The “I’s” Have It: Immigration and Innovation, the Perspective from Academe

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March 20, 2009

Draft

Prepared for NBER Conference on Research Innovation Policy and the Economy, Washington, DC, April 14, 2009

The author would like to thank Erin Coffman for her research assistance. Amitay Alter, Bill Amis, Grant Black, Josh Lerner and Scott Stern made useful comments on an earlier draft of this paper. The use of NSF data does not imply NSF endorsement of the research methods or conclusions contained in this paper.

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Abstract

Considerable attention has focused in recent years on the role the academy plays in fostering innovation. Here we demonstrate that the foreign born are a large and growing component of the U.S. university community. They compose more than 25 percent of the tenure-track faculty, make up approximately 60 percent of the postdoctoral population and represent more than 43 percent of the doctoral degrees awarded in science and engineering. Almost fifty percent of the latter come from the three countries of China, India and South Korea.

The foreign born contribute to the productivity of the university. For example, 44 percent of the first authors of U.S. papers in *Science* are foreign. There is some evidence that the foreign born contribute disproportionately to exceptional contributions in science and engineering and, at least at elite universities, that their marginal product is higher than that of the native born. They also constitute approximately one-third of the placements of new PhDs with U.S. firms—a major mechanism by which tacit knowledge is transmitted from the university to industry. Not all of the foreign born who come to study or work in the U.S. stay. The ten-year stay rate for those who received their PhDs, for example, is 58 percent. It increased dramatically in the 1990s but the pattern appears to have leveled off recently and is likely to decline as developing countries recruit scientists and engineers to work in newly emerging sectors as well as universities.

Despite spillovers to other countries, the simplest of calculations leads one to conclude that in the past the U.S. has gained far more than it has lost by the foreign born coming to study and work in science and engineering at U.S. universities. Whether these benefits persist depends upon whether the foreign born continue to come in large numbers and to stay in large numbers. The Stimulus Package and President Obama's proposed 2010 budget, with its funds for R&D, provide resources that could encourage studying and working in the U.S. They also provide for resources that could make careers in science and engineering more appealing to native born, something that will be essential if the foreign born cease to come or stay.

Section I: Introduction

Considerable attention has focused in recent years on the role the academy plays in fostering innovation. The mechanisms through which universities contribute to innovation are generally seen as following three paths. First, the academy is the primary source of codified knowledge, contributing almost 75 percent of all articles (fractional counts) written in the U.S. (National Science Board 2008 Appendix Table 5-36). This codified knowledge in turn spills over and contributes to the innovation process (Cohen, Nelson and Walsh 2002) and economic growth (Adams 1990). Second, universities train students and place them, and their knowledge, in industry, thus providing a major mechanism by which tacit knowledge is transmitted from the university to industry (Stephan 2006). These placements, as well as placements in academe, provide the seed corn for new knowledge and innovation. Third, the academic sector fosters technology transfer through patents and licenses, consulting activities and the formation of startups.

The foreign born are a key and growing component of U.S. university life, especially in the fields of science and engineering. As faculty the foreign born teach classes and undertake research. As graduate students they populate classes and work on projects as research assistants. As postdocs they play key roles in staffing university research labs.

Here we examine the role the foreign born play in the academy, weaving together various data sources and studies. In Section II we examine the presence of the foreign born as faculty, graduate students and postdoctoral scholars. We then examine in Section III the contribution of foreign born to publishing and patenting. While our primary focus is on the contribution of foreign-born graduate students and postdocs, we also have information, albeit limited, regarding the contribution of foreign-born faculty. Section IV discusses what we know concerning the placement of foreign-born graduate students in industry after receiving their PhDs. In Section V we examine the foreign born who leave the U.S. after training. We conclude in section VI.

Two particular challenges confront the analysis. First, there is no consistent measure or proxy for foreign born in the data that are available. By way of example, for some data, "foreign" is inferred only on the basis of whether the individual is a temporary resident; in other data one can determine whether the individual is a permanent or temporary resident, in still others one can ascertain where the individual was born or the country of undergraduate training. When no individual data are available regarding citizenship status or birth origin, inferences are based on identification by ethnicity of name. There is also the challenge of coverage. Scientists are highly mobile. This makes the analysis particularly difficult since no U.S. database consistently includes scientists in academe who received their doctoral training outside the U.S.; nor is there a database that follows those who received their training in the U.S. if and when they leave the U.S.

In spite of these data challenges, our results provide convincing evidence that the foreign born are a key and growing component of academic life in the U.S. A conservative estimate suggests that they constitute at least 25 percent of the tenure-track faculty; make up over 43 percent of graduate students and 60 percent of postdocs. They play a key role in publishing: we estimate that 44 percent of first authors of U.S. papers—the author who typically does the "heavy lifting" in scientific research—are foreign. We also find evidence that the foreign born contribute disproportionately to exceptional contributions in S&E. When it comes to working in industry, newly trained foreign-born PhD students are just as likely to work in industry in the U.S. as are the native born.

Not all of the foreign born who come to train or work stay in the United States. By way of example, approximately 40 percent of foreign-born PhD recipients have left the U.S. 10 years after receiving their degrees. Their going contributes to innovation and economic growth in their home or newly adopted countries. But some positives persist after they leave, in terms of stronger networks between U.S. and foreign firms and U.S. and foreign scholars. There are also knowledge spillovers. Knowledge, once published, is public. There is also, as Richard Freeman often points out, a national security aspect: those who leave often have more positive views and a greater commitment to maintaining friendly ties with the U.S. than they did before coming to the U.S. to study or work.

Section II: Faculty, Graduate Students and Postdocs

Faculty

A quick look at almost any department's web page convinces one of the large role that the foreign born play on the faculty of science and engineering departments. By way of example, one-third of the faculty in the School of Electrical and Computer Engineering at the Georgia Institute of Technology received their undergraduate degrees outside the U.S. The most likely source country is India (9), followed by China (7) and Taiwan (5).[1] One-twelfth of the Georgia Tech department received their doctoral training abroad. A second example comes from Stanford's Department of physics: thirty-nine percent received their undergraduate training outside the U.S.; 32 percent received their PhD outside the United States. [2]

Other indicators of the presence of foreign faculty are readily available. Li (2008), for example, reports counts of Chinese faculty at 95 U.S. institutions in 2007. The numbers are not insignificant. The University of Michigan, Ann Arbor, which heads the list, had 139 Chinese faculty in 2007; this represented 2.6 percent of the faculty. The University of Pittsburgh is a close second with 133 (3.1 percent of the faculty). In tenth position is the University of Florida with 111 (2.3 percent of the faculty). When institutions are ranked in terms of proportion Chinese rather than number of Chinese, Stevens Institute is at the top with 27.05 percent of the faculty being Chinese. The Georgia Institute of Technology is a distant second, with 7.57 percent. In 10th place is the University of Texas, Arlington with slightly more than 5 percent of the faculty who are Chinese. It is no surprise that many of these institutions have large programs in science and engineering.

Using a very different lens, Ben-David (2008) compares the number of Israeli scientists and engineers working at top-40 U.S. departments to the number remaining as senior faculty in

[1] There are 133 faculty in the school. Information could be found on the country of undergraduate degree for 124 of these. Among these 42 received their undergraduate degree outside the U.S. (http://www.ece.gatech.edu/faculty-staff/fac_profiles/bio.php?id=55).

[2] The 39 percent is calcualed for the 36 faculty members who provide details regarding their undergraduate training. (http://www.stanford.edu/dept/physics/people/faculty.html)

Israel. The percents are impressive: 9.6 percent in physics, 12.0 percent in chemistry, 28.7 percent in economics and 32.8 percent in computer science.

The hiring of foreign faculty by U.S. universities has undoubtedly been facilitated in recent years by changes in U.S. visa policy. It used to be that universities competed with firms for the limited number of available H-1B visas. However, since October 2001, and as a result of the American Competitiveness in the Twenty-First Century Act, the H-1B visa cap is no longer applicable to universities, government research labs and certain non-profits and many faculty and postdocs now initially take a position at a university on an H-1B visa.

As pervasive as the foreign born are on the faculty of U.S. universities, it is difficult to gather consistent data regarding the foreign born and foreign educated across departments and campuses and over time. This is because no one survey samples on faculty position.[3] The Survey of Doctorate Recipients (SDR), the largest survey of PhD holders, fielded by Science Resources Statistics (SRS), National Science Foundation (NSF), samples primarily those who received their PhD degree in the U.S., thus missing individuals who got their PhD outside the U.S. As the above examples suggest, this is a sizeable number, especially in certain fields. For example, the records of the American Institute of Physics report that one-third of all faculty hires in physics in 2005 received their PhD degrees outside the U.S.[4] The Association of American Medical Colleges reports that the proportion of basic-science faculty at Medical Schools who received MD and/or PhD (or their equivalent) degrees outside the U.S. was 21 percent in 2000; up from 16 percent in 1981.[5] Few other professional organizations keep such careful tabs on the job market and we are left to make inferences from the SDR or study the handful of fields whose professional societies keep such data.[6]

The SDR data are summarized in Table 1. Percents are reported for all full time (Academe), as well as being sudivided into a postdoc component (Postdoc) and all other full time positions (Faculty). Several things stand out from the table. First, academe became considerably more international during the 24-year period, going from about 12 percent to about 22 percent. Second, there are considerable differences by field. Engineering has by far the largest immigrant component, followed by math and computer science. The greatest increase in the percent international occurred in math/computer science, where the percent nearly tripled during the period. Third, the percent of postdoctoral positions filled by immigrants is much higher than the overall percent of positions held by immigrants, as measured by the SDR. Fourth, the percent in

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[3] It is problematic to study the nativity of faculty based on their CV's. Gaughan (2007), in her work on analyzing the CVs of scientists, finds that virtually none list country of birth on their CV. Considerably more listed their educational origins although --even using this criterion-- Guaghan was only able to identify known foreign-born scientists 64 percent of the time.

[4] American Institute of Physics Pub. Number R-392.6

[5] See http://www.aamc.org/data/aib/aibissues/aibvol3_no1.pdf. Trends Among Foreign-Graduate Faculty at U.S. Medical Schools, 1981-2000.

[6] Another way to study the ethnicity of faculty is by studying ethnic organizations of faculty in the U.S. By way of example, the Korean-American University Professor Association has 2500 Korean-born faculty members in the U.S. About two-thirds are in engineering and the natural sciences; the rest are in the humanities and social sciences. (Correspondence with Sunwoong Kim, President of the Association).

faculty positions is considerably lower but has almost doubled during the twenty-four year period.

A drawback to Table 1 is that the counts of tenure-track faculty are grouped together with faculty in non-tenure track positions. Table 2 corrects this deficiency for 2003, reporting the percent of foreign born among those who are tenured faculty or in a tenure-track position ("tenure track"), those who are not on a tenure track ("non-tenure track"), and those who are postdocs. The results are as one might expect. The largest concentration of foreign born is in postdoctoral positions, followed by non-tenure-track positions. Tenure track positions have the lowest proportion of foreign born, but even here fully one out of five of the tenure-track faculty educated in the U.S. in 2003 is foreign born. The highest percent of tenure track faculty who are foreign born is in engineering (34.1 percent) but math/computer science is a close second with 30.8 percent. The lowest percent is in chemistry (11.9 percent) and the biological sciences (12.0 percent).

The reader is reminded that the 20 percent figure reported in Table 2 is only for tenure-track faculty who received their PhDs in the United States. But a sizeable number did not receive their PhDs in the U.S. Taking their presence into account and using a conservative back-of the envelope calculation, leads us to conclude that at least 25 percent of tenure-track faculty at U.S. universities are foreign born.[7]

The question is often raised as to whether immigrants have displaced U.S. citizens from holding jobs in academe. Stephan and Levin (2007) undertake a thought experiment to address this question. They compare the actual employment growth of a specific "citizenship" group (citizen or noncitizen) in a specific sector with the growth predicted using the counterfactual of what would have happened to employment of U.S.-citizen/non-citizen S&E doctorates in different sectors if their employment had grown at the overall growth rate for all doctorates combined, regardless of citizenship status. The analysis adapts a technique originally developed in the regional science literature known as shift-share.[8]

Of particular interest are their findings with regard to academe. Figure 1 shows their estimates of the degree to which noncitizens have been substituted for citizens in academe where the type of appointment is partitioned into "faculty" vs. "postdoc" positions. Figure 2 drills down deeper and partitions the academic category into a permanent component—tenured or tenure-track faculty—versus a "temporary" component—postdocs and non-tenure track faculty such as lecturers, instructors, clinical faculty and staff scientists.

Figure 1 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

[7] Our methodology assumes that 22.9 percent of all tenure-track hires in recent years received their PhDs outside the U.S. The 22.9 percent is a weighted average of the physical sciences (where we assume the percent with foreign-PhDs to be 33); the biomedical sciences (where we assume the percent with foreign-PhDs to be 21) and engineering (where we assume the percent to be 8). Our conservative estimate assumes that approximately 3400 faculty hires have been made in each of the past ten years and that 22.9 percent of these received their PhD degrees outside the U.S.

[8] Details are spelled out in Stephan and Levin (2007) and Levin, Black, Winkler and Stephan (2004). The analysis is for the period 1979 to 1997.

appointments and not from faculty positions. Indeed, there is minimal evidence of displacement from faculty positions (-1.7 percent) for all fields taken together, and in the life sciences citizens (+5.3 percent) have actually fared relatively better than noncitizens have with regard to faculty appointments. This is not true, however, in engineering and in the physical sciences. Here the displacement of citizens from academe is largely accounted for by their displacement from faculty positions and not from postdoctoral positions.

But, as Figure 2 illustrates, the story is somewhat different when one considers who holds permanent versus temporary appointments within the academic sector. For all fields taken together, as well as for each subfield, the displacement from academe observed for citizens can be attributed primarily 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 percent), and in the life sciences citizens (+1.6 percent) have again fared relatively better than non-citizens in terms of holding permanent academic appointments.

The analysis indicates that 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 of permanent, tenured or tenure-track faculty, rather than positions as temporary members of the academic units.

The 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. The finding that the displacement from academe observed for citizens can be largely attributed to their displacement from postdocs and other temporary appointments within this sector suggests an element of pull. Specifically, citizens may have left these less desirable positions because citizens are more responsive than non-citizens to the lure of better opportunities elsewhere. Citizens also do not face the visa restrictions that can be encountered by non-citizens, affecting their transition from training positions to more permanent positions.

To summarize, although there is no definitive way to count the number of tenure-track faculty who are foreign born, we infer that the foreign born constitute at least 25 percent of the tenure-track faculty in science and engineering at U.S. institutions. The percent is highest in engineering and lowest in the life sciences and earth and environmental sciences. The foreign born make up a considerably larger percent of those holding non-tenure-track positions and postdocs than of tenure-track positions. We find some evidence that the foreign born displace native born in getting academic positions. However, to the extent that displacement occurs, it is from less desirable positions having less job security and independence, suggesting that there may have been some element of "pull" rather than "push."

Graduate Students

It is far easier to determine the number and percent of U.S. PhDs awarded in science and engineering to the foreign born, thanks to the Survey of Earned Doctorates (SED), which is administered to U.S. doctorate recipients at the time of graduation. The SED contains a wealth of information on citizenship status and country of birth, as well as information concerning plans after graduation and the primary type of support received while in graduate school. The high response rate (over 92 percent) means that it provides a fairly accurate view of the population.

The survey documents a large and growing proportion of PhDs being awarded to the foreign born. This is readily seen in Figure 3. In 1980 less than 3000 of the approximately 11,600 degrees in science and engineering were awarded to individuals who were either a temporary or a permanent resident at the time they received their degree (25.1 percent of degrees awarded). By 2006, more than 11,000 PhDs were awarded to the foreign born, defined as above in terms of visa status, which represented approximately 47.7 percent of all degrees awarded. To look at it somewhat differently, during the 26-year period, the number of foreign born receiving degrees in the U.S. almost tripled, while the number of native born grew by only 30 percent. Moreover, and what is not shown in the figure, virtually all of the growth for citizens was among women students. The number of U.S.-citizen males receiving PhDs in science and engineering changed little during the period.[9] The figure also shows that growth among the foreign born was especially strong during the mid-1980s to mid-1990s and again beginning in 2003.

When we focus exclusively on those holding temporary visas at the time of graduation (and thus those who are less likely to have been in the U.S. for a period of time before commencing their graduate study) a fairly similar pattern is observed. In 1980 approximately 19 percent of PhDs were awarded to those on temporary visas; in 2006 the figure was slightly more than 43 percent.

Almost half of non-citizen PhDs come from three countries: China, India, and South Korea (Falkenheim 2007, Table 10). The important role that China and South Korea play was made abundantly clear in 2008 when *Science* published the somewhat surprising news that the most likely undergraduate institution attended by individuals who earn PhDs in science and engineering in the U.S. is now Tsinghua University. Second place belongs to its neighbor Peiking University. Berkeley is third and Seoul National University takes fourth place.[10]

Certain fields have an exceptionally large proportion of foreign-born degree recipients. In engineering, for example, temporary residents currently receive close to 60 percent of the PhDs bestowed; in math and computer science they receive approximately 53 percent. By way of contrast, in the life sciences the foreign born make up a substantially smaller percent. These patterns are summarized in Table 3.

Data concerning the number of PhDs awarded reflect conditions and decisions made six to seven years prior to the award date. Thus, the increases that we have documented were put in motion long before 9/11. Following 9/11 considerable attention and concern was focused on the declining applications and admissions of international graduate students and what this would mean for graduate education in the United States. For example, between 2003 and 2004 graduate applications across the board declined by 28 percent, admissions by 18 percent, and

[9] The number of PhDs awarded to citizen women increased by 170 percent from 1980 to 2006.
[10] The calculations are for degrees awarded between 2004 and 2006 (Mervis 2008). Fifth place is held by Cornell University, and the University of Michigan, Ann Arbor holds sixth place. Just a few years earlier Berkeley was the number-one undergraduate institution.

enrollments by 6 percent (National Academies 2005, p. 31).[11] These concerns have been somewhat mitigated by the recent rise in the enrollment of international graduate students. For example, according to The Survey of Graduate Students and Postdoctorates in Science and Engineering for 2006, first-time, full-time enrollment for temporary residents in graduate science and engineering programs rose 16.4 percent between 2005 and 2006, compared to a meager 1.4 percent for U.S. citizens and permanent residents (Oliver, 2007). It remains to be seen whether this turnaround will continue. Clearly, enrollment patterns are affected not only by U.S. visa policy but also by opportunities for study outside the U.S., which in recent years have been increasing.

Many students play key roles in research while they are studying for their PhD. One indication of this is the prominent role that graduate students play as authors of published scientific works. In their study of articles published in *Science*, Black and Stephan (2008) found that 20 percent of all authors were graduate students. When the analysis is restricted to the first author position, the place reserved in most fields of science for the author who did the "heavy lifting" in the reported research, they find that 26 percent are graduate students.

Foreign-born graduate students are more likely to be in research positions than are U.S. citizens, as can be inferred from the fact that 49 percent of temporary residents report that their primary support mechanism while in graduate school was a research assistantship; while only 21 percent of U.S. citizens report that their primary means of support was a research assistantship. The difference may reflect the larger range of alternatives and resources available to citizens, including employer support for attendance at graduate school. An additional 13 percent of temporary residents are supported primarily on fellowships (22 percent of U.S. citizens) and another 6 percent on grants/stipends (15 percent of citizens).[12] Because many students on grants and fellowships work with faculty on research and many others work in research positions as a secondary means of support, we infer that more than two-thirds of all S&E PhD students who are temporary residents at the time of graduation worked in a research capacity while in graduate school.[13] The proportion is particularly high in engineering, reaching over 80 percent, while in the life sciences it is approximately 78 percent, and in the physical sciences it is about 65 percent.

Foreign students have a tendency to attend PhD programs populated by other students from the same country. Esra Tanyildiz (2008) estimates a random utility model of the choice of PhD institution by temporary residents from China, India, Korea and Turkey. She finds that regardless of quality of the programs in the choice set or the nationality of the student, students

[11] Comparable figures for engineering are -36.0, -24.0, and -8.0; for the life sciences, -24.0, -19.0 and -10.0; and for the physical sciences, -26.0, -17.0, and +6.0. Data come from the Council of Graduate Schools (National Academies 2005, p. 31). It should be noted that application and admission data "double count" to the extent that students apply and are admitted to multiple programs.

[12] The data come from National Science Board, 2008, Appendix, Table 2-1. They are calculated for individuals who received their PhD in 2005. S&E includes health fields. Alternative modes of primary support not mentioned above are "personal," "teaching assistantships," "other assistantships," "traineeships," and "other." It should be noted that although there are a large number of training grants (NIH alone supports over 3200 students on training grants each year) only 276 of all new PhDs reported this as their primary means of support. This reflects the fact that the duration of most training grants is one to two years and thus is not the primary means of support.

[13] The estimate for citizens is approximately 10 percentage points lower.

are drawn to programs having other students from the same country. The effect, however, appears to have a tipping point: after some critical mass the probability declines. Tanyildiz finds less support for the idea that students are drawn to programs with large numbers of alums sharing their ethnicity. This may reflect the high stay rate among foreign-born PhD recipients in the U.S. Potential applicants have little opportunity to interact with alums in their home country before applying. For a smaller set of institutions Tanyildiz also examines the degree to which students are attracted to institutions having faculty of the same ethnicity. She finds some evidence that Chinese students and Korean students are more likely to attend institutions with heavier concentrations of Korean and Chinese faculty but no support for such a finding for Indian and Turkish students.

Foreign graduate students also have a tendency to work with faculty of the same ethnicity. In another study, Tanyildiz (2009) paired labs in 82 departments of engineering, chemistry, physics and biology. In each case she matches a lab directed by a "native" PI (as established by name and undergraduate institution) to a lab directed by a foreign PI, either of Chinese, Korean, Indian or Turkish background. She then studies the graduate-student composition of the labs, assigning nationalities to the students based on the common-name methodology used by William Kerr (2008). She finds significant differences in the role that ethnicity plays in staffing. The mean paired difference in the percent of Chinese students in a lab directed by a Chinese PI versus a lab in the same department directed by a "native" U.S. faculty is 37.8 percent; that for Korean is 29.0 percent; that for Indian is 27.1 percent; that for Turkish (for a much smaller sample) is 36.3 percent. When she compares labs directed by natives to non-natives from one of the four groups, the mean paired difference is 28.9 percent. Clearly, clustering by ethnicity occurs in labs. Tanyildiz also finds that these affinity effects are more common in "bottom"-ranked departments and less common in "top" departments.[14] The findings are consistent with the fact that a large number of research assistantships are paid for out of grants that the PI has obtained and it is thus the PI who makes staffing decisions. Moreover, in interviews Tanyildiz found examples of labs which conducted much of the day-to-day business in the language of the principal investigator.

In much the same way that one can ask if the foreign born "crowd out" native faculty from jobs in academe, one can ask if foreign-born graduate students crowd out native graduate students. Asking is one thing; getting a cogent answer is quite another. Borjas (2007) attempts to answer this question by examining the relationship between native enrollment and the enrollment of the foreign born over time for individuals in all types of graduate programs.[15] He includes university and time-period fixed effects in the estimation. His results are consistent with a crowd-out effect for whites, especially white men, but only at institutions whose programs rank in the 50th quantile, the top quantile in his analysis. In the less elite institutions, he finds no evidence of crowd out.[16] An alternative explanation for the effect he finds is that universities increase their enrollment of foreign graduate students because white men are "pulled" into other careers. This

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[14] Using NRC rankings, she finds that the mean difference is 25.9 percent in "top" departments; 35.9 percent in "middle" departments and 53.2 percent in "bottom" departments. These calculations do not include mean differences between native students in native labs vs. native students in non-native labs.

[15] Regressions are weighted by the total enrollment in the graduate program in a particular university at a particular point in time, and standard errors are clustered by university to adjust for possible serial correlation within a particular institution.

[16] Borjas classifies institutions into four categories according to the quality of the institution: 1st to 10th quantile; 11th to 40th quantile; 41st-50th quantile and 50th quantile.

is consistent with the work of Attiyeh and Attiyeh (1997), which finds that graduate schools, in four out of the five fields they studied, gave preferential treatment to native applicants over foreign applicants.

To summarize, close to 50 percent of all U.S. PhDs in S&E are awarded to individuals who do not hold U.S. citizenship at the time the degree is earned. The foreign born are particularly prevalent in the fields of engineering and math and computer science; they are less prevalent in the biological sciences. Almost 50 percent of all foreign students come from China, India or Korea. Non-citizens are more likely to be supported on research assistantships than are citizen students. There is also evidence that they are drawn to PhD programs populated by others of their same nationality and are more likely to work in a lab with a PI sharing the same nationality. Whether this is a network or an affinity effect is difficult to determine, but the fact that native students are more likely to work with native faculty than with non-native faculty suggests that affinity effects may be at play.

Postdoctoral Scholars

University labs are heavily staffed by postdoctoral fellows and the use of postdocs has been on the rise in recent years—in part because they are a "relative bargain" compared to graduate students, for whom tuition must be paid. The critical role they play in research can be inferred from authorship patterns. Black and Stephan (2008), for example, find that 21 percent of the authors in their study were postdocs; an even more impressive 41.6 percent of first authors were postdocs.

Documenting that postdocs play a major role in research is one thing; estimating the population of scholars working in postdoctoral positions in the United States is entirely another and estimates of their number must be read with caution. Complications arise on several fronts, including survey sampling frameworks that omit or do not easily identify some postdocs or those with doctorates from foreign institutions, the timing of survey data collection that can miss increasingly migratory S&E PhDs, exclusions and discrepancies surrounding some S&E occupations in certain standard surveys, and institutional difficulties in identifying workers as postdocs and by visa status (National Science Board 2008; Regets 2007).[17] There is also the issue of job title. It is not uncommon for individuals who are essentially postdocs to be called by another title, such as research scientist. Classification problems such as this mean that many postdocs go uncounted because of a wide range of measurement issues.[18]

With these problems in mind, we turn to Figure 4, which shows the number of postdocs working at academic institutions in science and engineering in the United States from 1985 to 2006. The figure is based on the Survey of Graduate Students and Postdocs, which is fielded annually by NSF to departments and delineates postdocs into two citizenship categories: temporary residents

[17] Regets (2007) offers the anecdotal example of officials at a major research university who expressed confidence in their ability to identify all temporary visa postdocs at their institution on the assumption that only J-1 visas were used for postdocs. It was later discovered that the university had filed Labor Condition Applications – the first step in the H-1B visa process – for several hundred "postdoctoral appointments."
[18] NSF is in the process of designing a new methodology to measure the number and characteristics of postdoctoral scholars in the U.S.

and (grouped together) U.S. citizens and permanent residents.[19] We see that in 1985 there were approximately 16,000 postdocs at academic institutions. Within a decade, that number had grown to over 25,000 and by 2006 the number of postdocs had grown to slightly more than 34,000 – an increase of 110 percent from 1985 to 2006. This growth was steady up through the early 1990s and continued to increase in the remainder of the 1990s, but at a slower rate. The number of postdocs declined slightly in 2001 but has since increased, particularly in 2002-2003.[20]

The figure clearly shows that growth in the number of postdocs has been largely fueled by scholars coming from abroad. Indeed, the number of postdocs with temporary-resident visas almost tripled between 1985 and 2006, rising from about 7,000 in 1985 to over 20,000 in 2006; the percent went from 43 to approximately 60. In contrast, the number of postdocs who are U.S. citizens or permanent residents grew by less than half during the same period. Tightened visa security measures may have contributed to the slowdown observed in temporary resident postdocs in the early 2000s. In 2001, less than 8 percent of J-1 visa applications were denied; in 2003, almost 16 percent were refused (Regets 2005).[21]

While many postdocs earn their PhD in the U.S. prior to applying for a postdoctoral position, a remarkable number receive their PhD training outside the U.S. and come to the U.S. to take a postdoctoral position. Indeed, Regets (2005) estimates that almost five out of ten academic postdocs in the United States earned a doctorate in another country. Moreover, four out of five postdocs with temporary visas earned their doctorate outside the United States.[22]

Table 4 shows the distribution of foreign S&E postdocs by field for the period 1985-2006. The dominant role of the life sciences is striking: in 2006, almost six out of every ten postdocs on a

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[19] The data are for science and engineering--excluding the medical and social sciences--and account only for postdocs identified by surveys of academic institutions with graduate programs in science and engineering. Although the majority of postdoctoral positions are at academic institutions, postdocs can also be found in other sectors. Using the 2006 Survey of Doctorate Recipients, Hoffer *et al* (2008) estimate that 75 percent of postdocs in science, engineering, and health fields were at educational institutions, 12 percent were in government, 11 percent were at for-profit or non-profit organizations, and 2 percent were at other types of institutions.

[20] The number of postdocs depends not only upon the propensity to take a postdoc but also upon the duration of the postdoc period of training. Stephan and Ma (2005) show that not only the propensity to take a postdoc but also the duration of the postdoc training period relates to the state of the academic labor market, suggesting that the postdoc position can become a "holding tank" where people wait for better market conditions.

[21] Foreign postdocs have traditionally been in the U.S. on either a J or an H visa, with some on F-1's for one year of optional practical training. The Sigma Xi survey (with a non-representative sample) found that 51 percent of foreign postdocs were on J's; 41 percent on H's and 3 percent on F-1s; a remaining 4 percent were on "other" visas (http://www.sigmaxi.org/postdoc/by_citizenship/). See also Davis (2005). Mark Regets reports (informal correspondence) that there is some evidence that the proportion on H-1B visas has been growing, based on the number of Labor Condition Applications that explicitly contain the search string "postdoc." The number on F-1 visas is expected to grow because optional practical-training-time was recently increased from 12 months to 29 months for most S&E advanced degrees.

[22] These estimates are based on a comparison of counts from the NSF Survey of Doctorate Recipients and the NSF Survey of Graduate Students and Postdoctorates in 2001. For example, in 2001, 17,900 academic postdocs with temporary visas were reported through the Survey of Graduate Students and Postdoctorates, while only 3,500 postdocs with temporary visas were reported in the Survey of Earned Doctorates, which only collects data on doctorates earned in the United States. Regets attributes the difference in these counts to postdocs with PhDs earned outside the United States.

temporary visa were in the life sciences. In terms of raw numbers, the table shows that the life sciences also experienced the greatest growth in the number of postdoctoral positions held by those on temporary visas, going from 3,341 in 1985 to 11,694 in 2006. The magnitude of the change in the life sciences is likely a result of the increased demand for postdocs in the field occasioned by the doubling of the NIH budget in the late 1990s and early 2000s.

At least three factors explain the large presence of foreign-born postdocs in the U.S. First, and especially since the doubling of the NIH budget, funds have been readily available to support postdocs, and most of this funding—in contrast to funding available through traineeships—does not have visa restrictions attached to it. The opportunity to work in the U.S. with support at the level of $35,000 to $40,000 a year is an appealing prospect for many students who have received their PhDs outside the U.S. Second, the foreign born who receive their PhDs in the U.S. are more likely, other things equal, to take a postdoc position than are the native-born. This undoubtedly reflects visa restrictions and job opportunities (Stephan and Ma 2005). Third, the foreign-born who receive PhDs in the U.S. remain in postdoc positions longer than the native born (Stephan and Ma 2005). This, too, undoubtedly relates to relative opportunities and visa restrictions.[23]

We know very little about the country of origin of postdocs, since the NSF data on postdocs are gathered at the department level, not at the individual level. The Sigma Xi survey, which is not random in its sample design, found that the largest number of non-citizen postdocs came from China, followed next by India. Among postdocs who received their PhD outside the U.S., the most likely country of degree was China, followed again by India.[24]

To summarize, 60 percent of postdocs at academic institutions in the U.S. are temporary residents. Many of the postdocs—perhaps as many as half—earned their PhDs outside the U.S. Putting together the three pieces of the academic community—postdocs, graduate students and faculty—we see a clear pattern. The foreign born represent 60 percent of the postdocs, about 43 percent of those who get their PhDs (using temporary-resident status as a definition of foreign born), and at least 25 percent of the tenure-track faculty. Moreover, the large concentration of foreign born in the positions of graduate students and postdocs leads one to believe that the percent of tenure-track faculty who are foreign born will continue to grow, since graduate school and postdoctoral positions provide an important port of entry to a faculty position.

Section III: The contribution of foreign born to publishing and patenting

Academe produces two tangible outputs that play a key role in fostering innovation: publications and patents. A logical question is thus the degree to which the foreign born play a role in the production of articles and patents. A related question is whether the foreign born

[23] We know little about how the support mechanism for postdocs on temporary visas differs from that of U.S. citizens. This is because the Graduate Students and Postdoctorates in Science and Engineering Survey that collects data on postdocs does not collect source of support by visa status. What we do know, however, is that the number of postdocs supported in science and engineering on federal funds exceeds the number on temporary visas (Oliver 2008).

[24] http://postdoc.sigmaxi.org/results/tables/table8

disproportionately contribute to productivity. Here we discuss these topics, focusing first on publications and then on patents. As we will see, it is far easier to establish that foreign born work in research while at the university than to establish the degree to which they contribute to this research. It is even harder to establish whether their contribution plays a larger role than the contribution of native born. This is because the output of their research efforts—papers and patents—neither identifies individual by status nor by ethnicity. We begin with a discussion of publications and then turn to a discussion of patents.

Publications

Black and Stephan (2008) examine authorship patterns for articles appearing during a six month period in 2007-2008 in *Science.* They chose *Science* because of its multidisciplinary nature (the journal devotes 40 percent of its space to the physical sciences and 60 percent to the life sciences) and its position as a leading, if not the leading, journal in science. Moreover, and as is to be expected, the journal is highly selective. In 2007 the journal published 817 of the 12,450 articles that it received (6.6 percent); 461 of these (56.4 percent) had a first author from the U.S. (Chiara Franzoni, Giuseppe Scellato and Paula Stephan 2008).

The authors restrict their sample to articles having a last author with a U.S. academic address given the common convention in many fields of science that the last author is the principal investigator.[25] They use this criteria because of the convention followed in many fields of science that the last author position is held by the faculty member in whose lab the research was performed. They determine the status of authors through web searches; the primary source is the webpage for the last author's lab.[26] For the 133 papers with less than 10 authors, they determine the status for all authors. For 26 additional papers with ten or more authors they determine the status of the first and last author. Both positions provide key insight into the role that the author played in doing the research. The first author, as noted earlier, in most fields of science is the individual who played the lead role in the research, while the last author, as noted above, generally provided the resources for the research. In lab sciences, it is the last author in whose lab the research was performed.[27] While ideally one would want to know the citizenship status or birth origin of the students and postdoc co-authors, this is not possible, short of fielding a survey, because many authors--especially postdocs, graduate students, and staff scientists--do not put CVs on the web. Instead, Black and Stephan follow the approach used by Bill Kerr, drawing on the same ethnic-name database that he used to identify the ethnicity of U.S. inventors (Kerr 2008).

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[25] Had they instead used the country of the first author to determine origin, the sample would have had 150 papers rather than 159 papers .

[26] They are able to determine the position of 94 percent of the U.S. authors in the database.

[27] Authorship patterns vary by discipline. In the life sciences the last author is generally the PI and the one who supplied the resources. The first author is the one who contributed the greatest amount to the research. This pattern is also true in chemistry and can also be the pattern in physics. In some disciplines, such as the earth and environmental sciences, authorship order is arranged entirely in terms of contribution. Authors are rarely listed in alphabetical order on scientific papers. For example, only 26 of the 159 papers in the sample listed authors alphabetically; 19 of these papers had only two authors, implying that there was a 50 percent chance of their being alphabetical regardless of practice.

Specifically, ethnicity is identified using data that Kerr obtained from the Melissa Data Corporation.[28] The Melissa data is particularly strong at identifying Asian ethnicities, especially Chinese, Indian/Hindi, Japanese, Korean, and Vietnamese names. In addition to the Asian ethnicities, Black and Stephan are able to distinguish four other ethnicities: Russian, English, European and Hispanic.[29] The approach exploits the idea that authors with "the surnames Chang or Wang are likely of Chinese ethnicity, those with surnames Rodriguez or Martinez of Hispanic ethnicity and so on" (Kerr 2007). The methodology uses both first and last names and thus minimizes ambiguity in assigning names with multiple ethnicities, such as Lee and Park.

Using ethnic names to identify citizenship status of graduate students and postdocs clearly has some limitations. If Asian and Hispanic names are classified as being foreign, the technique overcounts the foreign representation, given the number of U.S. citizens with Asian and Hispanic names. On the other hand, if English and European names are used to classify individuals as "native," the native count will be overstated, given the number of European, English and Canadian students and postdocs working in the United States. After examining PhD award patterns by nativity and ethnicity, Black and Stephan conclude that, because these "biases" come somewhat close to cancelling each other out, one can get a fairly reasonable overall count of the citizenship status of PhD student authors by "keying" on ethnicity of name, classifying English and European names as "native" and all others as foreign. They go on to say that they believe this methodology undercounts the total number of noncitizens among postdoctorates, given the large number of individuals who come with PhD in hand to take a postdoc postion, often from European and English countries as well as from Asian countries. It is more difficult to ascertain the magnitude of the bias for positions such as faculty and staff scientist. For their purposes, however, they use the same convention as that noted above.

For the sample of 133 papers in which all authors were coded, Black and Stephan find that 57.2 percent of authors with a U.S. address have English names and 6.4 percent have European names; 4.3 percent have Hispanic names, 16.6 percent have Chinese names and 4.3 percent have Indian/Hindi names. Koreans, Japanese, Russians, and "other" make up the remaining 11.4 percent. Using the convention discussed above, they conclude that approximately 64 percent of the authors are "native;" 36 percent are "foreign."

Ethnicity relates to the status of the author: 71 of the 120 postdoc authors are neither English nor European (59.1 percent); 42 of the 108 graduate-student co-authors have neither English nor European names (39.6 percent). By way of contrast, 79.2 percent of the faculty authors are English or European; the next most likely ethnic group to be a faculty author is Chinese (8.8 percent). Authors are also classified according to whether they are a staff scientist or a technician; 60 percent of authors in such positions have English or European names; 13.6 percent have Chinese names. Results are summarized in Figure 5. The figure clearly shows the important role that the foreign born play as postdocs and graduate students.[30]

[28] We are grateful to Bill Kerr not only for providing us access to the database but also for doing the actual match.
[29] In some instances, the matching procedure attributes a name to several ethnicities, providing the probability of ethnicity associated with each match. In these instances we coded the ethnicity that had a greater than 50 percent probability. By way of contrast, Kerr (2008), who has a significantly larger database and addresses different questions, summed probabilities associated with an ethnicity rather than assuming a specific ethnicity in cases that he refers to as "ties."
[30] The figure is restricted to the 133 papers with less than 10 authors.

When Black and Stephan focus on articles instead of authors, they find that 70 of the 133 papers (53 percent) with fewer than 10 authors have a foreign student or postdoc as a coauthor. This represents approximately 60 percent of the 115 papers that have either a student or a postdoc author. This suggests that it is the norm, not the exception, to have an international student or postdoc as a coauthor in papers published in *Science.*

They also examine the ethnicity of U.S. first authors from their sample of all papers. They find that 55 percent are either of English or European ethnicity, the remaining 45 percent are "foreign"-- 17.8 percent are Chinese, 7.8 percent are Indian/Hindi, 4.7 percent are Hispanic, and 14.3 percent are drawn from other ethnicities. First authors are especially likely to be foreign if they are postdocs or graduate students. Using the same convention for native and foreign they determine that almost 59 percent of the graduate student first authors are foreign and 54 percent of the postdoc first authors are foreign. Clearly international graduate students and postdocs play lead roles in research.

The ethnicity of last authors is also examined. Following the same convention, 78 percent of last authors are "native"; 22 percent are foreign. Almost 50 percent of the "foreign" last authors are Chinese. The lower representation of the foreign in last author position reflects the fact that graduate students and postdocs are very unlikely to be last author; the position, at least in many fields of science, is taken by the principal investigator of the lab.[31]

Findings regarding nativity are summarized in Table 5. We see that slightly more than 44 percent of first authors are foreign; almost 60 percent of postdoc authors are foreign, 40 percent of graduate student authors are foreign. By way of contrast, a much smaller proportion of last authors and faculty are foreign.

The research of Black and Stephan demonstrates that the foreign born play a key role in publishing, especially foreign-born graduate students and postdocs. But their research does not address whether at the margin the foreign born are more productive than are the native born. Nor does the research address the related question of whether the foreign born contribute disproportionately to scientific productivity in the academy.

There are several reasons to argue that the foreign born may disproportionately contribute to U.S. science and engineering (Stephan and Levin 2001). Some of these factors apply specifically to graduate students and postdocs; others do not. 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 applicants from many countries, including those from the U.S., before being selected for further

[31] Only 6 of the 157 papers analyzed have a postdoc or graduate student as the last author; one has an undergraduate student as the last author.

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 the phenomenal growth that occurred in PhD 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.[32]

There are at least two other reasons why immigrant doctoral and postdoctoral scientists and engineers might contribute disproportionately to the productivity. First is the issue of "match." If professors populate their labs with individuals of like ethnicity, as Tanyildiz's work suggests (2009), other things being equal the students they select may be more productive, since the faculty doing the selection may have expertise in evaluating the credentials and abilities of individuals of the same ethnicity and a network from which to recruit students.[33]

Another reason to expect those on temporary visas to be disproportionately productive in a university setting relates to the fact that visa restrictions limit their opportunities (relative to U.S. citizens and permanent residents) to work outside the university. This constrained choice is especially relevant at the time that the PhD is received and undoubtedly contributes to the finding by Stephan and Ma (2005) that, other things being equal, newly minted PhDs on temporary visas have a much higher probability of taking a postdoctorate appointment than do newly minted PhDs who are citizens or permanent residents. Conditional on being trained in the U.S., such a constraint could raise the relative quality of postdocs on temporary visas compared to postdocs who are citizens or permanent residents.

In a study that is now somewhat dated, Stephan and Levin (2001) use six different indicators of exceptional work to test the hypothesis that the foreign born contribute disproportionately to U.S. science. Three of these indicators are based on publications: authorship of a citation classic, authorship of a "hot paper," and inclusions in the list of ISI's 250 most-cited authors. For purposes of analysis Stephan and Levin combine authors of citation classics and most-cited authors to form a fourth category called "outstanding authors." Data were collected in the early 1990s and represent the cumulative process of accomplishment during the preceding years. In all instances Stephan and Levin (2001) compare the proportion of foreign-born (and foreign-educated) authors to their underlying distribution in the U.S. scientific workforce as determined by the National Survey of College Graduates. They use a two-tail test to determine if the observed frequency by birth or educational origin was significantly different from the frequency one would expect.

The results are summarized in Table 6 for the life sciences and Table 7 for the physical sciences. In addition to the bibliometric indicators, we also include their findings concerning nativity of membership in the National Academy of Sciences. Regardless of benchmark data or indicator,

[32] There is evidence that the decline in quality continued through the 1990s. A study sponsored by the Sloan Foundation (Best and the Brightest 2000) found that among US–citizen GRE test-takers scoring 700 or above on the quantitative test the number going on to graduate school in an S&E field declined during the period between 1987-88 and 1997-98.

[33] While faculty clearly play a role in graduate admissions, the role of faculty choice is greater at the postdoctorate level when selection is generally made by the faculty member directing the lab and not by a committee of the department.

the foreign born are disproportionately represented among those making exceptional contributions in the physical sciences. For example, more than half (55.6 percent) of the "outstanding" authors in the physical sciences are foreign born compared to just 20.4 percent of physical scientists in the scientific labor force as of 1980. In the life sciences 29.1 percent are foreign born compared to the underlying benchmark of 15.4 percent. The foreign educated are also disproportionately represented for a number of the indicators—among most cited and outstanding authors, as well as first authors of hot papers.

Stephan and Levin have not updated the study for publications. They did, however, update the study for membership in the National Academy of Sciences for the year 2004. Chi-square tests indicate that the foreign born remain disproportionately represented in all NAS sections in which they were disproportionately represented in 1994. However, the authors note that the Chi-square tests are based on using the 1980 benchmark of the underlying distribution of the foreign born in U.S. science. If they had chosen to use a 1990 benchmark instead, they would have come up with a substantially different conclusion, finding the native born to be disproportionately represented among all members as well as members of the life science sections, and disproportionately represented (although at a lower level of significance) among members of the engineering section. In the other four fields of NAS membership, one could not reject the hypothesis that the distributions are the same as the underlying population.

The authors see the findings for membership in the NAS in 2004 as suggesting that the U.S. may be in a period of transition in terms of the contribution of the foreign born. One possibile explanation relates to a change in the underlying age distribution. The dramatic increase in the proportion of foreign born in the U.S. is due in large part to the immigration of young scientists and engineers. These younger foreign-born scientists and engineers have a lower probability of having made exceptional contributions, or if they have, of being recognized for their contributions by 2004. It is unclear whether the findings would change if one were to focus on different indicators of exceptional contributions, especially indicators that have a higher representation of "young" scientists and engineers than does the NAS.

A slightly different question is whether foreign-born graduate students have an edge in publishing compared to their native-born classmates. Stuen, Mobarak and Maskus (2008) address this by estimating what could be thought of as a knowledge production function for counts of publications and number of citations for 100 research-intensive U.S. universities for 23 fields in science and engineering. Included in the measure of inputs are counts of graduate students by visa status, as well as fixed effects for field-university pairs, field trends and university trends. What is particularly interesting about their research is that they estimate a first-stage instrumental variables equation for the number of foreign-born students in order to isolate the exogenous variations in student supply functions. The instrumental variables they use include various shocks in home countries as well as policies restricting emigration.

The results are striking. First, and not surprising, Stuen, Mobarak and Maskus find that the number of graduate students in a department is significantly related to the number of publications that a department produces, but the effect is not large, being generally less than 1 percent of total publications. Second, and of more interest for our work, they find that there is not a differential effect by visa status when all one hundred institutions are analyzed together. To quote: "Overall, the marginal foreign student is neither clearly better nor clearly worse than the marginal American." (p.3)

With regard to citations, they find that the foreign born contribute more than do citizen graduate students. When they break the sample into "elite" institutions and "non-elite institutions" they find that the citizen graduate student contributes approximately the same amount to publications in both sectors; but foreign students, who contribute about the same as the domestic students at non-elite institutions, contribute significantly more to publications at elite institutions. With regard to citations, they find that both citizen-doctoral students and foreign-born doctoral students make approximately the same contribution to citations in the non-elite sector. But while the contribution that domestic students make nearly doubles at elite institutions, the contribution of the foreign born more than triples at elite institutions.

The authors pose differential costs as a plausible explanation for the finding of differential productivity. In this framework, departments bring in citizen and foreign students until the ratios of the marginal products and marginal costs are the same. But foreign students cost the department more, both in terms of financial resources (in the case of out-of-state tuition) and in terms of time. Thus, to compensate, the marginal product of the foreign student must be higher.

To summarize, foreign-born graduate students make significant contributions to academic research. More than two-thirds are supported on research assistantships or fellowships while in graduate school. Their contribution to research is evidenced by the fact that foreign-born graduate students constitute approximately 40 percent of the graduate student authors of recent "U.S." papers in *Science* and, what is more telling, they make up approximately 59 percent of the graduate student first authors. There is evidence that foreign-born graduate students contribute marginally more than native- born graduate students to publications—especially at elite institutions.

Foreign-born postdocs play an even larger role in research. They constitute almost 60 percent of the authors who are postdocs and represent 54 percent of the postdoc first authors. A smaller percent of faculty authors are foreign born, reflecting the fact that the underlying population of faculty is considerably smaller than the population of postdocs or graduate students.

There is some evidence that the foreign born contribute disproportionately to exceptional contributions but the evidence is by now a bit dated.

Patenting

Although the academy plays a much smaller role in patenting than in publishing, university patent activity has been growing in recent years and universities devote considerable resources to both patenting and licensing inventions made within the university. A logical question thus to ask is whether the foreign born play a key role in this activity.

Just as it is difficult to study the birth and educational origins of authors, it is difficult to study the birth and educational origins of inventors. Patents do not come with bios and to date no one has examined university inventors to determine ethnicity of birth origin.

Gurmu, Stephan and Black (2009) address the question indirectly by estimating a patent production function for universities in much the same way that Stuen, Mobarak and Maskus estimate a publishing and citation production function. The unit of analysis is the number of patents issued to university x at time period t in one of five fields. Patent activity is related to R&D expenditure data, number of faculty, number of postdoctoral students and number of PhD students studying at the university in the specified field during the time the patent research was undertaken. All variables except faculty counts are measured at the field level. Faculty counts, however, are only available at the university level and the data do not permit identification of the nativity of faculty. The data do, however, allow for the identification of graduate students and postdocs by visa status.

The authors find strong evidence that graduate students and postdocs contribute to patenting activity: an additional graduate student or postdoc increases patents by approximately .10. The results are mixed when graduate students and postdocs are differentiated by visa status. In the case of postdocs they find positive and significant coefficients for both citizens and temporary residents,[34] but they cannot reject the hypothesis that the marginal contributions are the same for citizens and temporary residents in favor of the hypothesis that they differ. They conclude that postdocs, regardless of citizenship status, contribute to patenting activity.

The findings are more nuanced for graduate students: patents are positively and significantly related to the stock of permanent resident PhDs; they are not significantly related to the stock of U.S. PhDs or the stock of PhDs who are temporary residents. They also find that patents are significantly related to the stock of PhDs whose visa status is not known.[35]

At a more global level, Chellaraj, Maskus and Mattoo (forthcoming) find a relationship between counts of graduate students (and their visa status) and counts of patents, both at universities and in the private sector. More specifically, they use aggregate annual data for the period 1963-2001 to estimate an innovation production function in which graduate students are an input into the production of patents, both at universities and in the private sector. They find the number of international graduate students to be positive and significant in both patent equations, holding constant the total number of graduate students and the cumulative number of doctorates in science and engineering. They conclude that a ten-percent increase in the number of foreign graduate students would raise patents granted to universities by 5.8 percent and non-university patent grants by 5.0 percent.

Section IV. The Placement of Foreign-born Graduate Students in Industry

[34] The "citizen" category includes permanent residents, given the way that the postdoc data are collected by NSF.

[35] In an effort to explain this result, the authors look at the background of those who don't disclose their visa status and find that many went to elite U.S. institutions. This leads them to hypothesize that the majority of "others" are international students who train in the U.S., many at elite programs. They speculate that their U.S. experiences may lead them to see themselves as in transition to becoming U.S. citizens, if not in fact, in spirit. Their ability and presence in the U.S. while an undergraduate may also facilitate their placement in PhD programs where they are an exceptionally good match and where they are exceptionally productive while graduate students. While this is speculative, the results clearly indicate that "other" PhD students contribute differentially to patenting.

The mechanism by which knowledge flows from universities to firms is varied, involving formal means, such as publications and patents, as well as less formal mechanisms, such as discussions between faculty and industrial scientists at professional meetings. Face-to- face transmission is most appropriate when tacit knowledge is involved, since, by definition, tacit knowledge cannot be codified. The placement of new PhDs in industry provides one mechanism for transmitting tacit knowledge. Much of a graduate student's training is of a tacit nature, acquired while working in her mentor's lab. These techniques can be transmitted to industrial R&D labs when the PhD takes a position in the firm upon graduating (Stephan 2006).

The foreign born who receive their PhDs in the U.S. play a significant role in this process of knowledge transfer. To wit, 32 percent of PhDs who received their degree between 1997 and 1999 in S&E and had definite plans to work in industry at the time of graduation were temporary residents (Black and Stephan 2007).[36] This is approximately the same proportion as the underlying representation of temporary residents in the population of new PhDs during the time period. Table 8 provides details concerning those with definite plans to work in industry by field of status and residence status. The proportion of PhDs going to industry who are temporary residents (column c) is particularly high in math (43 percent), civil engineering (42 percent), and electrical engineering (41 percent). The rate is also relatively high in mechanical engineering (40 percent) and computer science (38 percent).

The proportion going to industry closely resembles the underlying proportion of temporary residents in the population of newly minted PhDs during the same period (column d) for more than half of the fields. Only in math and oceanography is the proportion noticeably greater than the proportion of all doctorates in these fields who are temporary residents; it is slightly higher in computer science. The proportion is noticeably lower than the benchmark in agriculture, aerospace engineering, chemistry, chemical engineering, and biological sciences. The low placement in aerospace engineering in all likelihood reflects the fact that citizenship is often a requirement to work in the aerospace industry. The relatively low placement of those in the biological sciences can be explained by the strong inclination of new PhDs in the biological sciences to take a postdoctoral position before settling into a "permanent" career, be it in industry, academe, or government. The small percent of temporary residents trained in agriculture who take a job in industry in the U.S. reflects the high probability that foreign students in agriculture leave the country upon receiving their PhD (see discussion below).

The most likely industrial hire holding a temporary visa comes from China. Indeed, the Chinese representation among the industrial hires is so substantial that almost one in three of the temporary residents hired by U.S. industry is Chinese and close to one in ten of all industrial hires identified in the data (regardless of citizenship) is Chinese. Indian hires are a close second,

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[36] The authors are able to study placements of new PhDs in industry by coding the verbatim answers to the SED questions regarding the location of the firm and the name of the firm where the new PhD plans to work and then matching this information to the SED data (see Stephan 2006 for a discussion of the data). The counts underestimate the number of new PhDs who eventually go to work in industry because (1) many students who go to industry do not have definite plans at the time they fill out the survey and (2) many PhDs only work in industry after completing a postdoctoral appointment in academe. Stephan (2006) estimates that in the longer run approximately three times as many PhDs eventually work in industry as the number who indicate that they have definite plans to work in industry at the time of graduation.

with more than one in twelve of all industrial hires during the period being Indian. The high prevalence of hires from China is consistent with the 11 percent share of Chinese in the overall pool of new PhDs during this period; the prevalence of hires from India is considerably higher than the prevalence of Indians in the PhD population, which at the time was 5 percent; this may reflect conditions in IT at the time.[37]

Section V. Those Who Leave

Not all foreign-born PhDs stay in the U.S. after receiving their degrees. Some leave soon after graduating; some leave five to ten years later. Some follow careers that lead them to spend time both in the U.S. and abroad. Similar patterns are exhibited by those who receive their PhD training outside the U.S. but come to the U.S. either as postdocs or faculty members. As noted in the introduction, it is difficult to follow the careers of those who leave, although several studies have made inferences about their location and productivity. But thanks to an ingenious methodology designed by Michael Finn (2005) of Oak Ridge, we know a considerable amount about who among recent PhDs leave and who stays.[38] For example, as measured in 2003, the two-year stay rate for new PhDs was 71 percent. The five-year stay rate was slightly lower, at 67 percent, and the ten-year stay rate was lower at 58 percent. A comparison with stay rates calculated in earlier periods shows a dramatic increase during the 1990s (the two-year stay rate in 1989 was slightly less than 50 percent). This pattern appears to have leveled off recently.

Stay rates are field dependent. The agricultural and social sciences have the lowest stay rates (the five-year rate is 50 percent or lower, depending on field); the physical sciences, life sciences, computer sciences and computer and electrical engineering all have five-year stay rates that exceed 70 percent. In terms of country of origin, stay rates are highest for doctorates from China (90 percent five-year stay rate), India (86 percent) and Eastern Europe (83 percent). They are lowest for doctorates from Indonesia (19 percent), Mexico (20 percent), Brazil (25 percent), South Korea (34 percent) and Japan (37 percent). These country patterns have been stable over the past decade.

What do those who leave do? This proves difficult to answer because the SDR does not track PhD recipients who leave the country. But several studies provide some insight. First, the work of Stephan (2006) shows that 5 percent of all PhDs with definite plans to work in industry at the time they graduate indicate that they are taking a position with a firm outside the United States. While most of these recent graduates are foreign students, not all are. The most common foreign destination is Korea, where 22.5 percent of those with plans to work in industry abroad indicate

[37] A substantial proportion of temporary residents going to industry are employed in large, established firms. In terms of R&D intensity, 40 percent had definite plans for employment at a firm ranked in the top 200 for R&D expenditures or at one of these firms' subsidiaries. This is slightly higher than the placement rate of 37.8 percent in R&D intensive firms for all PhDs regardless of citizenship (Stephan 2006). The largest number of hires in a top-200 R&D firm were Indian, followed by Chinese and Taiwanese. Together, the three countries accounted for 70 percent of temporary resident hires at top-200 R&D firms; in comparison, they accounted for approximately two-thirds of temporary resident hires at non-top R&D firms.

[38] The methodology involves sending the Social Security Administration batches of social security numbers for specific groups of students and then having the Social Security Administration determine the number in each group that had an earnings report of more than $5,000 for the specified year.

that they will go; the next most likely destination is Germany (8.8 percent), followed by Japan at 8.5 percent. Canada attracts about 6 percent and Taiwan close to 5 percent. In light of recent discussions concerning increased innovative activity in developing Asian countries, it is interesting to note that only about 6 percent are headed to the countries of China (1.8 percent), India (2.1 percent) or Thailand (2.0 percent).[39]

Second, based on case studies for Korea and China, we know that foreign universities hire a considerable number of PhDs trained in the U.S. The case of Korean universities (Kim 2007) is particularly striking and indicates the degree to which the country has depended on the return of PhDs trained in the United States to staff its universities. Specifically, according to the Korean Research Foundation, 52.8 percent of the foreign PhDs who registered their degrees during the period from 2000 through August 2007 received their training in the U.S. At prestigious Korean universities, U.S. PhDs dominate. For example, at Seoul National University, 52.6 percent of the professors with PhDs received their training in the U.S. The two other premier science and engineering universities in Korea, Korea Advanced Institute of Science and Technology and Pohang School of Technology, also have high proportions of U.S. PhDs. At the former, for example, 84 percent of science professors received their doctorates in the U.S. and almost three-quarters of the engineering faculty were trained in the U.S. At the latter, seven-eighths of the science professorate were trained in the U.S. and five-sixths of the engineering professorate were trained in the U.S.[40]

While Korea has been hiring U.S. trained PhDs for a number of years, China has only recently begun to hire those trained in the U.S. Some insight into these patterns is provided in data collected by Qiao and Stephan (2007) for 45 institutions of higher education.[41] The study was limited to programs in economics and in biology and was based on data provided on the web.

Thirty-eight of the 45 institutions had a program in economics and maintained web pages with details concerning faculty degrees. Among the 38 institutions, 29 had one or more faculty members with a PhD degree from outside of China; 18 employed one or more faculty with a U.S. PhD, for a total of 130 faculty educated in the U.S. The 130 represent approximately 6 percent of the faculty at the 38 institutions.[42] They are heavily concentrated at three institutions.[43] The mass hiring of western-trained PhDs started in 2004 when the central government of China initiated a special fund to attract western-trained, especially U.S.-trained, PhDs. A back-of-the envelope estimate suggests that the hires represent more than 50 percent of all Chinese

[39] The data are for the period 1997 to 2002.

[40] Return patterns have not been constant over time but reflect economic conditions in Korea. For example, Kim (2007) shows how the labor market problems caused by the Korean financial crisis of 1997-98 discouraged Korean PhDs trained abroad from returning. This was reinforced by the adoption of increased performance criteria by Korean universities.

[41] These 45 institutions, known in China as the "985 Institutions," constitute a select group singled out by the Chinese government in an effort to direct resources to a handful of institutions which the government sees as having the greatest potential for success in the international academic community.

[42] The PhDs received their degrees at 60 distinct U.S. institutions; eight institutions bestowed five or more of these degrees. Almost 60 percent of the degrees were granted by a top-25 program as rated by the 1993 NRC report.

[43] Forty of the 145 faculty members in economics at Peiking University have a PhD from the U.S.; 17 out of 43 faculty at Tsinghua University have a PhD from the U.S., and 29 out of 72 faculty have a PhD from the U.S. at Central University of Finance and Economics.

economists trained in the U.S. who left the U.S. subsequent to receiving their PhD in recent years.

Qiao and Stephan use the same methodology to examine hiring patterns in biology departments at the same 45 institutions. Here 34 of the 37 institutions with programs in biology maintain web pages that provide degree information on faculty. Among these, 21 programs have one or more faculty members trained in the U.S. for a total of 67.[44] The U.S.-educated faculty represent about 3 percent of those working at the 34 institutions. The 67 represent approximately 7 percent of U.S.-trained Chinese biologists who left the country during the period.

The work of Qiao and Stephan, as well as the work of Li (2008), documents that Chinese universities are hiring U.S.-trained PhDs. But the methodology only picks up a small piece of labor-market activity, given that research in China is often carried out at research institutes instead of at universities and that universities engage short-term visitors who are not officially listed as faculty. These visiting positions, known as jiangzuo, or lecture chairs, were created with an eye to attracting top researchers to universities and institutes (Normile 2006). The Changjian Scholar Incentive Program, for example, according to the Ministry of Education "provides financial support to young and middle-aged leading scholars of certain disciplines who have studied abroad." The Ministry reports that 537 scholars are supported through the program. The Ministry also sponsors a "Program of Academic Short-return for Scholars and Research Overseas" for outstanding Chinese scholars studying or doing research abroad to give lectures or do research "during their short holidays or returns to China." Since its inception in 2001, 104 scholars have reportedly been supported on the program. (http://www.moe.edu.cn/english/international_2.htm).[45]

Firms located in China also hire PhDs. Although we know little about the magnitude of such hires, what we know suggests that some of the hires are of repatriated Chinese as well as non-Chinese. For example, Hutchison MediPharma (the R&D subsidiary of Hutchison China MediTech) expected to employ 150 scientists in research in 2007, 15 to 20 percent of whom were to be returning Chinese scientists. The motivation was the tacit knowledge embodied in the hires. According to Samantha Du, a U.S. citizen who was born in China, and the managing director of the R&D facility, "…the key when I hire scientists back to China is really technical expertise." (Pinock 2007). Dow Chemical planned to inaugurate an R&D center in 2008 that would employ "hundreds of scientists" in more than 60 laboratories. Novartis has a long-run plan of hiring 400 to 500 scientists in its research facility in Shanghai (Pinock 2007).

[44] The 67 trained at 47 different U.S. institutions.

[45] Other incentive programs exist, as well. Some are aimed at faculty; others are aimed at attracting talent to work at institutes. For example, in early 2009 the Chinese Academy of Sciences (CAS) announced that it would begin offering top scientists funding that "will be higher than their research funding outside China," through the creation of two new programs: Specially Hired Foreign Research Fellows, targeted at the associate professor level, and Youth Foreign Scientist Project, targeted at newly minted PhDs. The Fellows program is designed to attract established researchers to engage in research collaborations in China, lasting from three to six months. The program for newly-minted PhDs will offer support for up to two years. The Academy reports a goal of attracting 200 foreign scientists per year and 1,500 scientists in total. The Academy also has unveiled a new program designed to attract Chinese scientists working abroad to return to China. The reported goal: to attract 600 Chinese scientists a year to return. Returning scientists will receive yearly funding in excess of $397,058. (The Scientist: NewsBlog:China gunning for brain gain.)

The demand for scientists and engineers is growing, not only in China and Korea, but in many other countries. Much of the increase in demand is related to the need for faculty to staff the expansion of graduate education outside the U.S. One indicator of this expansion is the ratio of the number of S&E PhDs from foreign universities to the number from U.S. universities that Freeman (2007) computes. He estimates that the ratio for Japan rose from .11 in 1975 to .29 in 2001; in all EU countries the ratio went from .93 in 1975 to 1.54 in 2001; in "major" Asian nations it went from .22 to .96 during the same period. A cursory look at the media would lead anyone to a similar conclusion. The *New York Times* runs ads for scientific positions outside the U.S. on a regular basis as does the journal *Science.* The implication is clear: the pull for those educated in the U.S. to work outside the U.S. will only increase. Moreover, the opportunities for those who might have come to the U.S. in the first place to study will also expand, creating competition for graduate training. We will return to the issue of competition in the conclusion.

If we know little about the placement of U.S.-trained PhDs outside the U.S, we know even less about the contributions they make, as measured by such metrics as publishing and patenting. Indeed, to the best of our knowledge, no one has yet developed a systematic way for tracking the productivity of U.S.-trained scientists and engineers who work outside the U.S. We are left with only anecdotes and case studies. Kahn and MacGarive's recent study of Fulbright Scholars is a case in point (2008). Designed to measure the effect of location on productivity, the study collects publication counts for Fulbright Scholars and a matched control group of foreign students, all of whom received their PhDs. at U.S. universities.[46] The bottom line: U.S.-trained individuals working outside of the U.S. publish, but about 50 percent less than those working in the U.S. Neither group publishes a great deal. Those who work in the U.S. publish approximately .90 articles a year; those working outside the U.S. publish approximately .50 articles a year on average. The differential effect is greater for forward citations. The mean for those working outside the U.S. is 3.90; for those working in the U.S. it is 10.77. The study also demonstrates the gray line between "stayers" and "leavers." Twenty-two percent of the Fulbright scholars' post-degree years are spent in the U.S. and 77 percent of the control scholars' post-degree years are in the U.S. In many instances they have repeated bouts of being in the U.S. or abroad.

We should also point out that PhDs who leave the U.S. often continue to contribute to U.S. science by working with U.S. faculty on research.[47] Although we have no idea of the degree of such collaboration, the work of Adams, Black, Clemmons, and Stephan (2005) finds a strong and

[46] There has long been the conviction among those who study science that location matters: individuals working in institutions or countries rich with resources in terms of equipment and colleagues are more productive than those who don't work in such an environment. At the country level, it is generally perceived that the U.S. offers advantages that other countries cannot offer. It is difficult to test the hypothesis because scientists are rarely randomly assigned to a location, and location is related to ability. Kahn and MacGarvie address the endogeneity issue by studying Fulbright Scholars who, because of their J-1 visa, must return to their home country for a period of two years.

[47] The growing number of U.S.-trained individuals working outside the U.S. undoubtedly contributes to the large increase in the proclivity of U.S. faculty to coauthor with scientists abroad. Other factors, such as increased connectivity and the development of international databases and instruments, also clearly contribute. Regardless of the specific cause, the pattern is impressive. In 1991 approximately 8 percent of articles authored by U.S. faculty had one or more foreign authors. By 2007 the percent had grown by a factor of 2.5 and stood at 21.14. Among institutions with a high proclivity to have foreign coauthors, as measured by being in the 90^{th} percentile, the percent grew from 15.74 to 34.01 (Levin, Glanzel, Stephan and Winkler 2008).

significant relationship between the fraction of U.S. trained PhDs placed in top-12 research countries and the relative foreign contribution to articles written by faculty at top-110 universities.[48] Moreover, in a broader sense those who leave continue to contribute to innovation in the U.S., since knowledge, once published, flows across international boundaries and patents can give rise to new products and processes that affect productivity worldwide.

We would be Pollyannaish, however, to oversell the benefits that the U.S. receives by educating people who eventually leave. Their going contributes to innovation and economic growth in their home or newly adopted countries. But we would also be remiss not to point out the positives to the U.S.—some of which are noted above—which include stronger networks between U.S. and foreign firms and U.S. and foreign scholars. There is also, as Richard Freeman often points out, a national security aspect: those who leave often have more positive views and a greater commitment to maintaining friendly ties with the U.S. than they did before coming to the U.S. to study or work.

Section VI. Conclusion

We take as given that U.S. universities play a key role in fostering innovation. Here we demonstrate that the foreign born are a large and growing component of the U.S. university community. They compose more than 25 percent of the tenure-track faculty, make up approximately 60 percent of the postdoctoral population and represent more than 43 percent of the doctoral degrees awarded in science and engineering. In certain fields, such as engineering and computer science, their presence is more strongly felt. Some of our data on the foreign born in academe is based on surveys, such as the SED, that do an excellent job in detailing the number of foreign born among those receiving PhDs at U.S. universities. In other instances, we have good counts, but not for the entire population. For example, we know with reasonable certainty that 20 percent of the tenure-track faculty who received their doctoral training in the U.S. are foreign born. The 25 percent figure given above is an estimate, based on this survey as well as hiring patterns by field, since no one survey consistently covers all faculty—regardless of doctoral origin. In counting postdoctoral students, there is the problem that the relevant survey misses people who in truth are postdocs but, because of the fairly nebulous definition of what a postdoc is and the proclivity of academe to invent "creative job titles," are missed in the counts. Nevertheless, and in spite of these problems, our data go a long way toward convincing us that the foreign born are a significant and growing population at U.S. universities.

In spite of data challenges, we are also able to establish that the foreign born contribute to the productivity of the university, both in publishing and in patenting. By way of example, 44 percent of the first authors of U.S. papers in *Science* are foreign. Do the foreign born contribute disproportionately, especially with regard to what could be called exceptional contributions? Levin and Stephan (1999) think the answer is "yes" and make a strong case for scientists whose significant contributions were determined approximately 15 years ago. They have not updated

[48] The dependent variable is log(Foreign Share/(1-Foreign Share). The top-12 research countries are Australia, Canada, France, Germany, Israel, Italy, Japan, the Netherlands, New Zealand, Sweden, Switzerland, and the United Kingdom.

their study for all indicators, but the update they did in terms of membership in the National Academy of Sciences suggests that the answer may no longer be "yes." Is the marginal product greater than that of the native born? Stuen, Mobarak and Maskus's work (2008) suggests yes but only at elite institutions. Gurmu, Black and Stephan (2008) find no differential effect between the productivity of postdoctoral citizens and non-citizens with regard to patenting. Their work does, however, suggest that graduate students who are permanent residents contribute more to the patenting process than do citizens.

Is there a "cost" to U.S. citizens of having the foreign born populate U.S. campuses? The analysis of Stephan and Levin (2007) suggests that to the extent citizens have been displaced in academic positions, it has been in "postdoctoral" positions and temporary positions, rather than from "permanent" positions. Such results suggest an element of "pull" rather than push. The work of Borjas (2007) suggests that foreign students may have displaced white male students from top graduate programs. An alternative explanation for the effect Borjas finds is that universities increase their enrollment of foreign graduate students because white men are "pulled" into other careers.

Publications and patents are not the only mechanism by which knowledge spills over from academe to the larger community. The placement of students in industry provides a major mechanism by which tacit knowledge is transmitted from the university to industry. The foreign born constitute approximately one-third of these placements.

We rest our case that the foreign born play key roles at U.S. universities in fostering innovation. Moreover, their contribution to economic growth is not restricted to the U.S. but has global dimensions. Knolwedge, once published, flows across international boundaries; technology transfer gives birth to new products and processes that can have worldwide impact. Tacit knowledge flows as scientists and engineers leave the U.S. to return to their home countries or to work in other countries. Despite these spillovers, the simplest of calculations would lead one to conclude that in the past the U.S. has gained far more than it has lost by the foreign born coming to study and work in science and engineering in the U.S. Whether these benefits persist depends upon whether the foreign born continue to come in such large numbers and to stay in such large numbers.

With regard to the first question, there are three major career points at which the foreign born enter the U.S. university system: as graduate students, postdoctoral fellows, or established scientists. By far the largest entry point is graduate school. To paraphrase a comment made by Richard Freeman recently, *the U.S. immigration policy for highly skilled workers is our educational policy.* But will the foreign born continue to study in the U.S.? In the past the foreign born have had limited alternative opportunities that provide financial support for graduate studies and employment at a relatively favorable salary after the completion of graduate school. This has been particularly the case for students coming from less-developed countries. But the alternatives open to the foreign born are changing. Programs outside the U.S. are becoming more and more competitive. As noted earlier, since the late 1980s the number of S&E PhD degrees awarded in Europe has surpassed the number in the U.S. In the late 1990s the number of degrees awarded in Asian countries has surpassed the number awarded in the U.S. In China alone the number accelerated from virtually zero in 1985 to approximately 13,500 by 2004

(National Science Board 2008, Appendix Tables 2-42 and 2-43). At the same time, programs in the U.S. are at risk of becoming less attractive to foreign-born students. This is, in part, because of diminished funds for graduate support, as agencies such as NIH have experienced real decreases in funding levels. In the short run, these decreases likely will be offset by the large increases that have just been allocated to NIH ($10.4 billion) and NSF ($3 billion) as part of the 2009 Stimulus Package, although it remains to be seen exactly how the funds will be used. Programs in the U.S. are also at risk of becoming less attractive to foreign-born students because of problems faced by foreign nationals in the U.S. since 9/11. A case in point is the special vetting required for foreign nationals to work on research supported by federal agencies and considered "sensitive but unclassified."[49]

Postdoctoral appointments have been another mechanism by which the foreign born enter U.S. universities. We estimate that five out of ten postdocs received their PhDs outside the U.S. But here, too, U.S. support for postdoctoral fellows has diminished, as federal budgets for university research have declined in real terms, although again this may be temporarily offset by the large increases that have just been allocated to NIH and NSF in the 2009 Stimulus Package. Finally, the U.S. has benefitted by the entry of established scientists. Their entry has often been facilitated by exogenous shocks. In the 1930s the U.S. benefitted from the dismissal of Jews from German universities. More recently, the U.S. has benefitted from eased emigration policies that resulted from the collapse of the Soviet Union. Forecasting exogenous events is outside the scope of this paper.

There is also the question of whether the foreign born will continue to remain in the U.S. in such large numbers. Finn's work suggests that the stay-rate for newly trained PhDs increased during the 1990s. But it has leveled off recently, no doubt reflecting the increased demand for scientists and engineers outside the U.S. as developing economies grow their graduate and research programs, and as firms in developing economies recruit scientists and engineers to work in newly emerging sectors. This growth in demand is likely to increase, although the global financial meltdown of 2008-2009 may put it on hold for a while.

What would happen to the U.S. if the foreign born ceased to come or stay? Could they be replaced by native born? In the long run, the answer is a probable "yes"--but it would require major change. Careers in science and engineering would need to be made considerably more attractive than careers in fields such as law and business, both in terms of salary and the amount of time required to train. Moreover, support for graduate study would need to be increased. Third, more effort would need to be directed at recruiting women and underrepresented minorities into science and engineering careers. All of this is possible, and previous work suggests that supply could be responsive to such actions. But it would require considerable resources and a will to change. The United States exhibited such will in the 1950s with the passage of the National Defense Education Act (NDEA). It has taken steps in this direction with the passage of the 2009 Stimulus Package and the FY 2009 omnibus bill, and President's

[49] This may change in the near future. In June of 2008 DOD Under Secretary John Young wrote a directive stating that "classification is the only appropriate mechanism" for restricting participation by foreign nationals or for restricting publication (Bhattacharjee 2008, p. 325).

Obama's 2010 budget proposal has resources that could be allocated to such programs.[50] It is less clear that--unless the U.S. ratchets up the quality of elementary and secondary education--the U.S. could maintain the quality of the science and engineering workforce if the foreign born quit coming to the U.S. to study and work. What is certain is that currently the "I's" have it: immigration and innovation are closely linked at U.S. universities. Whether the "I's" continue to have it depends on policies both within and outside the U.S.

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[50] The 2009 omnibus bill has $151.1 billion for federal R&D, an increase of 4.7 percent over the FY 2008 estimate. The Department of Energy's Office of Science was a major beneficiary, with a 17.3 percent increase, as were NSF with a 8.2 percent increase, and NIST with a 7.5 percent increase. NIH received a 3.2 percent increase. These figures do not include funding coming from the Stimulus Package.

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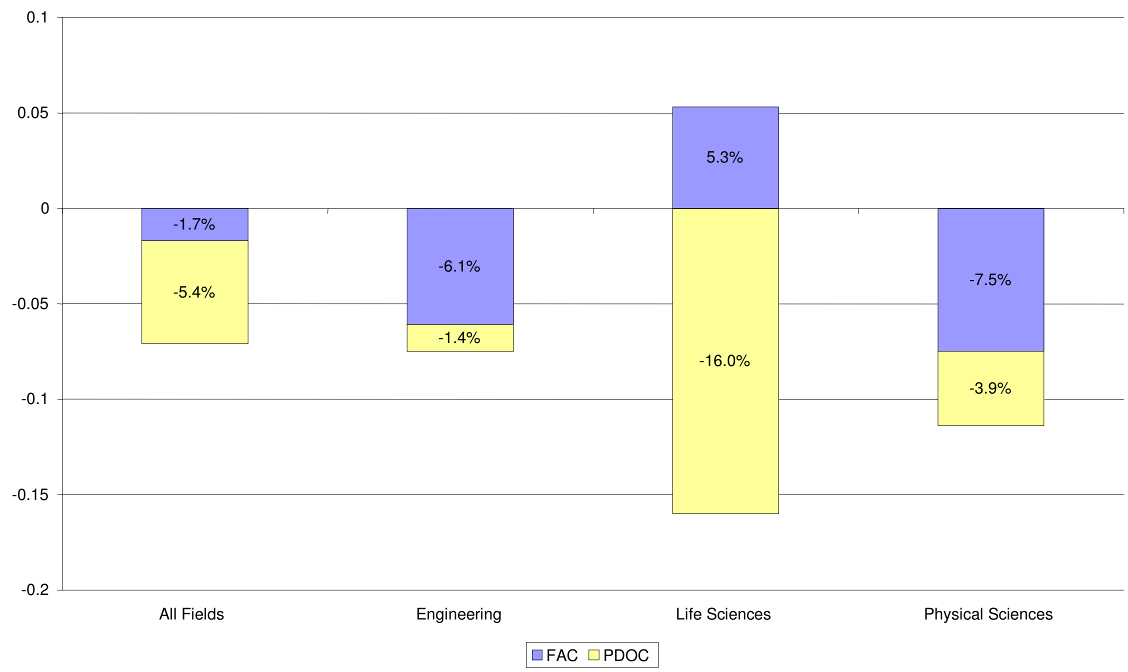
Figure 1
Displacement within Academe, 1979-1997, Faculty positions (FAC)
vs. Postdoctoral positions (PDOC)



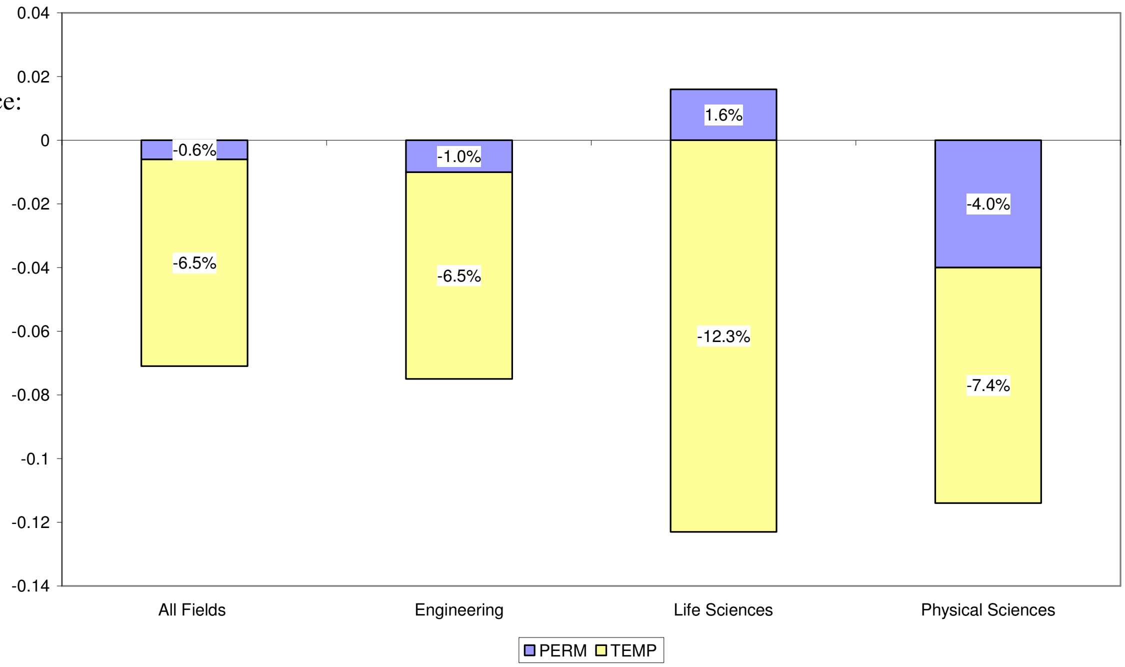
Source: Stephan and Levin (2007)

Note: Displacement is defined to be the difference between citizen and non-citizen growth in positions in academe relative to positions elsewhere in the economy, having controlled for changes in the citizen and non-citizen share of PhDs due to differential rates in obtaining PhDs. Here displacement is broken into a faculty portion (FAC) and a postdoctoral portion (PDOC).

Figure 2

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

Source:

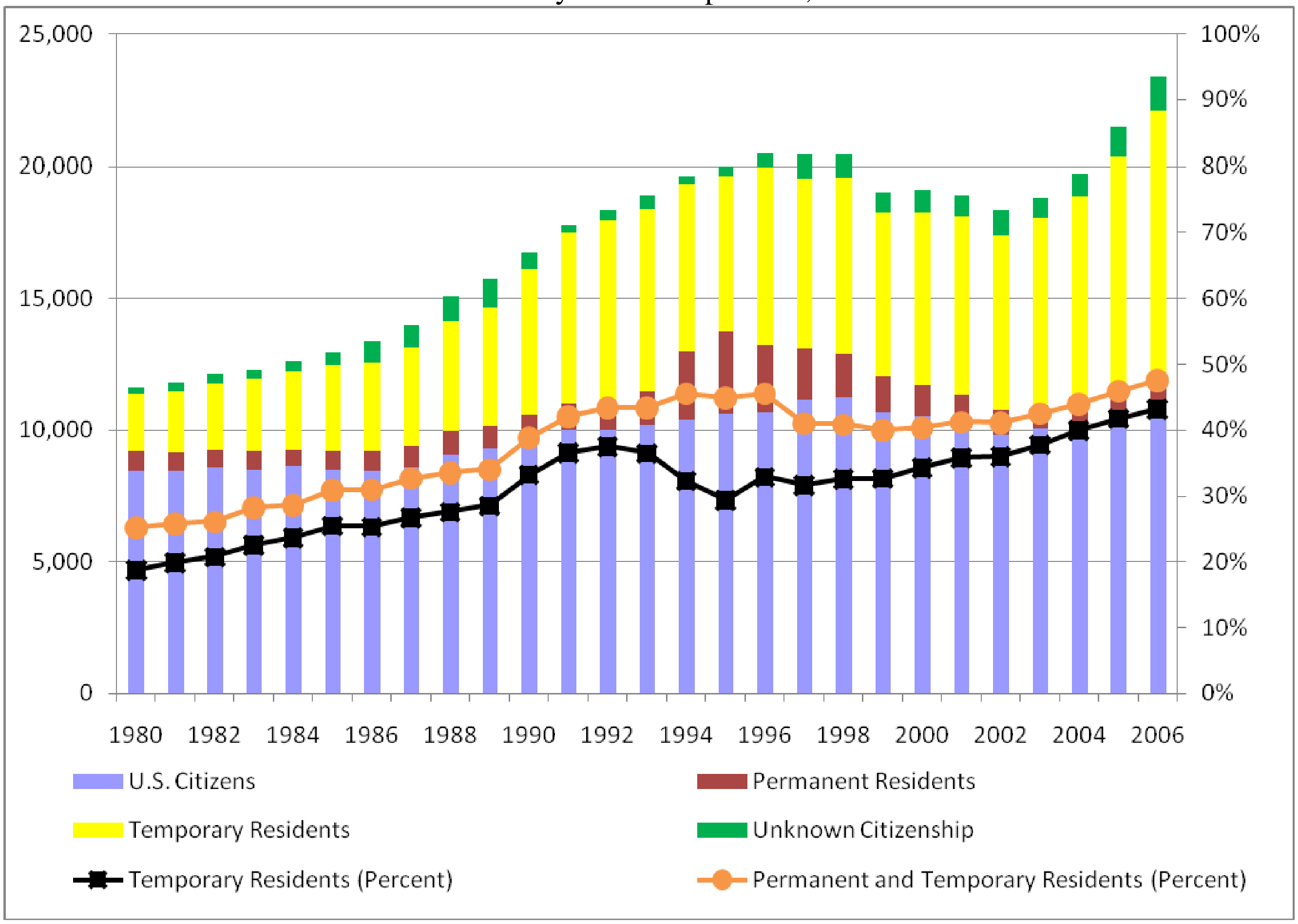


Stephan and Levin (2007)

Note: Displacement is defined to be the difference between citizen and non-citizen growth in positions in academe relative to positions elsewhere in the economy, having controlled for changes in the citizen and non-citizen share of PhDs due to differential rates in obtaining PhDs. Here displacement is broken into a tenure-track portion (PERM) and a non-tenure track portion (TEMP).

Figure 3

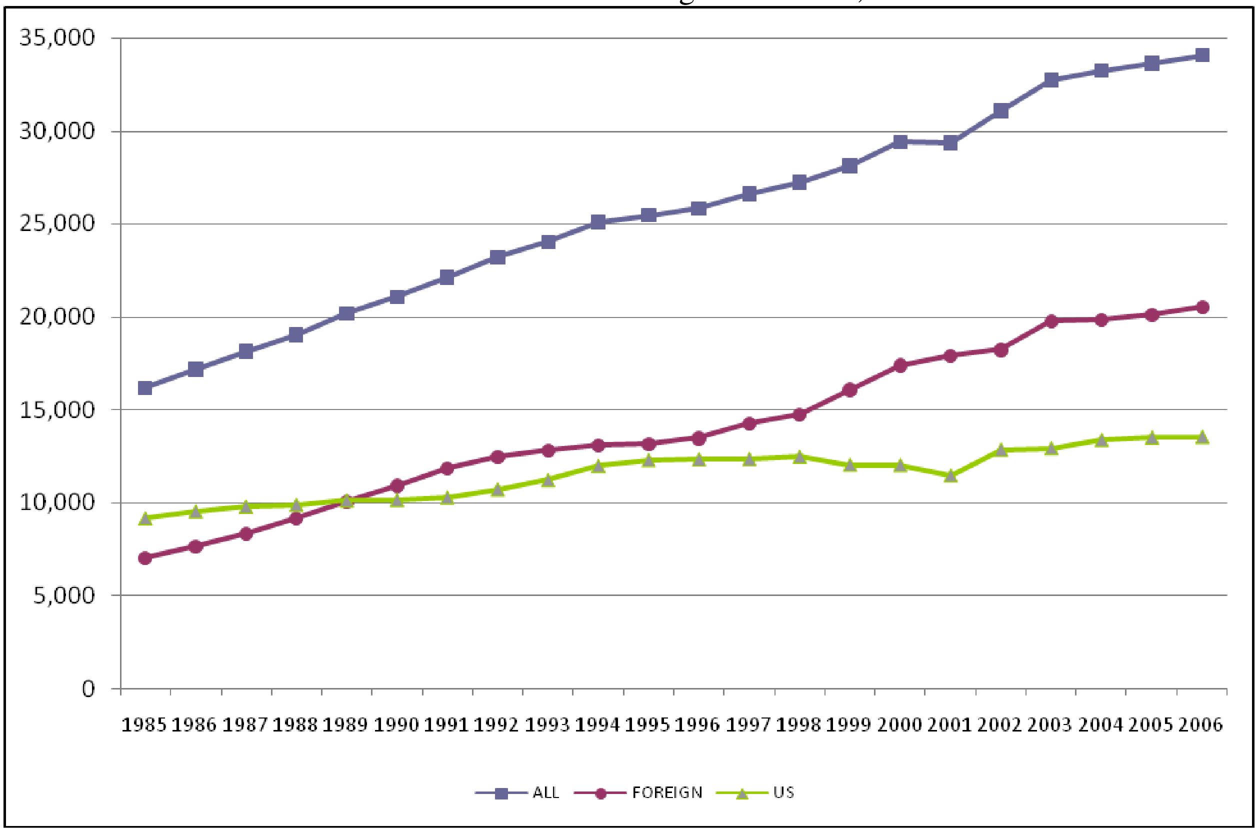
S&E PhDs Awarded by Citizenship Status, 1980-2006



Source: National Science Foundation, WebCASPAR database

Figure 4

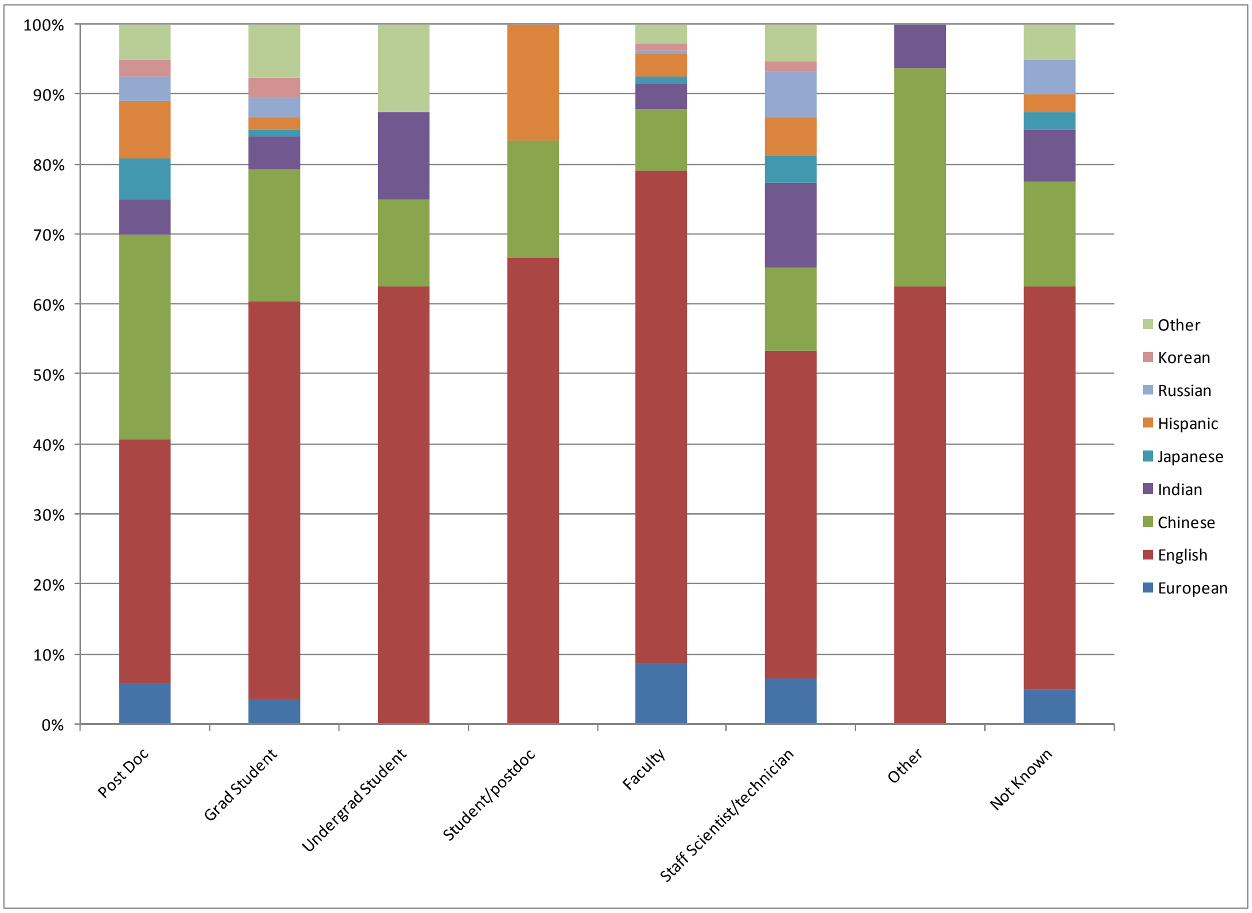
Number of S&E Postdocs Working in Academe, 1985-2006



Source: National Science Foundation, WebCASPAR database

Figure 5

Ethnicity of Author by
Academic Position



Source: Black and Stephan (2008)

Note: The table identifies ethnicity for authors of papers published in *Science* during a six-month period in 2007 and 2008. All articles have a U.S. academic last author and have fewer than ten authors.

Table 1

Percentage of Academic Positions Held by Foreign Born at U.S. Universities and Colleges by Field and Type of appointment, 1979, 1997, and 2003, for Individuals Who Received a PhD at a U.S. University

	1979			1997			2003		
	Academe	**Postdocs**	**Faculty**	**Academe**	**Postdocs**	**Faculty**	**Academe**	**Postdocs**	**Faculty**
All fields	12.2	17.9	11.7	18.6	37.6	16.3	22.2	39.1	20.6
Engineering	18.2	52.8	17.5	29.9	52.8	28.4	34.1	54.3	33.2
Life Sciences	10.3	13.0	10.0	13.8	33.2	12.1	17.5	33.2	15.3
Biological sciences	9.1	10.2	8.9	14.2	31.6	10.5	17.9	31.1	15.6
Physical Sciences	11.5	22.6	10.7	19.9	43.8	17.8	23.5	53.0	21.8
	10.2	6.5	10.3	19.9	43.8	12.4	17.1	48.6	15.7
Earth/environmental									
Chemistry	11.4	26.8	9.5	15.6	49.0	11.6	18.5	63.2	15.2
Math/comp. science	10.4	7.4	10.4	25.1	43.1	24.6	29.5	48.4	28.9
Physics & astronomy	13.2	22.0	12.4	20.3	39.9	17.7	24.5	47.8	22.4

Source: Survey of Doctorate Recipients (SDR), Science Resources Statistics, NSF. The use of NSF data does not imply NSF endorsement of the research methods or conclusions contained in this paper. Foreign born refers to permanent and temporary residents and those who indicated they had applied for citizenship at the time the doctorate was received. Sample is restricted to those working full time who received their doctoral training in the U.S. Academe includes all full-time personnel, including postdoctoral fellows, working at a campus. Postdoc counts those who self-identified as holding a postdoctoral position; faculty are all other full time positions.

Table 2
Percentage of Academic Positions Held by Foreign Born at U.S. Universities and Colleges by Field and Type of Appointment, 2003, for Individuals Who Received a PhD Degree at a U.S. University

Field	Non-tenure track	Postdoc	Tenure Track	Academe
All Fields Combined	22.1	39.1	19.9	22.2
Engineering	30.2	54.3	34.1	34.1
Life Sciences	21.1	33.2	12.5	17.5
Biological sciences	22.2	31.1	12.0	17.9
Physical Sciences	20.5	53.0	22.2	23.5
Earth/Environmental	16.9	48.6	15.0	17.1
Chemistry	23.8	63.2	11.9	18.5
Math/Computer Science	16.9	48.4	30.8	29.5
Physics	21.9	47.8	22.8	24.5

Source: Survey of Doctorate Recipients (SDR), Science Resources Statistics, NSF. The use of NSF data does not imply NSF endorsement of the research methods or conclusions contained in this paper. Foreign born refers to permanent and temporary residents and those who indicated they had applied for citizenship at the time the doctorate was received. Sample is restricted to those working full time who received their doctoral training in the U.S. Academe includes all full-time personnel, including postdoctoral fellows, working at a campus. Postdoc counts those who self-identified as holding a postdoctoral position; tenure-track includes those who have tenure or have the possibility of obtaining tenure; non-tenure track includes all other full time academic employees.

Table 3
Number and Percent of U.S. PhDs Awarded to Temporary Residents,
by Field, Selected Years

Field	1980	1985	1990	1995	2000	2006
Engineering	2,479	3,166	4,894	6,008	5,323	7,191
	(34.7)	(44.9)	(46.7)	(42.1)	(46.0)	(59.4)
Physical Sciences	2521	2,916	3,493	3,814	3,378	3,925
	(17.2)	(21.3)	(30.6)	(24.1)	(34.0)	(43.9)
Geosciences	588	575	719	726	694	757
	(13.1)	(19.5)	(23.6)	(23.4)	(26.2)	(31.7)
Math/Computer Science	962	998	1,597	2,187	1,910	2,779
	(19.0)	(33.3)	(43.8)	(34.2)	(42.3)	(52.6)
Life Sciences	5,062	5,307	6,059	7,267	7,817	8,735
	(12.2)	(15.3)	(22.2)	(20.7)	(25.2)	(27.7)
All Fields	11,612	12,962	16,762	20,002	19,122	23,387
	(18.7)	(25.5)	(33.2)	(29.4)	(34.3)	(43.3)

Source: WebCASPER database.

Table 4

Number and Percent of Postdoctorate Appointments Awarded to Temporary Residents, By Field, Selected Years

Field	1985	1990	1995	2000	2006
Engineering	913 (67.3)	1,337 (68.6)	1,649 (62.3)	2,244 (67.7)	3,106 (67.1)
Physical Sciences	2,513 (55.4)	3,379 (60.4)	3,273 (55.9)	3,999 (63.8)	4,366 (65.4)
Geosciences	126 (33.2)	217 (36.5)	343 (40.6)	450 (39.0)	760 (50.9)
Math/Computer Science	139 (47.0)	181 (56.6)	245 (51.6)	451 (61.9)	595 (57.7)
Life Sciences	3,341 (34.7)	5,799 (46.0)	7,655 (48.9)	10,242 (57.1)	11,694 (57.8)
All Fields	7,032 (43.4)	10,913 (51.8)	13,165 (51.7)	17,386 (59.1)	20,521 (60.3)

Source: WebCASPER

Table 5
Authorship Patterns by Nativity (Percent)

	Native	Foreign Born
First Authors	55.7	44.3
Last Authors	73.6	26.4
Postdoc Authors	40.8	59.2
Graduate Students	60.4	39.6
Faculty	79.2	21.8
Staff Scientist/Technician	60.2	39.4

Source: Black and Stephan (2008)

Note: Data re for articles appearing in *Science* during a six-month period in 2007-2008. All articles have a U.S. academic last author

Table 6

Scientists Making Exceptional Contributions in the Life Sciences in the U.S.

		Percent Foreign-Born		Percent Foreign-Educated			
				Bacc.		PhD	
Indicator (Size of Group)	**Benchmark Year**	**(Information**	**n)**	**(Information**	**n)**	**(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)
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)
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)

(Bacc., baccalaureate degree; PhD, doctoral/medical degree; n/a, not applicable.)
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.
Source: Stephan and Levin (2007, Table 8.4).

Table 7

Scientists Making Exceptional Contributions in the Physical Sciences in the U.S.

Indicator (Size of Group)	Benchmark Year	Percent Foreign-Born (Information n)		Percent Foreign-Educated: Bacc. (Information n)		PhD (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)

(Bacc., baccalaureate degree; PhD, doctoral/medical degree.)

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.

Source: Stephan and Levin (2007, Table 8.5).

Table 8

Field of Training of S&E Temporary Residents with
Definite Plans to Work in Industry in the US, 1997-99

Field	Number of Doctorate Industrial Placements who are Temporary Residents (a)	Number of Doctorate Industrial Placements (b)	Percent of all Doctorate Industrial Placements who are Temporary Residents (c=a/b)	Percent of Doctorate Recipients who are Temporary Residents (d)
Aerospace Engineering	36	159	22.6%	33.1%
Chemical Engineering	254	754	33.7%	42.0%
Civil Engineering	122	292	41.8%	43.2%
Electrical Engineering	763	1,860	41.0%	40.4%
Mechanical Engineering	293	738	39.7%	40.8%
Other Engineering	436	1,238	35.2%	37.5%
Agriculture	57	272	21.0%	39.1%
Astronomy	9	44	20.5%	20.7%
Biological Sciences	86	574	15.0%	20.9%
Chemistry	207	1,175	17.6%	27.3%
Computer Sciences	282	737	38.3%	35.2%
Earth Sciences	59	219	26.9%	26.2%
Mathematics	197	457	43.1%	37.2%
Medicine	73	415	17.7%	17.8%
Oceanography	s	s	33.3%	26.6%
Physics	181	626	28.9%	32.9%
All S&E	3,055	9,560	32.0%	30.3%

Note: s=suppressed if count is 6 or less. Suppressed counts not included in the "all" total.
Source: Black and Stephan (2007)