

How Much Does Immigration Boost Innovation?[†]

By JENNIFER HUNT AND MARJOLAINE GAUTHIER-LOISELLE*

We measure the extent to which skilled immigrants increase innovation in the United States. The 2003 National Survey of College Graduates shows that immigrants patent at double the native rate, due to their disproportionately holding science and engineering degrees. Using a 1940–2000 state panel, we show that a 1 percentage point increase in immigrant college graduates' population share increases patents per capita by 9–18 percent. Our instrument for the change in the skilled immigrant share is based on the 1940 distribution across states of immigrants from various source regions and the subsequent national increase in skilled immigration from these regions. (JEL J24, J61, O31, O33)

Economists have studied the impact of immigration on a variety of host country outcomes. For example, David Card (2009) considers US immigration's impact on population growth, skill composition, internal migration, wages, rents, taxes, and the ethnic and income composition of neighborhoods and schools. In contrast, the impact of immigration on innovation has received less attention. In addition to the direct contributions of immigrants to research, immigration could boost innovation indirectly through positive spillovers on fellow researchers, the achievement of critical mass in specialized research areas, and the provision of complementary skills such as management and entrepreneurship. Some tantalizing facts hint at the possible importance of these effects for the United States. Compared to a foreign-born population of 12 percent in 2000, 26 percent of US-based Nobel Prize recipients from 1990–2000 were immigrants (Giovanni Peri 2007), as were 25 percent of founders of public venture-backed US companies in 1990–2005 period (Stuart Anderson and Michaela Platzer 2006), and founders of 25 percent of new high-tech companies with more than \$1 million in sales in 2006 (Vivek Wadhwa et al.

*Hunt: Department of Economics, McGill University, 855 Sherbrooke Street West, Montreal, Q.C. H3A 2T7, Canada, and National Bureau of Economic Research (e-mail: jennifer.hunt@mcgill.ca); Gauthier-Loiselle: Department of Economics, Princeton University, Fisher Hall, Princeton, NJ 08544 (email: mgauthie@princeton.edu). We are grateful to David Munroe for excellent research assistance, and for helpful comments from Francisco Alvarez-Cuadrado, Leah Brooks, David Card, Lee Fleming, Rachel Friedberg, David Green, Francisco Gonzales, Judy Hellerstein, Chad Jones, Bill Kerr, Daniel Parent, Giovanni Peri, Steve Pischke, Regina Riphahn, Eric Stuen, and Dee Suttiphisal, seminar participants at the London City University, London School of Economics, NBER (Productivity and Labor Studies), Nürnberg, Simon Fraser, University College London, and the SoLE/EALE Transatlantic Conference, and several friends holding patents. We thank Bill Kerr, Nicole Fortin, and Jim Hirabayashi of the USPTO for data, and Deven Parmar for obtaining and formatting the USPTO data. Hunt is also affiliated with the Center for Economic and Policy Research, Institute for the Study of Labor, and DIW-Berlin, and acknowledges the Social Science and Humanities Research Council of Canada grant number 410-2006-0257 for financial support.

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2007). Immigrants are over-represented among members of the National Academy of Sciences and the National Academy of Engineering, among authors of highly-cited science and engineering journal articles, and among founders of biotech companies undergoing initial public offerings (IPOs) (Paula E. Stephan and Sharon G. Levin 2001). William R. Kerr (2008) documents the surge in the share of US patents awarded to US-based inventors with Chinese and Indian names to 12 percent of the total by 2004, and Wadhwa et al. (2007) find that non-US citizens account for 24 percent of international patent applications from the United States.

The goal of our paper is to assess the impact of skilled immigration on innovation as measured by US patents per capita. The purpose of studying patents is to gain insight into technological progress, a driver of productivity growth, and ultimately economic growth. If immigrants increase patents per capita, they may increase output per capita and make natives better off. This is an important consideration for the debate concerning how many and what type of immigrants should be admitted to the United States, and particularly for the discussion of the appropriate number of employer-sponsored H-1B visas for skilled (especially science and engineering) workers. The context of the discussion is the shift from European to low- and middle-income source countries since the Immigration Act of 1965, and the concomitant faster increase in unskilled immigration than skilled immigration.

One way skilled immigrants could increase patenting per capita is through a greater concentration than natives in science and engineering occupations. Immigrants are likely to be over-represented in such occupations. Scientific and engineering knowledge transfers easily across countries, since it does not rely on institutional or cultural knowledge, is not associated with occupations with strict licensing requirements like medicine, and does not require the sophisticated language skills of a field like law.¹ Skilled immigrants could also increase patenting per capita if a combination of immigration policies and immigrant self-selection leads them to be more educated or of higher unobserved inventive ability. Immigrant inventors may, in turn, make natives more inventive. Even immigrants who do not patent themselves may increase patenting by providing complementary skills to inventors, such as entrepreneurship. Conversely, immigrant inventors' contributions could be offset by negative spillovers, for example, if their presence discourages natives from working in science and engineering.²

We begin our analysis by examining how much immigrants patent using the 2003 National Survey of College Graduates (NSCG). The individual-level data allow us to gauge the impact of immigrants on patents per capita under the assumption that immigrants do not influence the behavior of natives or other immigrants, and allow us to examine whether immigrants patent more than natives because they have higher inventive ability or merely different education or occupations. In order to account for immigrants' possible influence on natives or other immigrants, we turn to a panel of US states from 1940–2000, based on data from the US Patent and

¹ See Barry R. Chiswick and Sarinda Taengnoi (2007) and Peri and Chad Sparber (2008) for empirical evidence, and Hunt and Gauthier-Loiselle (2009) for theoretical analysis.

² In the most relevant paper, George J. Borjas (2007) finds that immigrants do not crowd out natives as a whole from graduate school.

Trademark Office (USPTO), the decennial censuses, and other sources. To obtain the causal effect of immigrants despite their endogenous choice of destination state, we difference the data across census years, and instrument the change in the share of skilled immigrants in a state's population with the state's predicted increase in the share of skilled immigrants. We base the latter on the 1940 distribution across states of immigrants from various source regions and the subsequent national increase in skilled immigrants from these regions.

We contribute to two understudied areas, the impact of immigration on innovation and the individual determinants of innovation, as well as to the study of the regional determinants of innovation. At the end of the paper, we set our work in the context of the literature.³ Our work is also relevant for the macroeconomic growth literature, where the link between innovation and the number of researchers is the key to growth.⁴

Our empirical analysis of the NSCG data shows that immigrants account for 24 percent of patents, twice their share in the population, and that the immigrant patenting advantage over natives is entirely accounted for by immigrants' disproportionately holding degrees in science and engineering fields. The data imply that a 1 percentage point increase in college-graduate immigrants' share of the population increases patents per capita by 6 percent. This could overestimate the contribution of immigrants if immigrants crowd out natives from science and engineering, or could underestimate the contribution if immigrants have positive spillovers. The state panel analysis shows evidence of positive spillovers of immigrants, since the estimates of their impact on patents per capita are higher than in the NSCG. A 1 percentage point rise in the share of immigrant college graduates in the population increases patents per capita by 9–18 percent. The state-level results mean that the 1990–2000 increase in the population share of this group from 2.2 percent to 3.5 percent increased patents per capita by 12–21 percent in a period when patents per capita rose 63 percent. We find that immigrants who are scientists and engineers, or who have post-college education, boost patents per capita more than immigrant college graduates.

I. Empirical Methodology

We use individual-level data to measure and explain differences in patenting behavior between immigrants and natives, and to gauge the contribution of immigrants to patenting per capita under the assumption that immigrants do not affect the behavior of natives or other immigrants. We then use state-level data to estimate the effect of immigrants on patenting per capita, including any positive or negative spillovers.

³ The most closely related previous papers are Peri (2007); Eric T. Stuen, Ahmed Mushfiq Mobarak, and Keith E. Maskus (2007); Gnanaraj Chellaraj, Maskus, and Aaditya Mattoo (2008); and Kerr and William F. Lincoln (2008).

⁴ Paul M. Romer (1990); Gene M. Grossman and Elhanan Helpman (1991a, 1991b); Philippe Aghion and Peter Howitt (1992); and Charles I. Jones (1995).

A. Individual-Level Data

A measure of the increase in patenting per capita owing to skilled immigrants can be calculated as follows.⁵ Let the skilled immigrant share of patents be α_0 (we obtain this value from the NSCG) and the skilled immigrant share of the population be α_1 (we obtain this value from the census). Let M^S be the number of skilled immigrants and let P^{MS} be their patents. If the skilled immigrant share of the population increases by 1 percentage point, the percent increase in skilled immigrants is $(\Delta M^S/M^S) = (1/\alpha_1) (0.01/(0.99 - \alpha_1))$, the percent increase in the population is $(\Delta M^S/POP) = 0.01/(0.99 - \alpha_1)$, and the percent increase in patents is $(\Delta P^{MS}/P) = (1/P) \times (P^{MS}/M^S) \Delta M^S = \alpha_0(\Delta M^S/M^S)$. Therefore, the percent increase in patents per capita is

$$(1) \quad \frac{1 + \frac{\Delta P^{MS}}{P}}{1 + \frac{\Delta M^S}{POP}} - 1 = (0.01) \frac{\alpha_0 - \alpha_1}{\alpha_1(1 - \alpha_1)}.$$

Below, we shall establish that skilled immigrants patent more than skilled natives, and that this difference is driven by the difference in patenting at all. To explore the reasons for the difference, we estimate a probit for the probability of having a patent granted, or the probability of commercializing or licensing a patent, weighted by the survey weights:

$$(2) \quad P(\text{patent}_j) = \beta_0 + \beta_1 IM_j + X_j \beta_2 + \epsilon_j,$$

where j indexes individuals, and IM is a dummy for the foreign-born. The coefficient of interest is β_1 . We are interested in how much of the raw patenting gap between immigrants and natives (the value of β_1 with no X covariates) can be explained by adding the covariates X : field of study of the highest degree, the highest degree, and demographic variables. We perform the regressions for three samples: college graduates, post-college degree holders, and scientists and engineers.

B. State-Level Data

We supplement the analysis using a panel of US states with decennial data from 1940–2000. By extending the period of observation back to 1940, we are able to distinguish long-run and short-run effects by differencing the data in lengths varying from 10 to 50 years.⁶ We estimate

$$(3) \quad \Delta \log \frac{P_{i,t+1}}{POP_{i,t+1}} = \gamma_0 + \gamma_1 \Delta I_{it}^S + \gamma_2 \Delta N_{it}^S + \Delta X_{it} \gamma_3 \\ + Z_{i,1940} \gamma_4 + \mu_t + \Delta \eta_{it},$$

⁵ The full algebra is presented in the Mathematical Appendix.

⁶ Strictly speaking, we should refer to low-frequency and high-frequency effects.

where i indexes states, P is the number of patents, POP is state population, I^S is the share of the population or workforce (18–65) composed of skilled immigrants, N^S represents the corresponding share for skilled natives, $Z_{i,1940}$ are characteristics of the state in 1940, X are contemporaneous state characteristics, and μ_t are year dummies. The coefficient of interest is γ_1 , though its size relative to γ_2 is also of interest. We also present results from specifications in which the dependent variable is not in logs.⁷

We define a skilled person variously as one with a college degree or more, one with post-college education, or one working in a science, engineering, or computer science occupation. We include characteristics of the state in 1940 (including land area), to capture the convergence in patents per capita occurring over the time period. The X covariates comprise the log of defense procurement spending and the log of the average age of state residents (18–65). We deliberately do not include research and development (R&D) spending, as we believe this to be a variable that responds to the supply of scientists and engineers and complements their effect on patenting.⁸ We lead the dependent variable by one year to allow for a year of research time between the change in the inputs and the patent application, as anecdotal evidence suggests the lag can vary between a few months and two years.

There were several major changes to the patent system between 1980 and 1998 (see Bronwyn H. Hall 2004). One change led to a large increase in patenting in electrical engineering relative to other sectors. To capture potentially differential effects of this by state, we include among the X 's the share of employment in electrical engineering-related sectors in 1980, interacted with year dummies.⁹ Alternatively, we capture this by controlling for region-specific dummies interacted with a dummy for differences involving years beyond 1980.

We use state populations to weight the regressions, since in some small states one company drives the time series of patenting,¹⁰ and we cluster standard errors by state to allow for serial correlation. Because we account for state fixed effects by estimating equations differenced across time, we elect not to include the change in the patent stock among the regressors as would be suggested by patent models. Furthermore, because we analyze long-run changes, we have chosen not to use a partial adjustment model.¹¹

Equation (3) suffers from an endogeneity problem. Skilled workers are likely to migrate to states which are experiencing positive shocks to innovation, either narrowly or as part of more general skill-biased technological change, unobservable to

⁷ All patents are filed in Washington, DC. They are attributed to states based on the home address of the first inventor.

⁸ However, the results are little changed by controlling for R&D spending by industry from all sources. This National Science Foundation (NSF) series is only available from 1963 and many observations are withheld, missing or imputed. The sample on which we test the robustness therefore contains only 112 observations.

⁹ We use 1980 values as electrical engineering employment was still tiny in most states in the 1940–1970 period.

¹⁰ Specifically, we weight by $1/(1/pop_{i,t+1} + 1/pop_{i,t-k+1})$, where k is the length of the difference. Idaho's emergence as the state with most patents per capita has been driven by one semi-conductor company, Micron Technology Inc., founded in 1978, which was granted 1,643 patents in 2001 and was the fourth-ranked company in this regard.

¹¹ We have estimated these models. The coefficient on the change in the stock of patents is close to one, rendering all other coefficients insignificant, while the coefficient on the partial adjustment term is insignificant.

the econometrician. The resulting correlation with the error term causes $\hat{\gamma}_1$ and $\hat{\gamma}_2$ to be biased upward in least squares estimation. On the other hand, $\hat{\gamma}_1$ in particular could be biased towards zero owing to measurement error, although weighting by state population should reduce this bias.¹² We devise an instrument to address these problems for skilled immigrants, inspired by a shift-share type analysis of the change in popularity of a state stemming from changes in the origin regions of skilled immigrants at the national level.¹³ To illustrate, if immigrants from Europe prefer the northeastern United States because it is closer to home and because other Europeans are already there because of geography, and Asian immigrants prefer the West Coast for analogous reasons, the large national increase in the share of skilled immigrants that are Asian will lead to an increase in skilled immigration to the West Coast relative to the Northeast. If the national increase in skilled Asian immigrants is caused by the change in US immigration policy in 1965, the opening of China to the world in 1979, along with increases in tertiary education in China and India, it is orthogonal to shocks to West Coast patenting.

For a state i , the predicted change in the number of skilled immigrants, caused by changing origin regions k , can be written as

$$(4) \quad \Delta \hat{M}_i^S = \sum_k \frac{M_{ik}}{M_k} \Delta M_k^S = \sum_k \lambda_{ik} \Delta M_k^S,$$

where λ_{ik} is state i 's share in 1940 of the national total of immigrants who originate from region k , and ΔM_k^S is the national change in the number of skilled immigrants from that region. We use 18 source regions or countries, listed in Appendix Table 1. Because the variable to be instrumented, ΔI_{it}^S , is a percentage point change, we convert $\Delta \hat{M}_i^S$ to percentage points by dividing by the population level at the start of the period to which Δ refers, to define our final instrument as:

$$(5) \quad \frac{\Delta \hat{M}_i^S}{POP_i}.$$

We deliberately base the λ_{ik} on immigrants of all education levels (and ages) to emphasize the role of geography and taste, and minimize the role of economic factors that might attract skilled workers specifically. We can control for the λ_{ik} in the regressions, to ensure that the instrument is not correlated with the error term due to their omission, and the year dummies control for all national trends. If controlling for λ_{ik} and the other covariates does not account for state-specific patenting shocks which are very persistent and influence national inflows of particular immigrant groups (e.g., California has serially correlated positive patenting shocks which caused low-skill Chinese to settle there before 1940 and which incited skilled Chinese to move to the

¹² There is measurement error for small states in the 1950 census, a smaller sample than later years which asked certain questions of only one quarter of the sample. There is also measurement error for the share of immigrant post-college and scientists and engineers in small states in the 1940–1970 censuses.

¹³ This instrument is similar to the instrument developed by Card (2001). For ΔN^S , the change in the share of native skilled workers, we have experimented unsuccessfully with lagged college enrollments as an instrument. The enrollment data only begin in the 1970s.

United States in more recent years), the instrument could be correlated with the error term. We present evidence below that suggests this is not the case.

Information on Alaska and Hawaii is not available until 1960. If the instrument is constructed using the 1960 shares for Alaska and Hawaii, Hawaii is such an outlier (due to its high share of Asian immigrants in 1960) that the instrument does not statistically significantly predict immigration patterns even in weighted regressions. We therefore drop Hawaii from the state-level analysis, and, for simplicity, we drop Alaska as well. This makes an imperceptible difference to weighted least squares regressions, and only a small difference to the less preferred unweighted least squares regressions.

II. Data and Descriptive Statistics

A. Individual-Level Data

We use the individual-level data from the 2003 NSCG. These data are a stratified random sample of people reporting having a bachelor's degree or higher on the long form of the 2000 census. In 2003, all respondents who had ever worked were asked whether they had applied for a US patent since October 1998, whether they had been granted any US patent since October 1998, and if so, how many, and how many had been commercialized or licensed. The survey will not capture patents by those with less than a college degree, but we assume that most patents are captured. The Web Data Appendix provides more information on the NSCG. We include in our sample respondents 65 years old or younger (the youngest respondent is 23, but few are younger than 26). Immigrants are those born outside the United States.

We define three (not mutually exclusive) skill categories, motivated in part by consistency with categories that can be distinguished in the censuses: college graduates (i.e., the full sample); holders of a post-college degree; and those working as scientists and engineers in the survey week. Only 51 percent of respondents who had been granted a patent reported working in a science or engineering occupation. Another 18 percent reported a management occupation (a research team's manager is sometimes listed as a co-inventor on a patent, and all inventors listed are captured in the data; also, many inventors will have been promoted to management since obtaining a patent).

Table 1 shows details of how patenting varies by immigrant status for the three skill groups. For college graduates (the whole sample, columns 1 and 2), 1.9 percent of immigrants were granted patents compared to 0.9 percent of natives, a ratio of 2.1, and patents per capita were 0.057 for immigrants and 0.028 for natives, a ratio of 2.0. Immigrants, therefore, patent at about twice the native rate, with the difference being principally in the probability of patenting at all. Immigrants held a slightly smaller advantage in patents commercialized or licensed, patents likely to benefit society more than others. While 1.2 percent of immigrants had commercialized a patent compared to 0.6 percent for natives, commercialized patents per capita were 0.029 for immigrants and 0.017 for natives. The immigrant-native gap is larger for the sample with post-college education (columns 3 and 4), but much smaller for the sample working in science and engineering occupations (columns 5 and 6). For example, 6.2 percent of

TABLE 1—PATENTING BY IMMIGRANT STATUS

	College graduates		Post-college graduates		Scientists and engineers	
	Immigrant (1)	Native (2)	Immigrant (3)	Native (4)	Immigrant (5)	Native (6)
Any patent granted	0.019	0.009	0.036	0.013	0.062	0.049
Number patents granted	0.057	0.028	0.112	0.036	0.178	0.132
Any patent commercialized	0.012	0.006	0.021	0.008	0.037	0.030
Number patents commercialized	0.029	0.017	0.054	0.019	0.084	0.074
Share immigrant	0.136		0.161		0.240	
Observations	20,294	71,186	11,729	30,410	6,724	15,502

Notes: Shares weighted with survey weights. Patents questions only asked of respondents who had ever worked. Whether a patent has been granted refers to period from October 1998 to the survey in 2003, and whether a patent has been commercialized or licensed refers to those patents granted in the same period.

Source: 2003 National Survey of College Graduates

immigrants in the latter sample had been granted a patent, compared to 4.9 percent of natives; and immigrants hold 1.35 times the patents per capita of natives. Appendix Table 2 contains the means of variables used in the regression analysis below.

B. State-Level Data

The patent data used in the state-level analysis come from the USPTO. Patents are attributed to states based on the home address of the first inventor on the patent. We merge a series based on electronic data from 1963 onward with a series from paper records for the period 1883–1976 (see the Web Data Appendix for the merging procedure). Patents are classified according to application (filing) date. Figure 1 shows the evolution of total patents and patents per 100,000 residents from 1941–2001, which is our study period.

In Figure 2, we use patent data from 1929 to 2001 to display the long-run convergence across states in patenting and patenting per capita, as measured by the fall in the (unweighted) standard deviation of log patents or patents per capita.¹⁴ However, there is divergence in patents per capita for the period 1990–2001, and there have historically been other periods of divergence. California is a force for divergence, as may be seen by the growing gap between the inequality of state patent counts with California (top line) and without California (middle line).

We have also used an extract from the Harvard Business School patent data file, which contains information on patents granted from 1975 to 2007, arranged by year of application and patent class.¹⁵ We have aggregated the patent classes to six categories using the classification of Hall, Adam B. Jaffe, and Manuel Trajtenberg (2001), and our own classification of patent classes created since 1999. The extract contains the number of citations made to patents in each patent class, state, and application year. These may be viewed as a proxy for the quality of the patent. We

¹⁴ Papers such as Catherine Y. Co, John S. Landon-Lane, and Myeong-Su Yun (2006) have previously noted cross-state convergence in patents per capita.

¹⁵ We are very grateful to Bill Kerr for making this extract for us.

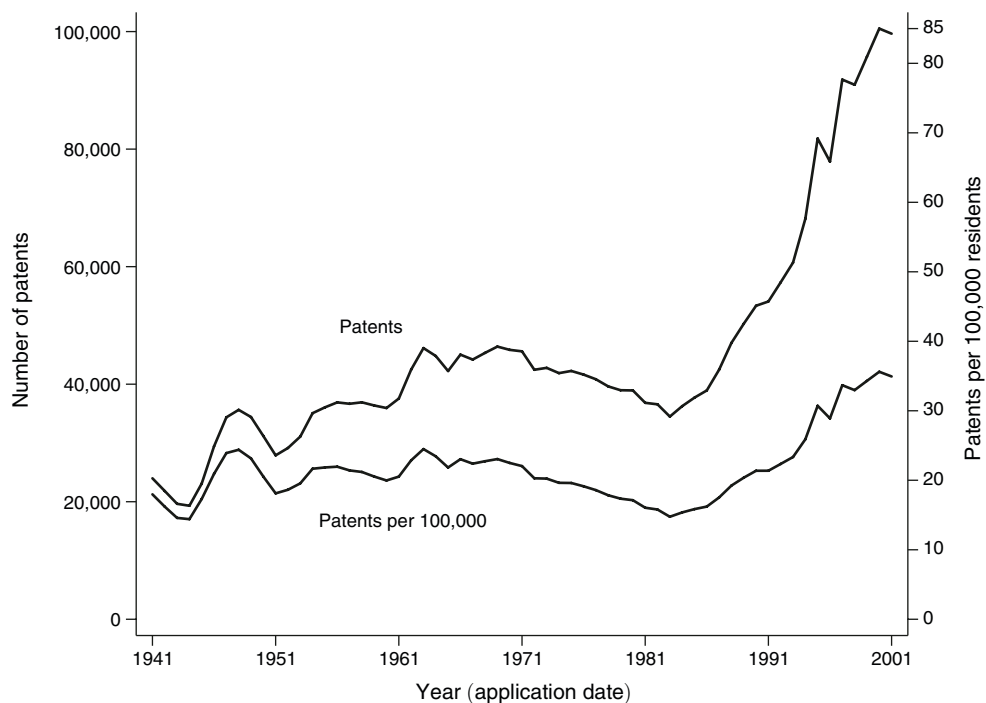


FIGURE 1. US ORIGIN US PATENTS 1941–2001

Source: USPTO, US Bureau of Economic Analysis (BEA), and authors' calculations

analyze 1971–2001 data using this extract (see the Web Data Appendix for how we approximate 1971 values).

To compute the shares of the population 18–65 years of age in various education and occupation classes, to divide these into immigrant and native, and to calculate the average age of the state's population, we use the IPUMS microdata of the decennial censuses (Ruggles et al. 2010). Post-college education is the highest education level that can be measured consistently throughout the 1940–2000 period. We define immigrants to be the foreign born. Figure 3 shows how the shares of skilled immigrants have evolved at the national level.

The variable means for the 1940–2000 sample, weighted by population and excluding Hawaii and Alaska, are reported in Table 2. Between 1940 and 2000, the share of the population 18–65 years old composed of immigrants with college education or more increased twelvefold to 3.5 percent, while the equivalent share for post-college increased twelvefold to 1.6 percent. The population shares comprising natives with at least college and with post-college education increased from 4.1 percent to 20.0 percent and from 1.1 percent to 7.7 percent, respectively. The share of workers composed of immigrant scientists and engineers multiplied elevenfold to 0.9 percent, while the native share rose from 0.6 percent to 3.5 percent. The Appendix Table 1 contains information about the variables used in the construction of the instruments.

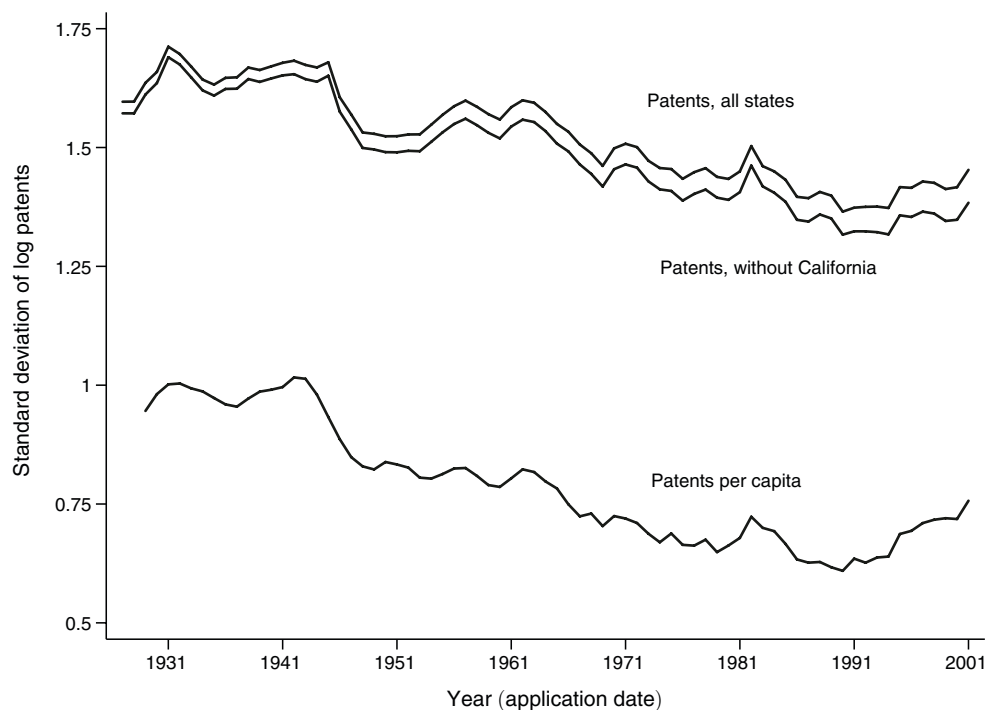


FIGURE 2. CONVERGENCE IN PATENTING ACROSS STATES 1929–2001

Source: USPTO, BEA, and authors' calculations

III. Results

A. Individual Determinants of Patenting

The NSCG data may be used to estimate the direct effect of immigration on patenting, ignoring possible crowd-out or spill-over effects, using equation (1). Immigrants hold 24.2 percent of patents in the (weighted) data ($\alpha_0 = 0.242$), and in the 2000 census (the basis of the NSCG sampling frame), college-graduate immigrants were 3.5 percent of the US population ($\alpha_1 = 0.035$). A 1 percentage point rise in the share of college immigrants in the population therefore implies an increase in patents per capita of 0.061, or 6.1 percent. The same exercise may be performed for natives, with the result that a 1 percentage point rise in the share of college natives increases patents per capita by 3.5 percent. As immigrants with post-college education have 2.0 ($=0.112/0.057$) times as many patents per capita as immigrants with only a college degree (see Table 1), the direct impact of an extra percentage point of post-college immigrants in the population is likely to be 2.0 times higher, or an extra $2.0 \times 6.1 = 12.2$ percent. Similarly, the contribution of an additional percentage point of immigrant scientists and engineers is likely to be $3.1 \times 6.1 = 18.9$ percent.

To assess the reasons for the immigrant patenting advantage, we first observe that in Table 1 immigrants' patenting advantage over natives is much smaller in the scientist and engineer sample (columns 5 and 6) than in the overall sample

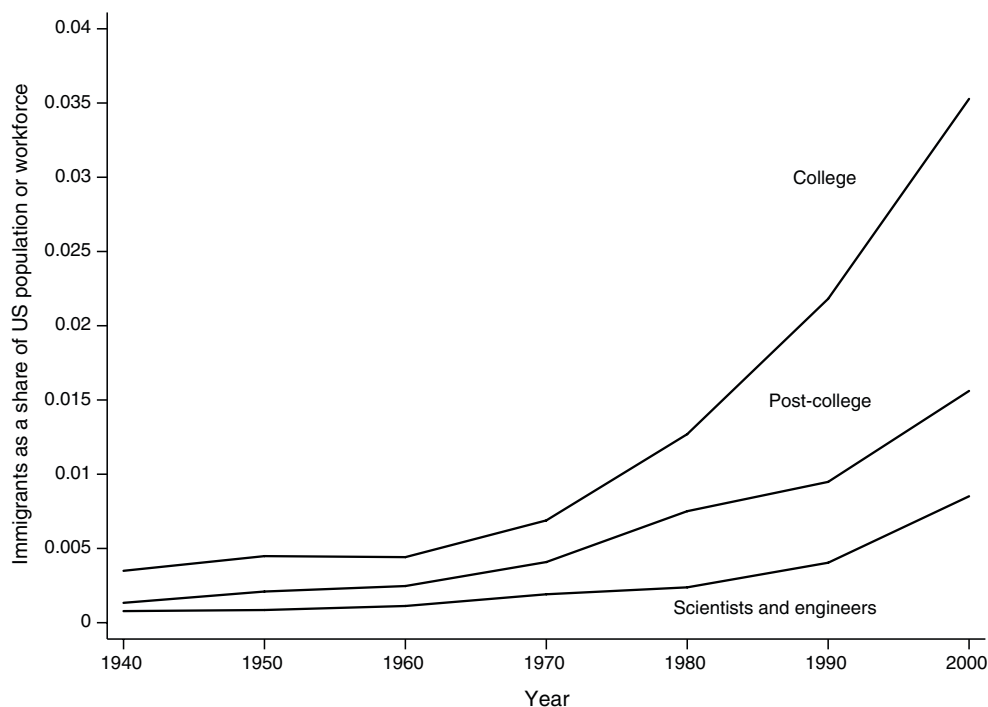


FIGURE 3. SKILLED IMMIGRANTS AS SHARE OF US POPULATION OR WORKFORCE 1940–2000

Note: Shares based on population or workers 18–65 years old.

Source: US Census

(columns 1 and 2). This suggests that the advantage for immigrants is due in large part to a greater science and engineering orientation. Table 3 lends further support to this. Column 1 shows that, for the whole sample, 6.6 percent of those with a highest degree in physical science, and 6.1 percent of those with a highest degree in engineering, had patented, far ahead of other fields. Column 2 shows a qualitatively similar picture for commercialized or licensed patents. The education of immigrants is therefore well suited to patenting, since columns 3 and 4 show that the share of immigrants with physical science and engineering degrees is more than twice as high as that of natives.

In Table 4, we pursue this explanation using the probit of equation (2) for the probability of patenting. Column 1 shows that immigrants are 1.0 percentage point more likely to have been granted a patent in the sample of college graduates (top panel), 2.3 percentage points more likely in the sample of post-college educated (second panel), and 1.3 percentage points more likely in the sample of scientists and engineers (third panel). In the second column, we control for the field of study of the highest degree obtained by the respondent by adding 29 dummies. For all three samples, the gap becomes small: 6–9 percent of the original size for college and post-college graduates, and 24 percent for scientists and engineers. In the third column, we control for the highest degree obtained by the respondent. For college graduates and scientists and engineers, the direction of the gap is reversed. Immigrant scientists and

TABLE 2—MEANS OF AGGREGATE VARIABLES

	1940–2000 (1)	1940 (2)	2000 (3)
Patents/population, $\times 100$	0.023 (0.015)	0.018 (0.013)	0.035 (0.020)
Share of population 18–65 that is:			
Immigrant, college education and above	0.015	0.003	0.035
Native, college education and above	0.127	0.041	0.200
Immigrant, post-college education	0.007	0.001	0.016
Native, post-college education	0.050	0.011	0.077
Share of workers 18–65 that are:			
Immigrant, scientists and engineers	0.003	0.001	0.009
Native, scientists and engineers	0.022	0.006	0.035
Age of population 18–65	38.7 (1.0)	37.7 (1.0)	39.5 (0.6)
DoD prime military procurement contracts (millions of nominal \$)	3,236 (4,386)	1,500 (1,679)	5,528 (5,809)
State personal income per capita (nominal \$)	11,976 (11,098)	594 (204)	29,851 (4,094)
Land area (millions of square kilometers)	0.190 (0.161)	0.166 (0.145)	0.207 (0.173)
Observations	343	49	49

Notes: Means of state-level variables for the population 18–65 years old, weighted by state population the year after the census. Standard deviations in parentheses. Patents and population are led by one year. Alaska and Hawaii are excluded. Patents are classified by year filed. The 1940 value of DoD procurement spending is not available. The 1950 value is given instead of 1940, and the 1950–2000 average instead of 1940–2000.

Sources: Education, age, occupation, nativity: U.S. Census Bureau, IPUMS decennial census microdata usa.ipums.org/usa/; patents: U.S. Patent and Trademark Office, electronic and paper data; state income, population: Bureau of Economic Analysis www.bea.gov/regional/spi/; land area: US Census Bureau www.census.gov/population/censusdata/90den_stco.txt

TABLE 3—PATENTING BY FIELD OF STUDY AND FIELD OF STUDY BY IMMIGRANT STATUS, COLLEGE GRADUATES

	Any patent granted (1)	Any patent commercialized (2)	Share immigrants (3)	Share natives (4)
Field of highest degree				
Computer science, math	0.017	0.012	0.079	0.036
Biological, agricultural, and environment sciences	0.023	0.011	0.055	0.040
Physical sciences	0.066	0.039	0.036	0.017
Social and related sciences	0.004	0.002	0.093	0.108
Engineering	0.061	0.042	0.137	0.053
Other S&E (mainly health)	0.007	0.004	0.166	0.121
Non-S&E	0.004	0.003	0.434	0.624
All fields	0.011	0.007	1.00	1.00

Notes: Shares weighted by survey weights. “S&E” means science and engineering. Full sample (i.e., college graduates), 91,480 observations. Whether a patent has been granted refers to period from October 1998 to the survey in 2003, and whether a patent has been commercialized or licensed refers to those patents granted in the same period.

Source: 2003 National Survey of College Graduates

engineers are a statistically significant 0.95 percentage points less likely to patent than natives. Controlling for age, age squared, sex, and current employment status in column 4 changes little. The advantage of skilled immigrants is therefore entirely due to the nature of their education, and not to any selection on unobservables such

TABLE 4—EFFECT OF IMMIGRANT STATUS ON PATENTING

	Any patent granted?				Any patent commercialized?	
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Panel A. Sample of college graduates (91,480 observations)</i>						
Immigrant	0.0100* (0.0010)	0.0009* (0.0005)	−0.0007 (0.0004)	−0.0005 (0.0003)	0.0062* (0.0008)	−0.0004 (0.0003)
Pseudo- R^2	0.01	0.15	0.19	0.21	0.01	0.18
<i>Panel B. Sample of post-college graduates (42,139 observations)</i>						
Immigrant	0.0226* (0.0018)	0.0014* (0.0008)	0.0004 (0.0006)	0.0005 (0.0006)	0.0135* (0.0014)	0.0002 (0.0004)
Pseudo- R^2	0.02	0.21	0.24	0.26	0.02	0.21
<i>Panel C. Sample of scientists and engineers (22,226 observations)</i>						
Immigrant	0.0131* (0.0039)	0.0031 (0.0031)	−0.0095* (0.0027)	−0.0074* (0.0026)	0.0063* (0.0030)	−0.0052* (0.0020)
Pseudo- R^2	0.00	0.08	0.12	0.13	0.00	0.09
Major field of highest degree	—	Yes	Yes	Yes	—	Yes
Highest degree	—	—	Yes	Yes	—	Yes
Age, age ² , sex, employed	—	—	—	Yes	—	—

Notes: Marginal effect on immigrant dummy from weighted probits. All scientists and engineers are employed in the reference week. Post-college degrees include master's (including MBA), PhD, and professional. There are 29 major field of study dummies (we combine the two S&E teacher training categories into one). Standard errors are in parentheses.

*Indicates coefficients significant at the 5 percent level.

as ability. In columns 5 and 6, we show that the same conclusions may be drawn for the probability of commercializing or licensing a patent.

B. State Determinants of Patenting

In Table 5, we estimate the state determinants of log patenting per capita using differences of varying lengths, with a college degree as the measure of skill and least squares estimation of equation (3). The regression in column 1 is unweighted, while those in the other columns are weighted. A 10 year difference is taken in columns 1 and 2, a 30 year difference is taken in column 3, and a 50 year difference is taken in column 4. The coefficients on the changes in the immigrant college shares are positive and significant. A 1 percentage point increase in the share of the population composed of immigrant college graduates is associated with a 12–15 percent increase in patenting per capita. These effects are larger than the 6 percent impact calculated based on the NSCG data, implying positive spillover effects of immigrants.

The coefficients on the change in the share of native college graduates are smaller than the coefficients for immigrants. The point estimate increases as the difference length increases, and for 50 year differences, the coefficient is a significant 5.8 in column 4. The immigrant/native ratio is 2.6, somewhat larger than the 1.9 ratio in the NSCG. The coefficient suggests that skilled natives also have positive spillovers, as the effect of a 1 percentage point increase in their population share based on the NSCG data was 3.5 percent. The absence of significance at short differences probably reflects the emphasis of short differences on high-frequency events (Michael Baker, Dwayne Benjamin, and Shuchita Stanger 1999), since the share of native college graduates changes only gradually.

TABLE 5—EFFECT OF SHARE OF IMMIGRANT COLLEGE GRADUATES ON LOG PATENTS PER CAPITA

	Difference:			
	10 year (1)	10 year (2)	30 year (3)	50 year (4)
Δ Immigrant college as share of population	14.7* (5.3)	13.2* (4.3)	12.1* (3.2)	14.9* (4.3)
Δ Native college as share of population	4.1* (1.9)	1.9 (2.3)	4.8* (1.8)	5.8* (2.1)
Δ Age (average)	0.064* (0.028)	0.104* (0.035)	0.163* (0.041)	0.137* (0.066)
Δ DoD procurement (log)	−0.033 (0.025)	−0.039* (0.017)	−0.081* (0.035)	−0.063 (0.041)
Land area (log)	0.046* (0.007)	0.063* (0.013)	0.169* (0.032)	0.281* (0.055)
Population 1940 (log)	−0.056* (0.015)	−0.062* (0.015)	−0.161* (0.032)	−0.252* (0.060)
State personal income per capita 1940 (log)	−0.223* (0.037)	−0.162* (0.048)	−0.544* (0.103)	−1.006* (0.189)
Weighted	No	Yes	Yes	Yes
R^2	0.47	0.64	0.63	0.70
Observations	294	294	196	98

Notes: The dependent variable is the difference in log patents per capita across periods ranging from 10 to 50 years, with a lead of one year compared to the independent variables. Weighted least squares regressions have weights $1/(1/pop_{t+1} + 1/pop_{t-k+1})$, where k is equal to the length of the difference. Regressions also include year dummies. Standard errors clustered by state are in parentheses.

* Indicates coefficients significant at the 5 percent level.

Older populations appear to be more innovative, as indicated by the positive coefficients on the average age of the state. This may reflect the importance of management or other skills complementary to innovation. As suggested by time series work in Zvi Griliches (1990), Department of Defense (DoD) procurement spending lowers patenting, presumably in part because military invention is primarily protected by secrecy rather than patents. Finally, the importance of the 1940 conditions (and land area) increases with the difference length, and the coefficients indicate that patent growth was lower for initially richer and more densely populated states.

We reproduce key Table 5 results in Table 6, panel A, columns 1 and 2, to facilitate their comparison with the equivalent coefficients for post-college education (panel B) and scientists and engineers (panel C). The coefficients for immigrant post-college are 20.7 and 29.8 in columns 1 and 2, and 1.6–2.0 times as high as for immigrant college graduates, compared to a ratio of 2.0 the NSCG data. The coefficients indicate positive spillovers, as the effect of a 1 percentage point increase in the immigrant post-college share in the individual data was 12 percent. The coefficients for the share of native post-college educated are not statistically significant, though the point estimates are higher for the longer differences, yielding an immigrant/native ratio of 3.5 at 50 year differences compared to 3.1 in the NSCG. For scientists and engineers in panel C, columns 1 and 2, a 1 percentage point increase raises patents by 52 log points. This is high compared with the direct NSCG effect of about 19 percent and compared with the effect of natives at 50 year differences (25 log points), given that in the NSCG the immigrant patenting advantage over

TABLE 6—EFFECT OF SKILLED IMMIGRANT SHARES ON PATENTS PER CAPITA

	Difference:			
	Δ log patents per capita		Δ patents per capita	
	10 year (1)	50 year (2)	10 year (3)	50 year (4)
<i>Panel A. Skilled: college graduates as share of population</i>				
Δ skilled immigrant	13.2* (4.3)	14.9* (4.3)	0.368* (0.173)	0.271 (0.158)
Δ skilled native	1.9 (2.3)	5.8* (2.1)	−0.010 (0.108)	0.134 (0.081)
R^2	0.64	0.70	0.49	0.42
<i>Panel B. Skilled: post-college educated as share of population</i>				
Δ skilled immigrant	20.7 (10.7)	29.8* (10.9)	0.686 (0.501)	0.538 (0.403)
Δ skilled native	−1.3 (3.3)	8.4 (5.8)	−0.086 (0.138)	0.127 (0.224)
R^2	0.63	0.66	0.48	0.38
<i>Panel C. Skilled: scientists and engineers as share of workers</i>				
Δ skilled immigrant	52.4* (20.7)	52.6* (16.1)	2.318* (0.990)	1.354* (0.661)
Δ skilled native	9.4 (5.4)	24.7* (8.0)	0.212 (0.239)	0.665* (0.278)
R^2	0.67	0.74	0.56	0.52
Observations	294	98	294	98

Notes: The dependent variable is the difference in (log) patents per capita across periods ranging from 10 to 50 years, with a lead of one year compared to the independent variables. Weighted least squares with weights $1/(1/pop_{t+1} + 1/pop_{t-k+1})$, where k is equal to the difference length. All regressions include the covariates of Table 5. Standard errors clustered by state are in parentheses. Coefficients in columns 3–4 are multiplied by 100.

*Indicates coefficients significant at the 5 percent level.

natives was only 35 percent among scientists and engineers. We return to this discrepancy below.

In columns 3 and 4, we repeat the regressions of columns 1 and 2, using the unlogged dependent variable and reporting coefficients multiplied by 100. For immigrants, the 50 year difference yields smaller coefficients than the 10 year difference. For immigrant college graduates in panel A, a 1 percentage point increase in their share is associated with a 0.000037 (column 3) or 0.000027 (column 4) increase in patents per capita, which represent, respectively, 16.1 percent and 11.7 percent increases compared to the mean, close to the estimates in columns 1 and 2. The coefficients for post-college immigrants (panel B) are 1.9–2.0 times the magnitude of the college immigrant coefficients, as we would expect, but are statistically insignificant. The disparity between 10 year differences and 50 year differences is large for the regressions using scientists and engineers (panel C). The 50 year coefficient is similar in magnitude to the results from the log specification. The coefficient of 1.35 (column 4) means that a 1 percentage point increase in the skilled immigrant share is associated with a 58.7 percent increase compared to the mean. The skilled immigrant coefficients in columns 3 and 4 are not very sensitive to the covariates included, while the results in columns 1 and 2 are much smaller if the 1940 covariates (including land area) are not included.

Before presenting instrumental variables results, we display, in Figure 4, the correlation between the change in the immigrant college share and its instrument (the predicted change) for each decade, and plot the weighted regression line. If the

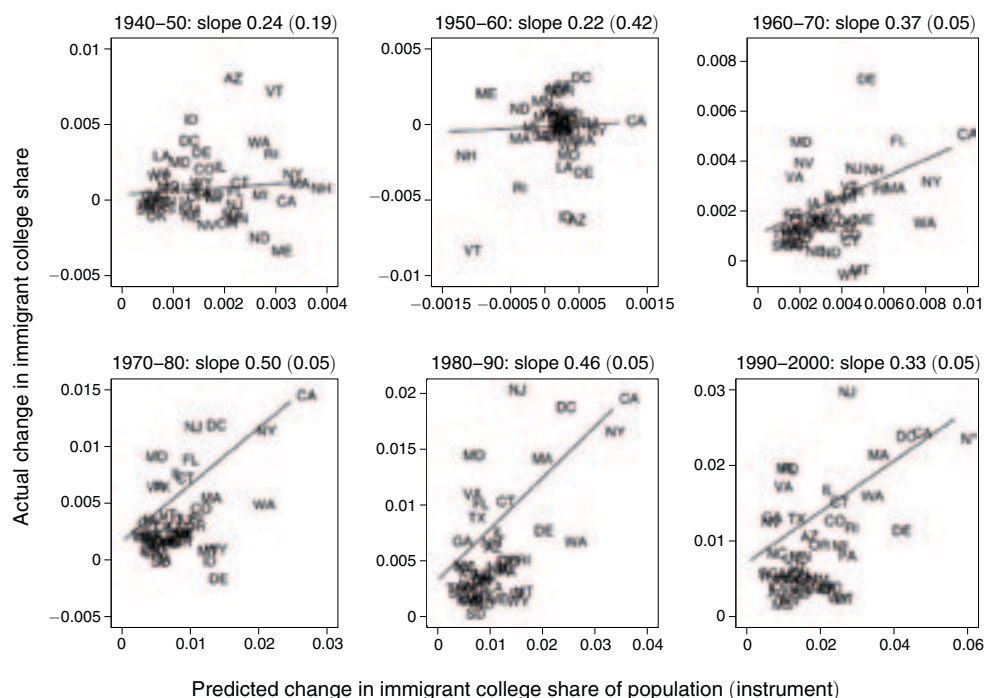


FIGURE 4. ACTUAL AND PREDICTED CHANGES IN IMMIGRANT COLLEGE SHARES OF POPULATION

Note: Regression lines based on least squares weighted by state population.

Source: Authors' calculations based on US Census

instrument were picking up shocks to patenting from around 1940, we would expect the instrument to gradually weaken over time. Instead, the instrument is weak in the low-immigration decades of 1940–1950 and 1950–1960, and strong thereafter. The unreported figures for immigrant post-college and scientist and engineer shares indicate similar correlations, though they are less significant for scientists and engineers.

We now present the results of instrumental variables estimation and other specification checks, focusing on the log specification and 10 year differences, and report only the coefficient on the change in the skilled immigrant share. For conciseness, in Table 7, we present the full results only for the case of college proxying for skill. Panel A shows that in the base specification, using instrumental variables increases the coefficient to 30, more than twice the least squares coefficient of 13. The instrument is strong in the first stage, as indicated by the value in brackets of 27 for the F -statistic for the excluded instrument's significance in the first stage (the first stage itself, along with all other first stages for the table, is shown in Appendix Table 3). Our prior was that the upward bias in least squares due to the endogenous location choice of immigrants would be larger than the bias toward zero due to measurement error, so the larger instrumental variables point estimate is unexpected (though Card and John DiNardo 2000 encounter the same phenomenon in a similar context). The instrumental variables coefficient reflects the effect on patenting of skilled immigrants whose behavior is affected by the instrument. It is possible that skilled

TABLE 7—EFFECT OF COLLEGE IMMIGRANT SHARES ON LOG PATENTS PER CAPITA, TEN-YEAR DIFFERENCES, FURTHER SPECIFICATIONS

	WLS (1)	IV (2)
<i>Panel A. Base specifications</i>	13.2* (4.3)	30.3* (7.2) [27]
<i>Panel B. Base specifications without California (288 observations)</i>	9.2* (4.3)	26.3* (7.1) [24]
<i>Panel C. Base specifications without year 2000 (245 observations)</i>	8.8* (3.5)	18.9* (7.1) [51]
<i>Panel D. Include BEA region dummies</i>	11.5* (4.5)	23.4* (5.4) [30]
<i>Panel E. Include state dummies</i>	11.6* (5.6)	24.5* (6.3) [31]
<i>Panel F. Include BEA region dummies and percent electrical workers 1980 × year dummies</i>	9.6* (4.7)	23.1* (7.0) [28]
<i>Panel G. Include BEA region dummies and percent electrical workers 1980 × year dummies and 1940 immigrant shares (λ)</i>	10.1 (5.8)	24.5* (7.8) [39]
<i>Panel H. Include BEA region dummies and percent electrical workers 1980 × year dummies; exclude share college natives</i>	8.6 (4.3)	17.6* (5.6) [27]
<i>Panel I. Include BEA region dummies × post-1980</i>	8.4* (3.4)	18.6* (7.6) [9]
<i>Panel J. Include BEA region dummies × post-1980; exclude share college natives</i>	7.0* (3.4)	12.3* (6.1) [10]

Notes: Each coefficient reported is the effect of a change in college immigrant share of the population from a different regression. The dependent variable is the difference in log patents across ten years, with a lead of one year compared to the independent variables. There are 294 observations unless otherwise noted. Weighted least squares (column 1) or instrumental variables (column 2) with weights $1/(1/pop_{t+1} + 1/pop_t)$. The instruments are the predicted increase in college immigrant shares, based on states' shares of 1940 immigrants from various countries and subsequent national growth in college graduates from those countries (see text). *F*-statistic for test of joint significance of excluded instrument in the first stage in brackets. All regressions also include the covariates of Table 5 including (except panels H and J) the appropriate differenced share of skilled natives. Standard errors clustered by state are in parentheses.

* Indicates coefficients significant at the 5 percent level.

immigrants whose location decision is affected by historical geographic or taste considerations are more inventive than other immigrants.

In panels B and C, we check the robustness of the results to different samples. Without California (panel B), the least squares estimate falls from 13.2 to 9.2 and the instrumental variables estimate from 30 to 26. Without differences involving the year 2000, the point estimates fall more. In panel D, we return to the full sample and add seven dummies for BEA regions, which pick up region-specific trends in per capita patenting. This decreases the point estimates compared to panel A. The

region coefficients are jointly significant, as are the coefficients for all sets of covariates we add in this table. In panel E, we use state instead of region dummies, which mainly serves to increase the standard errors. In panel F, we revert to using BEA region dummies, and add controls for the share of workers in electrical engineering in 1980 interacted with year dummies, which decreases the least squares estimate from 11.5 in panel D to 9.6, but leaves the instrumental variables estimate little changed at 23. In panel G, we add controls for the state's 1940 shares of the 18 immigrant groups that enter the calculation of the instruments (λ_{ik}). This increases the coefficients slightly as well as the standard errors, rendering the least squares estimate insignificant. As the point estimates change little, we do not include the 1940 shares in the remaining panels.

Since the change in the native skilled share is endogenous, the instrumental variable estimate of the effect of the change in the immigrant skilled share is only unbiased if the two variables are independent. Since this is obviously not the case (the correlation in the first stage is significantly negative), we experiment in panel H with dropping the control for the change in the share of college natives. Compared to panel F, the least squares coefficient falls slightly, but the instrumental variables coefficient falls considerably, from 23.1 to 17.6.

In panel I, we propose a more parsimonious specification aimed at capturing post-1980 patenting changes, adding to the base specification only BEA region dummies interacted with a dummy for post-1980 (i.e., for differences including 1990 or 2000). These results are very close to those of panel H, although the addition of these covariates has weakened the instrument considerably in the first stage, as evidenced by the fall in the F -statistic in brackets. In panel J, we drop the change in the native college share from the covariates of the panel I specification, and the estimates fall to the lowest values in the table; 7.0 for least squares and 12.3 for instrumental variables.

Our preferred specifications for least squares are panels F and I (which include the native skilled share), while for instrumental variables they are the counterparts excluding the native skilled share in panels H and J. We present their results in Table 8 for all three skill groups (repeating the college results). For immigrant college graduates (columns 1 and 2), a 1 percentage point increase in share increases patenting per capita by 8–10 percent in least squares and 12–18 percent in instrumental variables, more than the 6 percent based on the individual-level data (statistically significantly so in the case of the highest coefficient), and therefore implying positive spillovers. For post-college immigrants (columns 3 and 4), the upper specifications lead to insignificant coefficients similar in size to the college coefficients; 11.3 and 18.9 for least squares and instrumental variables, respectively. It seems implausible that the effects would not be larger than for college immigrants (and this specification is unusual in this regard), so we put more weight on the lower specifications which yields coefficients of 15.9 and 27.0, about double the college coefficients as would be expected from the individual-level analysis. The individual-level effect calculated for the immigrant post-college share was 12 percent, so overall the coefficients imply considerable positive spillovers.

We do not present instrumental variables results for immigrant scientists and engineers, as the instrument is too weak in the first stage, but the least squares

TABLE 8—EFFECT OF SKILLED IMMIGRANT SHARES ON LOG PATENTS PER CAPITA, TEN-YEAR DIFFERENCES, PREFERRED SPECIFICATIONS

	Skill represented by:				
	College graduates		Post-college		Scientists/ engineers
	WLS (1)	IV (2)	WLS (3)	IV (4)	WLS (5)
<i>Panel A. Include BEA region dummies, percent electrical workers 1980 × year dummies; IV excludes share college natives</i>	9.6* (4.7)	17.6* (5.6) [27]	11.3 (8.3)	18.9 (14.3) [18]	38.2 (20.3)
<i>Panel B. Include BEA region dummies × post-1980; IV excludes share college natives</i>	8.4* (3.4)	12.3* (6.1) [10]	15.9* (6.2)	27.0* (13.4) [11]	30.7 (16.3)

Notes: Each coefficient reported is the effect of a change in skilled immigrant share from a different regression. The dependent variable is the difference in log patents across ten years, with a lead of one year compared to the independent variables. Weighted least squares (odd columns) or instrumental variables (even columns) with weights $1/(1/pop_{t+1} + 1/pop_t)$. The instruments are the predicted increase in skilled immigrant shares, based on states' shares of 1940 immigrants from various countries and subsequent national growth in college graduates from those countries (see text). *F*-statistic for test of joint significance of excluded instrument in the first stage in brackets. All regressions also include the covariates of Table 5 (for odd columns) including the appropriate differenced share of skilled natives. Standard errors clustered by state are in parentheses. There are 294 observations.

*Indicates coefficients significant at the 5 percent level.

coefficients in column 5 are 38.2 and 30.7 (significant only at the 10 percent level), compared to a 19 percent effect calculated with the individual-level data. The scientist and engineer coefficients are 3.7–4.0 times their college counterparts in column 1, which still seems slightly high compared to the ratio of 3.1 in the individual-level data. For immigrant scientists and engineers in the specifications of this table, contrary to the cases of immigrant college and post-college, the coefficient on the share generally falls as the difference length increases. This means that at longer differences, the immigrant and native shares of scientists and engineers have similar coefficients, as would be expected based on the individual-level results. For example, in the 50 year counterpart to the upper specification of Table 8, the coefficient on the immigrant scientist and engineer share is 27.0 (standard error 16.2), while the native coefficient is 22.9 (standard error 5.8). These values imply ratios of immigrant to native and of immigrant scientists/engineers to immigrant college very similar to those in the NSCG. The instrument is also more powerful at this long difference (an *F*-statistic of 11 in the first stage), and the instrumental variables coefficient is 61.4 (standard error 28.7). These are our preferred coefficients for scientists and engineers.

In Table 9, we investigate further using the Harvard Business School patent data for 1971–2001. In panel A, we repeat the least squares base specification for log patents per capita for this smaller sample, and obtain slightly smaller point estimates for immigrant college (10.7), post-college (15.2), and scientists and engineers (45.7) compared to those in Table 6. In panel B, we change the dependent variable to be the log of patent citations per capita, and, in panel C, we add region dummies to this specification. The results are not very different from the results for patent counts, suggesting immigrants are not generating patents of lower quality than native patents. Unreported instrumental variables coefficients are larger (21 for college graduates in the base specification), but insignificant.

TABLE 9—EFFECT OF SKILLED IMMIGRANT SHARES ON LOG PATENT CITATIONS PER CAPITA AND LOG PATENTS PER CAPITA BY TYPE, TEN-YEAR DIFFERENCES, 1970–2000

	Skill represented by:		
	College graduates (1)	Post-college (2)	Scientists/engineers (3)
<i>Panel A. Patents</i>	10.7* (4.6)	15.2 (11.6)	45.7* (22.0)
<i>Panel B. Patent citations</i>	9.9* (4.8)	18.5 (12.4)	54.4* (24.2)
<i>Panel C. Patent citations, include BEA region dummies</i>	11.3* (5.6)	24.2 (12.2)	56.2 (29.6)
<i>Panel D. Computer and communications patents (137 observations)</i>	10.2 (7.4)	1.7 (19.5)	35.0 (23.5)
<i>Panel E. Electrical and electronic patents (145 observations)</i>	0.1 (6.1)	−2.2 (15.4)	6.9 (23.9)
<i>Panel F. Drug and medical patents (146 observations)</i>	12.5 (6.7)	9.2 (14.8)	50.6 (30.7)
<i>Panel G. Chemical patents (145 observations)</i>	7.5 (6.4)	8.7 (14.9)	10.3 (26.5)
<i>Panel H. Mechanical patents</i>	−3.0 (3.9)	−15.7 (9.0)	3.8 (16.1)
<i>Panel I. Other patents</i>	−7.7* (2.6)	−19.2* (4.9)	−15.5 (9.7)

Notes: Each coefficient reported is the effect of a ten-year change in skilled immigrant share from a different regression. The dependent variable is the difference in log patents per capita or log of patent citations per capita across ten years, with a lead of one year compared to the independent variables. Weighted least squares for 1970–2000 with weights $1/(1/pop_{t+1} + 1/pop_t)$. All regressions include the covariates included in Table 5. Standard errors clustered by state are in parentheses. There are 147 observations, unless otherwise specified.

*Indicates coefficients significant at the 5 percent level.

In panels D–I, we present the results for the six categories of patent. The standard errors are high when the data are split in this way, and we elect simply to present the least squares base specification rather than various specifications with insignificant coefficients. From the reported results as well as the unreported results, the only firm conclusions are that there is no effect for mechanical patents, and a negative effect for “other” patents. The beneficial effects of immigration are therefore spread across computer and communications patents, electrical and electronic patents, drug and medical patents, and chemical patents.

C. Contribution to the Literature

We have gone beyond the most closely related paper linking immigration and innovation, Peri (2007), by adding individual-level analysis, extending the state panel, using instrumental variables to correct for endogeneity, and defining skilled immigration more broadly and consistently across time. These considerations also distinguish our paper from the time-series analysis of Chellaraj, Maskus, and Mattoo (2008). Both of these papers find skilled immigration increases US patenting. Our analysis is more general than that of Stuen, Mobarak, and Maskus (2010) and Kerr

and Lincoln (2010). The former authors find that immigrant students increase US university patenting and science and engineering publishing. The latter authors find that when the national population of H-1B visa-holders increases, patenting by inventors with Indian and Chinese names rises in states that have many H-1B applications.¹⁶ We are not aware of previous papers with regression analysis of the individual determinants of patenting, though Robert P. Morgan, Carlos Kruytbosch, and Nirmala Kannankutty (2001) note in passing the immigrant advantage in patenting, and economic historians have studied the characteristics of nineteenth century inventors (e.g., B. Zorina Khan and Kenneth L. Sokoloff 1993).

There is a large literature on the regional determinants of patenting, but the analysis relies primarily on cross-section variation or qualitative analysis. The literature considers the effects of private and public R&D spending, the presence of a university, the presence of small firms, the competitiveness of product markets, the presence of an airport, geographic centrality, population density and size, and the presence of skilled workers, especially scientists and engineers.¹⁷ The most closely related paper is by Lynne G. Zucker and Michael R. Darby (2006). Zucker and Darby (2006) pool data on Bureau of Economic Analysis regions for 1981–2004, and find that non-university patenting is not affected by the presence of star scientists, a high wage (proxying for education), or a high stock of relevant journal publications (representing the stock of knowledge).¹⁸

IV. Conclusions

In this paper, we have combined individual and aggregate data to demonstrate the important boost to innovation provided by skilled immigration to the United States in 1940–2000 period. A calculation for the period 1990–2000, when patenting per capita rose 63 percent, puts the magnitudes of the effects in context. The 1.3 percentage point increase in the share of the population composed of immigrant college graduates, and the 0.7 percentage point increase in the share of post-college immigrants, each increased patenting per capita by about 12 percent based on least squares¹⁹ and 21 percent based on instrumental variables. The 0.45 percentage point increase in immigrant scientists and engineers increased patenting per capita by about 13 percent based on least squares²⁰ and 32 percent based on instrumental variables. These impacts include the positive spillovers of skilled immigrants, which are a substantial share of the total impact. Calculations based on individual-level data of the impacts without spillovers suggest impacts of about 8–9 percent for all three skill groups.²¹

¹⁶ Relevant papers for other countries include Annekatrin Niebuhr (2006) and Daniele Paserman (2008).

¹⁷ See, for example, Diana Hicks et al. (2001); Zoltan J. Acs (2002); the papers in Acs, Henri L. F. de Groot, and Peter Nijkamp (2002); and Laura Bottazzi and Peri (2003); Jaffe, Trajtenberg, and Rebecca Henderson (1993) and successor papers study geographic patterns of patent citations.

¹⁸ See also Toby E. Stuart and Olav Sorenson (2003); Zucker et al. (2007); and Matt Marx, Deborah Strumsky, and Lee Fleming (2007).

¹⁹ College: Table 8, column 1 average coefficient 9.0, $9.0 \times 1.3 = 11.7$ log points = 12 percent; Post-college: Table 8, column 3 coefficient 15.9, $15.9 \times 0.7 = 11.1$ log points = 12 percent.

²⁰ Coefficient 27.0 from text, $27.0 \times 0.45 = 12.1$ log points = 13 percent.

²¹ $6.1 \text{ percent} \times 1.3 = 7.9 \text{ percent}$; $12.2 \text{ percent} \times 0.7 = 8.5 \text{ percent}$; $18.9 \text{ percent} \times 0.45 = 8.5 \text{ percent}$.

We find that a college graduate immigrant contributes at least twice as much to patenting as his or her native counterpart. The difference is fully explained by the greater share of immigrants with science and engineering education, implying immigrants are not innately more able than natives. Indeed, immigrants are less likely to have patented recently than observably similar native scientists and engineers. Despite this, the fact that immigrants increase patenting per capita shows that their presence in the United States provides a previously uncharacterized benefit to natives, assuming the immigrants would have been less innovative or less able to commercialize their innovation elsewhere or that US natives benefit more from innovation and commercialization in the United States than abroad. We can make a crude calculation of the benefit using the results of Jeffrey L. Furman, Michael E. Porter, and Scott Stern (2002), who find that the elasticity of a country's GDP with respect to its patent stock is 0.113, controlling for capital and labor. This elasticity implies that the influx of immigrant college graduates in the 1990s increased US GDP per capita by 1.4–2.4 percent.

One should be cautious in drawing the conclusion that innovation could be sustained by simultaneously subsidizing natives to study science and engineering and cutting immigration of scientists and engineers. The additional natives drawn into science and engineering might have lower inventive ability than the excluded immigrants, and such natives might have contributed more to the US economy outside science and engineering. While evidence in the paper of positive spillovers from scientists and engineers appears to support the dual policies of subsidizing native science and engineering study and increasing immigration of scientists and engineers, it is possible that members of other skilled professions provide equally large spillovers that are simply more difficult to measure.

MATHEMATICAL APPENDIX

PROOF OF EQUATION (1):

If immigrants' share of the population grows by 1 percentage point,

$$(A1) \quad \frac{M^S + \Delta M^S}{POP + \Delta M^S} - \frac{M^S}{POP} = 0.01,$$

which implies after some rearranging that

$$(A2) \quad \Delta M^S = \frac{0.01 POP^2}{0.99 POP - M^S}.$$

Therefore, the percent increase in the immigrant population can be calculated as

$$(A3) \quad \frac{\Delta M^S}{M^S} = \frac{POP}{M^S} \frac{0.01}{0.99 - \frac{M^S}{POP}} = \frac{1}{\alpha_1} \frac{0.01}{0.99 - \alpha_1}.$$

APPENDIX TABLE 1—STATES' 1940 SHARES OF NATIONAL-LEVEL IMMIGRANTS FROM VARIOUS ORIGINS

Origin	State's 1940 share of national total, all immigrants			College graduate immigrants
	Mean (1)	Maximum (2)	State of maximum (3)	National total 2000 – national total 1940 (4)
United Kingdom	0.050	0.19	New York	192,750
Ireland	0.059	0.32	New York	22,667
Italy	0.062	0.35	New York	45,368
Germany	0.052	0.23	New York	216,513
Poland	0.060	0.28	New York	66,284
Russia	0.064	0.37	New York	236,052
Other Europe	0.050	0.19	New York	348,471
Canada	0.038	0.21	Massachusetts	208,124
Mexico	0.043	0.39	California	263,006
Puerto Rico	0.096	0.90	New York	121,761
Cuba	0.047	0.41	Florida	125,089
Other Caribbean	0.073	0.61	New York	234,065
Central America	0.052	0.26	California	130,725
South America	0.069	0.47	New York	368,186
China	0.058	0.39	California	617,482
India	0.047	0.26	California	773,840
Other Asia	0.045	0.62	California	1,426,943
Rest of world	0.054	0.26	New York	549,302

Notes: State-level variables, means weighted by state population. Standard deviations in parentheses. There are 49 observations. Alaska and Hawaii are excluded. The minimum share is zero for all origins except for the United Kingdom, Germany, other Europe, and Canada. Columns 1–3 are based on the full population, while column 4 is based on the population 18–65 years old.

APPENDIX TABLE 2—MEANS OF INDIVIDUAL-LEVEL VARIABLES

	College graduates		Post-college		Scientists/engineers	
	Immigrant (1)	Native (2)	Immigrant (3)	Native (4)	Immigrant (5)	Native (6)
Highest degree:						
Bachelor's	0.58	0.65	–	–	0.44	0.68
Master's	0.28	0.26	0.66	0.74	0.39	0.26
Doctorate	0.07	0.03	0.17	0.08	0.16	0.06
Professional	0.07	0.06	0.17	0.17	0.01	0.01
Field of highest degree						
Computer science, mathematics	0.076	0.036	0.091	0.027	0.219	0.168
Biological, agricultural, environment science	0.056	0.040	0.061	0.030	0.092	0.093
Physical science	0.035	0.017	0.044	0.017	0.077	0.072
Social science	0.091	0.108	0.069	0.078	0.026	0.046
Engineering	0.132	0.053	0.131	0.037	0.397	0.321
Other S&E	0.164	0.121	0.199	0.157	0.069	0.058
Non-S&E	0.446	0.624	0.406	0.653	0.120	0.243
Sex (female)	0.48	0.50	0.43	0.49	0.24	0.23
Age	43.4 (9.9)	44.7 (10.3)	43.8 (9.9)	46.6 (10.3)	40.4 (9.0)	42.4 (9.5)
Employed	0.86	0.85	0.89	0.87	1.00	1.00
Observations	21,248	71,304	12,042	30,460	6,840	15,519

Notes: Means weighted with survey weights. S&E means science and engineering.

Source: National Survey of College Graduates

APPENDIX TABLE 3—FIRST STAGE OF INSTRUMENTAL VARIABLES REGRESSIONS FOR TEN-YEAR DIFFERENCES

	Skill represented by:	
	College graduates (1)	Post-college (2)
<i>Panel A. Base specifications</i>	0.31* (0.06)	0.29* (0.06)
R^2 [R^2 without excluded instrument]	0.78 [0.69]	0.75 [0.67]
<i>Panel B. Sample without California (288 observations)</i>	0.25* (0.05)	0.24* (0.06)
R^2 [R^2 without excluded instrument]	0.70 [0.63]	0.69 [0.63]
<i>Panel C. Sample without year 2000 (245 observations)</i>	0.45* (0.06)	0.40* (0.06)
R^2 [R^2 without excluded instrument]	0.79 [0.59]	0.69 [0.55]
<i>Panel D. Include BEA region dummies</i>	0.29* (0.05)	0.27* (0.06)
R^2 [R^2 without excluded instrument]	0.83 [0.76]	0.80 [0.74]
<i>Panel E. Include state dummies</i>	0.34* (0.06)	0.33* (0.07)
R^2 [R^2 without excluded instrument]	0.89 [0.82]	0.86 [0.79]
<i>Panel F. Include BEA region dummies and percent electrical workers 1980 \times year dummies</i>	0.25* (0.05)	0.25* (0.06)
R^2 [R^2 without excluded instrument]	0.83 [0.79]	0.80 [0.76]
<i>Panel G. Include BEA region dummies and percent electrical workers 1980 \times year dummies and 1940 immigrant shares</i>	0.29* (0.05)	0.30* (0.06)
R^2 [R^2 without excluded instrument]	0.89 [0.85]	0.85 [0.81]
<i>Panel H. Include BEA region dummies and percent electrical workers 1980 \times year dummies; exclude native skilled share</i>	0.27* (0.05)	0.29* (0.06)
R^2 [R^2 without excluded instrument]	0.83 [0.78]	0.84 [0.80]
<i>Panel I. Include BEA region dummies \times post-1980</i>	0.25* (0.09)	0.26* (0.08)
R^2 [R^2 without excluded instrument]	0.81 [0.77]	0.78 [0.73]
<i>Panel J. Include BEA region dummies \times post-1980; exclude native skilled share</i>	0.27* (0.09)	0.26* (0.08)
R^2 [R^2 without excluded instrument]	0.81 [0.76]	0.77 [0.73]

Notes: The dependent variable is the ten-year difference in the share of the population that is a skilled immigrant, with skill proxied by college in column 1, post-college in column 2. The coefficient reported is that on the excluded instrument, which is the predicted increase in immigrant college shares, based on states' shares of 1940 immigrants from various countries and subsequent national growth in college graduates from those countries (see text). Weighted least squares with weights $1/(1/pop_{t+1} + 1/pop_t)$. All regressions also include the covariates of Table 5 (except the difference in the skilled immigrant share). Standard errors clustered by state are in parentheses. There are 294 observations unless otherwise specified.

* Indicates coefficients significant at the 5 percent level.

The percent increase in the population is

$$(A4) \quad \frac{\Delta M^S}{POP} = \frac{0.01}{0.99 - \frac{M^S}{POP}} = \frac{0.01}{0.99 - \alpha_1}.$$

We calculate the percent increase in patents assuming that the additional immigrants continue to patent at rate P^{MS}/M^S :

$$(A5) \quad \frac{\Delta P^{MS}}{P} = \frac{1}{P} \frac{P^{MS}}{M^S} \Delta M^S = \alpha_0 \frac{\Delta M^S}{M^S}.$$

The expressions (A4) and (A5) can then be substituted into the expression for the percent increase in patents per capita on the left-hand side of equation (1) to obtain the expression on the right-hand side.

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