Foreign Scientists and Engineers and Economic Growth

Giovanni Peri, Kevin Shih, and Chad Sparber

ABSTRACT

Attracting highly educated immigrants—especially scientists and engineers—is a potentially effective economic growth–promoting strategy. This paper evaluates the contribution of foreign-born scientists and engineers to the wage and employment growth of native-born workers. First, we analyze the effects of an increase in the number of foreign H-1B workers across U.S. cities and Federal Skilled Worker Program immigrants across Canadian cities. Second, we compare the effects of attracting scientists and engineers as a growth strategy against alternatives such as pursuing fast-growing industries and expanding tertiary education institutions. We conclude by arguing that the H-1B program can explain a quarter of the wage growth of U.S. college-educated workers from 1990 to 2010, and that the currently proposed enlargement of the program could generate an additional 2 percentage points of wage growth for highly educated natives over the next 20 years.

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1. INTRODUCTION

Skilled workers are highly mobile across international borders. Their high mobility is in part because many countries have adopted immigration policies that favor skilled immigrants.[1] Ostensibly, such policies are intended to attract investors, entrepreneurs, and workers with scarce talents who can capably generate direct economic benefits for the receiving country and its native populace. An immigrant business owner, for example, might hire local labor and decrease the unemployment rate. Similarly, an increase in the science and engineering work force should lead to increased production of knowledge, creativity, and innovation. When localized in one area (such as a city or region), the agglomeration of skilled individuals and the knowledge creation and diffusion that they promote generate productive spillovers to other industries and sectors, increasing economic activity.[2]

This paper estimates the size of the macroeconomic gains for host countries generated by skilled immigrants by evaluating the role of foreign-born scientists and engineers (S&E) in affecting the wage and employment outcomes of native-born workers. By analyzing together the native employment and wage effect of foreign-born S&E, we are able to characterize whether they enhanced productivity (labor demand) growth or, instead, created competition for native workers. We find strong evidence that such immigrants generated large wage benefits for native-born college-educated workers in the United States and Canada. Wage effects for native workers without a college education, as well as employment effects for all native workers, are mostly statistically insignificant. Those long-run results indicate that foreign-born S&E have contributed to productivity growth, particularly of the "skill-biased" type.

[1] See OECD (2010, 2011, 2012).

[2] See Griliches (1992), Ellison and Glaeser (1999), Jones (1995), Moretti (2004a, 2004b), and Iranzo and Peri (2009) for examples.

Section 2 of this paper provides an overview of international trends in skilled-labor mobility, with a particular emphasis on S&E. It begins with a brief discussion and an overview of international skilled-labor mobility. The subsections describe the skilled-migration policies of two countries that attract a very large share of the world's S&E and will be the focus of our analysis: the U.S. H-1B visa program and the Canadian points-based Federal Skilled Worker Program (FSWP).

Section 3 describes a simple framework to interpret our results and discusses the empirical model. Section 4 presents the data and describes and discusses the identification strategy. We exploit cross-city variation to assess the effect of foreign-born S&E on the wages and employment of native-born workers with high and low levels of education. Importantly, such immigrants do not randomly choose their work locations. Thus, much of Section 4 is devoted to outlining our method of identifying the causal effects. We combine historical cross-city variation of skilled-immigrant populations with national-level skilled-worker (H-1B or FSWP) inflows to create exogenous instruments for a city's foreign-born science and engineering work force. We devote significant time to establishing the validity of our instruments and exploring alternatives to verify the robustness of our methodology.

We perform the primary regression analysis for the United States and Canada in Sections 5 and 6, respectively. An increase in foreign-born S&E by 1 percentage point of employment increased the wage growth of native-born college-educated workers by around 5 percentage points in the United States. The analogue estimate for Canada ranges from 2.8 to 5.5 percentage points. No regression uncovers statistically significant detrimental effects on wages paid to non-college-educated natives or on the employment levels of native workers. The results, interpreted within the framework of our simple labor demand-and-supply model at the local level, imply that foreign S&E have increased the labor demand and productivity of highly educated native-born workers, leaving unchanged the wage and employment of less educated native workers. The skill-biased growth brought by foreign S&E more than offsets the direct competition–complementarity effect from their presence in the labor market.

One interesting difference between the U.S. and Canadian experience does emerge. For the United States, science and engineering immigrants benefit only highly educated natives, suggesting that such immigrants facilitate skill-biased technological change. For Canada, natives who have dropped out of high school also appear to reap some benefits from skilled immigration (especially in the form of faster employment growth), suggesting that such immigrants might have contributed to the polarization of the labor market (i.e., growth at the high and low ends of the education spectrum at the expenses of intermediate-level jobs), as described by Autor, Katz, and Kearney (2006) and Autor (2010).

Section 7 focuses on the U.S. experience and assesses whether the beneficial effects of immigration remain after controlling for other potential growth-promoting factors, such as efforts to attract high-growth industries. Not only do the immigration results remain, but they also reveal wage-enhancing effects larger in magnitude than those from other skill-promoting policies. Moreover, we find that the strongest positive productivity effects of H-1B-driven scientists and engineers are in metropolitan areas with a large share of fast-growing industries. The section closes by highlighting an important aspect of our analysis: since our identification strategy is driven by changes in the available number of H-1B visas, our regression strategy also serves as an evaluation of the H-1B program. Therefore, we combine our regression results with observed visa data to estimate that H-1B-driven science and engineering labor flows increased the wage growth of native-born college-educated workers by 3.5 percentage points between 1990 and 2010, about a quarter of the observed wage growth over that period. Current proposals to raise annual H-1B issuances by 50,000 per annum would translate to an additional 1.8 percentage points in wage growth rates of native college-educated workers over the next 20 years.

2. INTERNATIONAL COMPETITION FOR S&E

Competition to attract skilled immigrants has intensified in recent years, and it may grow even more in the near future. Australia, Canada, and New Zealand have long used points-based systems (PBSs) where work permits and immigration visas are awarded to applicants who accrue enough points to exceed a predetermined point threshold. Having high educational attainment, being young, speaking the local language, and offering other broadly defined skills confer an advantage to potential immigrants by endowing additional points to applicants with such characteristics. Since 2008, PBSs have also been used in Austria, Denmark,[3] Japan, the Netherlands, South Korea, and the United Kingdom. Countries without PBS policies but with selective immigration criteria favoring high-skilled immigration include Germany, Lithuania, Malaysia, Norway, Singapore, Switzerland, Taiwan, and the United States (through the H-1B program). Importantly, Asia has traditionally been a major supplier of skilled migrants to countries that are members of the Organization for Economic Cooperation and Development (OECD), and Asia continues to educate large numbers of people. However, Asia's gross domestic product is rising, Asian countries are taking steps to adopt skill-biased immigration policies, and fertility rates in Asia are falling. Those developments may intensify the international competition for skilled workers.

Although the stated goals of skilled-immigration policy consist in attracting particular attributes (e.g., entrepreneurship, investment, scientific capability), countries' immigration policies have used a broad definition of skills that is strongly linked to educational attainment, as opposed to a narrow definition more closely linked with occupations. The U.S. H-1B program requires immigrants to be employed in a job from a list of approved occupations, but that list is wide-ranging. Both Australia and Canada recently dropped occupation-specific point criteria in their PBS programs in favor of points awarded for more general skill sets.

Despite the absence of occupational targets, however, large numbers of migrants work in science and engineering positions because of the inherent nature of such work. Hunt and Gauthier-Loiselle (2010), for example, note that foreign-born workers are likely to be overrepresented in science and engineering occupations because the required knowledge does not rely on institutional or cultural knowledge, nor does it demand the sophisticated language fluency necessary in fields like law. Thus, science and engineering knowledge and skills transfer easily across countries. Similarly, Peri and Sparber (2011) argue that skilled immigrants have a comparative advantage in math and science, whereas natives have a comparative advantage in communication skills.

Reliable cross-country data on S&E and highly educated labor mobility are somewhat limited. Two new data sets provide some

[3] Denmark has since discontinued its PBS.

numerical insight. First, the OECD (2012) and its Database on Immigrants in OECD Countries report that the overall emigration rate for non-OECD countries in Asia is 3.8 percent for the highly educated, but just 0.3 percent for medium- and low-education workers. Second, Franzoni, Scellato, and Stephan (2012) have developed a new "GlobSci" survey data set that records the characteristics of scientists employed in four fields (biology, chemistry, earth and environmental science, and materials) within 16 countries that account for 70 percent of academic articles published in those fields.[4] The source country with the greatest mobility is India; nearly 40 percent of Indian scientists work abroad. Though India is an outlier, emigration rates are high in other countries as well: more than 20 percent of Belgian, British, Canadian, Dutch, German, and Swiss scientists are currently working outside their home countries. For 13 of the countries covered, over half of their native-born scientists have some international work experience, with Italy (40 percent), Japan (39.5 percent), and the United States (19.2 percent) being the three exceptions.

In some ways, highly educated foreign labor is concentrated in just a few countries. In 2005–2006, for example, roughly 60 percent of highly educated Asian migrants in OECD countries lived in the United States, with another 30 percent living in Australia, Canada, and the United Kingdom.[5] The United States accounts for 45 percent of the OECD's highly educated immigrant stock from all regions, followed by Canada (11 percent), the United Kingdom (9 percent), and Germany (6 percent).[6] In proportional terms, other countries are far more reliant on foreign-born labor. In Switzerland, 56.7 percent of scientists are foreign-born, with about a third of those workers coming from Germany. Immigrants make up roughly 45 percent of scientists in Australia and Canada, and about 38 percent in the United States and Sweden.[7]

How much those concentrations of foreign S&E contribute to the productivity of the receiving country is the open question we seek to

[4] China is the most significant destination country omitted from the survey.

[5] Inferred from Table III.1 of OECD (2012).

[6] Data from Database on Immigrants in OECD Countries.

[7] Also see National Science Board (2012); Kerr and Lincoln (2010); Hunter, Oswald, and Charlton (2009); and Auriol (2007, 2010).

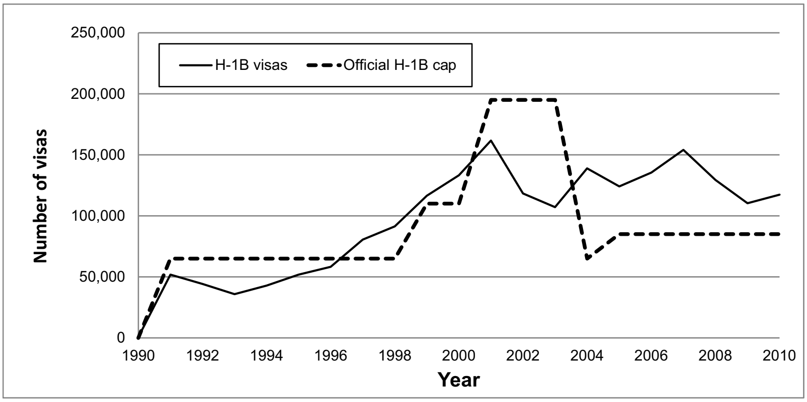
address. Past research on the United States tends to provide evidence of productivity gains from skilled immigration. Kerr and Lincoln (2010) find that H-1B workers increase Indian and Chinese invention in the United States without crowding out natives from the innovation process. Hunt and Gauthier-Loiselle (2010, p. 33) argue that immigrants account for 24 percent of U.S. patents—twice their share of the population—and that the immigrant patenting advantage over natives is accounted for by immigrants' disproportionate tendency to hold degrees in science and engineering fields. Similarly, Hunt (2011, p. 421) finds that immigrants are more entrepreneurial and innovative than natives and that much of that advantage is explained by immigrants' higher education and field of study. Thus, U.S. firms, universities, and teaching hospitals identify innovative immigrants mainly on the basis of their educational qualities rather than on superior innate creative or inventive abilities at a given educational level. Immigrants do, however, exhibit higher publication rates than natives even after controlling for education. Recent work by Scellato, Franzoni, and Stephan (2012, p. 2) complements that result by finding that (a) foreign-born scientists maintain research links with colleagues from their home country and (b) internationally mobile researchers contribute significantly to extending the international scope and quality of the research network in destination countries at no detriment to the quality of the research performed.

2.1 The U.S. H-1B Visa Program

The Immigration Act of 1990 created the H-1B visa for college-educated foreign-born temporary workers in the United States. The H-1B visa is the most common route of entry for temporary skilled workers. U.S. State Department statistics, for example, reveal that 117,409 new H-1B visas were issued in 2010—a figure that is 57 percent larger than the next most important temporary worker program, the L-1 visa for intracompany transferees.

Figure 1 illustrates the evolution of the actual number of H-1B flows and the legal cap on those flows for each year since the program's inception. Congress initially limited the number of new H-1B visas to 65,000 per year. The cap was not reached until 1997 and 1998. In October 1998, Congress raised the cap to 115,000 for 1999 and 2000, but those limits were also reached (or exceeded). Thus, Congress took two actions in October 2000. First, it exempted employees of

Figure 1
Evolution of the H-1B Visa



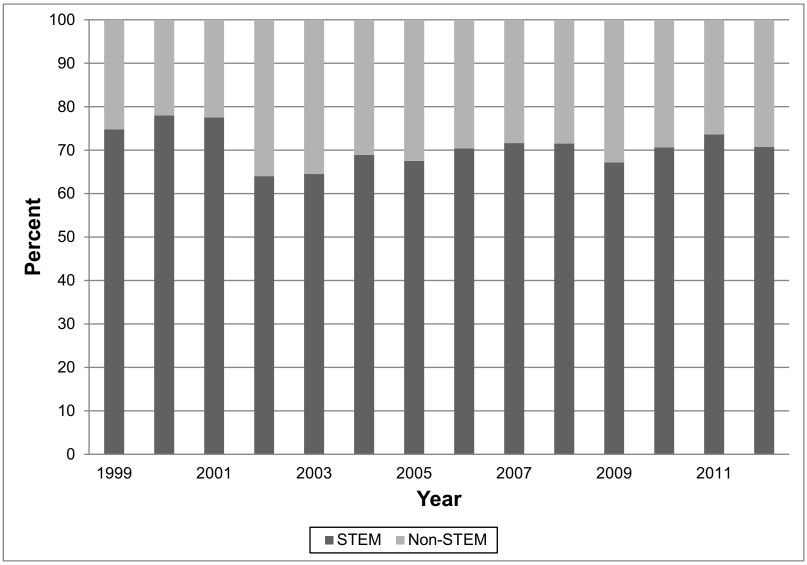
Source: Data on H-1B visas issued available from Department of State, http://www.travel.state.gov/xls/FYs97-12_NIVDetailTable.xls.

universities, nonprofit research organizations, and government research organizations from the H-1B limit. Second, it raised the annual cap to 195,000 for 2001, 2002, and 2003. In 2004, the cap reverted back to the original 65,000, but the exemptions remained. In 2005, Congress began exempting 20,000 visas for workers who have obtained a master's degree or higher in the United States, effectively raising the cap to 85,000. Nonetheless, the H-1B cap has been binding every year since 2004.

The H-1B visa is not limited to S&E, and publicly available data on formal links between H-1B issuances and S&E work are limited at the individual level.[8] However, the U.S. Citizenship and Immigration Services annual reports (1998–2011) on the "Characteristics of H-1B Specialty Occupation Workers" provide aggregate statistics on H-1B petitions granted by occupational category. Figure 2 displays the share of H-1B visas awarded to science, technology, engineering, and mathematics (STEM) workers, who clearly dominate the program. The figure shows that STEM occupations (categorized as

[8] This point is also noted in Kerr and Lincoln (2010).

Figure 2
STEM Workers as a Percentage of H-1B Visa Recipients



Source: Data from U.S. Citizen and Immigration Services reports from 1999–2012 entitled "Characteristics of H-1B Specialty Occupation Workers."
Note: STEM = science, technology, engineering, and mathematics.

computer-related, engineering and architecture, medical and health sciences, life sciences, and math and physical sciences) accounted for about 70 percent of the H-1B visas issued. Computer-related occupations accounted for 47 percent of STEM H-1B visas, while engineers represented almost 12 percent.

Whereas data from the U.S. Department of Homeland Security provide key information on H-1B visa issuances, the U.S. Labor Department's Office of Foreign Labor Certification provides an alternative data set on Labor Condition Applications (LCAs) that provides insights into the nature of temporary H-1B work demanded by U.S. employers. Firms wishing to employ H-1B workers must first submit an LCA describing the available occupation, the prevailing wage, and the wage offer to the foreign worker. The Labor Department can then approve or deny the request. LCAs, therefore, contain a wealth of information on the types of workers that firms wish to hire.[9]

Data from fiscal year 2011 show that 91 percent of LCAs were filed for science and engineering positions.[10] Among S&E, computer systems analyst (76.5 percent) is the most commonly sought position, followed by computer programmer (10.7 percent). No other occupation exceeds 5 percent of the LCA pool for S&E. Among non-S&E filings, the most common occupations are accountants and auditors (9.7 percent), management analysts (8.2 percent), financial analysts (6.8 percent), and farm labor contractors (6.2 percent).[11] Statistics from the Department of Homeland Security's *Report on Specialty Occupation (H-1B) Workers* (2011) compare with some of those figures. Some 73.6 percent of approved petitions are in STEM occupations, including 50.8 percent for computer-related occupations, 2.4 percent for life sciences, 2.2 percent for math and physical sciences, 7.0 percent for medicine and health, and 11.3 percent for architecture, engineering, and surveying. Overall, those aggregate statistics suggest that it is reasonable to view the H-1B program as being responsible for bringing the bulk of foreign scientists and engineers into the United States between 1990 and 2010.

2.2 The Canadian Points-Based Federal Skilled Worker Program

Canada has been using PBS since 1967, with significant legislative changes occurring with the Immigration Act of 1976 and the Immigration and Refugee Protection Act (IRPA) of 2002. Unlike the U.S. H-1B visa, Canada's FSWP offers foreign-born skilled laborers permanent residency. Like the U.S. H-1B visa, Canada's skilled-immigration

[9] Page 5 of the Department of Labor's 2011 "Annual Report" notes, "Certification of a position, however, is not a guarantee of a foreign worker's admission, since many visa categories . . . have numerical limitations or caps set by legislation, and each individual must meet admission standards and requirements of [the Department of Homeland Security] and [the Department of State]." See Kerr and Lincoln (2010, 485) for further comment.

[10] In the LCA data, the science and engineering class includes science managers and instructors, but not medical doctors or health practitioners.

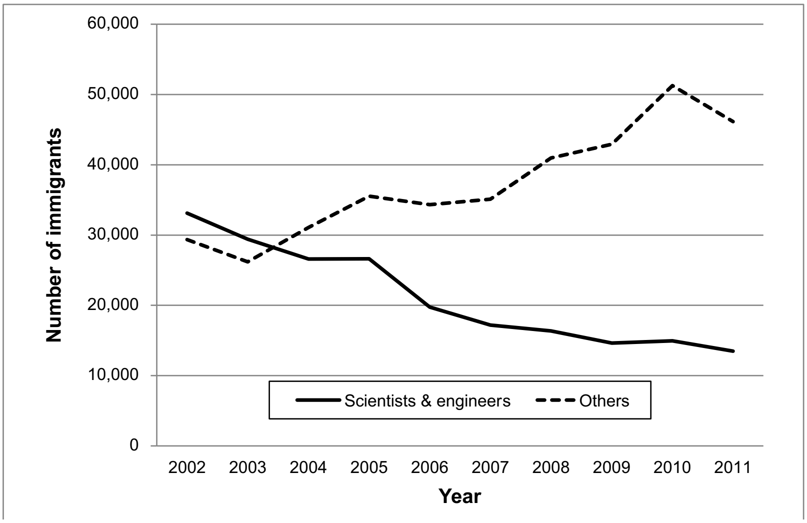
[11] For comparison, Lofstrom and Hayes (2011) used the Freedom of Information Act to obtain data on actual H-1B recipients (in 2009) through I-129 forms. They find a more modest 74 percent of H-1B workers to be employed in science, technology, engineering, and math professions, with only 57 percent of those individuals working in information technology jobs.

policy has become both more and less restrictive at different points over the past decade and a half. For example, the minimum score required for permanent residency was reduced in September 2003, whereas recent years have seen somewhat subtle but perhaps significant restrictions on skilled immigration, ostensibly to attract a foreign-born work force capable of adjusting to Canadian life. Though there has never been a limit on the number of permanent resident visas awarded to qualified skilled immigrants with Canadian job offers, a cap of 20,000 was introduced in 2010 for skilled immigrants without job offers. That cap declined to 10,000 in 2011 and is currently at just 5,000 for the next year. Moreover, Canada suspended applications for immigrants without job offers from July 1, 2012, through May 4, 2013.

Perhaps most important, pre-IRPA criteria favored specific occupations by giving more points to some over others. IRPA, however, abandoned the occupation-specific points scheme and focused on rewarding broader measures of human capital, such as educational attainment, to improve labor-market flexibility among Canada's foreign-born work force. Citizenship and Immigration Canada's (2010) evaluation of those program changes found that IRPA diversified the skilled-immigrant pool. Proportionally fewer immigrants now come from Asia, and the share of skilled immigrants working in the natural and applied sciences fell. Figure 3 illustrates trends since 2002 and demonstrates that it is not just the science and engineering share of foreign-born permanent Canadian residents that has fallen, but the overall number of immigrant S&E as well.

International comparisons of science and engineering reliance are difficult, in part, because different countries use different occupational coding schemes. The OECD, for example, provides information from 2000–2001 and 2005–2006 about Canadian residents working as professionals, technicians, and other assorted professions (excluding managers), whereas it records the number of computer and mathematical scientists; architects and engineers; and life, physical, and social science occupations for the United States. If we define S&E to be PhD recipients in those occupational groups, then the OECD data in 2000–2001 indicate that 52 percent of Canadian S&E were foreign-born, compared with 38 percent for the United States. In 2005–2006, the foreign-born share decreased to 51 percent for Canada and rose to 43 percent for the United States. Those numbers are slightly higher

Figure 3
Permanent Foreign-Born Residents in Canada



Source: Citizenship and Immigration Canada, 2011 facts and figures.

than the foreign-born share of scientists recognized in Franzoni, Scellato, and Stephan's (2012) GlobSci data set (46.9 percent for Canada, 38.4 percent for the United States).

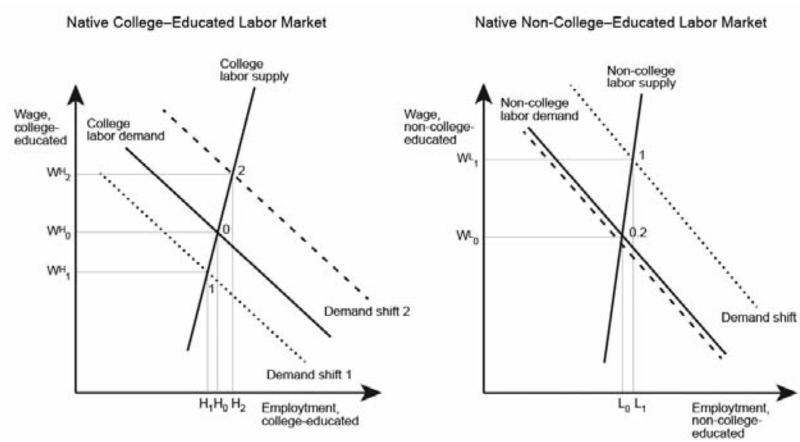
As discussed earlier, many countries have implemented different policies with the goal of attracting highly skilled foreign workers. The United States and Canada have received the largest number of high-skilled immigrant workers by far and thus provide unique settings to study the effect of foreign workers on the receiving economy. In particular, the United States and Canada have targeted high-skilled workers through quite different types of policies. Furthermore, the structure and design of their immigration policies have varied over recent decades. Despite the differences in policies, both countries have seen foreign S&E continually dominate the inflow of foreign high-skilled workers. What has been the effect of inflows of S&E, and does the United States' experience differ from Canada's? We turn to those questions in the next sections.

3. FRAMEWORK FOR THE EMPIRICAL ANALYSIS

The goal of the empirical analysis in this paper is to establish the long-run effects of foreign S&E on the wages and employment of natives. We consider local labor markets for college-educated and non-college-educated workers, and we estimate the effects on the employment and wages of both sets of native workers while using the variation of foreign S&E across metropolitan areas. Using those estimates, we can characterize the effect of foreign S&E on the demand for each native group. Foreign S&E may affect the demand for each group of natives through substitution, complementarity, and productivity effects. We illustrate a simple labor demand-and-supply model for more educated and less educated native workers at the local level to interpret the empirical findings. The model can be fully formalized, and it is similar to the ones presented in Docquier, Odin, and Peri (forthcoming) and Peri (2011).

Consider Figure 4 as representing the demand and supply of native college-educated workers (left panel) and non-college-educated workers (right panel) in one small, open economy, such as a U.S. metropolitan area. An exogenous inflow of foreign S&E into the economy corresponds to a potential shift in the demand for each group (such as those illustrated by the dashed and dotted lines). The demand shift for a native group will be to the left if foreign S&E

Figure 4
Potential Demand Shocks in Labor Market



substitute for native workers of that group. It will be to the right if they complement that type of native workers. Moreover, the productivity of each group can be increased or decreased by the research activity of S&E. They, in fact, contribute to generating innovations and developing technologies that may, in turn, complement or substitute for the abilities of specific workers. Productivity effects, therefore, will also contribute to positive or negative demand shifts. The relative response of native employment and native wages to those shifts will be regulated by the elasticity of the local supply of each type of workers. Lower mobility of workers (or a larger response of local prices) would imply larger wage and smaller employment adjustment (rigid supply). Higher mobility and lack of adjustment of local prices would imply, instead, larger employment and smaller wage adjustment for a given shift in demand (elastic supply). Admittedly, the supply elasticity of a group in our simple model combines moves in and out of employment, the local economy, and education groups (in the long run). Our employment effects do not distinguish across those margins.

To fix ideas, we illustrate two possible effects of a change in foreign S&E on the labor demand for natives, as shown in Figure 4, by the shifts labeled "Demand shift 1" (dotted line) and "Demand shift 2" (dashed line). The first shift produces a negative wage effect for college-educated workers and a positive one for non-college-educated workers. Employment moves in the same direction as wages for each group, but not as far (as the labor supplies are drawn as rather inelastic). Such would be the effect of foreign S&E were they substitutes (competitors) for native college-educated workers, as well as complements for native non-college-educated workers, while having no productivity effect.

A very different shift, however, is shown with the dashed lines marked "Demand shift 2." In that case, the wage of college-educated native workers increases, while the wage and employment of less educated natives remain the same. Such a shift would imply a positive and college-biased productivity effect of S&E that offsets the substitution effect and increases the demand for college-educated natives. It also reveals that the skill bias of productivity is strong enough to offset the positive complementarity with the less educated, and their wages and employment are not affected by the shock.

Estimating the response of employment and wages of natives to an increase in foreign S&E provides an assessment of the demand shock that each group experienced. It also allows us to evaluate the elasticity of the supply of that group. For instance, a positive wage effect on a group accompanied by a null employment effect implies a positive demand shift for that group and a rather rigid labor supply.[12] With this framework in mind, we describe our empirical specifications, and we later interpret the findings.

3.1 Empirical Specification

Empirically, we analyze the effect of foreign S&E on wages and employment using variation across 219 U.S. metropolitan areas (and later on 17 Canadian areas) over time. For the United States, we use the uneven distribution of H-1B visa holders across nationalities and the pre-policy distribution of foreign S&E by nationality across metro areas to construct a policy-driven increase in S&E. This variable is unaffected by the local productivity shocks and is heterogeneous across metropolitan areas. We then measure the effect of this policy variable on actual foreign S&E, and then on the wage and employment growth of natives across U.S. metropolitan areas.

The basic specifications that we will estimate in Section 5 take the form of the following equations (1) and (2):

$$(1)\quad \frac{\Delta W_{c,t}^{X,Native}}{W_{c,t}^{X}} = \varphi_t + \varphi_c + b_{y,X} \cdot \frac{\Delta(S\&E)_{c,t}^{Foreign}}{Emp_{c,t}} + \gamma \cdot Controls_{c,t}^{X} + \varepsilon_{c,t}$$

$$(2)\quad \frac{\Delta Emp_{c,t}^{X,Native}}{Emp_{c,t}} = \varphi_t + \varphi_c + b_{y,X} \cdot \frac{\Delta(S\&E)_{c,t}^{Foreign}}{Emp_{c,t}} + \gamma \cdot Controls_{c,t}^{X} + \varepsilon_{c,t}$$

The dependent variables are, alternatively, the percentage native wage change (specification [1]) and the change in native workers, over a decade, relative to total initial employment (specification [2]). Each regression is estimated separately for type X, which can be either college-educated (also defined as highly educated) or non-college-educated (also defined as less educated), in city c. By distinguishing workers of different skills (college-educated and non-college-educated), we identify whether the potential productivity, complementarity, and substitution effects of foreign S&E differ across groups of natives.

[12] Considering specifications such as equations (1) and (2), the ratio of the estimated response of employment and of the estimated response of wages to a change in foreign S&E gives the elasticity of the labor supply for that group.

The term $\frac{\Delta(S\&E)_{c,t}^{Foreign}}{Emp_{c,t}}$ is the main explanatory variable, and it measures the change of foreign S&E, $\Delta(S\&E)_{c,t}^{Foreign}$, expressed as percentage points of $Emp_{c,t}$, the total employment in the metro area at the beginning of the period. The coefficient of interest is $b_{y,X}$. In equation (1), it captures the response of native wages, in percentage points, to an increase of foreign S&E by 1 percentage point of total employment. In equation (2), it captures the response of the group employment, as percentage points of total initial employment.

In estimating equations (1) and (2), we are concerned about the potential for omitted variables bias in generating spurious results. Our decision to first-difference the data helps account for time-invariant features correlated with the level of foreign S&E wages and employment across cities. We then include fixed effects (φ_c, for either states or metropolitan areas) and time period effects (φ_t,) to capture features correlated with growth rates across space and time. Further, we add a set of $Controls_{c,t}^{X}$, representing other metro-area factors potentially affecting local labor demand, such as the 1980 share of native S&E, or the 1980 share of college-educated, or the effect of the industrial composition on wages and employment growth at the metro-area level. $\varepsilon_{c,t}$ is a zero-mean random error.

If foreign S&E were assigned exogenously across U.S. metropolitan areas, after accounting for fixed effects and other controls, the ordinary least squares (OLS) estimates of equations (1) and (2) would capture the causal effect of that group on native labor-market outcomes. However, unobserved changes in productivity realized over time in specific metropolitan areas might still be present and might generate a spurious correlation that would bias the estimates. To address those issues, we construct a policy-driven change in foreign S&E. In particular, we use the changes in H-1B numbers by nationality across decades at the U.S. level (which are hardly affected by individual city demand conditions as, except for the top 5 percent, each metro areas accounts for less than 1 percent of national science and engineering employment)[13] and the pre-1980 distribution of foreign S&E across U.S. metropolitan areas (which are unaffected

[13] The top four cities—New York, Los Angeles, San Francisco, and Washington, D.C.—attracted between 4 and 10 percent of the total national foreign S&E in the 1990s and 2000s. We run a specification in Table 6 omitting them, and the results are unchanged.

by demand shocks in the 1990s and beyond) to construct the policy-driven variable $\frac{\Delta(S\&E)_{c,t}^{H\text{-}1B}}{Emp_{c,t}}$. This variable captures changes in foreign S&E driven by national-level fluctuations in H-1B flows and the existence of stronger or weaker networks of immigrants in metro areas as of 1980. We discuss in detail the identification assumptions implied by this variable and some tests of their plausibility in Section 4.3.

4. DATA ON U.S. METROPOLITAN AREAS AND THE POLICY VARIABLE

Our data on occupations, employment, wages, age, and education of individuals come from the Integrated Public Use Microdata Series (IPUMS) 5 percent census files for 1980, 1990, and 2000. We also use the 1 percent sample for 2005 and the 2008–2010 three-year samples of the American Community Survey to obtain a 3 percent sample that we call "2010." We only use data on 219 metropolitan areas that can be consistently identified over the full 1980–2010 period.[14] Those metropolitan areas include all the largest metropolises in the United States (Los Angeles, New York, Chicago, Dallas–Fort Worth, Philadelphia, and Houston are the six largest) down to metropolitan areas with close to 200,000 people (Danville, Va.; Decatur, Ill.; Sharon, Pa.; Waterbury, Conn.; Muncie, Ind.; and Alexandria, Pa. are the six smallest). Data on aggregate H-1B flows by nationality and year, which we use to construct our policy variable, are publicly available from the U.S. Department of State (2011).

Although the U.S. government recognizes a list of official STEM college degrees for the purpose of permitting foreign students to work under the Optional Practical Training program, there is no official definition of science and engineering occupations. We consider two alternative definition criteria. The first is based on the skills used within an occupation. We use the Occupational Information Network (O*NET) database provided by the U.S. Bureau of Labor Statistics, which provides Standard Occupational Classification measures of the importance of several dozen skills and abilities required to perform the job. We select four skills: (a) mathematics in problem solving, (b) science in problem solving, (c) technology design, and

[14] In a robustness check, we will limit the analysis to using data since 1970 for 116 identifiable metropolitan areas.

(d) programming. We consider the average score for each occupation across the four skills and rank the 333 occupations that are identified consistently in the 1980–2010 censuses according to those average scores. We categorize science and engineering occupations as those in the highest decile of STEM skills used by employees in 2000, and we call individuals in those occupations "O*NET S&E." The list of occupations included in this definition is reported in Table A1, Part A, of the Appendix.[15]

The second definition of S&E that we use is also based on occupations, and it classifies them according to the percentage of workers who have obtained college degrees in science and engineering majors as identified by the American Community Survey of 2010.[16] This second definition identifies science and engineering jobs—listed in Table A1, Part B, of the Appendix—as those occupations in which at least 25 percent of workers have graduated with a science or engineering major. This definition is more stringent than the first and comprises about 5 percent of the labor force.[17]

4.1 Aggregate Statistics on S&E

Even a cursory look at the data shows that foreign-born individuals are overrepresented among S&E.[18] Moreover, foreigners have substantially contributed to the aggregate growth of science and engineering jobs in the United States. Table 1 shows the foreign-born share of five different employment groups for each census year from 1980 to 2010. From left to right, we show the percentage of foreign-born among all workers, among college-educated workers, among college-educated workers in metropolitan areas, among science and engineering (O*NET-based) occupations in metropolitan areas, and among college-educated S&E in metropolitan areas. Although foreign-born individuals represented 16.3 percent of total employment in 2010, they counted for a quarter of college-educated S&E in the metropolitan sample that we analyze. Remarkably, that figure has more than doubled since 1980.

[15] The aggregate summary statistics for this definition are shown in Table 1. They are sometimes restricted to those workers with college degrees only.

[16] The science and engineering majors are listed in Table A1, Part C, of the Appendix.

[17] The correlation between the S&E dummies defined for each occupation across the two definitions is 0.45.

[18] In the summary statistics and in the empirical analysis, we use the O*NET S&E definition, unless we note otherwise.

Table 1
Summary Statistics: Percentage of Foreign-Born Groups, United States

	Foreign-Born % of Employment	Foreign-Born % of College-Educated	Foreign-Born % of College-Educated in 219 Metro Areas	Foreign-Born % of S&E in Metro Areas	Foreign-Born % of College-Educated S&E in Metro Areas
1980	6.1	6.7	8.9	9.8	10.9
1990	8.7	8.9	11.9	13.8	14.8
2000	13.2	12.7	16.3	19.6	21.0
2005	15.3	14.7	18.8	23.0	24.4
2010	16.3	15.4	19.4	24.0	25.5

Note: The figures were obtained by the authors from IPUMS census data. The relevant population includes only noninstitutionalized individuals between ages 18 and 65 who have worked at least one week in the previous year.

Table 2 shows that college-educated S&E increased from 2.8 percent of total employment in 1980 to 4.6 percent in 2010. Even more remarkable, the share of college-educated foreign-born S&E in employment grew from 0.3 percent to 1.2 percent. The 1990s were a period of particularly fast growth in S&E jobs relative to other

Table 2
College-Educated O*NET S&E as a Percentage of Total Employment (219 U.S. metropolitan areas)

	Foreign S&E	Total S&E
1980	0.3	2.8
1990	0.5	3.3
2000	0.9	4.5
2005	1.1	4.4
2010	1.2	4.6

Note: The figures were obtained by the authors from IPUMS census data. The relevant population includes only noninstitutionalized individuals between ages 18 and 65 who have worked at least one week in the previous year.

decades in the analysis, as the science and engineering percentage of employment grew by 1.2 points. Of that increase, 0.4 points were due to foreign S&E. Also remarkable, the first decade of the 2000s saw an increase in total S&E by only 0.1 percent of employment, whereas foreign-born S&E increased by 0.2 percent of employment.

Table 3 shows absolute numbers (in thousands), suggesting that the H-1B program was large enough to drive all or most of the increase in foreign college-educated S&E. Column (1) reports the net total increase in college-educated S&E in the United States, and column (2) displays the increase in foreign college-educated S&E. Column (3) shows the cumulative number of H-1B visas issued during the corresponding decade. It is clear that in the 1990s, the H-1B visas were enough to cover the whole growth in college-educated foreign S&E in the United States, even accounting for some returnees. Even more remarkable, H-1B issuances were three times as large as the net increase in college-educated S&E between 2000 and 2010. That increase implies that many foreign S&E, including H-1B recipients, must have left the United States, while many native S&E must have retired, lost their jobs, or changed occupations. Overall, the figures presented emphasize the importance of foreigners for science and engineering jobs in the United States. Foreign-born labor is over-represented among S&E, and the overall size of the H-1B program was large enough to contribute substantially to the foreign science and engineering job growth between 1990 and 2010.

Table 3
Net Increase in College-Educated S&E and Cumulative H-1B Visas (Thousands)

	(1) Net Change in Total College-Educated S&E	(2) Net Change in Foreign College-Educated S&E	(3) Cumulative H-1B Visas
1980–1990	793	196	0
1990–2000	1779	547	707
2000–2005	281	221	650
2005–2010	228	110	647

Note: Data on the change in total S&E occupations are from the IPUMS Census. Data on the total number of H-1B visas are from the U.S. Department of State (2011).

4.2 The Constructed H-1B Policy Variable

We begin by defining for each metro area (city), c, its employment share of foreign S&E from each of 14 specific foreign nationalities,[19] n, in 1980 as $\frac{\Delta(S\&E)^{FOR_n}_{c,1980}}{Emp_{c,1980}}$. The overall foreign S&E employment share in a metro area is the sum of the shares from each specific nationality, $\frac{\Delta(S\&E)^{FOR}_{c,1980}}{Emp_{c,1980}} = \sum_{n=1,14}\left(\frac{\Delta(S\&E)^{FOR_n}_{c,1980}}{Emp_{c,1980}}\right)$. We choose 1980 as a base year for three reasons. First, it is the earliest census that allows the identification of the 219 metropolitan areas that we can consistently follow to year 2010. Second, it is well before the creation of the H-1B visa program, and hence it does not reflect the distribution of foreign S&E produced by the policy. Third, it is early in the information technology (IT) revolution so that the distribution of S&E was hardly affected by the geographic location of the computer and software industries that could be correlated with subsequent positive changes in productivity.[20] Instead, the nuclear, military, chemical, and traditional manufacturing sectors were demanding a large number of science and technology workers in 1980. We also use 1970 as the initial year to determine the foreign S&E distribution for a subset of cities as a robustness check. The instrument based on the 1970 distribution, however, is significantly weaker than the one based on the 1980 distribution.

After defining the 1980 foreign science and engineering employment share, we calculate the growth factor of foreign S&E for each nationality n in the United States between 1980 and year t. We do so by adding the total countrywide inflow of S&E from each nationality during the period between 1980 and t to its initial 1980 countrywide level $(S\&E)^{FOR_n}_{c,1980}$. For the decades 1990–2000 and 2000–2010, we use the cumulative H-1B visas allocated to nationality n $\left(\#ofH\text{-}1B^{FORn}_{1980\text{–}1990}\right)$ to proxy for the net aggregate increase

[19] The national groups are from Canada, Mexico, the rest of the Americas (excluding the United States), western Europe, eastern Europe, China, Japan, Korea, the Philippines, India, the rest of Asia, Africa, Oceania, and other.

[20] Although early video games and computers were introduced in the late 1970s, the IBM personal computer was not introduced until 1981.

in $(S\&E)^{FORn}$.[21] For the decade 1980–1990, we simply add the net increase in S&E from nationality n as recorded in the U.S. census, $\Delta(S\&E)^{FORn}_{1980\text{–}1990}$. The imputed growth factor for S&E of each foreign nationality in year t = 1990, 2000, 2005, 2010 is therefore

$$(3) \qquad \frac{\widehat{(S\&E)}^{FORn}_{t}}{(S\&E)^{FOR_n}_{1980}} = \frac{(S\&E)^{FOR_n}_{1980} + \Delta(S\&E)^{FOR_n}_{1980\text{–}1990} + \#ofH\text{-}1B^{FOR_n}_{1990\text{–}t}}{(S\&E)^{FOR_n}_{1980}}$$

To impute the number of foreign S&E in city c in year t, we then multiply the growth factor calculated above for each nationality by the number of foreign S&E of that nationality in 1980 in the city, and then we sum those figures across all nationalities within each city:

$$(4) \qquad \widehat{(S\&E)}^{FOR}_{c,t} = \textstyle\sum_{n=1,14} (S\&E)^{FOR_n}_{c,1980} \left(\dfrac{\widehat{(S\&E)}^{FOR_n}_{t}}{(S\&E)^{FOR_n}_{1980}} \right)$$

The H-1B-driven change in foreign S&E that we use as our explanatory variable in the main empirical specifications is the change in $\widehat{(\mathrm{S\&E})}^{\mathrm{FOR}}_{c,t}$ over a decade, as percentage points of the initial employment in the city, $Emp_{c,t}$:[22]

$$(5) \qquad \frac{\Delta(S\&E)^{H\text{-}1B}_{c,t}}{Emp_{c,t}} = \frac{\widehat{(S\&E)}^{FOR}_{c,t+10} - \widehat{(S\&E)}^{FOR}_{c,t}}{Emp_{c,t}}$$

This identification strategy is closely related to the one used by Altonji and Card (1991) and Card (2001) and is based on the initial 1980 distribution of foreign workers across U.S. cities. It is also similar to the

[21] Since the data on visas issued by nationality begin in 1997, while we know the total number of visas in each year, we must estimate #ofH-1B$_{n,1990\text{–}t}$, the total number of visas issued by nationality between 1990 and 1997, as

$$\#ofH\text{-}1B_{n,1990\text{–}t} = \#ofH\text{-}1B_{1990\text{–}t} \left(\frac{\#ofH\text{-}1B_{n,1990\text{–}2010}}{\#ofH\text{-}1B_{n,1990\text{–}2010}} \right)$$

where $\dfrac{\#ofH\text{-}1B_{n,1990\text{–}2010}}{\#ofH\text{-}1B_{n,1990\text{–}2010}}$ is the share of visas issued to nationality group n among the total visas issued from 1997 to 2010. For t larger than 1997, we have the actual number of yearly visas by nationality $\#ofH1B_{n,t}$.

[22] To avoid the possibility that endogenous changes in total employment at the city level affect the standardization, we also use the imputed city employment (obtained using employment in 1980) augmented by the growth factor of national total employment. Hence, $Emp_{c,t} = Emp_{c,1980}\left(Emp^{US}_{t}/Emp^{US}_{1980}\right)$.

one used by Kerr and Lincoln (2010), who consider the employment share of foreign S&E in an initial year and the effect of H-1B on subsequent innovation. Our variable, however, is based on foreign S&E in a city in 1980 or 1970 (rather than in 1990 as done by Kerr and Lincoln [2010]) and uses the distribution of foreign S&E across 14 nationalities rather than only an aggregate measure. Hence, it should be less subject to correlation with recent economic conditions and should have stronger power if immigrant networks are country specific.[23]

As is clear from Section 2.2, not all foreign S&E enter on H-1B visas, as there are workers entering with other visas or with permanent residency. Moreover, some of the H-1B workers return to their home countries after six years. Hence, as a first step, we need to establish whether our policy-driven variable has predictive power on $\frac{\Delta S\&E^{FOR}_{c,t}}{Emp_{c,t}}$, the observed change in foreign S&E workers in a metropolitan area.

4.3 Identification and Power of the Policy Instrument

Our identification strategy is based on the assumption that a city's employment share of foreign S&E in 1980 was due to the differential presence of immigrants caused by persistent agglomeration of foreign communities. Those differences subsequently affected the supply of foreign-born S&E, but they were not otherwise correlated with future technological and demand shocks that affected wages and employment. A challenge to this assumption is that a city's employment share of foreign S&E in 1980 may be correlated with its productive and industrial structure, specifically with regard to its sector composition and its scientific and technological base in 1980, which, in turn, may subsequently affect future productivity growth.

[23] Note that aggregate flows of H-1B workers at the national level are often constrained (and determined) by changes in federal policy, but they sometimes reflect other conditions occurring in the United States and in origin countries. The fluctuations do not violate exogeneity conditions required for the validity of our instrument so long as they are uncorrelated with individual city-level shocks. This is a reasonable and commonly held assumption used in a number of papers since Altonji and Card (1991). In a robustness check in Table 6, we also check that the few individual metro areas that contribute more than 5 percent to the national number of foreign S&E are not driving the results.

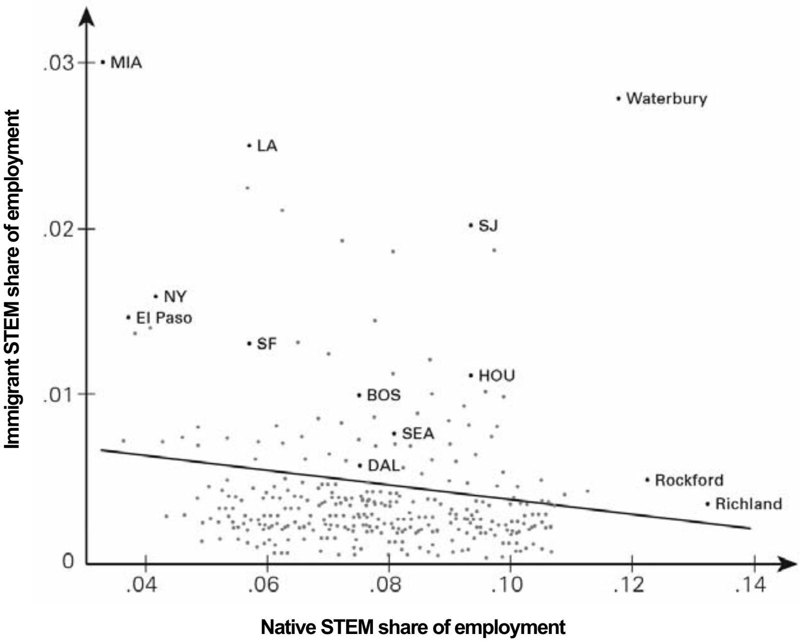
We take several steps to partially address these concerns. First, in this section, we show that the employment share of foreign S&E in 1980 across metropolitan areas has little correlation with the employment share of native S&E, at least when we use the O*NET-based definition. Foreign S&E as a share of employment were much more strongly affected by a city's foreign-born residents. We also show that the share of foreign S&E in 1980 is correlated with the H-1B-driven growth in S&E between 1990 and 2010, independent of the presence of native S&E.

Second, we estimate very demanding empirical specifications. Our data set is composed of a panel of 219 metropolitan areas from 1990–2000, 2000–2005, and 2005–2010. Our models are estimated in first differences so that effects are identified by changes in H-1B-driven foreign S&E supply across cities. That strategy should eliminate bias arising from unobserved time-invariant determinants of the level of our outcome variables and the level of foreign S&E. We add rigor to the models by including controls for 50 state-specific effects and period effects. Thus, identification relies on variation of growth rates across cities in the same state. In robustness checks, we also estimate the more demanding specifications that include 219 city-specific effects. In all specifications, we include controls for the 1980 employment share of native S&E, which proxies for the research intensity of the metro area as of 1980.

And third, we perform robustness checks using the foreign S&E share of employment in 1970 to construct the instrument, and we include other time-varying controls for metro area–specific variables in the regression. In particular, Section 7.1 explicitly controls for the effect of sector composition in 1980 on subsequent growth and analyzes how it affected wage and employment growth in metropolitan areas in comparison with foreign S&E.

The employment share of native and foreign S&E varied dramatically across the 219 U.S. metropolitan areas in 1980, and those two variables had little correlation with each other. Several of the top native science and engineering cities were in the Midwest and the East. Most were associated with traditional sectors—such as nuclear energy, oil products, and industrial machinery—that attracted many S&E in the 1970s. In contrast, the metropolitan areas with large foreign science and engineering employment shares included a more diverse group of cities. Some were larger and had more diversified economies; others were smaller centers with large immigrant communities.

Figure 5
Foreign and Native S&E Employment Shares
(U.S. metro areas, 1980)



Note: The foreign and native S&E employment shares are calculated using 1980 census data for 219 metropolitan areas. The coefficient of the best-fit line = −0.045 (standard error = 0.029). Points are labeled for Boston (BOS), Dallas (DAL), Miami (MIA), New York (NY), Los Angeles (LA), San Francisco (SF), San Jose (SJ), Seattle (SEA), Houston (HOU), El Paso (Texas), Rockford (Ill.), Richland (Wash.), and Waterbury (Conn.).

Figure 5 and column (1) of Table 4 show no correlation between foreign and native science and engineering employment share across cities, when we choose the O*NET-based definition. The OLS correlation obtained after controlling for state effects (column [1]) is negative and insignificant at standard confidence levels (t-statistics are smaller than 1.6). The visual impression of Figure 5 is also clear: there was little correlation between foreign and native S&E employment shares in 1980. That fact is a hint that foreign science and engineering

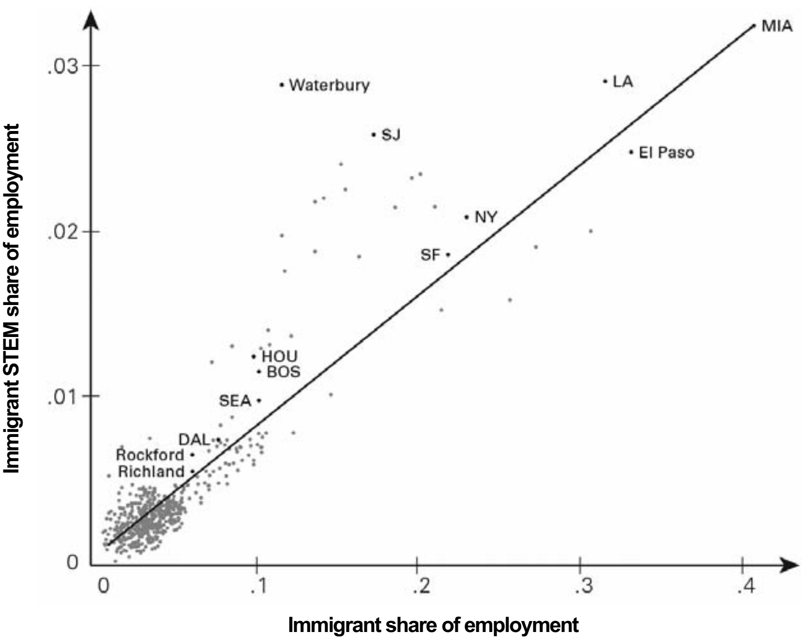
Table 4
Native and Foreign S&E as Shares of Employment in 1980 and the H-1B Predicted S&E Change
(219 U.S. metropolitan areas; 1990–2000, 2000–2005, and 2005–2010)

	(1) Foreign S&E as a Share of Employment, 1980	(2) Foreign S&E as a Share of Employment, 1980	(3) H-1B-Predicted S&E Growth	(4) H-1B-Predicted S&E Growth
Foreign-S&E as a share of employment, 1980			0.54*** (0.12)	
Native S&E as a share of employment, 1980	−0.031 (0.032)			0.040** (0.019)
Foreign-born share of population, 1980		0.067*** (0.0065)		
Observations	219	219	657	657
F-statistic	0.94	106.64	20.3	4.38
Period effects	No	No	Yes	Yes
State effects	Yes	Yes	Yes	Yes
Partial *R*-square "Partialing out" state and period effects	N/A	N/A	0.39	0.03

Note: Each column represents a separate regression. The dependent variable is written at the top of the corresponding column. Specifications (1) and (2) include 219 metropolitan areas in 1980. Regressions (3) and (4) include the H-1B-predicted change in S&E in 1990–2000, 2000–2005, and 2005–2010 regressed on the 1980 S&E dependence (foreign or native). The standard errors are heteroskedasticity-robust, and when there is more than one observation per metro area, they are clustered at the metro-area level. The S&E definition is based on O*NET skills. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively. N/A = not applicable.

had little to do with the S&E employment share of a city in 1980. Column (2) of Table 4 and Figure 6 show that a city's employment share of foreign S&E in 1980 had more to do with the presence of other foreign-born residents as a share of the population. When including state fixed effects, the foreign-born population share has an extremely significant association with its foreign S&E employment share (*t*-statistic of 10.3). Anecdotally, cities such as Miami, Los Angeles, and El Paso, Texas, had a large presence of both foreign

Figure 6
Foreign S&E Employment Share and
Foreign-Born Employment Share
(U.S. metro areas, 1980)



Note: The figures are calculated using 1980 census data. The population of reference used to calculate the foreign-born share of S&E in a city is the total adult (ages 18–65) noninstitutionalized population. The coefficient of the best-fit line = 0.071 (standard error = 0.006). Points are labeled for Boston (BOS), Dallas (DAL), Miami (MIA), New York (NY), Los Angeles (LA), San Francisco (SF), San Jose (SJ), Seattle (SEA), Houston (HOU), El Paso (Texas), Rockford (Ill.), Richland (Wash.), and Waterbury (Conn.).

S&E and foreign workers overall in 1980. Their native-born work force, in contrast, had few S&E.[24] San Francisco, New York, and Los Angeles had a relatively high share of foreign S&E in 1980 but a very unremarkable share of native S&E. Those cities had a large proportion of immigrants, however, and their subsequent growth of S&E has been quite large.

Column (3) of Table 4 goes on to show that the 1980 foreign S&E employment share has extremely significant power to predict the H-1B-driven increase in S&E across cities. (It has an F-statistic of 20.30, and the partial R-squared explained by that variable is 0.39.) Column (4) of Table 4 shows instead that the 1980 native S&E employment share has very limited power to predict the H-1B-driven increase in S&E (F-statistic of 4.38 and partial R-squared of 0.03). Cities with larger foreign S&E shares in 1980 were not necessarily associated with a high share of S&E overall in 1980. Even controlling for their native S&E, the fact that the H-1B program allowed a significant increase in the highly educated foreign science and engineering work force during the 1990s and 2000s enabled those cities to increase the size of their science and engineering employment. The initial advantage in employment share of foreign S&E made those cities a more likely destination for foreign-born S&E entering with an H-1B visa. The presence of a network, the easier diffusion of information across foreign groups, and the familiarity of firms with foreign S&E likely reduced the costs for U.S. companies to connect with foreign S&E and for H-1B visa recipients to locate in those cities.

Finally, let us emphasize that our identification strategy relies on more than just the overall foreign S&E share. Since we consider H-1B visas by nationality, we exploit variation in the immigrant presence across U.S. cities by nationality. A very large share of H-1B visas were awarded to Indian, Chinese, and other Asian workers (see Table A2 in the Appendix). Hence, aggregate flows of S&E from those countries more significantly affected cities with large employment shares of S&E from those nationality groups.

[24] Table 4 and Figures 5 and 6 use our first (O*NET-based) definition of science and engineering occupations. Our second definition of those occupations (based on the majors of college graduates) does exhibit correlation between foreign and native S&E shares across cities in 1980. That is why in all regressions we control for the 1980 native S&E share of employment in order to control for the initial science and technology intensity of the metro area.

The H-1B-driven increase in S&E, defined in expression (5), is the policy instrument. It captures the potential effect of the aggregate H-1B visas on S&E in U.S. cities. First, we want to establish that it significantly affected the actual increase in foreign S&E across cities. Then, we would like to determine the effect of S&E on native employment and wages, and hence we use the policy variable as an instrument for the actual increase.

We estimate the following specification:

$$\frac{\Delta(S\&E)^{FOR}_{c,t}}{Emp_{c,t}} = \varphi_t + \varphi_s + b_1 \frac{\Delta(S\&E)^{H\text{-}1B}_{c,t}}{Emp_{c,t}} + \varepsilon_{c,t} \tag{6}$$

The coefficient of interest is b_1, which measures the effect of H-1B-driven S&E inflows on the actual increase in foreign S&E (as measured from the U.S. census). The term φ_t captures period fixed effects, and φ_s represents local area effects (we will include different effects, state or metro-area level, in alternative specifications). We include $t = 1990, 2000, 2005$ so that the changes Δ refer to the periods 1990–2000, 2000–2005, and 2000–2010.[25] $\varepsilon_{c,t}$ is a zero-mean random error uncorrelated with the explanatory variable.

In Table 5, we show estimates of the coefficient b_1 from different specifications and samples. They illustrate the robustness of the H-1B policy instrument in predicting actual changes in foreign S&E across U.S. metropolitan areas. Columns (1) and (2) show the estimates of the coefficient b_1 in equation (6). In column (1), we include the time dummies and state fixed effects. In column (2), we include the very demanding metro-area fixed effects. The effect of H-1B-driven S&E is always significant at the 5 percent level, and in the basic specification it is close to 0.7, implying that a 1 percentage point increase in the growth of H-1B-driven foreign S&E standardized by initial employment (i.e., the growth rate of foreign S&E) produces an actual increase in the growth rate of foreign S&E in a city by 0.7 percentage points. We can interpret this regression as the first stage in a two-stage least squares (2SLS) estimate of the effect of science and engineering workers. Note that the F-statistic of 17.86 in the basic specification is well above the critical value for the weak instruments test. Only when we include city effects, in column (2), does the policy-driven

[25] We also estimate a specification that uses only decade changes 1990–2000 and 2000–2010, reported in the fifth row of Table 6. The results are very similar to the basic specification.

Table 5
Power of the H-1B Policy Variable as a Predictor of Foreign-S&E Change (219 U.S. metropolitan areas; 1990–2000, 2000–2005, and 2005–2010)

Dependent Variable	(1) Change in Foreign S&E as a % of Initial Employment (O*NET def.)	(2) As (1) with MSA Effects (O*NET def.)	(3) Change in Total S&E as a % of Initial Employment (O*NET def.)	(4) As (1), including 1980 Share of College-Educated as a Control	(5) As (2) Using Major-Based S&E Definition and MSA Effects	(6) As (5) omitting the Outliers (San Jose, Calif., and Stamford, Conn.)	(7) IV Constructed Using 1970 Foreign Major-Based S&E (116 Metro Areas)
H-1B Driven Growth in Foreign-S&E	0.70*** (0.17)	2.62** (1.19)	0.87** (0.42)	0.63** (0.21)	3.56*** (0.80)	2.68*** (0.49)	0.29* (0.17)
1980 Employment Share of Native S&E	−0.03 (0.02)	N/A	−0.09 (0.08)	−0.02 (0.02)	N/A	N/A	N/A
Observations	657	657	657	657	657	651	348
Period Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State Effects	Yes	No	Yes	Yes	No	No	Yes
Metro-Area Effects	No	Yes	No	No	Yes	Yes	No
Other Controls	No	No	No	1980 college-educated share of population	No	No	No
F-test of the Coefficient	17.86	4.85	4.34	9.25	20.02	29.85	2.96

Note: IV = instrumental variable; MSA = metropolitan statistical area; N/A = not applicable. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.

variable (though still significant) become less powerful in predicting actual foreign S&E growth (F-statistic equal to 4.85).

In column (3) of Table 5, we explore whether the H-1B policy-driven variable had a significant effect on the total increase in S&E. Although less powerful than in predicting foreign S&E growth, the H-1B policy variable has a significant effect (at the 5 percent level) on the growth of total S&E (always standardized by initial employment). That effect implies that more H-1B workers in a city produced more S&E overall.

In columns (4)–(7) of Table 5, we perform several robustness checks of the basic specification (6). Column (4) shows the power of the H-1B-driven growth on foreign S&E when we control for the initial share of college-educated workers in the city. Although the power is somewhat reduced, it is clear that our instrument captures much more than a simple proxy for initial human capital intensity of the metro area. In specification (5), we use the alternative definitions of science and engineering occupations according to college major, and we include occupations whose share of total workers with a science or engineering degree is at least 25 percent or more. We also include the very demanding metropolitan area effects. We find that the policy variable is a very strong predictor of foreign S&E growth. The college major–based definition shows a very strong predictive power: the F-statistic remains high (20.02), even with the demanding inclusion of metro-area fixed effects in column (5). That result is reasonable since H-1B visa policy generally restricts admission to highly educated foreign workers, who mainly work in highly science- and technology-intensive occupations, as described in Section 2.2.

In column (6), we omit from the analysis two clear outlier cities whose foreign S&E growth as share of employment has been much larger than in any other city. Those cities are San Jose, Calif., the core of Silicon Valley and its computer industry; and Stamford, Conn., a service center for both technology and financial services. The predictive power of the instrument becomes even stronger, implying that the extraordinary success of Stamford and San Jose in attracting foreign S&E could not be fully predicted by their share of foreign S&E in 1980.

Finally column (7) addresses the possibility that the 1980 foreign S&E distribution might have been influenced by the presence of early IT industries, which, in turn, might have driven productivity in the 1990–2010 period. We construct the H-1B-driven variable using the foreign S&E employment share of cities as revealed by the 1970 census, a year in which computer and information technologies were in their very early infancy. Unfortunately, this approach restricts our analysis to just the 116 metropolitan areas that can be consistently identified for the whole 1970–2010 period. The power is drastically reduced (F-statistic of 2.96); however, we still find that the H-1B-driven variable significantly predicts the foreign S&E growth in the 1990–2010 period.

5. THE EFFECT OF FOREIGN S&E ON NATIVE WAGES AND EMPLOYMENT

Our H-1B-driven variable has significant predictive power, even after controlling for the technological intensity of metropolitan areas in 1980 and several other observed and unobserved features of those metro areas. Using this source of exogenous variation of foreign S&E, we now analyze their effects.

5.1 Basic Specification

In Table 6 we report the estimated values of the coefficient $b_{y,X}$ from regressions specified in equations (1) and (2). Each of the four columns represents a different outcome. In column (1), the dependent variable is the percentage change of the weekly wage paid to native college-educated workers, $\frac{\Delta w_{c,t}^{College,native}}{w_{c,t}^{College,native}}$, in each of 219 metropolitan areas over the 1990–2000, 2000–2005, and 2005–2010 periods. In column (2), the dependent variable is the percentage change of the weekly wage of native non-college-educated workers, $\frac{\Delta w_{c,t}^{NoCollege,native}}{w_{c,t}^{NoCollege,native}}$.[26] Columns (3) and (4) show the effect of foreign S&E on the change in employment of native college-educated workers and native non-college-educated workers as a percentage of initial total employment (respectively, $\frac{\Delta H_{c,t}^{nat}}{Emp_{c,t}}$ and $\frac{\Delta L_{c,t}^{nat}}{Emp_{c,t}}$).[27]

[26] Weekly wages are defined as yearly wage income divided by the number of weeks worked. Employment includes all individuals ages 18–65 who have worked at least one week during the previous year and do not live in group quarters. Individual weekly wages are weighted by the personal weight in the census. We convert all wages to current 2010 prices using the consumer price index deflator provided by IPUMS.

[27] Column (5) of Table 6 shows the Kleinberger-Paap Wald F-statistic for the first-stage regression to give a sense of the strength of the instruments (essentially identical for all the regressions in the row, as the first stage is the same). A value of 10 is considered a threshold above which issues of weak instruments should not arise.

Table 6

Effects of Foreign S&E on Wage and Employment Growth of Native Workers
(219 U.S. metropolitan areas; 1990–2000, 2000–2005, and 2005–2010)

Explanatory Variable: Growth Rate of Foreign S&E **Instrument:** H-1B Imputed Growth of Foreign-S&E	**(1)** **Weekly Wage, Native College-Educated**	**(2)** **Weekly Wage, Native Non-College-Educated**	**(3)** **Employment, Native College-Educated**	**(4)** **Employment, Native Non-College-Educated**	**(5)** **K-P Wald *F*-Statistic of the First Stage**
Basic: O*NET S&E state and year effects	4.97*** (1.15)	–0.15 (0.91	2.04 (1.54)	–3.04 (2.66)	17.86
Major-based S&E, metro-area and year effects	6.84*** (1.93)	1.27 (1.41)	0.69 (1.51)	–5.92 (3.27)	20.02
As Basic, omitting San Jose, Calif., and Stamford, Conn.	6.31*** (1.73)	–1.03 (1.59)	1.51 (1.48)	–5.13 (4.57)	42.07
As Basic, omitting NY, LA, SF, and DC	4.58*** (1.16)	0.2 (0.87)	2.38 (1.73)	–2.04 (2.75)	15.18
As Basic, using decade changes	4.20*** (1.26)	–1.02 (0.97)	1.76 (1.22)	–2.45 (2.54)	20.28
As Basic, adding control for 1980 share of college-educated	3.97** (1.47)	–0.63 (1.28)	–1.16 (1.86)	–5.45 (3.65)	9.25
Imputation of IV-based on 1970 foreign- major-based S&E	5.20*** (1.37)	–1.24 (1.43)	–2.92 (1.87)	–8.33 (4.46)	6.05
Total S&E as explanatory variable	3.99*** (1.64)	–0.12 (0.75)	1.64** (0.75)	–2.44 (3.08)	4.34
OLS, basic specification	2.50*** (0.83)	1.17*** (0.41)	3.52** (1.53)	3.19** (1.22)	N/A

Note: Each cell includes the estimate of the effect of growth of foreign-S&E (or total S&E) on the dependent variable listed at the top of the column. The instrument used is the H-1B-driven growth of foreign S&E workers. The basic specification estimated is described in the text. It always includes state and period effects and, where not absorbed by the fixed effects, it also controls for the 1980 employment share of native S&E. The specification using 1970 IV does not include the state fixed effect. The last row shows the OLS estimate of the basic specification. The standard errors are heteroskedasticity-robust and clustered at the metro-area level. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively. DC = Washington, D.C.; IV = instrumental variable; LA = Los Angeles; N/A = not applicable; NY = New York; OLS = ordinary least squares; O*NET = Occupational Information Network; SF = San Francisco.

The different rows of Table 6 represent different specifications and samples. Each includes period effects, state or metro area effects, and—when not absorbed by the metro-area effect—the 1980 native S&E share of employment. In this section, we focus on the first row, which reports 2SLS estimates from the basic specification using the O*NET S&E-based definition of occupations. In this specification, we use the 1980-based H-1B variable as an instrument for the actual foreign S&E growth.

Four interesting results emerge, and they are then confirmed by robustness checks. First, there is a positive and significant effect of H-1B-driven increases in S&E on wages paid to college-educated workers. The estimated effect is significantly different from zero at the 1 percent level, and the point estimate is close to 5, implying a 5 percentage point increase in the growth rate of wages for each increase in the H-1B-driven S&E growth by 1 percentage point of initial employment.[28] This elasticity seems large; however, recall that foreign S&E are a very small fraction of employment, and they grew by only half a percent of employment over the 20 years from 1990 to 2010. Second, H-1B foreign workers did not have any significant effect on wages of non-college-educated workers. The point estimate is much smaller than that for college-educated wages and is insignificantly different from zero. Third, the inflow of foreign S&E did not significantly affect the employment of college-educated natives. Fourth, H-1B-driven S&E growth had no significant effect on non-college-educated employment. The point estimate in column (4) (row 1) is negative, but it is also imprecisely estimated and not significant. Importantly, the remaining rows of Table 6 that use 2SLS estimation (discussed in greater detail in the next section) find the same four regularities, pointing to the robustness of the results.

The null effect on non-college-educated workers and the positive wage effect on college-educated workers together suggest that H-1B workers contributed to skill-biased productivity growth. With regard to our simple model of Figure 4, those changes reveal a positive

[28] In nonreported regressions, we also estimated the effect of foreign S&E on wages of native S&E only. The results are, in most cases, similar to the effect on native college-educated workers. Hence, we considered college-educated natives (S&E and non-S&E) as a homogeneous group.

shift to the labor demand for native college-educated workers and no shift of the demand for non-college-educated workers. The weak employment response of college-educated natives might also suggest that other adjustment mechanisms were at work at the metropolitan-area level, thus implying a rather rigid labor supply. In a related check (not reported), we find that the rental cost of housing for college-educated workers was positively affected by the inflow of foreign S&E in the metropolitan areas.[29] A new spatial equilibrium in which local prices (rents) respond to wages would imply little labor mobility. Ottaviano and Peri (2006) find a similar effect of immigrant diversity on wages and rents.

It is particularly important to understand the magnitude of the one significant S&E coefficient in row 1 of Table 6: the 4.97 value in the college-educated natives' wage regression. We offer several alternatives. First, we can combine the results of Tables 5 and 6 to better understand the role of the H-1B visa. A shock of 1 standard deviation to our imputed H-1B growth variable across cities and time periods equals 0.00038. From column (1) of Table 5, we see that shock would translate into a 0.000266 (= 0.00038 × 0.70) increase in foreign S&E. That would then imply a 0.00132 (= 0.000266 × 4.97) rise in the growth rate of real wages paid to college-educated natives. That figure amounts to roughly 3.4 percent of a standard deviation of the dependent variable, a seemingly small response.

Interpretation at the national level, in contrast, suggests a larger wage response. First, note that foreign S&E represent only 1–3 percent of employment, depending on how they are measured. Moreover, their growth was only about 0.4 percentage points of total employment during the 1990s and 0.3 percentage points in the following decade. Applying the 2SLS estimates of row 1 in Table 6 to the average growth in foreign S&E nationally implies that the foreign-driven net increase in S&E increased real wages of college-educated natives by about 2 percentage points (0.4 × 4.97) between 1990 and 2000,

[29] A regression of the median rental cost per room on the policy-instrumented increase in foreign S&E shows that a 1 percentage point increase in the policy instrument increased rents for college-educated individuals by 4.11 percentage points (standard error 1.29). For non-college-educated individuals, the effect was a nonsignificant −1.90 percentage points (standard error 1.45). Hence, part of the purchasing power from increased wages for the college-educated was absorbed by increased rental costs.

and by an additional 1.5 percentage point (0.3 × 4.97) between 2000 and 2010. Thus, overall foreign S&E increased the cumulated wage growth of college-educated natives by 3.5 percentage points between 1990 and 2010. From our census data, we can calculate that the average real weekly wage of U.S. college-educated workers increased by a cumulative 13 percentage points over that 20-year period. The wage of non-college-educated workers, in contrast, remained essentially stagnant. Therefore, about one-fourth of the college-educated wage growth can be attributed to productivity growth from foreign S&E. Given that foreign labor accounted for nearly a quarter of U.S. science and engineering employment in 2010 (see Table 2) and that science and engineering are primary drivers of U.S. productivity and wage growth, we find those estimates quite plausible. In Section 7, we will compare the foreign S&E-related wage gains to those related to other growth determinants.

Before we discuss the other rows of Table 6 in the next section, it is worth highlighting that a comparison between the first and last rows of Table 6 provides insight into the validity of our causal estimates. The last row shows the OLS analogue of the 2SLS results in the first row; coefficients obtained by regressing the dependent variables on foreign S&E growth, state effects, and period effects. The OLS regression finds positive and significant effects of S&E on all variables with higher values (compared with 2SLS results) in three of the four cases. S&E are attracted to cities in which employment and wages of all workers are growing (reverse causality).

Our instrument, in contrast, allows us to separate S&E's positive effect on the demand for college-educated workers from the null effect on the demand for non-college-educated labor. Our intuition is that the endogeneity bias—namely, the tendency to have positive effects in boom cities—may be very strong for employment and for less educated workers' wages, therefore contributing to a more severe upward bias in OLS estimates. Somewhat surprising, however, the OLS estimate of S&E's effect on wages paid to college-educated natives is actually smaller than the 2SLS estimate. In this case, we suspect that endogeneity bias itself might be comparatively small. Measurement error, especially in the construction of the relevant S&E share from an imperfect collection of occupations—common to all variables—could be responsible for the downward bias visible in the college-educated native wage regressions.

5.2 Robustness Checks

The remaining rows of Table 6 show the estimates of the same four coefficients ($b_{w,Coll}$, $b_{w,no\text{-}Coll}$, $b_{E,Coll}$, and $b_{E,no\text{-}Coll}$) using different specifications. In row 2, we use the S&E definition that is based on college major, and, given that the instrument is quite powerful (as noted in Table 5), we also include the metropolitan-area fixed effects. In those two specifications, we also modify the H-1B-based instrument accordingly. The *F*-test of this specification is stronger than for the basic one (row 1).

The rows 3 and 4 explore the sensitivity of the regression to outliers. First, we omit metropolitan areas with unusually large growth in foreign S&E (row 3). Then, we omit metro areas with very large sizes and hence large numbers of foreign S&E relative to the national total. The results are qualitatively and quantitatively very similar to the basic specification. Though we prefer to think of 1990–2000, 2000–2005, and 2005–2010 as three distinct periods (in light of the very different economic conditions introduced in the second half of the 2000s by the Great Recession), we also recognize that it is somewhat unusual to use three panels of nonuniform length.[30] Row 5 therefore uses a panel of two decade-long changes (1990–2000 and 2000–2010) instead.

Row 6 adds a control for the 1980 share of college-educated people in the population. The control captures the human capital intensity of the city that has been found to be important in determining its growth and can be correlated with the foreign S&E share. Row 7 uses the 1970-based instrument that, as illustrated in Table 5, might suffer from weak-instrument problems. Moreover, to have sufficient power in this case, we do not include state fixed effects. The standard errors, especially in column (4), are quite large. Still, the main results are very consistent with those obtained in the basic specifications. Finally, row 8 shows the result when we consider the total change in S&E (rather than foreign only), which is still instrumented with the H-1B policy measure.

The main results and the point estimates of row 1 are clearly confirmed in the robustness checks. Only the effect on wages paid to college-educated natives is significantly different from zero in each

[30] Borjas, Grogger, and Hanson (2012) and Ottaviano and Peri (2012) also use a panel that includes periods of different lengths because of data availability.

specification. Estimates for that effect range between 3.9 and 6.8. Let us emphasize that several of our specifications are very demanding by including a full set of 219 metropolitan areas' fixed effects in a differenced panel (with only three periods). The coefficients are identified on differences in the growth rates of S&E in a city across periods. The main characteristics of the coefficients in all robustness checks are consistent with those of the basic specifications. Finally, the estimated effects on non-college-educated employment are negative but not significant in any specification. The standard errors of those estimates, however, are usually large.

5.3 Extensions

Taking all the specifications together, our estimates reveal that the demand for native college-educated workers received a significantly positive boost from foreign S&E. At the same time, however, the demand for non-college-educated labor was not positively affected. In this section, we analyze in greater detail how S&E might have affected the city's economy beyond the broad groups previously considered. First, we analyze whether the null effect on the demand for non-college-educated labor is concentrated mainly in the very low part or the intermediate part of the educational distribution. That is, we assess whether the wage and employment effects are different among individuals with and without a high school diploma, or if instead the effects are uniform across all non-college-educated natives. Second, we analyze whether S&E growth pushed college-educated native workers toward specific sectors.

Table 7 shows the effect of foreign S&E on the weekly wages (columns [1] and [2]) and employment (columns [3] and [4]) of native workers without a college education. We separate between high school dropouts (columns [2] and [4]) and high school graduates (columns [1] and [3]). In rows 1 and 2, we show the estimates from the 2SLS regression—either in its basic specification or using the growth of total S&E as the explanatory variable—instrumented with the H-1B policy variable. The last row reports the OLS coefficients. By distinguishing high school graduates from high school dropouts, we can check whether the two groups are differentiated in their responses to productivity shocks brought on by foreign S&E. It is also a test for whether S&E workers produced the type of change in labor demand often referred to as the polarization of the labor market.

Table 7

Effect of Foreign-S&E on Wages and Employment of Native Workers: Split Non-College-Educated into Two Groups (219 U.S. metropolitan areas; 1990–2000, 2000–2005, and 2005–2010)

	Dependent Variable: Growth Rate of				
Explanatory Variable: Growth rate of foreign (total) S&E	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Instrument: H-1B Imputed Growth of Foreign-S&E	**Weekly Wage, Native HS Graduates**	**Weekly Wage, HS Dropouts**	**Employment, Native HS Graduates**	**Employment, Native HS Dropouts**	**K-P Wald *F*-Statistic of the First Stage**
Basic: O*NET S&E state and year effects	0.25 (0.96)	−3.84 (2.41)	−3.57 (2.35)	0.53 (0.46)	17.86
Total S&E as explanatory variable	0.2 (0.73)	−3.09 (2.48)	−2.87 (2.98)	0.43 (0.27)	4.34
OLS, basic specification	1.21** (0.44)	0.30 (1.30)	2.51** (1.07)	0.69** (0.20)	N/A

Note: Each cell includes the 2SLS estimate of the impact of growth of foreign S&E (or total S&E) on the dependent variable listed at the top of the column. The instrument used is the H-1B-driven growth of foreign S&E. Each specification includes state and period effects and controls for the 1980 share of native S&E. The last row shows the OLS estimate of the basic specification. The standard errors are heteroskedasticity-robust and clustered at the metro-area level. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively. HS = high school; N/A = not applicable; OLS = ordinary least squares; O*NET = Occupational Information Network.

This phenomenon is characterized by higher employment growth at the high and low ends of the education spectrum at the expense of intermediate-level jobs (see, e.g., Autor 2010; Autor, Katz, and Kearney 2006). The estimates of Table 7 show that S&E effects on both high school graduates and dropouts are mostly negative and insignificant. Those estimates, therefore, do not support local positive employment effects for the least educated. They are instead consistent with claims that science and engineering–driven technological progress contributed to the skill bias of the labor market (rather than polarization) in the United States.

Table 8 shows how employment of native college-educated workers (column [2]) and all native workers (column [1]) across nine separate sectors responded to foreign S&E. We include all sectors except those that have very small employment shares in some cities and would, therefore, exhibit rather noisy estimates (e.g., mining, agriculture, and entertainment). We arrange sectors in Table 8 in three groups: (a) private sectors with low human capital intensity (measured as having a share of college-educated labor smaller than 25 percent in the year 2000), (b) private sectors with high human capital intensity (measured as having a college-educated share larger than 25 percent), and (c) the public sector (whose employment growth may not be driven by productivity considerations). The coefficients of column (2) in Table 8 are obtained using the basic specification (as in row 1 of Table 6), and they show that the employment of college-educated labor in high human capital sectors increased much more than in low human capital sectors in response to an inflow of S&E into the city. The college employment response is significant in two out of three sectors. In contrast, low human capital sectors and the public sector did not experience any significant college-educated job growth. Hence, cities with high S&E inflows experienced a reallocation of college-educated workers toward more human capital–intensive sectors. The coefficients of column (1) show that although two of the high human capital sectors experienced positive total employment changes (i.e., employment increases among workers of all education levels) in response to S&E, those effects were not significant.

In summary, our empirical analysis identifies a positive, large, and significant effect of foreign S&E growth on the growth of college-educated native wages across U.S. metropolitan areas. At the

Table 8
Effects of Foreign S&E on Employment by Industry (219 U.S. metropolitan areas; 1990–2000, 2000–2005, and 2005–2010)

	(1)	(2)
Explanatory Variable: Growth rate of foreign S&E	**Dependent Variable: Total Employment**	**Dependent Variable: College–Educated Employment**
Instrument: H-1B imputed growth of foreign S&E	**2SLS**	**2SLS**
Low Human Capital, Private Sector		
Construction	−0.23	0.02
	(0.25)	(0.03)
Transportation	−0.19	0.05
	(0.27)	(0.03)
Wholesale	−0.11	−0.04
	(0.11)	(0.03)
Manufacturing	0.46	0.06
	(0.76)	(0.17)
Retail	−0.14	0.1
	(0.48)	(0.07)
High Human Capital, Private Sector		
Finance	0.14	0.2
	(0.24)	(0.15)
Business	0.13	0.38***
	(0.15)	(0.08)
Professional Services	−0.28	0.68*
	(0.64)	(0.36
Public Sector		
	−0.25	−0.01
	(0.20)	(0.06)

Note: Each cell includes the 2SLS estimate of the effect of the growth of foreign S&E on the dependent variable listed at the top of the column within the sector listed in the row. Each regression includes state and year fixed effects. The instrument used is the H-1B-driven growth of foreign S&E workers (using the major-based definition of S&E). The standard errors are heteroskedasticity-robust and clustered at the metro-area level. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.

same time, we do not find any significant effect on the growth of wages and employment of non-college-educated natives. The employment of college-educated natives did not exhibit overall growth in response to foreign S&E, but instead shifted from sectors with low human capital content to high human capital sectors.

6. THE EFFECTS OF FOREIGN S&E IN CANADIAN METROPOLITAN AREAS

The estimates presented earlier show an important productivity effect of foreign S&E on the U.S. economy. The United States, however, is at the technological frontier and is the largest international magnet for high-quality S&E. In this section, we assess the Canadian experience as an alternative in order to test whether other countries experience similar productivity boosts from attracting international S&E. Although Canadian cities and provinces do not have the same number and concentration of innovation-based firms and institutions as the United States, Canada's FSWP has been structured to attract highly educated workers with a strong weight given to S&E. Hence, we use the same approach used for the United States, and we construct from Canadian census data the imputed inflow of foreign S&E in each of 17 geographical areas (mostly metropolitan areas) between 1990 and 2006, according to the distribution of foreign S&E by nationality in 1980 and the aggregate inflow of foreign S&E by nationality. Then, we use that imputed immigration factor as an instrument for the actual increase in the number of foreign S&E as a share of employment across geographical areas.

The Appendix describes in detail the Canadian data and the results from the first-stage regressions. Here, we simply note that despite the small number of observations (17) over three five-year periods (1991–1996, 1996–2001, and 2001–2006), the imputed-immigrant instrument has reasonably strong power in predicting foreign S&E growth in Canadian metropolitan areas. The *F*-statistic is equal to 14.05 for the basic specification, which indicates that the power of the Canadian instrument is comparable to that for the U.S. data.

Table 9 shows the estimated effects of foreign S&E in Canadian geographical areas for three different specifications. The structure of Table 9 is the same as that of Table 6. Each specification includes period fixed effects and controls for the 1980 employment share of native S&E. Row 1 reports results from the basic specification. The

Table 9

2SLS Regression of Foreign S&E on Wages and Employment of Native Workers: Canada (17 Canadian geographic areas; 1991–1996, 1996–2001, 2001–2006)

Explanatory Variable: Imputed growth in foreign S&E	**(1)** **Growth Rate in Weekly Wage, Native College-Educated**	**(2)** **Growth Rate in Weekly Wage, Native Non-College-Educated**	**(3)** **Growth Rate in Employment, Native College-Educated**	**(4)** **Growth Rate in Employment, Native Non-College-Educated**	**K-P Wald *F*-Statistic of the First Stage**
Basic specification, with period effects	5.55** (2.67)	2.96 (1.86)	0.53* (0.27)	0.39 (1.63)	14.05
Basic specification, with province fixed effects	2.80** (1.19)	0.54 (0.85)	0.80** (0.32)	−1.22 (0.86)	4.79
Total change in S&E as explanatory variable	4.89** (1.82)	2.61** (1.28)	0.47** (0.13)	0.35 (1.36)	6.43

Note: Each cell includes the 2SLS estimate of the effect of growth of foreign (or total) S&E on the dependent variable listed at the top of the column. The instrument used is the imputed growth of foreign S&E. The basic specification estimated includes period effects and the 1980 native S&E as share of employment. The standard errors are heteroskedasticity-robust and clustered at the province level. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.

specification in row 2 is the same as in row 1 but adds province effects. Row 3 uses the total change in S&E (native and foreign) as an explanatory variable, still instrumented by the imputed inflow of foreign S&E.

The estimated coefficients are qualitatively and quantitatively close to those estimated for the United States in Table 6. First, there is a positive and significant effect of foreign S&E on wages paid to Canadian college-educated workers. The estimated effect is always statistically different from zero at the 5 percent significance level, and the point estimates are between 2.8 and 5.5 percentage points for each percentage-point increase in the S&E share of employment.

The second consistent result is that foreign S&E also had a positive effect—although not always significant at the 5 percent level—on the employment of native college-educated workers. The point estimates of that effect are smaller than those on wages, but they are consistent with the fact that an increase in productivity of highly educated workers in cities experiencing large inflows of foreign S&E might have attracted more college-educated natives in those cities. It is possible that local prices in Canada did not respond as much as in the United States, and hence the inflow of highly educated workers was larger.

The third important takeaway is that the inflow of foreign S&E generally had an insignificant effect on the wages and employment of non-college-educated natives. The insignificant effect on non-college-educated workers and the positive wage effect on college-educated natives and on their employment, together, suggest that foreign S&E also had a positive productivity effect in Canadian geographical areas, with a skill bias. It is, however, worth looking more carefully at the effects within non-college-educated labor to see whether some subgroups benefited while others lost. Table 10 shows the effect of foreign S&E on the wages (columns [1] and [2]) and employment (columns [3] and [4]) of native non-college-educated workers. In the specifications, as in Table 7 for the United States, we refine this educational category by separating workers into high school dropouts (columns [2] and [4]) and high school graduates (columns [1] and [3]). That distinction allows us to check whether the two groups are differentiated in their complementarity with college-educated labor.

The estimates of Table 10 show that the S&E effects on high school graduates are insignificant (the point estimate is even negative

Table 10
Foreign S&E Effect on Wages and Employment:
Split Non-College-Educated into Two Groups, Canada
(17 Canadian geographic areas;
1991–1996, 1996–2001, 2001–2006)

Specification:	(1) Weekly Wage, Native High School Graduates	(2) Weekly Wage, Native No High School Diploma	(3) Employment, Native High School Graduates	(4) Employment, Native No High School Diploma
Imputed change in foreign S&E	2.15 (1.57)	4.28 (2.70)	−0.49 (1.40)	0.89** (0.27)
Observations	51	51	51	51
Period effects	Yes	Yes	Yes	Yes
K-P Wald *F*-Statistic of the first stage	14.05	14.05	14.05	14.05

Note: Each cell includes the 2SLS estimate of the effect of growth of foreign S&E on the dependent variable listed at the top of the column. The instrument used is the imputed growth of foreign S&E workers. The specification estimated includes period effects. The standard errors are heteroskedasticity-robust and clustered at the province level. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.

for the employment effect). Conversely, the effects on wages and employment of high school dropouts are positive, and the first is close to 10 percent significance, while the second is significant at 5 percent. In particular, a 1 percentage point increase in the growth of the foreign S&E share of employment raises wage growth of native high school dropouts by 4.2 percentage points and their employment growth by 0.9 percentage points of total employment. This result is consistent with claims that S&E-driven technological progress contributed to labor-market polarization by positively affecting the demand for low-education groups (dropouts) more than for intermediate-education groups (high school graduates).

That positive and significant effect on employment of workers without a degree is an interesting sign that the benefits from S&E may diffuse in the local economy, via local demand, to workers not directly affected by the increases in productivity driven by information technology. Foreign scientists and engineers benefit college graduates, but they possibly benefit workers with low skill levels through local labor demand linkages as well.

That effect on the productivity of less educated Canadian labor was not found in the United States. That finding suggests that foreign S&E may have contributed to labor-market polarization in Canada. Technological innovation spurred by S&E may have substituted for routine cognitive tasks typically performed by workers with a high school diploma (e.g., data processing and logistical, organizational, and secretarial activities). In contrast, however, this type of innovation did not decrease the demand for manual tasks in sectors such as construction, personal care, hospitality, and home services that are typically performed by workers who are not high school educated. Hence, IT innovation did not displace the lowest-educated workers and, in fact, may have even created new jobs for those workers as college-educated individuals became richer and demanded more services. Understanding why foreign S&E would affect the least-educated workers in the United States and Canada differently is an interesting topic for future research.

7. COMPARISON WITH OTHER LOCAL GROWTH POLICIES

Attracting S&E is just one of the possible strategies often considered by local governments to promote productivity growth for a local economy. In fact, U.S. federal and state spending on such place-based policies amount to $60 billion each year (Moretti 2010). Urban economists have recently emphasized that the presence of innovative, fast-growing, and highly productive plants and industries (Greenstone, Hornbeck, and Moretti 2010; Moretti 2010) and the presence of college-educated workers (Iranzo and Peri 2009; Moretti 2004a) as two important strategies that promote local productivity growth. In this section, we control for proxies of those two growth-promoting factors and compare their effects with those from increases in H-1B-driven S&E.

Let us also notice, before proceeding further, that our identification of the productivity effect of foreign S&E has relied on measures that encompass only effects within the metropolitan areas. If S&E had productivity spillovers that go beyond the boundaries of the metropolitan area, we would miss those effects. Hence, if spillovers are more global in nature, our estimates miss a significant part of the effects, and they represent lower-bound estimates of the national productivity effect of S&E.

7.1 The Effect of High-Growth Industries

As a growth strategy, urban planners have long pursued local agglomeration of human capital–intensive and fast-growing industries. For example, Silicon Valley is often cited as a successful and productivity-enhancing agglomeration of the computer and IT sectors, and several locations have tried to reproduce its model. Although it is not clear what ingredients are needed to create such a productive agglomeration, most economists consider the presence of companies in dynamic and innovation-intensive sectors and the availability of college-educated workers as key factors for productivity growth.

According to that view, we construct a control variable for our regressions to account for sector composition. First, we take the sector composition of each metro area (indexed by *c*) in 1980 as given, and record the share of employment in each of 243 sectors (indexed by *i*) spanning manufacturing and services, $s_{i,c,1980}$. Then, we construct the growth of average wages and employment that would have occurred if each industry grew at its industry-specific national average rate between 1980 and 2010. We call those variables the "Bartik" sector-driven wage and employment growth (from Bartik 1991) in the metropolitan area.

The variables are mathematically described in equations (7) and (8):

$$(7)\qquad \left(\frac{\Delta w_{c,t}{}^{Bartik}}{w_{c,t}{}^{Bartik}}\right) = \frac{\sum_{i=1,243} s_{i,c,1980}\, w_{i,t}}{\sum_{i=1,243} s_{i,c,1980}\, w_{i,t-1}} - 1$$

$$(8)\qquad \left(\frac{\Delta Emp_{c,t}{}^{Bartik}}{Emp_{c,t}{}^{Bartik}}\right) = \frac{\sum_{i=1,243} s_{i,c,1980}\, Emp_{i,t}}{\sum_{i=1,243} s_{i,c,1980}\, Emp_{i,t-1}} - 1$$

In those two equations, $s_{i,c,1980}$ is the share of workers in city *c* who are employed in industry *t* as of 1980.[31] The terms $w_{i,t}$ and $Emp_{i,t}$ are national average wages and national total employment of workers in industry *i* in year *t*. The effect of those variables on the metropolitan area's employment and wage growth captures the effect from the

[31] Formally, $s_{i,c,1980} = \frac{Emp_{i,c,1980}}{Emp_{c,1980}}$.

1980 industrial structure of metropolitan areas. The advantage is that we can think of the predetermined 1980 industrial structure as the cause for higher or lower growth, depending on the larger or smaller share of sectors that have subsequently grown at high rates.

Evaluating the effect of those constructed variables on wages and employment allows us to establish how important the industrial structure of a metro area in 1980 was for the subsequent growth of its employment and wages. We also explore the extent to which attracting fast-growing industries, such as the computer industry, would have changed wage and employment growth in the city. At the same time, we can compare the effect of that sector-composition variable on wage and employment growth with the effect of the H-1B-driven growth in S&E. To do so, we estimate a direct regression in which we include the H-1B policy variable as well as the sector-driven employment and wage growth. Namely, we estimate

$$(9)\quad y_{c,t}^{Native,X} = \varphi_t + \varphi_s + b_{y,X}\frac{\Delta(S\&E)_{c,t}^{H\text{-}1B}}{Emp_{c,t}} + d_1^{y,X}\frac{\Delta w_{c,t}{}^{Bartik}}{w_{c,t}{}^{Bartik}} + d_2^{y,X}\frac{\Delta Emp_{c,t}{}^{Bartik}}{Emp_{c,t}{}^{Bartik}} + \gamma \cdot Controls_{c,t}^{X} + \varepsilon_{c,t}$$

In equation (9), the term $y_{c,t}^{Native,X}$ represents alternatively the wage or employment growth for group X (college-educated or non-college-educated). We directly include as explanatory variables the H-1B-driven change in foreign S&E as well as the wage and employment Bartik instruments. The remaining terms in equation (9) are the same as in equations (1) and (2), which include period (φ_t) and state effects (φ_s) and a control for the 1980 native S&E share of employment. We estimate this specification by least squares and cluster standard errors at the metro-area level.

The upper part of Table 11 shows the coefficients of the three explanatory variables on the growth of weekly wages of native college-educated workers (column [1]), on the growth of weekly wages of native non-college-educated workers (column [2]), on the employment growth of college-educated workers as a share of total employment (column [3]), and on the employment growth of non-college-educated workers as a share of total employment (column [4]). The first finding that emerges is that the effects of the H-1B-driven policy variable are not altered when we control for the Bartik instrument. The H-1B variable retains a very significant effect on the wage of college-educated workers and an insignificant effect on the wages and employment of non-college-educated labor.

Table 11
Reduced-Form Regressions of Growth Determinants: H-1B Policy, Industrial Composition, and College Enrollment Rate
219 U.S. metropolitan areas; 1990–2000, 2000–2005, and 2005–2010

	(1)	(2)	(3)	(4)
Dependent Variable:	**Growth Rate in Weekly Wage, Native College-Educated**	**Growth Rate in Weekly Wage, Native Non-College-Educated**	**Growth Rate in Employment, Native College-Educated**	**Growth Rate in Employment, Native Non-College-Educated**
H-1B Policy and Sector Composition				
H-1B-driven growth of foreign S&E	3.42*** (0.88)	−0.21 (0.64)	1.51 (1.26)	−2.05 (1.84)
Industry-predicted employment growth	−0.09 (0.50)	0.25 (0.25)	0.35 (0.25)	1.16*** (0.49)
Industry-predicted wage growth	0.09 (0.34)	0.35*** (0.13)	0 (0.25)	0.43 (0.26)
H-1B Policy and Past College Enrollment Rates				
H-1B-driven growth of foreign S&E	3.37*** (0.89)	−0.17 (0.64)	1.27 (1.18)	-2.58 (1.86)
Lagged college enrollment rate	0.05 (0.07)	0.03 (0.04)	0.07 (0.04)	0.20* (0.10)

Note: The upper part of the table shows the estimates from regressions, including the H-1B policy variable and industry-predicted growth as explanatory variables. The lower part shows the estimates from regressions with the H-1B policy variable and the five-year lagged enrollment rate in college as an explanatory variable. Each regression includes year effects, state effects, and native S&E as a share of 1980 employment. The standard errors are heteroskedasticity-robust and clustered at the metro area level. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.

Second, the presence of industries that experienced fast employment growth nationally contributed to the employment growth of metro areas, especially for non-college-educated workers. For each 1 percentage point of faster sector-driven employment growth, a metro area experienced faster college-educated employment growth by 0.35 percentage points (not significant) and non-college-educated employment growth by 1.16 percentage points (significant at the 1 percent level).

Similarly, the presence of industries with fast national wage growth contributed to city-level wage growth for non-college-educated workers (by 0.35 percentage points for each percentage point of sector wage growth). Those results imply that the industrial structure of a city—in particular, the presence of fast-growing industries—was more relevant than the inflow of H-1B S&E in boosting wages and employment of non-college-educated labor. However, the H-1B policy variable seems to have the largest and most significantly positive effect on wages paid to college-educated workers. Thus, attracting S&E seems to be a key to productivity growth for the college-educated.

As the units for the explanatory variables are different, we cannot directly compare the magnitude of the estimated coefficients in Table 11. Therefore, we provide some calculations of the magnitude of each effect. The standard deviation across metro areas for both the industry-imputed growth of employment and of wages (Bartik) in a decade was about 0.01. The standard deviation for the H-1B imputed policy variable across metro areas in one decade was 0.004. Hence, an increase in the sector-driven wage variable by 1 standard deviation produced an increase in wage growth of non-college-educated workers of 0.35 percentage points in a decade, while an increase in the H-1B imputed inflow of S&E increased the wage growth of college-educated workers by 1.4 ($= 0.004 \times 3.42$) percentage points in the decade. A similar increase of 1 standard deviation in the employment-imputed Bartik would also increase employment growth of non-college-educated labor by 1.16 percentage points in a decade. Those effects are economically significant.

Perhaps a more interesting and policy-relevant exercise is to consider a specific case, such as the effect of increasing the size of the computer sector[32] in a metro area from its average value of 1.5 percent

[32] We consider the computer sector to be two industries called "computers and relative equipment" and "computer and data-processing services."

of total employment in 1990 to the value in San Jose, Calif.—home to Silicon Valley—of 10 percent of employment. Because the computer sector experienced much faster than average employment and wage growth, this jump from the national average to the Silicon Valley level would be captured by increases in our predicted (Bartik) employment and wage growth by 4 percent and 1 percent per decade, respectively. Those two changes together imply (using the statistically significant coefficients in Table 11) a 1.4 (= 4 × 0.35) percentage point faster growth for non-college wages during the decade and a 1.16 percentage point faster growth for non-college employment because of the larger computer industry (0.43 × 4 + 1.16). There would be, however, no significant effect on wages and employment of college-educated labor.

In comparison, if we were to change the H-1B-driven growth of foreign S&E in a city from the average value in the 1990–2000 decade (0.4 percent) to the value in San Jose (2 percent), the coefficient in Table 11 suggests that change would result in an increase in the wage growth of college-educated workers by 5.47 (= 1.6 × 3.42) percentage points in the decade. Overall, the inflow of foreign S&E had the most significant effect in raising the wage growth of college-educated native workers in U.S. cities. The presence of fast-growing industries, instead, seems to have affected employment growth in a broader way, especially for the non-college-educated, as well as for wages paid to non-college-educated workers.

7.2 The Effect of College Enrollment

College-educated workers are an important determinant of local wages and productivity through local externalities.[33] That is the reason we introduced the 1980 share of college-educated workers in one specification of Table 6: so we could control for preexisting human capital agglomeration and its effect on productivity growth. In this section, we consider city-level policies designed to attract workers with a college degree. Although explicitly targeting the inflow of college-educated workers is a rare policy, many cities attempt to increase the college enrollment of its college-aged citizens—either by increasing the number of local colleges or by expanding their size—in hopes that those individuals will graduate and improve the local work force. Therefore, we test enrollment rates lagged by

[33] See, for instance, Moretti (2004a).

five years as a predictor of a city's wage and employment growth. We do recognize that policies aimed at increasing enrollment will likely produce smaller effects than expected if the mobility of recent college graduates were not accounted for, since college students are not mandated to work and live in the same city after graduation.[34]

The bottom part of Table 11 shows the effect of the H-1B policy variable together with the effect of college enrollment rates, calculated as the number of individuals enrolled in college between ages 18 and 25 relative to the working-age population (18–65) in the period (10 or 5 years) before the considered interval. The regressions include the usual 219 metro areas in the time periods 1990–2000, 2000–2005, and 2005–2010. The estimated coefficients in rows 4 and 5 of Table 11 show that the inclusion of lagged college enrollment rates does not change the effect of H-1B visa-driven S&E. Enrollment itself has only a very mild effect on the employment growth of non-college-educated workers in the metro area. An increase in the lagged college enrollment rate by 1 standard deviation (0.05) would increase employment growth by 1 percentage point for non-college-educated labor. The effect on metro area wages is negligible.

7.3 Combining Policies

It is interesting to ask whether the effectiveness of the H-1B policy on native wages is particularly strong in metropolitan areas with the "right" sector composition. After all, foreign-born S&E have fueled the growth of the information, communication, and computer sectors, and it makes sense to check whether the productivity effects were stronger in metro areas where those sectors were large. That exercise will speak to the opportunity of potentially combining policies for growth (attracting industries as well as promoting immigration of S&E). To check the productivity effects, we construct a dummy that equals 1 in metro areas that experienced fast sector-driven employment growth. In particular, if a metro area had a sector-predicted (Bartik) employment growth of 20 percent or more in a decade, the

[34] Lagged enrollment also helps avoid spurious correlation caused if unobserved factors affect productivity and current college enrollment. Lagged enrollment is somewhat predetermined with respect to demand shocks taking place five years later. Moretti (2004a) uses the establishment of land-grant colleges in a metropolitan area as the exogenous factor affecting the share of college-educated workers decades later.

dummy is 1; otherwise it is 0. The dummy captures those metro areas with a large share of employment in sectors such as "computers and relative equipment" that grew very quickly during the observed time period. For about 25 percent of the observations, the dummy equals 1. We then interact that dummy with the H-1B-driven growth of S&E and include that interaction in a regression otherwise similar to Table 11.

Column (1) of Table 12 shows the estimated effects on the real wage growth of native college-educated labor when including that interaction. Very interestingly, we notice that the whole productive effect of the H-1B policy is concentrated in the cities with rapidly growing industries. The main effect of the H-1B variable is not statistically significant, whereas an increase of H-1B among the cities with fast-growing sectors (interaction term) by 1 percentage point of employment increased wages of college-educated natives by 8.3 percentage points. The combination of a high inflow of H-1B labor and the presence of fast-growing sectors is a powerful combination for wage growth.

Column (2) of Table 12 shows results from a regression interacting H-1B growth with an indicator for cities exhibiting a large lagged share of college enrollment (larger than 0.12), otherwise similar to the one in the lower part of Table 11, column (1). The estimated coefficients do not reveal any stronger effect of foreign S&E in cities with larger college enrollment.

7.4 Simple Policy Calculations: The Long-Run Effect of Raising the H-1B Cap

We close our analysis by combining the estimated effects of Table 11 and the average inflow of H-1B visas between 1990 and 2010 to calculate the overall effect of that program on the wages of native college-educated workers. First, the average estimates from Table 11 suggest an effect of H-1B-driven S&E on the wage of native college-educated labor equal to 3.4. Second, the average yearly inflow of H-1B visas during the same two decades (about 97,000 visas per year on average) corresponds to an annual increase of 0.05 percentage points of the labor force. Together, they suggest that a continued H-1B-induced inflow of S&E produced a faster growth of wages paid to native-born college-educated labor by ($0.05 \times 3.4 =$) 0.17 percentage points per year. Over 20 years, that result translates to real wage

Table 12
Interactions between H-1B Policy and Industrial Composition or College Enrollment Rate (219 U.S. metropolitan areas; 1990–2000, 2000–2005, and 2005–2010)

Dependent Variable: Growth rate in weekly wage, college-educated natives	**(1)** **Interaction H-1B-Sector Composition**	**(2)** **Interaction H-1B-College Enrollment**
H-1B Policy and Sector Composition		
H-1B-driven growth	−0.90 (0.99)	
Industry-predicted employment growth	−0.15 (0.50)	
H-1B-driven growth × high predicted employment growth	8.30*** (2.16)	
H-1B Policy and Past College Enrollment Rates		
H-1B-driven growth		3.37*** (0.91)
Lagged college enrollment rate		0.05 (0.09)
H-1B-driven growth × high predicted employment growth		0.01 (2.27)

Note: The dependent variable is the growth rate in weekly wage of college-educated natives. Each specification includes year effects, state effects, and the native S&E share of 1980 employment. The standard errors are heteroskedasticity-robust and clustered at the province level. ***, **, and * indicate significance at the 1, 5, and 10 percent levels, respectively.

gains equal to 3.5 percentage points. If we consider that the observed average growth of real wages paid to native-born college-educated labor over the period equaled about 13 percentage points,[35] then our accounting exercise attributes one-fourth of wage growth to H-1B-driven increases in S&E. As S&E are the drivers of technological growth, which is likely responsible for most of the long-run wage

[35] This combines the decade of the 1990s, in which there was rapid economic growth, with the first decade of the 2000s, in which the real wage slightly declined.

growth of college-educated workers, it is plausible that foreigners, who drove almost half of the S&E increase, are responsible for one-fourth of wage growth.

Next, suppose that the annual number of H-1B entrants were to rise by 50,000, as has been proposed by the current comprehensive immigration reform (from 65,000 to 115,000). That rise represents about 0.03 percent of the labor force and could, therefore, add an extra 2 percentage points to income per capita of native college-educated workers over the next 20 years (or roughly increase yearly wages by $1,330 per college-educated worker over that period). Those productivity effects, driven by the growth of S&E and their contribution to technology innovation, are certainly nonnegligible and persistent contributors to economic prosperity of the native economy.

8. CONCLUSIONS AND DISCUSSION

Many countries compete for internationally mobile S&E, believing that such labor will generate economic benefits for the domestic populace. This study provides a serious attempt at quantifying the effect of foreign S&E on the labor outcomes of native workers in local receiving economies. We analyze the United States and Canada, two countries that received a large majority of all international emigrant S&E. We then provide an evaluation of the H-1B program since its inception to the current decade and estimate the effect for the U.S. economy if the government approved an increase of 50,000 H-1B visas per year over the next 20 years.

Our analysis relies on an identification strategy exploiting historical variation in immigrant science and engineering populations across cities, combined with national-level changes in skilled-labor flows. For the United States, we use cross–metropolitan area variation and the aggregate H-1B visa flows as an exogenous shock, whereas in Canada we use cross-province variation and aggregate inflows of S&E driven by the FSWP. We test our instruments against a battery of robustness checks to see that they are robust to several controls and to validate that they are supply-driven determinants of S&E flows across cities. We find that foreign S&E increase the wages paid to college-educated natives without creating detrimental labor-market effects for any other group of native-born workers (non-college-educated overall, or separately considering high school graduates and high school dropouts). Our analysis of Canada shows possible signs that the inflow of foreign S&E may have contributed to labor-market polarization.

Political rhetoric and debate over immigration reform in the United States have been building momentum and were further elevated in 2013 by the passage of Senate Bill 744, a comprehensive proposal to reform immigration policy. Our methodology allows us to perform policy evaluation for skilled-immigration programs, namely, the H-1B program in the United States. We find that H-1B visas awarded from the program's inception in 1990 through 2010 resulted in an augmented science and engineering labor pool that raised the growth rate of wages paid to native-born college-educated workers by 3.5 percentage points—a figure accounting for roughly a fourth of their total wage growth over that period. If policymakers approve an additional 50,000 H-1B visas per year, as has been suggested by recent proposals, they should generate an extra 2 percentage points in wage growth for native-born college-educated workers over the next 20 years. We also find that, with regard to wage effects, those benefits far exceed those generated by other commonly advocated policies for promoting growth, such as attracting high-growth industries into a city or attracting college students. We also found some evidence that those beneficial wage effects are particularly strong in metro areas with fast-growing sectors.

Although we made no attempt to quantify the potential costs of the considered growth-promoting policies—an important part of full policy evaluation—there are three reasons that the cost of expanding the H-1B visa program may actually be negligible, could generate additional benefits (besides growth), or both. First, the cost of administering and expanding the H-1B visa program, linked mainly to labor verification and processing of forms, is essentially fully covered by the fees paid by companies that sponsor the workers. It does not entail further cost for the government. To the contrary, efforts to attract sectors or companies are usually achieved with tax cuts that cost the state revenue, while establishing or expanding new universities may also have a large investment cost. Second, temporary immigrants who work in science and engineering receive high incomes and pay more in taxes than they receive in public benefits, hence representing a net return for the federal and state governments. Third, an increase in the overall H-1B program could possibly benefit all local economies in the United States and could also have some larger national spillover effects.

Other city-level growth-promoting strategies, instead, might be a zero-sum game. For example, city policies to attract fast-growing industries often divert economic activity from other localities. Efforts to increase local university presence can easily lead to graduates who move and contribute economically elsewhere.

More research and quantitative assessment in this area are certainly needed to continue to provide insight into the importance of immigration policy's economic effects. In particular, understanding the effects of international labor flows would be improved with further examination of other countries that have similarly received high inflows but have institutional structures that differ from the United States.

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APPENDIX. CANADIAN DATA AND FIRST-STAGE ESTIMATES

The source of our Canadian data on occupations, employment, wages, rents, age, education, and nativity of individuals are provided by Statistics Canada. We use the Canadian Census Public Use Microdata File on Individuals (PUMFI)[36] in 1981, 1991, 1996, 2001, and 2006. The 1981 PUMFI is a 2 percent sample, and the 1991–2006 files are roughly 3 percent samples.[37] To protect the confidentiality of surveyed individuals, the Census Bureau recoded PUMFI variables to highly aggregate resolutions. In particular, PUMFIs identify only an individual's province[38] of residence and sometimes the census metropolitan area (CMA) in regions with large populations, thereby greatly reducing the available geographic variation. Thus, the geographical level at which we can aggregate our data is constrained by the available geographic codes in the PUMFIs.

We use data on 17 geographic areas that can be consistently identified over the period 1981–2006. Fourteen of those are metropolitan areas, including some large CMAs (Toronto, Montreal, Vancouver, Calgary, and Ottawa), and smaller CMAs (Quebec City, Hull, St. Catherines–Niagara, London, Hamilton, Winnipeg, Edmonton, Halifax, and Kitchener). We also include provinces that have no identified CMAs and hence are considered as such (Saskatchewan, New Brunswick, and Newfoundland and Labrador). That concatenation of provinces and CMAs into geographic areas is due largely to data constraints, but it does afford an interpretation of those geographic areas as labor markets. Metropolitan areas are compact economic units, and the three small provinces that we add can also be considered as relatively self-contained. Our study refers to those 17 geographic areas or local labor markets.

[36] These micro data of the Canadian Census are the only ones available to non-Canadians.

[37] The file for 1991 is a 3 percent sample; the 1996 file is a 2.8 percent sample; and the 2001 and 2006 files are 2.7 percent samples.

[38] Canada officially has 10 provinces: Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland and Labrador, Nova Scotia, Ontario, Prince Edward Island, Quebec, and Saskatchewan. The PUMFI identifies them and defines an 11th province, which is the aggregation of the three territories: Northwest Territories, Nunavut, and Yukon.

To construct the S&E occupations, we first rank occupations on their intensity of employment with a postsecondary degree in a science and engineering field.[39] Then, we classify S&E as the top-ranked in science-major intensity that constitute around 10 percent of employment in each year. Thus, a scientist or engineer is an individual who works in one of those science and engineering occupations.

We construct a variable that captures the supply-driven increase of foreign S&E in each of the 17 geographic areas between 1991 and 2006, similar to what we did for the United States, as described in Section 4.2. A key difference for Canada, however, is that we construct the aggregate growth of immigrant S&E by nationality in each period using Canadian census data (on all immigrants) rather than the H-1B data.

A.1 First Stage for Canadian Data

The growth of foreign S&E in a Canadian geographic area was driven in part by immigrant preferences, affected by the historical distribution of immigrants in 1981, but also by demand and productivity increases. In this section, we analyze how the supply-driven increase in foreign S&E affected the net observed increase in foreign S&E across Canadian geographic areas. We estimate specification (5) in the text using the imputed foreign S&E as the explanatory variable.

The coefficient of interest is b_1, which measures the effect of imputed–foreign S&E inflows on the actual increase in foreign S&E workers. It is reported in Table A3 for several specifications. We include t = 1991, 1996, 2001, 2006 so that the changes Δ refers to the periods 1991–1996, 1996–2001, and 2001–2006.

In specification (1) of Table A3, we do not include any fixed effects. In specification (2), we include period fixed effects (this is the basic specification), and in specification (3) we include the more demanding province and period fixed effects. If we consider that we have only 51 area-by-period observations, then the last specification with 13 fixed effects is very demanding. The effect of supply-driven S&E is always significant at the 5 percent level, and its value is always

[39] Postsecondary majors are identifiable from 1991 to 2006, and science and engineering fields are defined as agricultural science and technologies, engineering, applied sciences and related technologies and trades, nursing and nursing assistance, other health professions, and mathematics and physics.

close to 1. That finding implies that an increase in supply-driven immigrant S&E by 1 percentage point of employment increases the actual foreign S&E share of employment by 1 percentage point. Note that the *F*-statistic of 17.93 in the basic specification is well above the critical value for weak instrument tests (usually set around 10). Only when we include province effects does the imputed variable (though still significant) become less powerful in predicting foreign S&E (*F*-statistic equal to 4.91).

In column (4) of Table 4, we explore whether the imputed foreign S&E variable had a significant effect on the total increase in all S&E (including native workers). Although less powerful than in predicting foreign S&E, the imputed variable has a significant effect (at the 5 percent level) on the growth of total S&E (as percentage of the employment).

Table A1
S&E Classifications

A. O*NET Occupations Classified as Science and Engineering Jobs	
Actuaries	Licensed practical nurses
Aerospace engineers	Machine operators
Agricultural and food scientists	Machinery maintenance occupations
Airplane pilots and navigators	Machinists
Atmospheric and space scientists	Management analysts
Automobile mechanics	Managers of medicine and health occupations
Biological scientists	Mathematicians and mathematical scientists
Biological technicians	Mechanical engineers
Boilermakers	Medical scientists
Carpenters	Millwrights
Cementing and gluing machine operators	Not-elsewhere-classified engineers
Chemical engineers	Operations and systems researchers and analysts
Chemical technicians	Other science technicians
Chemists	Petroleum, mining, and geological engineers
Chief executives and public administrators	Physicists and astronomers
Civil engineers	Plant and systems operators, stationary engineers
Computer software developers	Plasterers
Construction inspectors	Plumbers, pipe fitters, and steamfitters
Drafters	Power plant operators
Drillers of oil wells	Programmers of numerically controlled machine tools
Drilling and boring machine operators	Rollers, roll hands, and finishers of metal
Electrical engineer	Sales engineers
Elevator installers and repairers	Secondary school teachers
Engineering technicians	Statistical clerks
Explosives workers	Supervisors of agricultural occupations
Farm managers, except for horticultural farms	Supervisors of mechanics and repairers

(continued)

Table A1
(continued)

A. O*NET Occupations Classified as Science and Engineering Jobs	
Geologists	Surveyors, cartographers, mapping scientists
Heating, air conditioning, and refrigeration mechanics	Tool and die makers and die setters
Industrial engineers	Veterinarians
Lathe, milling, and turning machine operatives	Water and sewage treatment plant operators

B. Occupations Classified as Requiring a Science and Engineering College Major	
Actuaries	Mechanical engineers
Aerospace engineers	Medical scientists
Agricultural and food scientists	Metallurgical and materials engineers
Airplane pilots and navigators	Not-elsewhere-classified engineers
Atmospheric and space scientists	Occupational therapists
Biological scientists	Optometrists
Biological technicians	Other health and therapy
Chemical engineers	Petroleum, mining, and geological engineers
Chemical technicians	Pharmacists
Chemists	Physical therapists
Civil engineers	Physicians
Clinical laboratory technologies and technicians	Physicians' assistants
Computer software developers	Physicists and astronomers
Computer systems analysts and computer scientists	Podiatrists
Dentists	Psychologists
Dietitians and nutritionists	Sales engineers
Electrical engineers	Speech therapists
Geologists	Subject instructors (HS/college)
Industrial engineers	Therapists
Management analysts	Veterinarians
Mathematicians and mathematical scientists	Vocational and educational counselors

(continued)

Table A1
(continued)

C. College Majors Classified as Science and Engineering Fields

Aerospace Engineering	Industrial and Organizational Psychology
Animal Sciences	Industrial Production Technologies
Applied Mathematics	Information Sciences
Architectural Engineering	Library Science
Astronomy and Astrophysics	Materials Engineering and Materials Sciences
Atmospheric Sciences and Meteorology	Materials Science
Biochemical Sciences	Mathematics
Biological Engineering	Mathematics and Computer Science
Biology	Mechanical Engineering
Biomedical Engineering	Mechanical Engineering Related Technology
Botany	Medical Technologies Technicians
Chemical Engineering	Metallurgical Engineering
Chemistry	Microbiology
Civil Engineering	Military Technologies
Clinical Psychology	Mining and Mineral Engineering
Cognitive Science and Biopsychology	Miscellaneous Biology
Communication Disorders Sciences	Miscellaneous Engineering
Computer and Information Systems	Miscellaneous Engineering Technologies
Computer Engineering	Miscellaneous Psychology
Computer Information Management	Molecular Biology
Computer Networking and Telecommunication	Multi-disciplinary or General Science
Computer Programming and Data Processing	Naval Architecture and Marine Engineering
Computer Science	Neuroscience
Counseling Psychology	Nuclear Engineering
Ecology	Nuclear, Industrial Radiology, and Bio
Educational Psychology	Nutrition Sciences
Electrical Engineering	Oceanography

(continued)

Table A1
(continued)

C. College Majors Classified as Science and Engineering Fields	
Electrical Engineering Technology	Petroleum Engineering
Engineering and Industrial Management	Pharmacology
Engineering Mechanics, Physics	Pharmacy, Pharmaceutical Sciences, and Treatment Therapy Professions
Engineering Technologies	Physical Sciences
Environmental Engineering	Physics
Environmental Science	Physiology
Food Science	Plant Science and Agronomy
General Engineering	Psychology
General Medical and Health Services	Social Psychology
Genetics	Soil Science
Geological and Geophysical Engineering	Statistics and Decision Science
Geology and Earth Science	Transportation Sciences and Technologies
Geosciences	Treatment Therapy Professions
Health and Medical Preparatory Programs	Zoology
Industrial and Manufacturing Engineering	

Table A2

H-1B Visas Composition by Place of Origin

Region	**Percentage of Total, 1990–2000**	**Percentage of Total, 2000–2010**
Africa	3	2
Canada	0	0
China	5	7
Eastern Europe	5	4
India	45	47
Japan	3	3
Korea	1	3
Mexico	3	4
Oceania	2	1
Philippines	3	3
Rest of Americas	5	8
Rest of Asia	1	9
Western Europe	16	11
Other	0	0
Total H-1B visas	709,505	1,321,028

Table A3
Predictive Power of the Imputed Increase in Foreign S&E, Canadian Data (17 Canadian geographic areas; 1991–1996, 1996–2001, 2001–2006)

	(1)	(2)	(3)	(4)
Dependent Variable:	**Change in Foreign S&E as % of Initial Employment**	**Change in Foreign S&E as % of Initial Employment**	**Change in Foreign S&E as % of Initial Employment**	**Change in Total S&E as % of Initial Employment**
	1.00***	1.16***	1.28**	1.32**
Imputed change in foreign S&E	(0.24)	(0.31)	(0.58)	(0.52)
Observations	51	51	51	51
Period Effects	No	Yes	Yes	Yes
Province Effects	No	No	Yes	No
F-test of the Coefficient	17.93	14.05	4.91	6.43

Note: Each column reports coefficients from a separate regression. The units of observations are 17 Canadian metro areas and provinces over the periods 1991–1996, 1996–2001, and 2001–2006. The dependent variable is described at the top of the column. Each regression includes the 1980 native S&E and share of employment as a control. The explanatory variable is always the imputed growth of foreign S&E workers as a percentage of initial employment. ***, ** and * indicate significance at 1, 5, and 10 percent level, respectively.

Comment

Daniel Shoag

Few papers attempt to address real-world policy questions and to demonstrate important theoretical concepts at the same time. Giovanni Peri, Kevin Shih, and Chad Sparber have done that in their intriguing paper on foreign scientists, H-1B visas, and economic growth. They find that those foreign science and technology workers have very large positive local externalities, with each one raising the incomes of his or her neighbors somewhere in the tens—or perhaps even hundreds—of thousands of dollars per year. Such large externalities obviously have important implications for H-1B visa limits and immigration policy. The authors also provide evidence of substantial local knowledge spillovers, a concept that is frequently discussed in the urban economics literature but that has mostly proved empirically intractable.

Although I think highly of this paper, as a discussant I am obliged to express some reservations. As with most empirical papers, the identification assumptions are imperfect, and omitted variable bias might inflate the externalities being estimated. Extrapolating from the cross-sectional results to aggregate effects, as the authors do in their discussion, requires a leap (or several) beyond the data. I discuss both of those issues in depth below. Still, I think theirs is an important contribution; I am very glad to have read it and I encourage you to read it too.

Identification Assumptions

Immigration patterns are related to city-level growth rates in complex, forward-looking ways. The major contribution of this paper is in wrestling with that problem seriously by taking an instrumental

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variables approach. The paper constructs a predicted inflow instrument for each city using the city's initial share of immigrants from each country and the aggregate flows from those countries to the United States. That instrument is a good predictor of actual city-level inflows because immigrants from specific countries tend to move to the same locations over time. In other words, Chinese immigrants tend to move to cities with large Chinese communities, Moroccan immigrants tend to move to cities with large Moroccan communities, and so on. The total number of Chinese immigrants to the United States is a good predictor of immigration to cities with large Chinese communities.

For the instrument to be 100 percent valid, though, it must be orthogonal to other changes in the local economy. If aggregate country-level flows were determined by national H-1B visa policy, that would be a natural assumption. Unfortunately, for most of the data examined in this paper, that is not the case. Until 2004, aggregate country-level flows seem to be driven more by the complex, forward-looking decisions of individual migrants than by arbitrary regulations.

The predictive power of the instrument stems from the fact that immigrants from one country are disproportionately likely to move to a subset of cities. It makes sense, then, that those aggregate flows would also be disproportionately influenced by the economic prospects of those cities. If that's the case, the instrument no longer reliably captures only the causal effect of immigration. For example, if Moroccan immigrants are concentrated in five cities, aggregate migration from Morocco will depend on the average economic shocks occurring in those cities. Using the aggregate flow as an instrument might still produce biased results, even if the aggregate flow is largely independent of the outcome of any single city.

Does that confounding effect explain all of the results the paper documents? I highly doubt it. Still, I think it's important to note that there are potential sources of bias working in the same direction as the estimated effect.

Setting aside those concerns, the analysis in the paper also relies on the assumption that initial settlement patterns were not correlated with subsequent "technological and demand shocks." If initial patterns are correlated with those shocks, the analysis, again, can't fully isolate the causal effect of migration.

The paper notes that the percentage of foreign-born scientists and engineers is not randomly distributed across locations. That percentage is, intuitively, highly correlated with the total percentage of foreign-born residents. In my clumsy fumbling with analogous Integrated Public Use Microdata Series data, I find both the share of foreign scientists and the share of foreign-born workers in 1980 were highly correlated with the total share of scientists,[1] college attainment, and income.

We know that workers with higher incomes and better education received a different set of shocks over the past 30 years than their lower-income, less educated contemporaries. Skill-biased technological change, import competition from China, and tax code changes all affected skilled and unskilled cities differently. Given the nonrandom assignment of foreign scientists, those effects could also generate omitted variable bias absent sufficient controls.

The authors try valiantly to address that problem, but I am concerned that the specifications used in this paper cannot completely control for the differential shocks. The type of bias I raised above calls for city-level fixed effects, evenly spaced time intervals and controls, and spatial correlation corrections.[2] The most convincing possible specifications would go further still and control for different time effects for skilled and unskilled cities and other interaction terms. Placebo tests could also demonstrate that their instrument does not correlate with industry or demographic predicted wage and employment growth. I doubt the data are sensitive enough to allow for those kinds of controls and tests in every regression, and the paper does a good job within the bounds of that constraint. Ultimately, though, the goal is to compare wage growth in otherwise identical places, one with foreign scientists and one without. I am worried that the results are sometimes driven by comparing changes in places that systematically differ along other dimensions.

No empirical study is ever perfect, and my concerns about identification in this exercise could be leveled against many papers. Still, I think some caution should be exercised in attributing the full effect of the wage growth to the immigration mechanism alone.

[1] Surprisingly, the paper finds no correlation between the percentage of foreign scientists and native scientists under one classification of scientific workers. Under the other definition, and in my replication attempts, there is an intuitive positive association.

[2] The authors do include some of these controls in robustness tests. They reassuringly have little effect on the results.

Interpretation

The paper shows that cities receiving more foreign science and technology workers, for whatever reason, experience faster wage growth than other cities. That is a relative, not absolute, effect. The data cannot say whether the effect occurs because cities with more immigrants grew faster or whether the "other" cities grew more slowly. The authors favor the first interpretation, and, in fact, tout immigration as an alternative to other "zero-sum" growth policies. I agree that this interpretation seems plausible. Even so, it is certainly possible that the latter interpretation is true. Immigration by foreign scientists may have caused industries to move or high-skilled talent to relocate in ways that magnify the local effect without increasing the overall pie. Simultaneously, the presence of foreign scientists might also affect the incentives of natives to pursue an education, thus altering the domestic skill mix. The paper does not, and perhaps cannot, address those possibilities or quantify them. As a result, it is hard to know whether the large local effects represent gains from allowing more immigration nationally or whether immigration simply creates geographic or skill-based winners and losers.

At the same time, it seems unlikely that the positive spillovers of foreign workers are primarily local. The paper imagines those spillovers as the result of immigrants "generating innovations and developing technologies." In general, it would seem like those types of advances would diffuse rapidly across cities. I have trouble assessing what the relative local gains estimated here imply about the national benefits. Could the benefits of foreign migration be an order of magnitude larger than the estimates here? Could they be several orders of magnitude larger? It is difficult to imagine, given that the local estimates alone imply that H-1B visas can account for 25 percent of the wage growth of college workers from 1990 to 2010. That said, the value of empirical work is to update one's priors, and this paper has certainly made me rethink just how important immigration policy might be.

To sum up, I think the authors have done a great job attacking a very challenging and relevant empirical problem. The paper deals with the problem carefully, and though I think there are still some issues with the analysis, the results highlight just how critical it is to design our immigration system well. I hope that this message and the thoughtful research underlying it have an effect on the policymakers who are designing that system.

Comment

Jeffrey Smith

In their fine contribution to this volume, Peri, Shih, and Sparber examine the economic effect of foreign scientists and engineers (S&E) who enter the United States via the H1-B visa program and who enter Canada via the qualitatively similar Foreign Skilled Worker Program. Doing so presents a serious challenge to the empirical researcher because both programs operate at the national level.

One natural approach would try to exploit variation over time in the number of visas issued. Several concerns militate against adopting that empirical strategy, however. First, the H1-B program began in 1990, meaning that only a relatively short time series exists with which to estimate effects. Second, the available time series provides only limited variation, and some of that variation comes in the form of changes in the nature of those eligible for H1-B visas rather than in the simple number of such visas. Third, the extent and timing of the changes we observe likely reflect endogenous policy responses to economic shocks, and so they lack the exogeneity required for straightforward interpretation.

Given those problems with relying solely on the time-series variation, Peri, Shih, and Sparber wisely choose an alternative empirical strategy. Their approach relies on variation across cities in the number of immigrant S&E to identify the effects of such immigrants on the labor-market outcomes of native workers. That strategy has a long tradition in the broader literature that examines the effects of immigrants on natives. Because immigrant S&E choose which cities to move to, rather than being randomly allocated in some vast favor to the research community, the authors cannot simply correlate

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native outcomes at the city level with some function of the number of current or past immigrant S&E. Instead, they rely on an instrumental variables strategy about which I will say more later.

The authors find quite large positive effects on the wages and employment of high-skill natives in both the United States and Canada. In Canada, they find some positive effects of immigrant S&E on low-skill workers as well.

The Quality of the Music Depends on the Quality of the Instruments

Following a long tradition in the literature, the authors use historical migration patterns as instruments for current migration patterns. I like to refer to this as an example of the "fine wine" theory of instrument selection, as it presumes that particular variables, like fine wine, improve with age by becoming more exogenous—and thus more pleasing to the "instrument police."

The particular instrument used here relies on historical shares of immigrant S&E from particular countries in particular cities. Those historical shares represent a valid instrument only if they do not correlate with the unobserved component of future outcomes (i.e., with the error terms in the authors' outcome equations). The authors recognize this issue and devote much of their Section 4.3 to providing evidence that the reader should not worry overmuch about it. I applaud the authors' efforts, but it remains the case that if you take their estimates seriously and project them back in time to early cohorts of immigrant S&E, then the instrumental variable condition should fail, as cities with more immigrant S&E in the past should have differentially large employment and wage growth (for the relevant groups) during the period the authors study. To avoid that conclusion, I think the authors would have to argue either that earlier cohorts had smaller effects than the cohorts they study, or that immigrant S&E effects fade out over time, which would affect the interpretation of their own estimates.

Interpretation: Heterogeneous Coefficients

We often speak of "the" effect of a program or policy, but in fact the effects of policies vary along many different dimensions. In the context of the authors' paper, I want to highlight three dimensions on which thinking more about heterogeneity in the effects of H1-B policy (or its analogue in Canada) would add to our understanding of their results and to their policy relevance. First, should we think of those effects as short-run effects, medium-run effects, or long-run effects? Given the 5-year and 10-year calendar time windows (and I would have used the results with windows of equal length as the primary results in the paper precisely to make the interpretation clearer on this dimension), it seems that they combine all three. The change in an outcome of interest from 1 year to 10 years later captures the short-run effects of S&E who arrive late in the window, the medium-run effects of workers who arrive in the middle of the window, and the long-run effects of workers who arrive early in the window. Given this sort of omnibus parameter, more discussion of the likely relative magnitudes of the effects at different points in time following worker arrival would aid the reader and improve the cost-benefit analysis.

Second, we care about the effect that existing H1-B workers have had on average on economic outcomes because we can compare that parameter with the costs of the H1-B program and provide an answer to the question of whether the existing program passes a cost-benefit test. However, we might expect—either because of diminishing marginal quality of H1-B visa recipients or for reasons related to the shape of the production function—that the effect of additional immigrant S&E at the margin of admission might differ from the average effect of those admitted under the current policy. In thinking about an expansion in the number of H1-B visas like that suggested by the authors, the average effect at current levels likely provides an upper bound on what additional workers would bring. The policy discussion would benefit from additional attention to that aspect of the problem.

Finally, in the context of heterogeneous coefficients, we might imagine that the particular instrumental variable employed here sweeps out a nonrandom subset of migrants and, as a result, a nonrandom subset of responses to migration. The analysis in this paper estimates the effect of immigrant S&E who choose their location in the United States or Canada based on the locations (or based on factors correlated with the locations) of earlier cohorts of immigrant S&E from the same source countries. Should we expect those immigrants to have the same effects on native outcomes as a randomly selected immigrant? One can tell different stories.

Such immigrants might have larger effects if the presence of a preexisting community of immigrant S&E from the same source country speeds assimilation or, perhaps, allows them to work more efficiently because they have colleagues with the same native language and background. Conversely, perhaps the immigrants who locate in that way represent the less adventurous and innovative immigrants in their cohorts. In this case, the instrumental variable estimates obtained by the authors might understate the effect of a randomly selected foreign science or engineering worker. Whatever the story, future research should pay more attention to that aspect of heterogeneity.

Interpretation: Size Matters

Peri, Shih, and Sparber credit H1-B visa holders with causing a quarter of the total wage growth for college-educated natives over the period 1990–2010. That is a huge effect! It also seems like an implausibly large effect. Let me give one reason as to why. According to their Table 1, immigrant S&E in metro areas average about 20 percent of the science and engineering work force over that period. If we assume that domestic S&E have the same effect on wages and employment as immigrant S&E, then S&E taken together explain 125 percent of the wage growth of college-educated natives over the period. Not only would that result leave no room for factors such as technological change, it implies that the net effect of other factors is to reduce wages. Thus, in my view, to make the magnitude of the authors' estimates credible requires, for example, an argument as to why immigrant S&E have differentially positive effects on wages.

Stepping back a bit to think more broadly about the estimates suggests further concerns. To the extent that immigrant S&E create general knowledge that leads to productive innovation, we would expect knowledge, at least in the medium to long run, to have effects everywhere, not just effects that are local to specific cities. If that process occurs within 5 or 10 years, then that aspect of what immigrant S&E do gets captured not in the coefficient estimates the authors focus on, but rather it gets differenced out as part of the implicit period effect. For that reason, the authors actually understate the total contribution of immigrant S&E to U.S. output growth, something I am surprised that the authors do not say more about.

This literature would benefit from additional efforts to parse out the overall contribution into its general and city-specific components and from efforts to determine how long it takes general contributions to fully spread.

Interpretation: Microfoundations and Alternative Frameworks

As Peri, Shih, and Sparber acknowledge, their estimated effects on employment and wages combine responses by natives on a number of dimensions. When employment of native S&E increases in cities that immigrant S&E choose to live in, for example, that increase could reflect (a) changes in the schooling response of natives (for example via college students in the relevant cohorts changing their majors), (b) occupational switches by S&E currently working in other types of jobs, (c) labor force participation choices by S&E initially out of the labor force, or (d) migration of S&E from other labor markets. Microfounding (my macroeconomist colleagues assure me that "microfound" is a proper verb) the aggregate effects by estimating the relative importance of those pathways would aid in understanding how the estimated effects come about.

Such analyses have precedent in the literature. For example, Cadena (2013) looks at migratory responses by natives in a more general immigration context; Jackson (2013) considers the response of natives' educational investments to immigrant shocks; and Cortes (2008) looks at the related issue of the effects of immigrants on price levels. All three papers operate within the city-level analytic framework employed by Peri, Shih, and Sparber.

To the extent that migration of native S&E between cities plays an important role, the framework here starts to wobble a bit, for it is ill-suited to either the interpretation or estimation of such general equilibrium effects. In that regard, further work using alternative frameworks that explicitly incorporate general equilibrium considerations, such as the search framework employed by Chassamboulli and Palivos (2014) or the spatial equilibrium models used in the urban economics literature, such as Albouy (2009), would add great value to the literature. Even in the context of the current paper, more attention to equilibrium effects in interpreting the results would enrich our understanding of the findings.

Bottom Lines

In sum, the authors deserve credit for tackling an important substantive problem with great policy relevance, despite the many difficulties with which it confronts the empirical researcher. And they have made some useful headway on the problem and have provided some valuable evidence in doing so. I think much work remains in this literature; thus, I have suggested some directions I think worth pursuing in the course of my comments. At the same time, I already agreed with the authors' policy proposal before reading the paper, but reading it has strengthened that agreement in my mind.

I would like to close with one last point, which relates to the odd welfare economics of migration. Economists have the praiseworthy habit of worrying about the well-being of people who live outside the arbitrary geographic boundary of their country of origin. Importing that concern into this literature, which focuses almost exclusively on the well-being of natives in the immigrant-receiving country, would make it intellectually deeper, dispel any odor of nationalism, and make its policy conclusions more relevant to those who think everyone matters, even foreigners.

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