uniquely applicable. See Siegel (1956, p. 59).

[14] We include biology and medicine in the life sciences. The physical sciences include chemistry and physics.

The proportion of foreign-educated life scientists making exceptional contributions is significantly different from the benchmark population at the baccalaureate and doctoral degree level in the case of most-cited and outstanding authors and for members of the NAS. At the baccalaureate level the proportion is significantly different for those authoring highly-cited patents for medical devices.

Scientists making exceptional contributions to the physical sciences. Regardless of benchmark data or indicator, we find the foreign-born to be disproportionately represented among those making exceptional contributions in the physical sciences (Table 5). For example, more than half (55.6%) of the "outstanding" authors in the physical sciences are foreign-born compared to just 20.4% of physical scientists in the scientific labor force as of 1980 (Table 1). We also find the foreign-educated are disproportionately represented for a number of the indicators—among most-cited and outstanding authors, as well as first authors of hot papers.

Discussion of Contribution. Our results indicate that, although there is slight variation by discipline, individuals making exceptional contributions to U.S. S&E are disproportionately drawn from the foreign-born. Only in the instance of hot papers were we unable to reject the null hypothesis that the proportion was the same as that in the underlying population and then only for the life sciences. We also find evidence that for a number of criteria individuals making exceptional contributions to U.S. S&E are disproportionately drawn from the foreign-educated, both at the undergraduate and at the graduate level.

We conclude that the U.S. has benefited from the inflow of foreign-born talent and that this talent was more likely to have been educated abroad than one would have predicted given the incidence of foreign-educated scientists in the scientific work force. Thus, to the extent that contributions in S&E are geographically bounded, as a country the U.S. has benefited from the educational investments made by others. It does not necessarily follow, however, that these benefits have been produced at no cost or at a low cost to citizens of the U.S. We investigate the issue of costs and the incidence of costs in the next section of the paper.

Section IV: The Issue of Costs[15]

Although there is a "widespread perception that 'immigrant hordes' have an adverse effect on the employment opportunities of U.S. citizens" (Borjas, 1994, p. 1667), the question of how immigrants affect employment outcomes in S&E has yet to be investigated. To date, the evidence is sketchy, consisting of anecdotal reports and selected data implying that in some fields, immigrants "take" coveted positions away from U.S. citizens in science, especially in academe. For example, the American Mathematical Society noted that "Immigrants won 40% of the 720 mathematics jobs available last year (1995) . . . and helped boost the unemployment rate into double digits among newly minted math Ph.D.s" (Phillips, 1996, p. A2). And, a study by the National Research Council reported a growing "imbalance between the number of life-science Ph.D.s being produced and the availability of positions that permit them to become independent investigators," a situation exacerbated by the "influx of foreign-citizen Ph.D. candidates … (1998, p. 4).[16]

Here we analyze the differential employment patterns of U.S.-doctoral recipients in S&E over the period 1979-1997[17] using data from the SDR. We seek to determine how U.S.-citizen S&E doctorates have fared relative to their non-citizen counterparts and, in particular, whether they have been displaced. In this analysis, citizens include those naturalized or native-born at the time the doctorate was earned; non-citizens include permanent and temporary residents and individuals that had applied for citizenship at the time the doctorate was earned. Although the SDR excludes two groups that are important to the scientific workforce, scientists and engineers working in the United States who received their doctoral training abroad and scientists with medical degrees who lack U.S.-earned doctoral degrees, it remains the best available data source for the purpose of studying changing patterns over time.

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[15]This section draws upon Levin, Black, Winkler & Stephan, 2003; Levin, Black, Winkler & Stephan, 2002.

[16]U.S.-citizen information technology (IT) workers also claim that the increased flow of H1-B visa holders are adversely affecting their careers in IT (Matloff, 1988).

[17]While data are available from 1973, we start with 1979 because of the poor quality of the survey questions concerning tenure status and academic rank found in the 1973 SDR (Levin & Stephan, 1991).

Methodology. To tackle the question of displacement, we undertake a thought-experiment. We compare the *actual* employment growth of a specific "citizenship" group (citizen or non-citizen) in a specific sector with the amount *predicted* using the following counterfactual. We ask what would have happened to employment of U.S.-citizen (non-citizen) S&E doctorates in different sectors of the economy if their employment had grown at the overall growth rate for all S&E doctorates combined, regardless of citizenship status. In doing so, we acknowledge that the growth in U.S.-trained S&E doctorates has been fostered both directly and indirectly by a variety of policies, including changes in immigration laws and the widespread availability of funds supporting graduate and postdoctoral study in science. In effect, we assume that the United States could have implemented a different set of policies that would have elicited an equal amount of growth from citizens alone. Whether this is the "correct" counterfactual is, of course, subject to debate. But the belief exists that "the United States should be able, if it so chose as a matter of social policy, to meet its needs for scientists from within its own population, especially by harnessing the talents of under-represented minorities and women" (Bouvier & Martin, 1995, p.3).[18]

We implement the analysis by adapting a technique originally developed in the regional science's literature, known as shift-share.[19] The conventional (regional science) application of shift-share decomposes employment growth for industry i in region j, G_{ij}, into three components: (1) a reference group or "overall" growth component (such as employment growth in the United States), $O_{ij;}$ (2) an industrial-mix component, $M_{ij;}$ and (3) a "competitive" component, C_{ij}. In the present analysis, the reference group is U.S.-S&E doctoral recipients; "regions" refer to the employment sectors of S&E doctorates (academe, nonacademe, and other); and "industries" refer to the citizenship status of S&E doctorates (citizen or non-citizen).

For each citizenship group in each sector, the following identity must hold:

[18]North (1995) observes that "while the large-scale presence of foreign-born S/Es, particularly at the Ph.D. level, was neither deliberately created by America's universities and corporations nor thrust upon them against their will (p. 145) . . . their presence and growing numbers are … permitting the status quo to continue without the awkward adjustments that would be needed were they not here" (p. 161).

[19]See, for example, Gordon, Hackett & Mulkey, 1980; Andrikopoulos, Brox, & Carvalho, 1990; Kiel, 1992; Grobar, 1996). In recent years, shift-share has been applied in a wide variety of contexts including Smith, 1991; Ishikawa, 1992; Geiger & Feller, 1995; Haynes & Dinc, 1997; Hoppes, 1997.

$$G_{ij} - O_{ij} = M_{ij} + C_{ij}$$

where

$$O_{ij} = b_{ij}\, r_{oo}$$

$$M_{ij} = b_{ij}\, (r_{io} - r_{oo})$$

$$C_{ij} = b_{ij}\, (r_{ij} - r_{io})$$

and b_{ij} = employment for citizenship group i in sector j during the base period, r_{oo}= the overall growth rate for all S&E doctorates, r_{io} = the growth rate for citizenship group i, and r_{ij} = the growth rate for citizenship group i in sector j.

Thus $G_{ij} - O_{ij}$ measures the difference between the *actual* growth in employment and the *predicted* growth in employment for group i in sector j; the difference is then divided into M_{ij}, now termed the "minting" effect and C_{ij}, the competitive effect. The minting effect measures the employment change citizens (non-citizens) experienced in a particular sector due to the differential in growth rates between its doctoral recipients and all doctoral recipients. By definition, the minting effect must sum to zero for the two citizenship groups. The competitive effect is the difference between the actual change in employment for each citizenship group in each sector and the employment growth that would have occurred had each group grown at its overall growth rate. By analogy, as in the case of international trade, competitive effects across sectors for a particular group (citizen or non-citizen) must sum to zero just as trade accounts must balance out. In addition, sub-sector additivity must hold. That is, for each citizenship group, if a sector such as academe is partitioned into two or more parts, the sum of the competitive effects for all parts must equal the competitive effect for the sector as a whole.

In effect, C_{ij} captures the differential rate at which jobs in various sectors of the economy have grown for each citizenship group, after accounting for the overall growth in the number of doctoral recipients and the differential minting effects observed. We define displacement from a sector to be the difference between the citizen and non-citizen competitive effect. Thus, suppose we observe that employment growth for citizens in academe is smaller than predicted given the counterfactual. There are two reasons why this may have happened: the citizen share of S&E doctorates may have declined (the minting effect); citizens may have experienced slower employment growth in academe than in the other sectors (the competitive effect). To determine whether citizens have fared poorly compared to their non-citizen counterparts in academe -- whether displacement has occurred -- we then subtract the non-citizen competitive effect from the citizen competitive effect (both measured in percentage terms to adjust for relative size differences).

Although the decomposition into a minting effect and a competitive effect is based on an accounting identity, from a public policy standpoint these are powerful distinctions to make since the prescriptions for remedy differ. For example, to the extent that the minting effect works against citizens, efforts are needed to help expand their numbers in doctoral programs. To the extent that the competitive effect works against citizens relative to their immigrant counterparts, then policy makers need to consider whether their displacement from academe is of an involuntary or voluntary nature. Have U.S.-citizens been pushed out of positions in academe by the inflow of foreign talent or have they been pulled out by the lure of better salaries and opportunities in other sectors?

Displacement from academe. Table 6 presents the estimates of displacement from the academic sector obtained from the decompositions performed for all fields combined and major subfield over the period 1979-1997.[20] This sector includes individuals under the age of 65 who are either employed full-time or hold a postdoctoral training position in a university, four-year college, or medical school. The negative competitive effects for both citizens and non-citizens indicate that both groups have lost employment share in academe relative to the remaining sectors in the analysis -- nonacademe and other. Moreover, for each field, and without exception, we find that citizens have been displaced from academe by their non-citizen counterparts since the citizen (negative) competitive effect is larger in absolute value than the (negative) competitive effect for the non-citizen. Displacement is largest for citizens in the life and physical sciences.[21]

[20]To conduct the analysis, the data are initially divided into three six-year year intervals (1979-1985, 1985-1991, 1991-1997). Then each component in the decomposition for each time period is summed over the three periods so that a single number captures the "dynamic" nature of employment growth for the entire 1979-1997 period. See Barff and Knight (1988) for insight into this procedure. Because beginning in 1991 several changes were made to the SDR in an attempt to increase its response rate, we use the older, mail-only weight for the interval 1985-1991 for better comparability with the pre-1991 data.

[21]Although not reported here, within the physical sciences, displacement is largest for those in the mathematical and computer sciences.

Displacement within academe. Not only has employment in academe fallen relative to the other two sectors for citizens and non-citizens alike, the types of appointment held by both citizenship groups have changed as well. Figure 3 examines displacement *within* academe where the type of appointment is partitioned into "faculty" versus "postdocs." Figure 4, on the other hand, examines displacement *within* academe, where the type of appointment is partitioned into "permanent" -- tenured or tenure-track faculty -- versus "temporary" -- postdocs and other non-tenure track and non-faculty positions such as lecturers, instructors, clinical faculty, research scientists, and technical staff. Again, we restrict the analysis to those who are full-time and under the age of 65.

Figure 3 shows that overall, for all fields combined, and in the life sciences, the displacement of citizens from academe can primarily be attributed to their displacement from postdoctoral appointments and not faculty positions within academe. Indeed, there is minimal evidence of displacement from faculty positions (-1.7%) for all fields taken together, and in the life sciences, citizens have actually fared relatively better than non-citizens (+5.3%) have when considering faculty appointments. This is not true, however, in engineering and in the physical sciences. Here we find that the displacement of citizens from academe is largely accounted for by their displacement from faculty positions and not postdoc positions.

But, as Figure 4 illustrates, the story is somewhat different when one considers who holds permanent versus temporary appointments within the academic sector. Now we see that for all fields taken together as well as for each subfield, the displacement from academe observed for citizens can primarily be attributed to their displacement from temporary rather than permanent positions. Moreover, for all fields taken together, there is scant evidence of displacement from permanent academic appointments (-0.6%), and in the life sciences, citizens have again fared relatively better than non-citizens (+1.6%) in terms of holding permanent academic appointments.

Discussion of displacement. Our analysis indicates that both citizens and non-citizens experienced employment shortfalls in academe (negative competitive effects) after accounting for the overall growth in the number of doctoral recipients and the differential rate at which the two groups minted degrees. Citizens, however, fared relatively worse than their non-citizen counterparts and, by our definition, have been displaced. But citizen S&E doctorates, except in the physical sciences and engineering, have been more successful than non-citizens in holding the choice positions as faculty members rather than postdocs within academe. Furthermore, citizen S&E doctorates have generally been more successful than their non-citizen counterparts in holding the coveted positions as permanent, tenured or tenure-track faculty, rather than positions as temporary members of the academic units.

Our analysis cannot reveal whether displaced citizens were, on balance, pushed out by the heavy inflow of foreign talent or pulled out by the lure of better opportunities elsewhere in the economy. One finding in particular indicates that an element of pull may be involved. The finding that the displacement from academe observed for citizens can largely be attributed to their displacement from postdocs and other temporary appointments within this sector suggests that citizens may have been more responsive than non-citizens to the lure of better opportunities elsewhere.

Section V: Conclusion

We conclude that the foreign born have contributed disproportionately to U.S. science. Moreover, a surprisingly large percent of the foreign-born are educated abroad, suggesting that the U.S. is benefiting from investments made by other countries. Our evidence, however, is somewhat dated, resting on indicators of contribution collected in the early 1990s. Whether the results hold when updated remains to be seen.

Our work suggests that the benefits are not without costs. One group that has borne the costs is citizen-scientists and engineers, having been displaced from jobs in academe by non-citizen scientists and engineers. The costs of displacement are mitigated, however, in two ways. First, displacement occurs mostly in "temporary" jobs in academe, not in "permanent" jobs in academe. Thus, citizen-scientists are losing the less valued as opposed to more highly valued positions within the academic community. Second, this result together with the finding that displacement is largest for those in the mathematical and computer scientists suggests that citizen-S&E doctorates, at least in certain fields, have been pulled and not pushed from the academic sector. In other words, citizen-scientists appear to be seeking better opportunities and higher paying positions elsewhere in the economy. From a broader perspective, this suggests that displacement of highly skilled scientists and engineers from academe is contributing to enhanced productivity elsewhere in the economy.

Our study of contributions and costs raises two questions for higher education. First, are we investing too many resources in "traditional" doctoral programs that prepare individuals for careers as independent investigators in academe? Second, are we investing in the "right" individuals—those who are the best and brightest, regardless of citizenship status, ethnicity and gender. Our work suggests that the answer to both questions is "no."

Overall, academic employment has not grown as fast as employment in the remaining sectors of the economy, especially employment in business and industry (Stephan et al. 2003). This is true for both citizen and non-citizen S&E doctorates who have experienced negative competitive effects in academe. Moreover, in large fields such as the life sciences, much of the academic growth that has occurred has been for postdoctoral appointments and other temporary appointments. In both instances, the traditional training obtained in doctoral programs that focuses on becoming an independent PI may not be the most appropriate given the career outcomes.

Furthermore, a sizeable proportion of the citizen-employment-shortfall in academe that Levin et al. estimate (2003) can be attributed to the differential minting effects found between citizens and non-citizens. Indeed, as we have seen, the citizen doctoral population grew at a much slower rate than the non-citizen doctoral population. Obviously, many factors have contributed to this outcome. Among them are societal pressures, and possibly discrimination, which work against women and underrepresented minorities in S&E, deficiencies in K-12 S&E education, and high dropout rates of S&E majors during the first two years of college (National Science Board 2002). Moreover, the high opportunity costs and the relatively low rewards expected from investing in a doctoral education in S&E, and the winner-take all nature of outcomes lead bright and talented individuals to invest in careers in medicine, law and business instead of in S&E. Taken together, this suggests that the composition of the doctoral S&E labor force in the United States could be enhanced if a different set of relative rewards and opportunities were in place.

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Figure 1. Growth in the native and foreign-born components of the highly-trained scientific labor force in the U.S., 1980-1990. Data are from the 1993 NSCG.

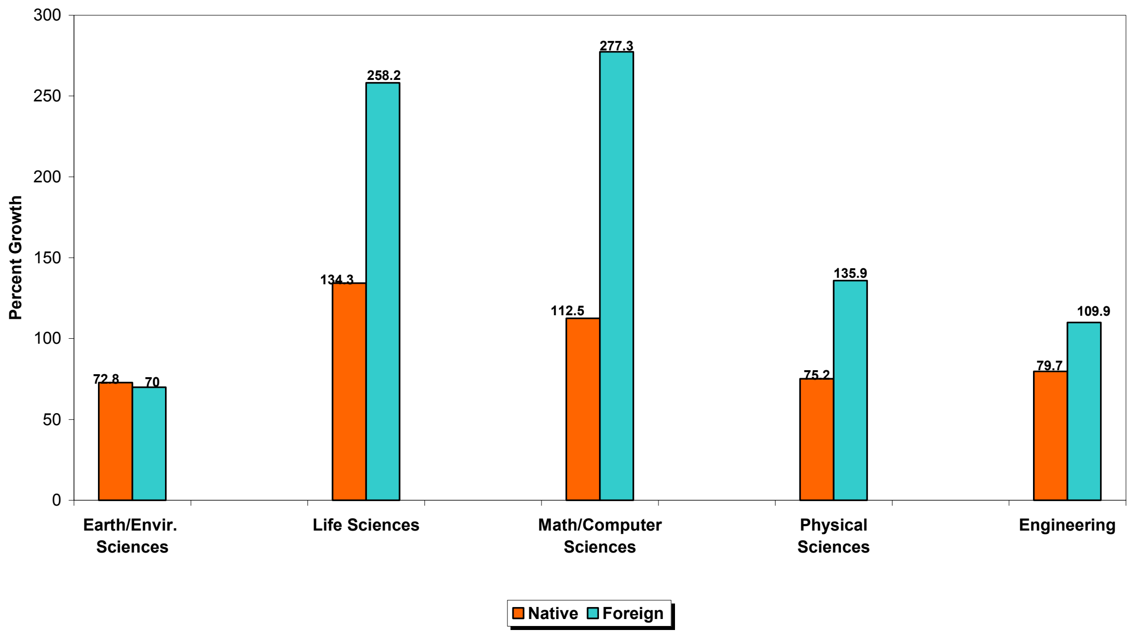

Figure 2

Citizenship Status of S&E Doctorates by Year of Degree

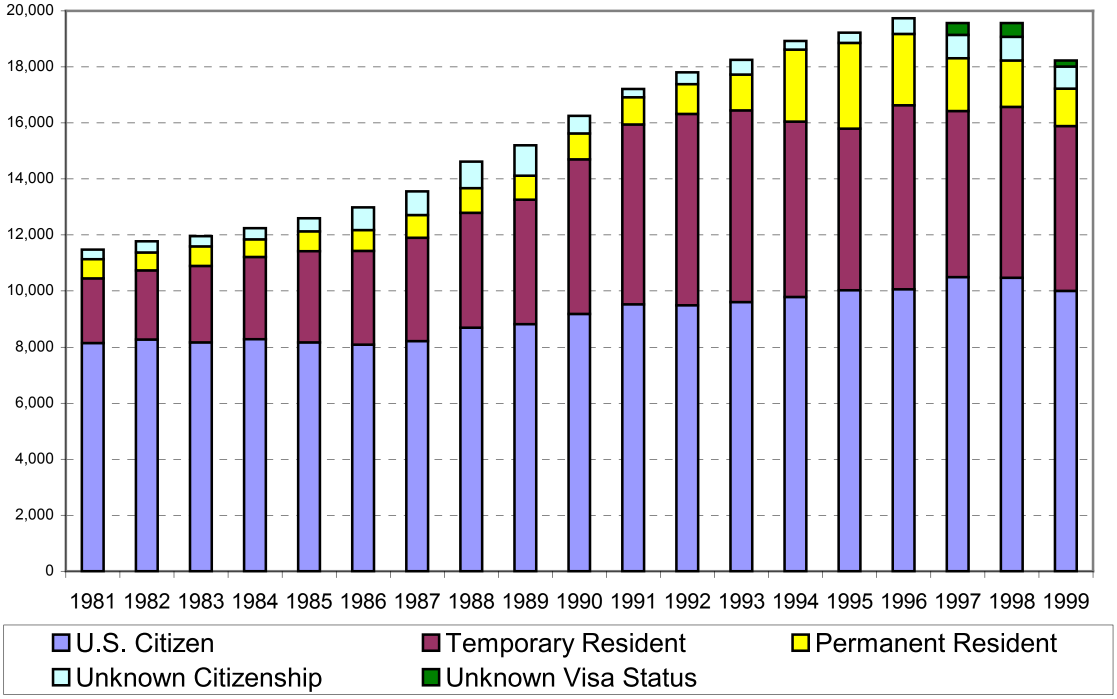

Figure 3. Displacement within Academe, 1979-1997.
Faculty positions (FAC) vs. Postdoctoral positions (PDOC).

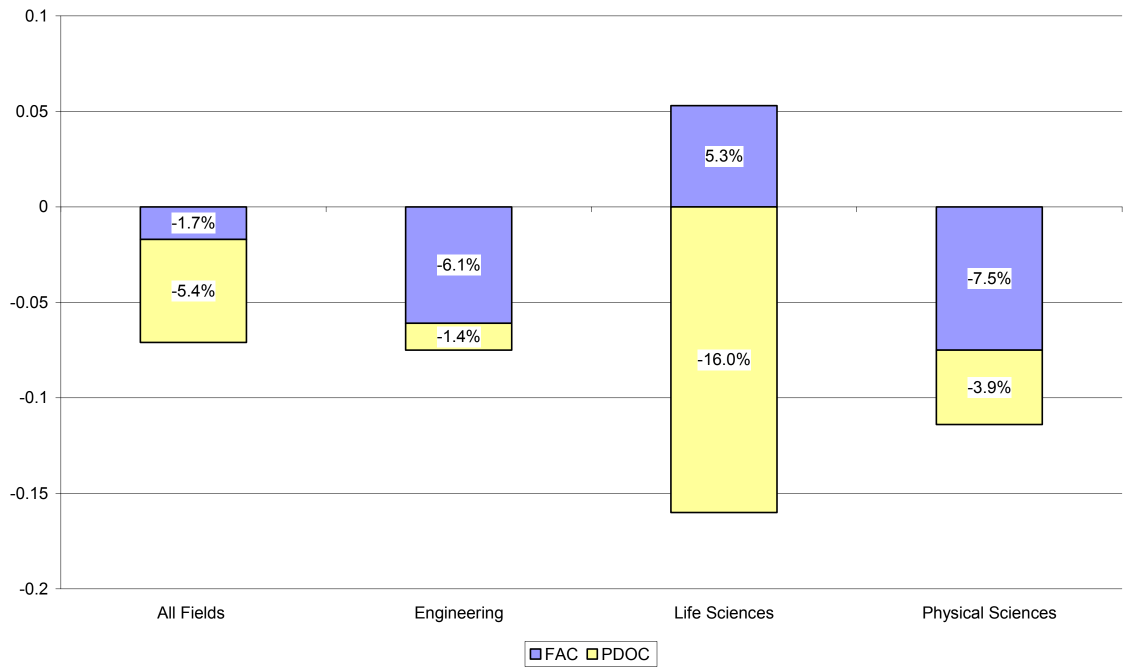

Figure 4. Displacment within Academe, 1979-1997.
Tenure-track faculty positions (PERM) vs. non-tenure track positions (TEMP).

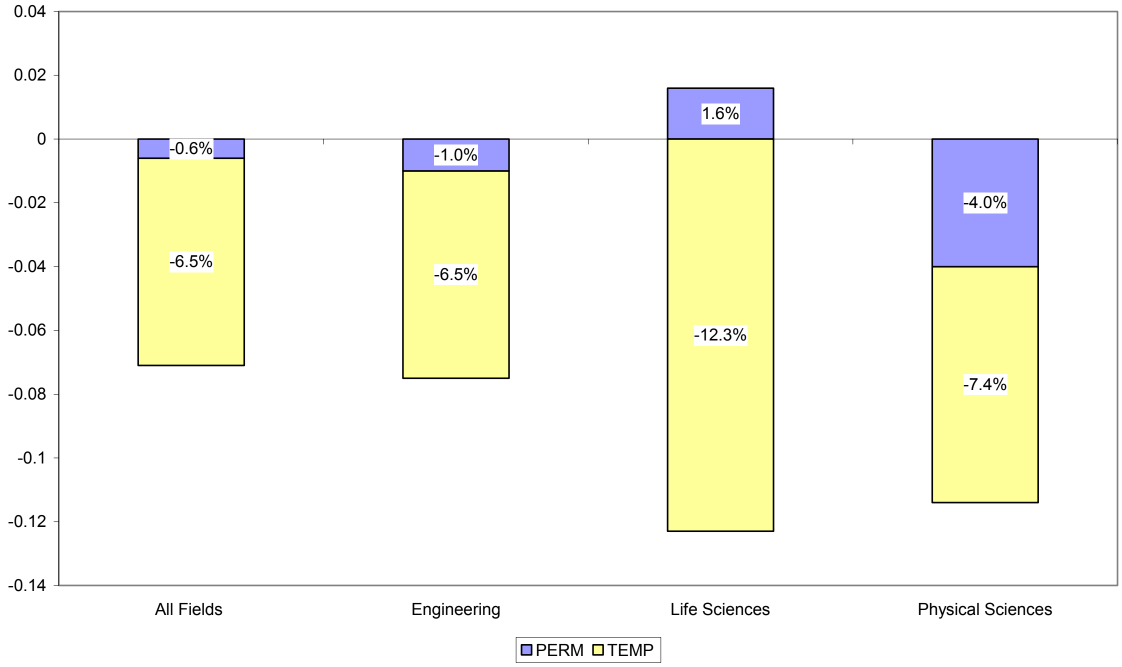

Table 1. Birth and educational origins of the scientific labor force in the U.S., 1980 and 1990. Estimated from the 1993 NSCG (see text). (%, percent; Bacc.,baccalaureate degree; Ph.D., doctoral/medical degree.)

	1980				1990			
Occupational Field	N	%Foreign Born‡	%Foreign Bacc.	%Foreign Ph.D.	N	%Foreign Born‡	%Foreign Bacc.	%Foreign Ph.D.
All Sciences*	55,697	18.3	13.6	8.8	120,888	24.7	16.0	10.7
Earth/Envir. Sciences	4,048	17.6	12.3	19.0	6,976	17.4	9.6	13.5
Life Sciences	14,890	15.4	12.2	9.4	37,717	21.7	12.8	11.6
Math/Comp.Sciences	13,149	18.4	13.9	7.2	31,916	28.5	18.1	7.9
Physical Sciences	23,610	20.4	14.5	7.5	44,279	25.6	18.1	11.6
Engineering†	602,722	13.9	7.4	§	1,108,367	15.9	7.4	§

*Excludes individuals without doctoral or medical degrees, those not in the labor force, those not in the U.S., those in the military, and those in engineering or social science occupations.
†Excludes individuals without a baccalaureate degree, those not in the labor force, those not in the U.S., and those in the military
‡Includes individuals born abroad to U.S. citizens who are classified as “immigrants” in the NSCG
§Professional engineers often do not have doctoral degrees

Table 2. Growth in science and engineering (S&E) doctorates by field of training and citizenship status at the time the degree was earned in the United States.

	ALL S&E Doctorates			Citizen Doctorates			Non-Citizen Doctorates		
	1973	1997	Growth	1973	1997	Growth	1973	1997	Growth
All Fields Combined*	110,914	367,617	231.4%	101,506	290,980	186.7%	9,408	76,637	714.6%
Engineering	26,649	87,585	228.7%	23,220	56,426	143.0%	3,429	31,159	808.7%
Life Sciences	36,050	142,330	294.8%	33,668	123,386	266.5%	2,382	18,944	695.3%
Biological Sciences	25,951	105,842	307.9%	24,342	91,882	277.5%	1,609	13,960	767.6%
Physical Sciences	48,215	137,702	185.6%	44,618	111,168	149.2%	3,597	26,534	637.7%
Earth/Environmental Sciences	4,621	15,916	244.4%	4,397	13,896	216.0%	224	2,020	801.8%
Chemistry	20,567	54,327	164.1%	18,936	44,968	137.5%	1,631	9,359	473.8%
Math/Computer Sciences	9,300	32,376	248.1%	8,680	24,305	180.0%	620	8,071	1201.8%
Physics and Astronomy	13,727	35,083	155.6%	12,605	27,998	122.1%	1,122	7,085	531.5%

*S&E includes engineering, the life sciences, the earth/environmental sciences, chemistry, the mathematical and computer sciences and physics and astronomy. Date are from the SDR.

Table 3

Birth and Educational Origins of Individuals Making Exceptional Contributions
Members of the National Academy of Engineering

(1) Indicator (size of Group)	(2) Benchmark Year	(3) Percent Foreign-born (Information n)		(4) Percent with Baccalaureate Earned Abroad (Information n)		(5) Percent Foreign-born of those born before 1945 (Information n)	
All Sections (1706)	1980	19.2***	(1705)	10.7***	(1615)	19.3***	(1677)
Mechanical Section (143)	1980	28.7***	(143)	16.3***	(135)	28.7***	(143)
Chemical Section (141)	1980	19.9	(141)	13.4**	(134)	19.9	(136)
Civil Section (217)	1980	15.7	(217)	8.3	(205)	15.7*	((216)
Electrical Section (411)	1980	22.6***	(411)	11.1***	(386)	22.9***	(407)
Industrial Section (85)	1980	12.9	(85)	11.1***	(85)	13.4*	(82)
Other Sections (709)	1980	17.1***	(708)	9.3**	(674)	16.9	(693)

Chi-square tests of observed and expected frequencies are used. If the expected frequency is <5, and the test is inapplicable, a two-tailed binomial test is used. *P=.05 or less. **P=.01 or less. ***P=.001 or less.

Table 4

Scientists making exceptional contributions in the life sciences in the U.S.
(Bacc., baccalaureate degree; Ph.D., doctoral/medical degree; n/a, not applicable.)

Indicator (Size of Group)	(Bechmark Year)	Percent Foreign-Born	(Information n)	Percent Foreign-Educated Bacc.	(Information n)	Ph.D.	(Information n)
Citation classics, 1st authors (43)	(1980)	27.5**	(40)	18.4	(38)	15	(40)
Citation classics, non-1st authors (104)	(1980)	22.7*	(75)	16.2	(74)	14.1	(71)
Highly-cited patents, medical devices (178)	(1980)	17.6***	(74)	11.1**	(72)	n/a	n/a
Most-cited authors (164)	(1980)	29.1***	(151)	19.4***	(144)	21.7***	(152)
Outstanding authors (204)	(1980)	28.7***	(188)	18.5**	(178)	20.1***	(189)
NAS members (744)	(1980)	21.1***	(733)	9.1**	(646)	12.4***	(712)
Founders/chairs biotech cos. (97)	(1980)	24.7**	(81)	16.9	(77)	14.1	(92)
Hot papers, 1st authors (74)	(1990)	17.8	(45)	13.6	(44)	10.6	(47)
Hot papers, non-1st authors (388)	(1990)	22.6	(235)	16.3	(221)	12.4	(226)

Chi-square tests of observed vs. expected frequencies are used. If the expected frequency is <5, and the test in inapplicable, a two-tailed binomial test is used. *P=.10 or less. **P=.05 or less. ***P=.01 or less.

Table 5

Scientists making exceptional contributions in the physical sciences in the U.S.
(Bacc., baccalaureate degree; Ph.D., doctoral/medical degree.)

Indicator (Size of Group)	Benchmark Year	Percent Foreign-Born	(Information n)	Percent Foreign-Educated Bacc.	(Information n)	Ph.D.	(Information n)
Citation classics, 1st authors	1980	‡	‡	‡	‡	‡	‡
Citation classics, 1st and non-1st authors (34)	1980	40.9**	(22)	21.1	(19)	33.3***	(21)
Most-cited authors (19)	1980	64.7***	(17)	56.3***	(16)	31.3***	(16)
Outstanding authors (29)	1980	55.6***	(27)	41.7***	(24)	30.8***	(26)
NAS members (474)	1980	26.7***	(465)	13.0	(429)	11.4***	(458)
Hot papers, 1st authors (87)	1990	35.5**	(76)	28.4**	(74)	18.1*	(72)
Hot papers, non-1st authors (299)	1990	35.4***	(192)	23.4*	(188)	13.0	(177)

Chi-square tests of observed vs. expected frequencies are used. If the expected frequency is <5, and the test is inapplicable, a two-tailed binomial test is used. *P=.10 or less. **P=.05 or less. ***P=.01 or less. ‡Combined with non-1st authors because of sample size.

Table 6. Displacement from Academe, 1979-1997

	Competitive Effects Citizens	Competitive Effects Non-citizens	Displacement*
All Fields Combined	-13.9%	-6.8%	-7.1%
Engineering	-16.3%	-8.8%	-7.5%
Life Sciences	-11.4%	-0.7%	-10.7%
Physical Sciences	-19.6%	-8.2%	-11.4%

*Calculated as the competitive effect for citizens (%) less the competitive effect for non-citizens (%).