POLICY FORUM: SOCIOLOGY OF SCIENCE

Are the Foreign Born a Source of Strength for U.S. Science?

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The heavy inflow of foreign talent, especially since the 1970s, is changing the face of American science. In 1980 fewer than one out of five doctoral scientists in the scientific labor force in the United States was born abroad, in 1990 one out of four was (*1*). Many foreign born come to the United States after receiving their doctoral training. There is every indication that these trends will be even more pronounced when new data are released early in the next decade.

Do foreign-born and foreign-educated scientists and engineers contribute disproportionately to U.S. science? Do they crowd the workplace and thereby increase unemployment, lower real wages, and possibly discourage native talent from pursuing scientific careers (*2*)? Here we examine the first of these questions by testing whether the foreign born and foreign educated are disproportionately represented among individuals making exceptional contributions to science and engineering (S&E) in the United States. Six criteria are used: individuals elected to the National Academy of Sciences (NAS) and/or National Academy of Engineering (NAE), authors of citation classics, authors of hot papers, the 250 most-cited authors, authors of highly cited patents, and scientists who have played a key role in launching biotechnology firms. We do not claim that this list is exhaustive, merely illustrative.

Members of the NAS and the NAE are elected in recognition of their distinguished and continuing contributions to knowledge. Included in the study were 1554 members of the NAS and 1706 members of the NAE (*3*). Citation classics are journal articles that the Institute for Scientific Information (ISI) defines as having a "lasting effect on the whole of science." We chose the 108 papers published after 1969 declared classics by ISI during the period June 1992 to June 1993 in the areas of life sciences; agriculture, biology, and environmental sciences; physical, chemical and earth sciences; and clinical medicine (*4*). Authors were considered to have made a contribution to U.S. science if located in the United States at the time of publication. For the classics, 62 first authors (54 unique) and 135 nonfirst authors (127 unique) were identified.

Each issue of *Science Watch* (*5*) contains a list of the 10 most cited or "hot papers" in chemistry and physics or medicine and biology. The selection is based on the number of times a paper has been cited by other authors in a given period, usually the 2-month period 8 weeks before the cover date. We chose the 251 papers declared "hot" between January 1991 and April 1993 and identified 170 first authors (161 unique) and 786 nonfirst authors (687 unique) located in the United States. ISI provided us with a list of most-cited authors during the years 1981 to 1990. Of the 250 most-cited authors, 183 were based in the United States (*6*).

We also studied authors of highly cited patents (*7*) (the top 3.5% over the period 1980–1991) in the field of "medical devices and diagnostics," a field where patents play a key role. In all, 206 (178 unique) U.S.-based scientists were identified out of 286 (249 unique). Finally, we identified the scientific founders and chairs of scientific advisory boards of biotechnology firms making an initial public offering from March 1990 through November 1992 (*8*). From the prospectuses of 50 firms, 98 founders and chairs (97 unique), all living in the United States, were identified.

Survey. The place of birth and educational origin of each scientist and engineer, as well as the date of birth and date of degree, or degrees, were obtained from organizations in the cases of NAS and NAE, and from directories such as *American Men and Women of Science* and the *Official ABMS Directory of Board Certified Medical Specialists* (*9*). For scientists involved with biotechnology firms, we used the company's prospectus (*10*). Addresses were then sought for those with missing data, and mail surveys were sent to 1050 individuals with three follow-ups, as necessary. The overall response rate was 64.8%, excluding returns for nondeliverables, and 54.5% if nondeliverables are included. A review of the names of the nondeliverables suggests that a disproportionate number may have been foreign born. For the nonrespondents, there does not appear to be a birth-origin bias. Overall, essential biographical data (such as country of birth) were ascertained for 89.3% of the study group.

Statistical analysis. For each indicator of scientific achievement, we determined whether the observed frequency by birth (or educational) origin was significantly different from the frequency one would expect given the composition of the scientific labor force in the United States. To do so, we used a nonparametric "goodness of fit test," computing the chi-square statistic. In cases where the chi-square statistic was inapplicable because of cell size, a two-tailed binomial test was applied (*11*). These tests were stratified by field and education level. A 1980 benchmark for the composition of the scientific labor force was chosen for individuals elected to the NAS or NAE, most-cited authors, authors of citation classics, and founders/chairs of biotechnology companies, because each of these indicators was based on a list of scientific accomplishments that began before that date. The remaining indicators used a 1990 benchmark, see Web table (*10*).

Scientists and engineers elected to NAS or NAE. We found that 23.8% of scientists and engineers elected to the NAS were foreign born, whereas 11.5% received their doctorates or medical degrees abroad. For those elected to NAE, 19.2% are foreign born and 10.7% received their baccalaureates abroad. Each of these proportions is significantly different from its 1980 benchmark at the $P = 0.01$ level or less. Results vary somewhat by field. For members of NAS, differences were significant for the birth origins of all except earth and environmental scientists, and for the education of life and physical scientists (*12*), but not for those in engineering, mathematics, and computer sciences and earth and environmental sciences. For NAE, differences were also significant for birth origins except in chemical, civil, and industrial sections, and the proportion educated abroad was significantly different from the benchmark for all except civil engineers (*12*).

Exceptional contributions in the life and physical sciences. In the life sciences, the foreign-born percentages are statistically significant for all indicators with a 1980 benchmark (Table 1 and ref. *13*). The proportion foreign born among first and nonfirst authors of hot papers is not, however, significantly different from the proportion found in the 1990 population of life scientists. For contributions in the physical sciences, regardless of indicator and benchmark date, the foreign born are disproportionately represented. The

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SCIENTISTS MAKING EXCEPTIONAL CONTRIBUTIONS IN THE LIFE AND PHYSICAL SCIENCES IN THE UNITED STATES

Indicator (Benchmark year)	% Foreign born		% Foreign educated				% Foreign born by cohort			
	Life sciences	Physical sciences	Life sciences		Physical sciences		Life sciences		Physical sciences	
			Bacc.	Ph.D.	Bacc.	Ph.D.	<45	≥ 45	<45	≥ 45
Citation classics, 1st authors (1980)	27.5**	†	18.4	15.0	†	†	24.1	36.4*	†	†
Citation classics, non-1st authors (1980)	22.7*	40.9**	16.2	14.1	21.1	33.3***	23.4	21.4	35.7	50.0*
Highly cited patents, medical devices (1980)	17.6***	NA	11.1**	NA	NA	NA	18.5	15.8	NA	NA
Most-cited authors (1980)	29.1***	64.7***	19.4***	21.7***	56.3***	31.3***	25.5**	37.8***	62.5**	66.7***
Most cited + 1st of citation classics (1980)	28.7***	55.6***	18.5**	20.1***	41.7***	30.8***	25.4***	37.0***	50.0**	63.6***
NAS member (1980)	21.1***	26.7***	9.1**	12.4***	13.0	11.4***	21.9***	9.3	26.5**	30.0
Founders/chairs, biotech co. (1980)	24.7**	NA	16.9	14.1	NA	NA	14.3	35.9***	NA	NA
Hot papers, 1st authors (1990)	17.8	35.5**	13.6	10.6	28.4**	18.1*	13.3	20.0	30.0	38.2**
Hot papers, non-1st authors (1990)	22.6	35.4***	16.3	12.4	23.4*	13.0	18.1	25.7	24.2	45.9***

Bacc., baccalaureate degree; co., company or companies; Ph.D., doctoral/medical degree; <45, born before 1945; ≥ 45, born 1945 or later; NA, not applicable.

Chi-square tests of observed versus expected frequencies are used. If the expected frequency is <5, and the test is inapplicable, a two-tailed binomial test is used. *P = 0.10 or less. **P = 0.05 or less. ***P = 0.01 or less. †Combined with non-1st authors because of sample size.

most frequent country of origin in the life sciences is the United Kingdom followed by Germany. In the physical sciences, the reverse is true.

In the life sciences, contributors of highly cited patents, most-cited authors, "outstanding" authors (most-cited and first authors of classics), and NAS members were more likely than expected to have received baccalaureate and doctoral degrees abroad. Authors of more recent contributions in the life sciences–hot papers–are not, however, disproportionately foreign educated. The results are roughly similar for contributors in the physical sciences, with one major difference. Authors of hot papers in the physical sciences are more likely than expected, given the proportion foreign educated in the benchmark population, to have been educated abroad, especially at the baccalaureate level.

We divided scientists into two birth cohorts: those born before 1945 and those born post–World War II (1945 or later). In the life and physical sciences, the older cohorts in NAS, but not the younger cohorts, are disproportionately foreign born. For most-cited authors in both fields, the proportion of younger and older foreign-born individuals are both significantly different than their benchmark populations.

Within the life sciences, younger foreign-born scientists are disproportionately represented among first authors of citation classics and founders or chairs of biotechnology companies. Within the physical sciences, the younger cohort is disproportionately represented among authors of citation classics. There is no evidence of cohort effects for authors of hot papers in the life sciences. This is not the case for authors of hot papers in the physical sciences, where the proportion foreign born is significantly different from the proportion in the younger, but not the older population.

Conclusion. We find that, although there is some variation by discipline, individuals making exceptional contributions to S&E in the United States are disproportionately drawn from the foreign born. Only in the instance of hot papers in the life sciences were we not able to reject the null hypothesis that the proportion was the same as that in the underlying population. Individuals making exceptional contributions are also disproportionately foreign educated, both at the undergraduate and at the graduate level.

Our research shows that the United States has benefited from the inflow of foreign-born talent and that this talent was more likely to have been educated abroad than one would have predicted given the incidence of foreign-educated scientists and engineers in the population. To the extent that contributions in S&E are geographically bounded, the United States has benefited from the educational investments made by other countries, presumably to their detriment. It remains to be determined whether native-born talent is disadvantaged by this inflow and, if so, whether the benefits outweigh the costs.

References and Notes

1. Data are from the 1993 National Survey of College Graduates (NSCG), a National Science Foundation survey of college-educated individuals at the time of the 1990 census, see *Science* Online for supplementary information. Occupational field, not field of education, defines who is a scientist or engineer. Individuals not in the labor force, individuals in the military, individuals not in the United States, and individuals in social science occupations are excluded, as are scientists without a doctoral or a medical degree and engineers without a baccalaureate. Estimates are weighted to adjust for different initial probabilities of sample selection and subsequent nonresponse. Individuals born abroad to U.S. citizens are counted as foreign born. Only those who had immigrated or completed their highest degree before 1980 are included in the 1980 estimates.
2. The National Research Council [*Trends in the Early Careers of Life Scientists* (National Academy Press, Washington, DC, 1998), p. 4] reports a growing "imbalance between the number of life-science Ph.D.'s being produced and the availability of positions that permit them to become independent investigators," a situation exacerbated by "the influx of foreign-born Ph.D. candidates together with the increase in foreign-trained Ph.D.'s who have sought postdoctoral training in the U.S." Also see, for example, G. J. Borjas, *J. Econ. Lit.* **37**, 1667 (1994); D. S. North, *Soothing the Establishment* (University Press of America, Inc., Lanham, MD, 1995); M. Rao, *J. Econ. Educ.* **26**, 274 (Summer 1995); R. Finn, *Scientist*, 27 November 1995, 1, 8–9; J. Glanz, *Science* **272**, 190 (1996); M. Teitelbaum, *New York Times*, 19 March 1996, A23; M. Phillips, *Wall Street Journal*, 4 September 1996, A2.
3. From the 2075 National Academy of Science (NAS) members in 1994, we excluded foreign associates living outside the United States, Public Welfare Medalists, members of the psychology and social science sections, and 20 for whom no section was specified. From the 1781 members of National Academy of Engineering (NAE) as of 30 June 1995, we excluded foreign associates living outside of the United States.
4. Institute for Scientific Information (ISI), *Current Contents*, various issues. Because of the difficulty in locating papers in engineering, technology, and applied science, these classics were excluded.
5. ISI, *Science Watch*, various issues.
6. In preparing the list of 250, some heavily cited authors with common names were omitted because attribution could not accurately be determined.
7. CHI Research Inc., Haddon Heights, NJ. Citations to patents can be used as an index of their importance. M. Trajtenberg, *Rand J. Econ.* **21**, 172 (1990); M. B. Albert, D. Avery, F. Narin, P. McAllister, *Res. Policy* **20**, 251 (1991).
8. D. B. Audretsch and P. E. Stephan, *Am. Econ. Rev.* **86**, 641 (1996).
9. *American Men and Women of Science* (Bowker, New York, 1992); *Official ABMS Directory of Board Certified Medical Specialists, 1993* (American Board of Medical Specialities, Princeton, NJ, 4 vols., 1993).
10. See the supplementary information in *Science* Online at www.sciencemag.org/feature/data/1041439.shl.
11. S. Siegel, *Nonparametric Statistics for the Behavioral Sciences* (McGraw-Hill, New York, 1956), p. 59.
12. When statistically significant, the proportions observed were always higher than expected.
13. The life sciences include NAS members in sections 21–27, 41–43, 61, and 62; the physical sciences, members in sections 12, 13, 14, and 33.

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