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The Changing Career Outcomes of Citizen and Non-Citizen Scientists and Engineers in Higher Education

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Abstract

Using data from the 1973-1997 Survey of Doctorate Recipients, this study documents recent trends in the career outcomes of doctorates in science and engineering (S&E) and then, using a modified version of the shift-share technique, it examines the role that non-citizen doctorates in S&E may have played in the changing outcomes of citizen S&E doctorates in academe. The analysis shows that citizens hold fewer positions in academe than expected after accounting for the overall growth in S&E doctorates and the differential rates at which degrees were minted to the two groups. Notably, this shortfall cannot be attributed to citizens' lack of success in holding the "choice" positions within academe --full-time tenure track or permanent positions-- rather to their lack of success in holding postdocs or other temporary, soft money appointments. The analysis cannot determine whether the "displacement" that occurred was a voluntary response of citizens to the lure of opportunities elsewhere or an involuntary response indicative of having been pushed out by foreign talent.

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The shortfall in Ph.D. production predicted for the early 2000s (Atkinson, 1990; Bowen & Sosa, 1989; National Science Foundation (NSF), 1989) has not materialized. Instead, in many fields, new doctorates are experiencing difficulty in obtaining permanent positions in higher education that would enable them to pursue careers as independent investigators and the number of entry-level academic positions that have become "temporary" or based on soft-money have proliferated. These include appointments as lecturers, instructors, clinical faculty, research scientists, or technical staff that are typically funded by external grants received (Duderstadt, 2001). Moreover, in some fields, there has been a significant increase in the number of individuals holding one or more postdoctoral appointments over time. Tension in the academic labor market has come both from financial challenges that depress demand as well as an increase in supply brought about by the significant expansion in the number of doctoral degrees awarded over time (National Science Board (NSB), 2002).

Not surprisingly, as the signs of distress in the market for new Ph.D.s have magnified, especially in the biosciences (Marincola & Solomon, 1998; National Research Council (NRC), 2000), proposals have been made to restructure the academic research enterprise, making it less dependent, for example, on postdocs and graduate students (Freeman, Weinstein, Marincola, Rosenblum & Solomon, 2001; Gerbi, Garrison & Perkins, 2001; NRC, 2000). Some scientists and policy-makers have even called for "population control" arguing “it's time to apply the brakes to production of new Ph.D.s (Holden, 1995).” The implicit target in much of these discussions is foreign talent.

Indeed, especially since 1986, foreign citizens have fueled the growth in doctorate production in S&E in the United States (Henderson, Clarke & Woods, 1998; Levin, Black, Winkler & Stephan, 2003).

Higher education has also not been immune to the accusation that "immigrants are cheap labor and steal American jobs (Anderson, 1996)." For example, the American Mathematical Society reported in 1996 that "immigrants won 40% of the 720 mathematics jobs available last year . . . and helped boost the unemployment rate into double digits among newly minted math Ph.D.s (Phillips, 1996, p. A2)."[1] A recent NRC (1998) study partly attributed the 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," in the United States to the "influx of foreign-citizen Ph.D. candidates (p. 4)." Moreover, not only may immigrants have adverse employment effects on the academic careers of citizens; it is also feared that they discourage native talent from pursuing careers in S&E (North, 1995; Stephan & Levin, 2001).

The current study has two purposes: to document recent trends in the career outcomes of S&E doctorates in the United States and to examine the role that immigrant S&E doctoral recipients have played in the changing outcomes faced by U.S. citizens in academe. This study builds on earlier work by Levin, Black, Winkler, & Stephan (2003) that examined the differential employment patterns of citizens and non-citizens in science and engineering, more broadly defined, and introduced the methodology that we use to measure displacement. This methodology, based on the shift-share technique which is well known in the regional science literature, permits us to account for the relative dynamism of different fields and sectors of employment as well as the changing

composition of the pool of U.S. trained doctoral recipients over time. To our knowledge, we are the first to introduce this technique to the study of displacement. Our goal in the present study is to gauge the extent to which immigrant doctorates in S&E are displacing their citizen counterparts in higher education.[2] Recognizing the changing structure of academic employment, we not only examine displacement from the academic sector, but we also examine displacement within this sector, from all full-time positions as well as from the subset of full-time positions that are permanent--tenure-track.

Data

For the analysis we propose, it would be desirable to have data tracking the doctoral population of all scientists and engineers in the United States regardless of their birth origin or country of education, by field of training and employment over a number of years. But such data do not exist. Instead, we use the best alternative: the biennial Survey of Doctoral Recipients (SDR), a longitudinal survey of doctoral recipients in the United States, for the period 1973-1997. This survey, which is administered by Science Resources Statistics of the National Science Foundation, uses the Survey of Earned Doctorates (SED) for its sampling frame.[3]

From our perspective, a weakness of the sampling frame is that it excludes scientists and engineers working in the United States who received their doctoral training abroad.[4] For example, in the life sciences, numerous postdoctoral positions are filled by foreign doctorates (NRC, 1998). In the physical sciences, foreign doctorates also fill numerous faculty positions. The American Institute of Physics (Ivie, Stowe & Czujko, 2001), reported that thirty-four percent of new faculty hires in Ph.D.-granting physics

departments in 2000 were non-U.S. doctorate recipients. In addition, the SDR excludes scientists with medical degrees who lack U.S.-earned doctorates, a group that has been active in research in the life sciences.[5] Thus we have only a partial view of the displacement issue. We expect that better data would magnify the outcomes with respect to displacement since the incidence of foreign talent would be more completely captured.

We define S&E doctorates as individuals educated in engineering, the mathematical sciences, computer and information sciences, physics and astronomy, chemistry, earth, environmental and marine sciences, agricultural sciences (excluding agricultural economics), medical sciences, and the biological sciences as indicated at the time the doctorate was received. Sectors of employment are defined as ACADEME, NONACADEME, and OTHER. ACADEME refers to individuals who are either employed full–time or hold a postdoctoral training position in a university, four-year college, or medical school. NONACADEME refers to individuals who are employed full-time or hold postdoctoral positions in other sectors of the economy. We focus on full-time appointments since these are typically the most preferred by those under retirement age. OTHER refers to "all else" and includes individuals who are employed part-time time (regardless of employment sector), as well as those who are retired, unemployed, or are students pursuing additional degrees.[6]

The sample is limited to those who meet the following criteria: respondent is located in the U.S. at the time of the survey; respondent earned a U.S. doctorate in S&E and respondent's age is 65 or less. Observations with missing information on employment status, citizenship or birth year are excluded. Sample observations are

weighted to adjust for differential initial probabilities of sample selection and subsequent non-response.[7]

Recent trends in employment outcomes

Table 1 shows that the number of S&E doctorates in all fields combined more than tripled (an increase of 231.4%) over the period 1973-1997. Physics and astronomy grew the least (155.6%), with chemistry a close second (164.5%). The biological sciences grew the most, having more than quadrupled over the period. Figure 1 shows that the academic sector's share of employment for all doctorates combined fell from 58.2% to 40.2% over this period. Offsetting this decline, NONACADEME grew by almost a third, from 37.6% to 49.5%, while the share of "employment" in OTHER, although still small, more than doubled, increasing from 4.3% to 10.4%. Recall that ACADEME and NONACADEME include only full-time positions; all part-time positions are included in OTHER. Moreover, as Figure 2 shows, the academic sector's share fell in every field; the earth, environmental and marine sciences experienced the smallest decline and mathematics and computer sciences the largest.

Employment in academe has not only fallen relative to the other two sectors; within academe, as noted earlier, the type of appointment held by scientists and engineers has changed as well. Here we characterize academic positions two different ways. The first grouping, presented in Table 2, divides the sector ACADEME into the categories: faculty (FAC) and postdocs (PDOC). The faculty category is broad and includes all those holding full-time appointments whether they are tenure-track or funded by soft money. Table 3 provides a second grouping, dividing positions in ACADEME into full-time appointments that are permanent (PERM) and those that are temporary (TEMP) and

hence less desirable. Here "permanent" designates tenure-track positions; "temporary" includes postdocs and all other non-tenure track positions including research scientists. In distinguishing between the types of academic positions held, we restrict the analysis to the period from 1979 to 1997 because of the poor quality of the questions concerning tenure status and academic rank in the 1973 SDR (Levin & Stephan, 1991).[8]

As Table 2 shows, from 1979 to 1997 the percent of postdocs among all S&E doctorates in academe rose from 8.0% to 11.1%, with all fields except chemistry experiencing increases. By 1997, the largest percent of postdoctoral appointments was in the biological sciences (17.9%) and in the life sciences -- the agricultural, medical and biological sciences combined (14.9%).

On the other hand, as Table 3 shows, the percent of temporary positions held by all S&E doctorates fell slightly from 36.1% to 34.7% over the period 1979 to 1997. Since Table 2 showed that the percent of postdocs among all S&E doctorates rose, this means that the number of other temporary or soft-money appointments fell in percentage terms. There are exceptions, however. In the combined life sciences, biological sciences, and earth, environmental and marine sciences, both the percent of postdocs and all temporary positions increased. By 1997, approximately 40% of all S&E doctorates in these three areas held temporary, non tenure-track positions in academe. This finding is even more dramatic if one takes account of the fact that part-time positions in academe are included in OTHER. Thus, in these fields, not only has the employment share in academe fallen over time, as we saw in Table 1, but the shares of faculty and permanent positions have fallen as well.

Of particular interest to this study is how U.S.-citizen S&E doctorates have fared relative to their immigrant counterparts during this period. Using the designations made in the SDR, we define U.S. citizens to be those who are native born or naturalized at the time the doctorate was received; immigrants are permanent and temporary residents and those who indicated they had applied for citizenship at the time the doctorate was received. As Table 4 from (Levin, Black, Winkler & Stephan, 2003) shows, immigrant S&E doctorates grew 221.3%, while U.S.-citizen doctorates grew by only 96.4% over the period 1979-1997. As a result, the immigrant share of doctorates increased from 13.9 to 20.8 percent. It is not surprising, given the report of the American Mathematical Society mentioned earlier, that the immigrant-citizen growth differential was largest in the mathematical and computer sciences.

While employment in academe has fallen for all S&E doctorates, we see in Table 5 that immigrants' share of employment in academe has actually increased, with the largest increase occurring for those trained in the mathematical and computer sciences. For all fields together, immigrants also increased their share of appointments as postdocs and temporary, non-tenure track, employees. While these data suggest that immigrants have fared relatively better than citizens in the academic sector, immigrants have done less well in holding the desirable permanent positions as tenure-track faculty. In the remainder of this paper we take a more systematic look at the relative changes in employment outcomes experienced by citizens and immigrants, especially within academe, and examine evidence regarding displacement.

Methodology

How to measure displacement is not obvious. One possibility is to specify a multi-equation econometric model that attempts to capture the complexity of the labor market for scientists and engineers. Such an exercise, however, is fraught with problems as witnessed by the difficulty that researchers have in successfully forecasting scientific labor markets (Leslie and Oaxaca, 1993; National Research Council, 2000).[9] The approach taken here is to compare the actual changes in employment for U.S.-citizen (immigrant) S&E doctorates in different sectors of the economy with an explicit counterfactual: the changes that would have occurred had their employment in each sector grown at the overall growth rate for all S&E doctorates together, regardless of citizenship.[10] In doing so, we acknowledge that the growth in U.S.-trained S&E doctorates has been fostered both directly and indirectly by a variety of policies, including changes in immigration laws and the widespread availability of funds supporting graduate and postdoctoral study in science. The counterfactual makes explicit the assumption that in the absence of these policies the United States could have implemented a different set of policies that would have elicited an equal amount of growth from citizens alone. Whether this is the "correct" counterfactual is, of course, subject to debate. But many believe that "the United States should be able, if it so chose as a matter of social policy, to meet its needs for scientists from within its own population, especially by harnessing the talents of under-represented minorities and women" (Bouvier & Martin, 1995, p.3).[11]

Applying shift-share

As discussed in Levin, Black, Winkler & Stephan (2003), we adapt a technique originally developed in the regional science literature, known as shift-share. (See, for example, Andrikopoulos, Brox, & Carvalho, 1990; Dunn, 1960; Esteban-Marquillas, 1972; Gordon, Hackett & Mulkey, 1980; Grobar, 1996; Kiel, 1992). Although the "classic" shift-share methodology has been criticized, and several alternative formulations have been suggested to remedy its perceived defects, with careful application it remains a valuable took for exploring changes over time (Loveridge & Selting, 1998). Indeed, shift-share has been applied in a variety of contexts in recent years including the study of disease death rates (Hoppes, 1997), migration (Ishikawa, 1992), occupational sex composition (Smith, 1991), productivity growth (Haynes & Dinc, 1997), and the dispersion of academic research (Geiger & Feller, 1995).

The classic (regional science) application of shift-share decomposes employment growth for industry i in region j, G_{ij}, into three components: (1) a reference group or "overall" growth component (such as employment growth in the United States), $O_{ij;}$ (2) an industrial-mix component, $M_{ij;}$ and (3) a "competitive" component, C_{ij}.

The present study employs a "dynamic" variant of the classic shift-share technique. Details are provided in the Appendix. Here the reference group is U.S.-S&E doctoral recipients; "regions" refer to the employment sectors of S&E doctorates (academe, nonacademe, other); and "industries" refer to the citizenship of S&E doctorates (citizen or immigrant). For each citizenship group in each sector, the following identity must hold:

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

where

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

$M_{ij} = b_{ij}\, (r_{io} - r_{oo})$ -- now termed the "minting" effect

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

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

That is, we compare the *actual* employment growth of a specific "citizenship" group (citizen or immigrant) in a specific "sector" (e.g. academe, nonacademe, other) -- G_{ij} -- with a *predicted* measure of employment growth, as determined by the counterfactual -- O_{ij}. The resulting differential is divided into two components: the minting effect, M_{ij},, and the competitive effect, C_{ij}. The minting effect is the employment change citizens (immigrants) experienced in a particular sector due to the differential in growth rates between its doctoral recipients and all doctoral recipients. By definition, the minting effect must sum to zero for the two citizenship groups. The competitive effect is the difference between the actual change in employment for each citizenship group in each sector and the employment growth that would have occurred had each group grown at its overall growth rate. By analogy, as in the case of international trade, competitive effects across sectors for a particular group (citizen or immigrant) must sum to zero just as trade accounts must balance out. Further, if a sector such as academe were broken into two parts, sub-sector additivity must hold. That is, for each citizenship group, the sum of the competitive effects for each sub-sector within academe must equal the competitive effect for the sector as a whole.

C_{ij} captures the differential rate at which jobs in various sectors of the economy have grown for each citizenship group, after accounting for the overall growth in the number of doctoral recipients and the differential minting effects observed. We define displacement as the difference between the citizen and immigrant competitive effects. Suppose, for example, that we observe that employment growth for citizens in academe is smaller than predicted by the counterfactual. This may occur for two reasons: the citizen share of S&E doctorates may have declined (the minting effect) or citizens may have experienced slower employment growth in academe than in the other sectors (the competitive effect). Consequently, to determine how citizens have fared compared to their immigrant counterparts in academe, we subtract the immigrant competitive effect from the citizen competitive effect (both measured in percentage terms to adjust for relative size differences). If the resulting difference is negative, then, in our terms, immigrants have displaced citizens in academe. While the term "displacement" seemingly has a negative connotation, the shift-share methodology does not imply causality. Indeed, citizens may have been displaced from choice positions in academe because they are more likely than their non-citizen counterparts to opt for and be hired into better employment opportunities elsewhere in the economy than to have been 'forced out."

Measuring displacement

Table 6 illustrates the decomposition for all fields combined over the period 1973-1997. Total employment growth for citizen-S&E doctorates in the sector ACADEME was 72,545, which was 46,196 fewer than would have been expected based on the overall

growth in S&E doctorates, 118,741 (the overall effect). This difference can be decomposed into the minting effect [-16,637] and the competitive effect [-29,559].

The negative minting effect indicates that one reason growth for citizen doctorate-holders in academe was lower than expected was the lower growth rate at which Ph.D.s were being awarded to citizens compared to immigrants during the period. Indeed, slightly more than one third of the employment shortfall for citizen scientists and engineers in ACADEME [-16,637/46,196] is accounted for by the changing composition of the doctoral population. The competitive effect [-29,559] indicates that almost two thirds of the shortfall in citizen employment growth in ACADEME is explained by the slower growth of positions held by citizens in academe relative to the remaining sectors.

For immigrants the story shown in Table 6 is considerably different. Altogether, growth in the academic sector was 8,807 [25,192-16,385] greater for immigrants than would have been predicted based on the overall growth in doctorates. But, because of the exceptionally strong minting effect, we would have predicted immigrant employment growth in ACADEME to be even greater than this (an increase of 14,858). The difference is reflected in a competitive effect of –6,051.

Thus, not only did citizens experience a negative competitive effect during this period but immigrants did as well. A critical point, however, is that the competitive disadvantage for citizen S&E doctorates was not only absolutely larger, but also relatively larger than that faced by immigrants. For citizen S&E doctorates, the competitive disadvantage was 15.0 percent [-29,559/197,299], where the denominator is the total change in citizen S&E doctorates. For immigrants, the competitive disadvantage was but 8.7 percent [-6,051/69,671], where the denominator is the total change in

immigrant S&E doctorates. In other words, after controlling for overall growth and minting effects, both immigrant and citizen shares' of employment in ACADEME fell, but the effect was considerably larger for citizens. Thus, using the terminology introduced earlier, the displacement of citizens from the sector ACADEME for all fields combined was -6.3 percent [-15.0%-(-8.7%)].

Since citizens and immigrants held fewer jobs in academe than expected given the overall growth and minting effects, competitive gains occurred outside of academe for both groups. These are also shown in Table 6. Percentage-wise, the competitive effects in NONACADEME are similar for citizens and immigrants, 6.6% and 6.8%, respectively. But "employment" in OTHER, the "catch-all" for those employed part-time, retired, or not presently employed, is considerably larger for citizens than for immigrants. The competitive "advantage" in this sector for citizens is 8.4%, but only 1.8% for immigrants. Thus citizens have been more likely than their immigrant counterparts to experience part-time work, early retirement, unemployment, or to engage in additional schooling.[12]

Results

Displacement from academe

Table 7 from Levin, Black, Winkler & Stephan (2003) presents the estimates of displacement derived from the decompositions performed for all fields combined and major subfield over the periods 1973-1997 and 1979-1997. With few exceptions, which are all quite small, both citizen and immigrant S&E doctorates lost employment share in academe relative to the other sectors as evidenced by the negative competitive effects in

this sector. For each field, and without exception, the competitive effects are relatively greater in absolute value for citizens than immigrants, resulting in what we have defined as displacement. The largest effects have been felt by citizen doctorate-holders in mathematics and computer sciences and in the biological sciences.

Comparing the two time periods, we see evidence of increased displacement in academe for U.S.-citizens in all fields except the earth, environmental and marine sciences and physics and astronomy. While our intermediate results, which are not presented here, show that the competitive disadvantage in ACADEME (relative to NONACADEME and OTHER) incurred by citizens and immigrants lessened in almost all fields over time,[13] the measured displacement of citizens increased --became more negative-- because the competitive position of citizens did not improve as much as the competitive position of immigrants.

Displacement within academe

Table 8 probes deeper into what has happened to employment in academe. The left-hand panel distinguishes between full-time positions (FAC) and postdoctoral appointments, where FAC includes tenure-track and non-tenure track positions. The right-hand panel distinguishes between permanent (PERM) and temporary positions. The difference between the two designations is that non-tenure track positions are classified with tenure-track faculty in the left panel and with postdocs in the right panel. The time period analyzed is 1979-1997, given the problems noted earlier regarding the tenure status and academic rank variables in the 1973 SDR. Table 9 is also included to summarize the information on displacement drawn from Tables 7 and 8. As can be seen in Table 9, the findings regarding displacement from the sub-sectors of academe reported

in Table 8 (for instance, FAC plus POSTDOC) sum to the findings regarding displacement from academe as a whole, reported in Table 7. This is because of the property of sub-sector additivity in shift-share noted earlier.

Table 8 shows that with respect to the number of full-time faculty positions held by S&E doctorates (FAC), citizens and immigrants have lost employment share relative to the remaining sectors (POSTDOC, NONACADEME and OTHER). However, as Table 9 shows, for all fields taken together, there is minimal evidence of displacement from faculty positions, (-1.7%), compared to displacement from academe as a whole, (-7.1%). The difference is due to postdocs. In fact, as Table 9 shows, most of the displacement of citizens from academe can be attributed to their lower likelihood of holding postdoctoral appointments[14] and not their lack of success in holding full-time faculty positions.

The findings, however, vary considerably by field. In engineering, the broad field of physical sciences, mathematics and computer sciences, and physics and astronomy, the majority of the displacement from academe has been from full-time faculty positions, while in chemistry, displacement from academe can largely be attributed to displacement from postdocs. Moreover, once the distinction has been made, citizen S&E doctorates in the life sciences (agricultural, medical, and biological combined), the biological sciences, and especially in the earth, environmental, and marine sciences, have actually fared better than their immigrant counterparts in holding full-time faculty positions. This is evident from the positive displacement figures in Table 9 for the sub-sector FAC that shows that their competitive disadvantage in academe can be attributed entirely to their displacement from postdocs and not from full-time faculty positions.

Displacement from permanent positions, given in Table 8, is even smaller than from all faculty positions (-0.6% compared to -1.7%). Thus, for all scientists and engineers taken together, the relative competitive disadvantage incurred by citizens in academe is almost entirely attributed to their displacement from the so-called temporary positions within academe rather than from postdocs alone. Once again there are differences by field. While engineering, the broad field of physical sciences, and the mathematical and computer sciences follow the overall displacement pattern, in physics and astronomy most of the displacement has been from permanent and not temporary positions.

Citizen S&E doctorates in chemistry, as well as those again in the life sciences (agricultural, medical, and biological combined), the biological sciences, and the earth, environmental, and marine sciences, have actually fared better than their immigrant counterparts in holding permanent faculty positions. Thus, for citizens in these disciplines, all the displacement from academe evident in Table 7 can be attributed to their displacement from the less desirable temporary positions within academe and not from permanent faculty positions.

S*ummary and discussion*

The first goal of this paper was to document recent trends in the career outcomes of U.S.-trained S&E doctorates. Not surprisingly, the data confirm many of the concerns voiced by the higher education and scientific communities. Notably, in each and every field, the share of employment held in academe (four-year colleges, universities, and medical schools) by S&E doctorates fell over the period 1973-1997. Overall, the decline

was dramatic, from 58.2% to 40.2%. Moreover, within academe, the type of appointment held also changed. From 1979-1997, for all S&E doctorates combined, the percent of postdoctoral appointments rose from 8.0% to 11.1% while the percent of temporary or soft money positions (including postdocs) fell slightly from 36.1% to 34.7%. There were, however, significant differences by field.

The second, and primary goal of this paper was to examine what role the heavy inflow of foreign talent into U.S. graduate schools may have played in the changing career outcomes of citizen S&E doctorates. The data show that, overall, immigrants increased their share of employment in academe as well as their share of appointments as postdocs and temporary, non-tenure track employees within academe, suggesting that immigrants have fared relatively better than citizens in holding positions within the declining academic sector. Part of their success, however, is due to their increased employment in the less desirable positions within the academic sector.

We employed an innovative adaptation of the classic shift-share technique to gauge the extent to which immigrants may take jobs from their citizen counterparts in academe. We compared the actual change in employment for a citizenship group in each sector with a counterfactual: the employment change that would have resulted had each citizenship group grown at the overall rate for all S&E doctorates. We then decomposed the employment "shortfall" or "surplus" for each group in each sector into a minting and competitive effect. The minting effect captures the change that occurred because each citizenship group "minted" doctorates at a different rate than that for all S&E doctorates together. The competitive effect captures whether a citizenship group experienced slower or faster employment growth in a particular sector compared to the alternatives, after

accounting for the overall and minting effects. We then measured displacement from a sector by subtracting the immigrant competitive effect from the citizen competitive effect (both measured in percentage terms to adjust for relative size differences). Displacement, by our definition, has occurred if the resulting difference is negative, that is, if citizens held fewer jobs than their immigrant counterparts in that sector.

The shift-share decompositions performed highlight the fact that citizen S&E doctorates have fewer jobs in the academic sector than expected both because immigrants have displaced citizens and because the citizen doctoral population has experienced slower growth than the immigrant doctoral population. Indeed, about one-third of the shortfall in positions held by citizen doctorates in academe over the period 1973-1997 can be attributed to this differential minting effect. This suggests that if policies designed to increase the number of citizens obtaining S&E doctorates were put in place, a sizeable portion of the differential would be remedied. Examples of such policies are increased emphasis on S&E in K-12 school curricula and scholarships targeted at students choosing S&E majors in college. The fact that a large number of students leave S&E majors during the first two years of college (NSB, 2002) also suggests that universities increase their efforts towards retaining these potential scientists and engineers (Tobias, 1990; Romer, 2000). Special efforts could also be directed to increasing the numbers of minorities and, in some fields where they are underrepresented, women, in S&E studies. Higher salaries would also draw more people into S&E as well as increase retention of those trained in S&E (Preston, 2004).

The minting effect is not the entire story, however. The analysis indicates that a significant number of citizen doctorate-holders in S&E have been displaced by

immigrants who received their doctoral training in the United States. This is not because immigrants escaped the competitive effects that led to shortfalls in employment in academe during this period. In fact, as we have seen, both citizens and immigrants experienced employment shortfalls in this sector. But citizens fared relatively worse than their immigrant counterparts and, by our definition have been displaced. Displacement was largest for those in the mathematical and computer sciences.

We find, however, that most of the displacement of citizens from academe cannot be attributed to their lack of success in holding faculty positions or permanent, tenure-track, positions. Rather, displacement can largely be attributed to the fact that citizens appear to have fared relatively worse than their immigrant counterparts in holding postdoctoral appointments and, more generally, temporary positions. Indeed, overall, citizen S&E doctorates are more likely to be in the choice positions within academe than are immigrants. This finding would in all likelihood be even stronger if we were to have data on the large number of foreign-educated doctorates who come to the United States for postdoctoral training.

The results vary somewhat by field. For example, most of the displacement incurred by citizens trained in physics and astronomy can be attributed to their lack of success in holding the choice positions within academe. This finding would be even stronger if foreign-born Ph.D.s were included in the analysis, given the recent hiring patterns in physics noted earlier. Displacement from the choice positions within academe, however, has not occurred in the fields where the signs of distress have been most prominent -- the combined life sciences, the biological sciences, and the mathematical and computer sciences.

Our analysis cannot reveal whether displaced citizens were, on balance, pushed out by the heavy inflow of foreign talent or pulled out by the lure of better opportunities elsewhere in the economy. That is, we do not know whether the displacement that we have identified is involuntary or voluntary. The finding that citizen-S&E doctorates in the mathematical and computer sciences incurred the greatest displacement from academe is, however, suggestive of pull, given the high salaries that industry pays in these fields (NSB, 2000, p. 3-19). Notably, the information technology sector expanded rapidly during the period examined in this study.

The implications for higher education are several. First, policies must be advanced to offset the negative minting effect. At the national level, some relief is in sight with the recent House approval of a bill to increase undergraduate science and math education.[15] At the institutional level, careful attention must be paid to the language skills of teaching assistants and faculty for whom English is a second language if the minting effect is not to be reinforced. In addition, institutions must continue to develop policies and practices that encourage women and underrepresented minorities to pursue careers in science and engineering and policies and practices aimed at retaining those who initially choose S&E majors.

Policies can also be directed towards ameliorating some of the displacement effects that we observe for citizen S&E doctorates. These include, but are not limited to, salary initiatives and structural reforms that enhance the attractiveness of careers in academe. There are those who would add changes in immigration law to this list. We would remind them that displacement is but one piece of the equation. As two of the current authors have shown elsewhere (Levin and Stephan, 1999; Stephan and Levin,

2001), the foreign born have also contributed disproportionately to science and engineering in the United States. Thus, any recommendation concerning changes in immigration law should pay careful attention to the costs that such a change could impose on the United States and its competitive position in the global economy.

Appendix

As discussed in the text and in Levin, Black, Winkler & Stephan (2003), this study employs a dynamic variant of the classic version of the shift-share. Here we discuss this version of shift-share in the context of the broader shift-share literature. For an excellent review, see Loveridge and Selting (1988).

Over the years, researchers have offered several critiques and modifications of the classic shift-share technique. For example, Esteban-Marquillas (1972), among others, has pointed to the lack of independence between the industry-mix and competitive effects. This has led to the development of various homothetic models of shift-share. There is not consensus, however, that using homothetic employment rather than actual employment in computing the competitive effect is actually beneficial. Keil (1992), for example, points to the "great danger" (p. 482) of using this approach when the regional industrial structure gravely differs for the national industrial structure. And, Loveridge and Selting find that the homothetic models "clearly do not solve the very problem they purport to eliminate (p. 54.)" In our preliminary work, we found that the classical competitive effect and the homothetic competitive effect were very similar and thus opted for the simpler classical technique.

In another vein, Richardson (1978), observed that classic shift-share focuses on employment change between two points in time, but ignores events between these time points. This is particularly problematic if a long time horizon is considered and/or there is a substantial change in employment, particularly in the industrial mix of employment. As a solution, Barff and Knight (1988) advocated "dynamic" shift-share analysis, in which the decomposition is done on an annual basis and then the annual figures for each

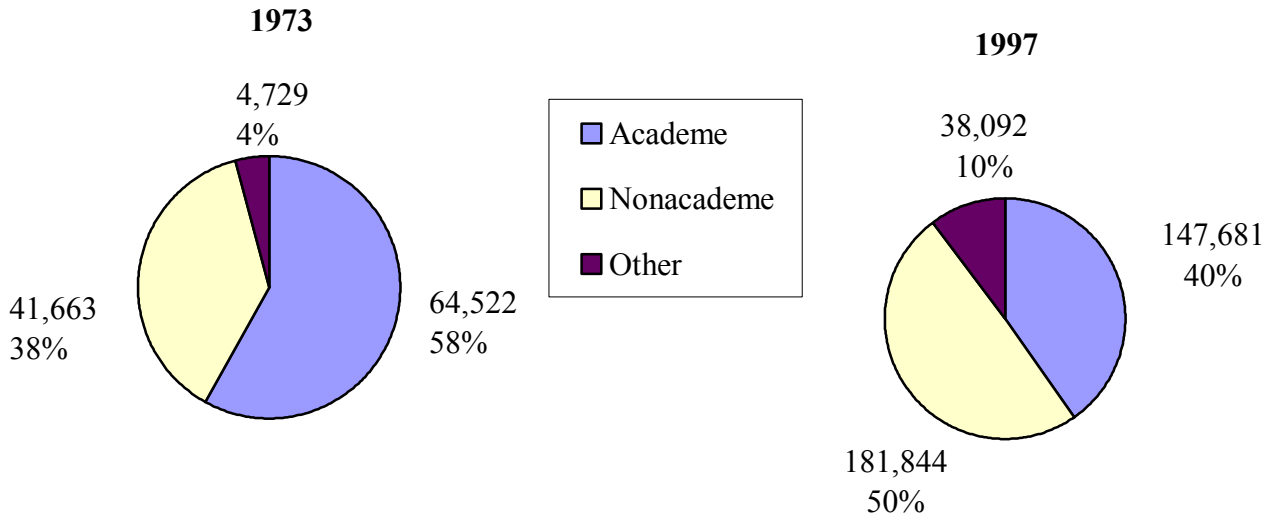
of the three shift-share components are summed. In the present study, we use a simpler dynamic variant in which the decomposition is done for each six-year interval and these interval changes are then summed.

Several other concerns about classic shift-share have also been voiced. Among these is the concern that the shift-share results may be sensitive to the degree of industrial disaggregation. In our work, since there are just two well-defined industries – citizen and non-citizen S&E doctorates – the appropriate level of disaggregation is not an issue. Furthermore, there has also been some discussion that the results may differ according to the degree of regional disaggregation. While this is generally true, as noted by Dunn (1980), such differences may usefully inform the analysis, rather than detract from it. This we believe is the case here, where we gain an a greater understanding of what has happened in S&E by sub-dividing this "region" into ACADEME, NONACADEME and OTHER, and then by further subdividing ACADEME. .

Finally, a general concern with all shift-share work is that it is lacking theoretical substance. While Loveridge and Selting (1998) point out that there has been only limited success in building a theoretical basis for shift-share using neoclassical microeconomics and location theory, nevertheless they conclude that

> The continuing use of shift-share seems to suggest its theoretical limitations may be outweighed by the information it supplies about regional economies. Given the growth in use of purely empirical models in other areas of economics, this aspect of shift-share is perhaps less of an issue than it appeared to be twenty years ago (p. 40).

FIGURE 1
Science and Engineering Doctorates by Sector of Employment, 1973-1997



SOURCE: SDR

FIGURE 2
Share of Doctorates in Academe by Field, 1973 and 1997

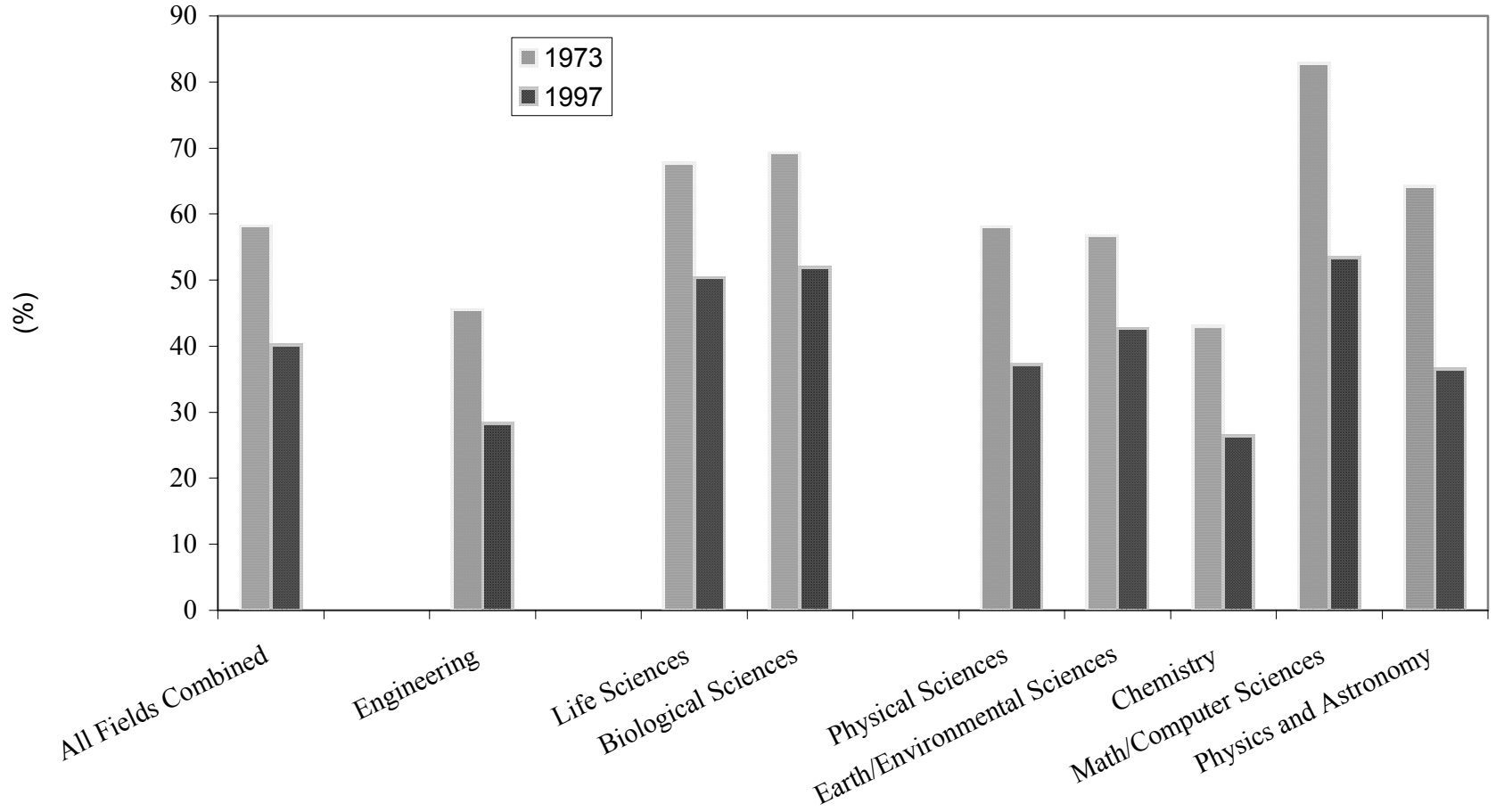


TABLE 1
Science and Engineering Doctorates by Field and Sector of Employment, 1973 and 1997

	1973				1997			
	TOTAL	ACADEME	NONACADEME	OTHER	TOTAL	ACADEME	NONACADEME	OTHER
All Fields Combined	110,914	64,522	41,663	4,729	367,617	147,681	181,844	38,092
Engineering	26,649	12,139	13,876	634	87,585	24,777	56,055	6,753
Life Sciences	36,050	24,397	9,708	1,945	142,330	71,651	53,652	17,027
Biological Sciences	25,951	17,979	6,383	1,589	105,842	54,983	38,370	12,489
Physical Sciences	48,215	27,986	18,079	2,150	137,702	51,253	72,137	14,312
Earth/Environmental Sciences	4,621	2,623	1,848	150	15,916	6,792	7,234	1,890
Chemistry	20,567	8,846	10,703	1,018	54,327	14,362	33,707	6,259
Math/Computer Sciences	9,300	7,705	1,244	351	32,376	17,281	12,083	3,012
Physics and Astronomy	13,727	8,812	4,284	631	35,083	12,819	19,113	3,152

SOURCE: SDR. Totals may not add up due to rounding errors. ACADEME and NONACADEME include only full-time employees.

TABLE 2
Postdoctorate (PDOC) and Other Full-time Faculty (FAC) in Academe by Field, 1979 and 1997

	1979				1997			
	ACADEME	FAC	PDOC	%PDOC	ACADEME	FAC	PDOC	%PDOC
All Fields Combined	88,851	81,702	7,149	8.0%	147,681	131,343	16,337	11.1%
Engineering	15,611	15,304	307	2.0%	24,777	23,221	1,556	6.3%
Life Sciences	37,402	32,951	4,451	11.9%	71,651	60,974	10,677	14.9%
Biological Sciences	28,169	24,272	3,897	13.8%	54,983	45,150	9,833	17.9%
Physical Sciences	35,838	33,447	2,391	6.7%	51,253	47,149	4,104	8.0%
Earth/Environmental Sciences	3,648	3,510	138	3.8%	6,792	6,203	590	8.7%
Chemistry	11,076	9,840	1,236	11.2%	14,362	12,837	1,525	10.6%
Math/Computer Sciences	10,207	10,044	163	1.6%	17,281	16,757	524	3.0%
Physics and Astronomy	10,907	10,053	854	7.8%	12,819	11,352	1,467	11.4%

SOURCE: SDR. Totals may not add up due to rounding errors. ACADEME includes only full-time employees.

TABLE 3
Permanent (PERM) and Temporary (TEMP) Positions in Academe by Field, 1979 and 1997

	1979				1997			
	ACADEME	PERM	TEMP	%TEMP	ACADEME	PERM	TEMP	%TEMP
All Fields Combined	88,851	56,736	32,115	36.1%	147,681	96,492	51,189	34.7%
Engineering	15,611	10,381	5,230	33.5%	24,777	18,398	6,378	25.7%
Life Sciences	37,402	23,323	14,079	37.6%	71,651	42,706	28,945	40.4%
Biological Sciences	28,169	16,935	11,234	39.9%	54,983	31,035	23,948	43.6%
Physical Sciences	35,838	23,032	12,806	35.7%	51,253	35,387	15,866	31.0%
Earth/Environmental Sciences	3,648	2,432	1,216	33.3%	6,792	4,086	2,707	39.8%
Chemistry	11,076	6,868	4,208	38.0%	14,362	9,466	4,896	34.1%
Math/Computer Sciences	10,207	8,385	1,822	17.9%	17,281	14,439	2,842	16.4%
Physics and Astronomy	10,907	5,347	5,560	51.0%	12,819	7,397	5,422	42.3%

SOURCE: SDR. Totals may not add up due to rounding errors. ACADEME includes only full-time employees.

Table 4

Growth in Science and Engineering (S&E) Doctorates by Field and Citizenship Status at the Time the Degree was Earned in the U.S., 1979-1997

	All S&E Doctorates			Citizen Doctorates			Immigrant Doctorates		
	1979	1997	Growth	1979	1997	Growth	1979	1997	Growth
All Fields Combined	172,026	367,617	113.7%	148,173	290,980	96.4%	23,853	76,637	221.3%
Engineering	40,527	87,585	116.1%	31,082	56,426	81.5%	9,445	31,159	229.9%
Life Sciences	59,910	142,330	137.6%	53,791	123,386	129.4%	6,119	18,944	209.6%
Biological Sciences	42,951	105,842	146.4%	39,028	91,882	135.4%	3,923	13,960	255.9%
Physical Sciences	71,589	137,702	92.4%	63,300	111,168	75.6%	8,289	26,534	220.1%
Earth/Environmental Sciences	7,671	15,916	107.5%	6,977	13,896	99.2%	694	2,020	191.1%
Chemistry	29,827	54,327	82.1%	26,189	44,968	71.7%	3,638	9,359	157.3%
Math/Computer Sciences	14,412	32,376	124.6%	12,801	24,305	89.9%	1,611	8,071	401.0%
Physics and Astronomy	19,679	35,083	78.3%	17,333	27,998	61.5%	2,346	7,085	202.0%

SOURCE: SDR. Totals may not add up due to rounding errors.

TABLE 5

Percentage of Positions Held by Immigrant S&E Doctorates in Academe by Field and Type of Appointment, 1979 and 1997

	1979			1997		
	ACADEME	PDOC	TEMP	ACADEME	PDOC	TEMP
All Fields Combined	12.2%	17.9%	14.1%	18.6%	37.6%	23.3%
Engineering	18.2%	52.8%	18.4%	29.9%	52.2%	29.0%
Life Sciences	10.3%	13.0%	13.3%	13.8%	33.2%	12.8%
Biological Sciences	9.1%	10.2%	11.4%	14.2%	31.6%	20.9%
Physical Sciences	11.5%	22.6%	13.3%	19.9%	43.8%	26.1%
Earth/Environmental Sciences	10.2%	6.5%	10.7%	14.8%	40.4%	23.2%
Chemistry	11.4%	26.8%	14.1%	15.6%	49.0%	28.7%
Math/Computer Sciences	10.4%	7.4%	9.6%	25.1%	43.1%	27.8%
Physics and Astronomy	13.2%	22.0%	14.5%	20.3%	39.9%	24.4%

SOURCE: SDR. ACADEME includes only full-time employees.

TABLE 6

Decomposition of the Growth in Sciece and Engineering (S&E) Doctorates, All Fields Combined, 1973-1997

	Citizens by sector			
	ACADEME	NONACADEME	OTHER	ALL
Total change	72,545	98,067	26,687	197,299
Overall effect[a]	118,741	99,348	12,017	230,106
Minting effect[b]	-16,637	-14,207	-1,933	-37,777
Competitive effect[c]	-29,559	12,925	16,633	0
	Immigrants by sector			
	ACADEME	NONACADEME	OTHER	ALL
Total change	25,192	39,893	4,586	69,671
Overall effect[a]	16,385	18,829	1,681	36,895
Minting effect[b]	14,858	16,297	1,620	32,775
Competitive effect[c]	-6,051	4,766	1,284	0

[a]The employment change that citizens (immigrants) in each sector would have experienced had their numbers grown at the same rate as all S&E doctorates together. [b]The employment change due to the differential rate at which citizens and immigrants earned doctorates. [c]The employment change due to the differential rate at which employment in each sector grew relative to the other sectors. Totals may not add up due to rounding errors. ACADEME and NONACADEME include only full-time employees.

TABLE 7
Displacement from ACADEME, 1973-1997 and 1979-1997

	1973-1997			1979-1997		
	Competitive Effects		Displacement[a]	Competitive Effects		Displacement[a]
	Citizens	Immigrants		Citizens	Immigrants	
All Fields Combined	-15.0%	-8.7%	-6.3%	-13.9%	-6.8%	-7.1%
Engineering	-17.2%	-10.4%	-6.8%	-16.3%	-8.8%	-7.5%
Life Sciences	-12.1%	-1.6%	-10.4%	-11.4%	-0.7%	-10.7%
Biological Sciences	-12.3%	0.5%	-12.8%	-12.8%	0.8%	-13.6%
Physical Sciences	-21.3%	-10.6%	-10.7%	-19.6%	-8.2%	-11.4%
Earth/Environmental Sciences	-6.5%	-2.3%	-4.2%	0.0%	1.3%	-1.3%
Chemistry	-17.1%	-9.4%	-7.7%	-16.3%	-5.5%	-10.8%
Math/Computer Sciences	-30.8%	-16.6%	-14.3%	-29.4%	-14.6%	-14.9%
Physics and Astronomy	-31.5%	-22.2%	-9.4%	-31.1%	-22.9%	-8.2%

[a]Calculated as the competitive effect for citizens (%) less the competitive effect for immigrants (%). Totals may not add up due to rounding errors. A negative competitive effect indicates that jobs in this sector for this group fell at the expense of offsetting increases in the remaining sectors, after accounting for the overall growth and minting effects. ACADEME includes only full-time employees.

TABLE 8
Displacement within ACADEME, 1979-1997

	From FAC (all positions except postdocs)			From PERM (tenure-track positions)		
	Competitive Effects		Displacement[a]	Competitive Effects		Displacement[a]
	Citizens	Immigrants		Citizens	Immigrants	
All Fields Combined	-14.3%	-12.5%	-1.7%	-6.6%	-6.0%	-0.6%
Engineering	-14.4%	-8.4%	-6.1%	-6.1%	-5.1%	-1.0%
Life Sciences	-11.1%	-16.4%	5.3%	-7.4%	-9.0%	1.6%
Biological Sciences	-13.1%	-17.1%	4.0%	-8.5%	-9.3%	0.8%
Physical Sciences	-18.8%	-11.2%	-7.5%	-7.8%	-3.8%	-4.0%
Earth/Environmental Sciences	-1.6%	-14.1%	12.6%	-3.6%	-17.7%	14.1%
Chemistry	-13.4%	-10.2%	-3.2%	-5.0%	-8.7%	3.8%
Math/Computer Sciences	-30.1%	-17.5%	-12.6%	-18.7%	-15.5%	-3.2%
Physics and Astronomy	-31.0%	-24.1%	-6.9%	-9.1%	-2.9%	-6.2%

[a]Calculated as the competitive effect for citizens (%) less the competitive effect for immigrants (%). Totals may not add up due to rounding errors. A negative competitive effect indicates that jobs in this sector for this group fell at the expense of offsetting increases in the remaining sectors, after accounting for the overall growth and minting effects. ACADEME includes only full-time employees.

TABLE 9

Summary Results of Displacement from ACADEME, 1979-1997, by Sub-sector[a]

	From broad sector ACADEME (See Table 7)	From full-time faculty (FAC)	From Postdocs (PDOC)	From tenure-track faculty (PERM)	From temporary positions. (TEMP)
All Fields Combined	-7.1%	-1.7%	-5.4%	-0.6%	-6.5%
Engineering	-7.5%	-6.1%	-1.4%	-1.0%	-6.5%
Life Sciences	-10.7%	5.3%	-16.0%	1.6%	-12.3%
Biological Sciences	-13.6%	4.0%	-17.6%	0.8%	-14.4%
Physical Sciences	-11.4%	-7.5%	-3.9%	-4.0%	-7.4%
Earth/Environmental Sciences	-1.3%	12.6%	-13.9%	14.1%	-15.4%
Chemistry	-10.8%	-3.2%	-7.6%	3.8%	-14.6%
Math/Computer Sciences	-14.9%	-12.6%	-2.3%	-3.2%	-11.7%
Physics and Astronomy	-8.2%	-6.9%	-1.3%	-6.2%	-2.0%

[a]Because of the sub-sector additivity property of shift-share, displacement from FAC and PDOC (or from PERM and TEMP) must sum to displacement from ACADEME. ACADEME includes only full-time employees.

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Notes

[1]Although Anderson disputes the validity of this statistic, it has received widespread attention.
[2]The question whether immigrant scientists and engineers discourage U.S. citizens from pursuing doctorates in S&E is not discussed here. Although this pipeline issue is of immense importance, it is beyond the scope of the present study.
[3]The SED is an annual census of new doctorate recipients at U.S. academic institutions.
[4]It also excludes non-citizens who received their doctorates in the United States but expressed no plans to stay in this country.
[5]Almost twenty percent of non-clinical research grants supported by the National Institutes of Health in 1997 were awarded to individuals possessing medical degrees and not doctorates (NRC, 2000).
[6]Prior to 1997, postdocs were not identified as full or part time in the SDR. For this period, they were included in the sectors ACADEME or NONACADEME. For 1997, when more detailed data are available, the few postdocs that reported part-time employment are included in OTHER.
[7]Because several changes were made to the SDR beginning in 1991 in an attempt to increase its response rate, including computer-assisted telephone interviewing of non-respondents, we use the mail-only weight for better comparability with the pre-1991 data for the interval 1985-1991. For the interval 1991-1997, we use the population weight that takes into account the changes in survey methodology.
[8]In addition, if individuals had missing tenure or rank information, we assumed they held "temporary" positions within academe.
[9]Because of the large number of exogenous factors that affect scientific labor markets (such as war, recession, changes in the federal budget, alternations in immigration policy, etc.) it is extremely difficult to specify a robust model of supply and demand. Moreover, key data are often unavailable. For example, the SDR the best source of information about doctoral scientists and engineers does not provide researchers with detailed information on the firms that employ S&E doctorates.
[10]Pollak (1998) stresses the importance of specifying explicit counterfactuals in the conduct of public policy analysis.
[11]North (1995) observes that "while the large-scale presence of foreign-born S/Es, particularly at the Ph.D. level, was neither deliberately created by America's universities and corporations nor thrust upon them against their will (p. 145) . . . their presence and growing numbers are … permitting the status quo to continue without the awkward adjustments that would be needed were they not here" (p. 161).
[12]This finding is somewhat troubling. To some extent it is likely an artifact of the data since citizens may be more likely to opt for part-time work than non-citizens because of the initial work requirements that non-citizens must meet to stay in the U.S. until their visa status is changed. Further examination of the data also suggests that early retirement (before the age of 65) seems to differ most between citizens and immigrants. While in 1973 the percent retired was virtually zero in all fields for both citizens and immigrants, in engineering it jumped to 37% for citizens and 17% for immigrants in 1997; in the life sciences, the comparable figures are 22% and 8%; in the physical sciences, 32% and 9%. Moreover, this difference in early retirement is apparent only for those 55 and above.
[13]Detailed tables of the decompositions by time period, field of training, and sector are available upon request. The conclusion drawn here is also supported by regression analysis (Levin, Black,

Winkler & Stephan, 2003).

[14]This may be due to the fact that citizens may be able to move more quickly than immigrants from the postdoc track into other positions in academe.

[15]Under H.R. 3130 "NSF would provide grants to improve undergraduate science, math and engineering education that are contingent on the grantee increasing the number of graduating majors in those fields by a specific amount (www.house.gov/science/press/107/107-253.htm)."