German-Jewish Émigrés and U.S. Invention

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How important are immigrants as a source of innovation? This paper examines the case of German-Jewish chemists who fled the Nazi regime in Germany. After Hitler took power in 1933, German scientists who had at least one Jewish grandparent were dismissed from German universities, and many of them fled to the United States. We use data on patents and patent citations to assess the effects of émigré chemists on U.S. invention. Specifically, we compare changes in U.S. invention research areas that build on inventions of émigrés with research areas that build on inventions of other German chemists. This analysis indicates that the arrival of German Jewish refugees had a positive and statistically significant effect on U.S. invention.

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On April 7, 1933 only 67 days after the Nazi government assumed power in Germany, the *Law for the Restoration of Professional Civil Service* expelled university professors with at least one Jewish grandparent from public service. More than 104,000 Jews from the German Reich fled to the United States between April 1933 and June 1941. By 1944, this number had risen to 133,000 nearly half the number of German-speaking Jews who had arrived in the 19^{th}-century. Most of these emigrants were white-collar city people, one fifth of them were university graduates, and more than half had completed 13 years of college-preparatory education (Sachar 1992, p.495). An unprecedented number of them were professionals. The National Refugee Service listed roughly 900 lawyers, 2,000 physicians, 1,500 writers, 1,500 musicians, and 3,000 academics (Sachar 1992, p. 496). Jewish refugees Leo Szilard, Eugene Wigner, John von Neumann, Edward Teller, Hans Bethe, Hans Staub, and Victor Weisskopf formed the core of the Manhattan project that achieved controlled nuclear reaction in Los Alamos between 1942 and 1945.

How much did the United States benefit from this enormous wave of high-skilled migrants? Immigrants account for a disproportionate share of members of the Academy of Sciences, are more likely to write highly-cited papers, and create successful technology start-ups than native born Americans (Stephan and Levin 2001; Hunt 2011). Empirical results on the effects of immigrants on the productivity of native-born workers, however, are inconclusive. State-level variation suggests that the arrival of high-skilled immigrants increases patenting among natives (Hunt and Gauthier-Loiselle 2010) but analyses at the level of cities indicate no significant effect (Kerr and Lincoln 2010). In fact, evidence from the arrival of Soviet mathematicians in the United States after 1992 suggests that competition with immigrants may discourage publications by native mathematicians (Borjas and Doran 2011). Related work on the contribution of star scientists in the life sciences (Azoulay, Graff Zivin, Wang 2010), however, suggests that the arrival of a large number of gifted scientists may create large positive effects on scientific productivity.

Émigré chemists such as Nobel laureates Otto Meyerhof, Otto Stern, and Otto Loewi but also Max Bergmann, Gustav Neuberg, and Kasimir Fajans had been respected names even before they arrived as refugees from Nazi Germany

> "Offered teaching posts not long after arriving, these men soon effected hardly less than a revolution in American academic chemistry…their work on the structures of proteins and amino acids, on metabolic pathways and genetics, almost immediately propelled the United States to world leadership in the chemistry of life" (Sachar 1992, p. 749).

But there is also evidence that the contributions of Jewish émigrés may have been slowed by administrative hurdles, anti-Semitism, and cultural differences. Scientists who wanted to move to the United States met with a "Kafkaesque gridlock of seeking affidavits from relatives in America, visas from less-than-friendly United States consuls, special permits from other nations whose territory was to be crossed in transit" (Sachar 1992, p. 495).[1]

> "If some two-thirds of these people ultimately found positions as teachers of one sort or another, it was hardly at the level they remembered from Europe. In the hungry 1930s, anti-Semitism was a fact of life among American university faculties as in other sectors of the economy. Physicists and chemists had the best chance of securing appointments…" (Sachar 1992, p. 498)

For example, Harvard, Yale, and Princeton did not hire Jewish professors until the late 1940s.[2] Cultural differences made it difficult for the émigrés who, in the Germanic tradition, often appeared aloof and condescending, and adapted only slowly to the more democratic atmosphere of American campus life (Sachar 1992, p. 499). Anti-Jewish bias also foreclosed attractive

[1] Following the *Anschluss* of Austria in 1939, Roosevelt increased the quota for German and Austrian immigrants and effectively dropped income qualifications; 30.000 refugees arrived from Germany and Austria in the next one and a half years (Sachar 1993, p. 533). A clause in the National Origins Act of 1939 exempted teachers and university professors from quotas on immigration (Ambrose 2001, p. 40). In September 1939, however, the outbreak of World War II, confronted the State Department with a host of new problems. Refugees became subject to stringent affidavit requirements, including guarantees of substantial cash deposits in American banks. Barely 10 percent of Jews on waiting lists were able to qualify. With the fall of France in spring 1940, Washington further tightened its visa policy to avoid infiltration by "enemy agents" (Sachar 1992, p.533).

[2] Albert Einstein, John von Neumann, Hermann Weyl and other émigrés worked at the Institute for Advanced Study at Princeton, instead of Princeton University. See Dinnerstein (1994, pp. 59-127) for a general discussion of the rise of anti-Semitism in the United States between 1933 and 1945.

private sector positions for the émigrés. The U.S. chemical firm Du Pont, for example, rejected Carl Neuberg, one of the founders of organic chemistry, as too Jewish (Sachar 1992, p. 495).

How much then did U.S. scientific innovation benefit from the emigration of German Jewish chemists? This paper uses the 1933 Law for the Restoration of the Professional Service (*Gesetz zur Wiederherstellung des Berufsbeamtentums*, 7 April 1933) in an empirical test to answer this question. The 1933 law required that "Civil servants who are not of Aryan descent are to be placed in retirement" (*Gesetz* §3).

> At a stroke, every Jew in Germany employed by the government or by state-sponsored local institutions was ordered to be dismissed from his or her post. From university professor to local postmistress, they all at to go…Prominence and reputation shielded no one, as over 1,200 Jewish academics were summarily dismissed. (Ambrose 2001, p. 20)

Politically unreliable persons, who "based on their previous political activities cannot guarantee that they have always unreservedly supported the national state" also lost their university appointments (*Gesetz* §4). After German soldiers marched into Austria on March 12, 1938, the law was extended to cover Austrian universities.

A total of 93 university chemists, 17.4 percent of all German and Austrian university chemists were dismissed between 1933 and 1941 (Table 1). Professors of Jewish origin who had been civil servants since 1914 or who had fought (or lost a father or son) in World War I were initially exempted, but became subject to dismissal under the Reich Citizenship Laws (*Nürnberger Rassengesetze*) in 1935. About 87 percent of the dismissed chemists were Jewish (Deichmann 2001), the remaining 13 percent were professors with Communist leanings and spouses of Jews. Although the dismissal of Jewish math professors lowered the productivity of their Ph.D. students, the dismissal of science professors had no noticeable effect on the productivity of other professors who were allowed to stay (Waldinger 2010, 2011).

Twenty-six of the dismissed chemistry professors worked in the United States for some part of their career after 1933 (Tables 2 and 3). Some of these émigrés became prolific patentees in the United States. For example, Arnold Weissberger, who was dismissed from the University of Leipzig in 1933, patented 75 inventions between 1939 and 1968. Ernst Berl, who was dismissed from his professorship at the Technical University of Darmstadt in 1933, patented 34 inventions. Other prominent inventors are Ernst Zerner (dismissed from the University of Vienna in 1938, 14 patents between 1914 and 1947), Willy Lange (dismissed from the University of Berlin in 1935, 12 U.S. patents between 1937 and 1949), and Walter Fuchs (dismissed from the Technical University in Aachen in 1935, 10 patents between 1933 and 1961).

Data on patents by émigré scientists create a unique opportunity to evaluate the effects of immigrants on invention in the receiving country. Specifically, the technology classification of patents allows us to precisely capture not only the émigrés areas of expertise but also the technology fields that were most influenced by their work. We then measure changes in domestic invention in those technology fields. Difference-in-differences regressions compare changes in U.S. invention in fields that built on inventions by émigré chemists with fields that built on inventions by other German chemists who did not have a Jewish grandparent and were therefore not dismissed from their professorships. Fields that build on inventions by émigré scientists are measured as United States Patent Office (USPTO) subclasses that include at least one citation to a patent by an émigré chemist. Thus we compare changes in the number of U.S. patents per subclass and year in subclasses that cite a patent by an émigré chemist with changes in subclasses that cite a patent by another chemists who did not emigrate to the United States.[3] This estimation strategy allows us to control for unobservable factors that may have caused U.S.

[3] Citations by later patents are the standard measure of knowledge flows. Jaffe (1989) uses citations as a measure of knowledge spillovers from academia to the private sector. Jaffe, Trajtenberg, and Henderson (1993) use variation in the origin of citing patents to show that knowledge spillovers from invention tend to be geographically localized.

invention to increase in fields where German chemists were active, independent of the arrival of German Jewish émigrés.

Data on changes in invention in treated and untreated subclasses are collected in five steps: In the first step we collect the complete roster of all 535 chemists who had the right to teach at German and Austrian universities in 1933 from German and Austrian year books of academic chemists.[4] Among those German chemists we identify dismissed chemists from records of relief organizations who advertised the names and research interests of dismissed scholars to help them find employment abroad. We complement these data with information on the emigration and employment histories of émigrés in the *International Biographical Dictionary of Central European Émigrés 1933 - 1945* (1983). In the second step, we match all 535 academic chemists with their U.S. patent records until 1970, when we expect a large number of the chemists that were active in 1933 to be at the end of their professional careers. This process yields a total of 1,120 patents between 1900 and 1970. In the third step, we identify patents that cite patents of émigrés and other German chemists; this yields a total of 4,905 citing patents. In the fourth step, we assign these citations to USPTO subclasses, which are narrowly defined technology areas. Patents by émigrés and other German chemists span a total of 4,873 USPTO subclasses. Subclasses that cite patents by an émigré are defined as treated technologies, while subclasses that cite patents by other German chemists are the control; 1,092 subclasses are treated and 3,781 are in the control. In the final step, we collect data on the outcome variable, patents per year by U.S. inventors, in each of these 4,873 subclasses of chemical inventions. This yields a total of 614,538 U.S. patents between 1900 and 1970.

Difference-in-differences regressions of these data indicate that the emigration of Jewish

[4] The Law of 1933 began to apply to Austrian scientists after the *Anschluss* of March 15, 1938, when Austria was incorporated in Nazi Germany. Names, university affiliations, and research fields for Austrian professors are collected from *Kürschner's Deutscher Gelehrtenkalender* (1931).

scientists provided a significant boost to U.S. invention. Subclasses that cite one additional émigré patent produce 0.09 additional patents after 1933 compared with subclasses that cite other German chemists. This implies an increase in domestic invention of 6.4 percent in subclasses that cite the work of émigrés. Estimates of time-varying effects become positive and statistically significant in the late 1930s and remain significant throughout the sample. They are robust to controlling for separate time trends for treated and untreated subclasses.

To examine the size and direction of selection effects, we use the dismissals of Jewish chemists as an instrument for emigration.[5] Dismissed chemists who worked in "hot" areas of invention may have been attracted to the high-income job research opportunities in the rapidly growing U.S. chemical industry. Anecdotal evidence, however, suggests that selection may have been negative, with younger, less prominent scientists moving to the United States. Prestigious U.K. universities, such as Oxford and Cambridge, were the first choice of many émigrés; many of the most prominent chemists found employment there (Snowman 2002, Ambrose 2001, p. 212-213),[6] while younger chemists continued their job search and eventually sought employment in the United States. Arnold Weissberger, for example, came to Britain first, but failed to procure an academic job and was deemed "unsuitable to industry" (Deichman 2005). Instrumental variable estimates, which are significant and larger than OLS confirm such anecdotal evidence on negative selection.

How did the arrival or prominent émigrés benefit invention in the United States? Were the benefits of émigrés due to the knowledge that they had acquired in Germany or to their

[5] Existing literature at the level of individuals (rather than research fields) indicates that high-skilled workers are generally more likely to move to countries with high returns to skills. Borjas' (1987) model of immigration implies that, émigrés are positively selected if returns to skills are higher in the receiving country and negatively selected if returns to skill are lower in the receiving countries. Data on Russian mathematicians who emigrated after 1992 (Borjas and Doran 2011) and immigrants from Puerto Rico (Ramos 1992, Borjas 2008) confirm these predictions. Immigrants from Mexico to the United States are positively selected even though returns to skill are higher in Mexico; this may be due to higher migration costs for low-skilled immigrants (Chiquiar and Hanson, 2005).
[6] Of 70,000 Jewish refugees, an estimated 55,000 remained in Britain, where they created lasting effects on culture and the sciences (Snowman 2002, Ambrose 2001).

response to research conditions in the United States and the demands of U.S. industry? U.S. chemical firms had been desperate for chemists with first hand experience of processes that were pioneered by the German chemistry. Du Pont, for example, had tried for years to attract German chemists who were familiar with the Haber-Bosch process, the filtration of alpha-naphtol, and other processes that German chemists had pioneered (Haynes 1948, p. 230; Hounshell and Smith 1988, p. 197).[7] To separate out such interactions we repeat the main specifications restricting the explanatory variable to U.S. patents by German chemists *before* 1933. These regressions indicate that the benefits to U.S. invention were driven by the research that émigrés performed after they arrived in the United States. Research fields where émigrés were active before 1933 were less productive areas of invention after 1933 compared with research fields of other German chemists.

An additional test to explore the mechanisms by which immigration increases invention expands the data to include the contributions of 129 younger, albeit less prominent academics. Regressions that include younger émigrés who had not yet reached the rank of *privatdozent* in 1933 yield smaller coefficient estimates. Subclasses that cite an additional patent by an émigré professor or a younger émigré produced 0.074 additional patents per year after 1933 compared with subclasses that cite patents by other German chemists. Thus, including younger émigrés who were less prominent and had worked fewer years in Germany slightly reduces the size of estimates suggesting that star scientists may have larger effects on innovation.

We also test whether émigrés to Britain encouraged invention in Britain. Historical analyses have documented the enormous impact of Jewish émigrés especially on the arts and humanities in Britain (Snowman 2002; Ambrose 2001). To identify such effects for Jewish

[7] For example, the German chemical company BASF had "cleverly avoided particulars as to the catalysts employed" in the Haber-Bosch process (Haynes 1945, pp.86-87), and, deprived of German chemists, U.S. firms required a "prolonged learning experience" of nearly a decade to understand the catalysis (Haber 1971, pp. 205-206).

chemists we examine changes in U.S. patents by U.K. inventors after 1933.[8] Estimates imply an increase of 0.00132 patents by U.K. inventors per subclass and year, equivalent to a 22 percent increase for each additional cited patent by an émigré to the U.K., compared with a mean of 0.0058 U.K. patents per subclass and year.

A series of robustness checks confirm the main results. Most importantly, we control for the fact that German chemists who stayed in Germany faced poor working conditions in the post-war period by using research areas that cited the work of Swiss chemists as an alternative control. Switzerland, like Germany, had a well-developed chemical industry, but Swiss chemists were less affected by the war. Thus we compare changes in U.S. invention after 1933 in fields where U.S. patents cite the work of émigrés with fields were U.S. patents cite the work of Swiss chemists. Regressions with Swiss research as an alternative control yield estimates that are very similar to the main specifications. Subclasses that cite one additional émigré patent produce 0.09 additional patents after 1933 compared with subclasses that cite other German chemists. An alternative tests that exploits differences between Russian-occupied and other parts of Germany also yields similar results.

The remainder of this paper is organized as follows. Section I describes the data; section II reports the main findings, section III investigates selection as well as the contributions of younger chemists, and section IV concludes.

I. THE DATA

Observations consist of the number of U.S. patents per subclass and year. A subclass is defined as treated if it includes at least one patent that cites a patented invention of an émigré scientist as a relevant piece of prior art. Changes in these subclasses are compared to control

[8] To identify U.K. inventors, we search for patentees from England, Scotland, Northern Ireland, and Wales.

subclasses, which include at least one patent that cites an invention of another German scientist who was allowed to stay in Germany. We construct these data in a five-step process.

A. A complete roster of chemistry professors in Germany in 1932

In the first step we collect the complete roster of all chemists who held a teaching appointment at a German university in 1932 or an Austrian university in 1931. This includes a total of 535 tenured professors and lecturers (*privatdozenten*) in chemistry. Data for chemistry professors at German universities are drawn from *Kalender der Deutschen Universitäten und Hochschulen* (1932/33), a compilation of university calendars that includes all university researchers at the level of *privatdozent* and above. Information on researchers at Austrian universities is drawn from *Kürschners Deutscher Gelehrtenkalender* (1931).

To identify dismissed chemists, we use a *List of Displaced German Scholars* (1937) that the relief organization Emergency Alliance of German Scholars Abroad assembled to help the dismissed to find employment abroad. The *List of Displaced Scholars* includes the names and fields of 84 German chemistry professors above the level of *privatdozent*. For example, the entry for Ernst Berl reads:

> BERL, Dr. Ernst, o. Professor; b. 77. (English.) 1916/19: Privatdozent Technische Hochschule, Vienna; 1919.33: O. Prof. Technische Hochschule, Darmstadt; since 1934: Research Prof. Carnegie Institute of Technology, Pittsburgh. Spec.: Inorganic Chem.; Organic Chem.; Technology; Heavy Chemicals and Derivatives; Cellulose. Perm.

Two secondary sources (Deichmann 2001 and Kröner 1983)[9] identify Austrian researchers that were dismissed after the *Anschluss* in 1938, and researchers who had died by 1937. This yields a total of 93 dismissed German and Austrian chemistry professors.

To identify émigrés to the United States, we record employment histories from

[9] Kröner (1983) extracts scientists by field from the *International Biographical Dictionary of Central European Émigrés 1933 – 1945* 1938.

International Biographical Dictionary of Central European Émigrés 1933 - 1945 (1983) for all dismissed scientists.[10] Counting any scientist who worked in the United States as an émigré to measure the effects of émigrés conservatively, yields a total of 26 émigrés (Table 2). Another 26 dismissed professors moved to the United Kingdom, 6 to Latin America, 5 to Palestine and Turkey each, 4 to Scandinavia and Switzerland each, 3 to France and Canada each, and 2 to Belgium and the Netherlands (Table 2).[11]

Additional information from the *Dictionary* includes all academic and private sector positions of dismissed scientists along with their main areas of expertise, and years of birth and death. We collect these data to help match scientists with patents. For scientists who are not listed in the *Dictionary* we collect data on employment history and death years from obituaries in the New York Times and other public sources. Biographical data indicate that, at 45.4 years, émigrés were on average 5 years younger than other German chemistry professors at 50.6 years in 1933, while dismissed scientists were of roughly the same age as other chemists (Table 1).

Arnold Weissberger (1898-1984) is one of the émigrés in our data. In 1933, Weissberger was a *privatdozent* at the University of Leibzig and lost his position because he was Jewish. Weissberger moved to England in 1933, but, having difficulties in finding employment, continued to the United States in 1936. Weissberger began to work at the research labs of Eastman Kodak Co. in Rochester in the same year and stayed there until 1975. His research focused on the chemistry of color photography; he formulated and developed many of the organic compounds used in processes of color photography today.

Carl Neuberg (1856-1956), the "founder of biochemistry," is another émigré. Neuberg's work laid the foundation for experiments of chemotherapy in mice. He also discovered seven

[10] Research for the *Dictionary* was conducted by the German *Institut für Zeitgeschichte* in München and the *Research Foundation for Jewish Immigration* in New York.
[11] Across disciplines, roughly half of the 1,200 dismissed scientists emigrated to Britain and the United States (Ambrose 2001, p. 179).

enzymes, including the Neuberg-ester (in 1913, fructose-6-phosphate). Neuberg was allowed to keep his professorship at the University of Berlin during the first wave of dismissals in 1933 because he had served as an artillery expert in the First World War, but eventually lost his position in April 1934.[12] He was also initially allowed to remain the director of the Kaiser Wilhelm Institute for Biochemistry,[13] which he had founded in 1925, but lost that post in 1936. In 1939, Neuberg moved to Palestine via Amsterdam; he served as a professor of chemistry at Hebrew University until 1940. Neuberg arrived in the United States in 1941, and became a research professor at NYU (Conrads and Lohff 2006).

B. Matching German chemists with U.S. patents

In the second step of our data collection, we hand-match émigrés and other German chemists with U.S. patents between 1900 and 1970. First, we search the online database of Google Patents (www.patents.google.com) for the name of the inventor. For example, a search for patents by "Arnold Weissberger" between 1900 and 1970 yields

> USPTO 2,350,127, granted on May 30, 1944, application filed September 26, 1940, Inventors: Henry Dudley Porter and Arnold Weissberger, Rochester N.Y., Assignors to Eastman Kodak Company, Rochester N.Y., for a "method of forming sulphonic acid chlorides of couplers groups."

Then two researchers separately check the patent title, patenting date and the location of the patentee of each patent to ensure that the patent is an actual match. Scientists with common names like Hermann Fischer are more difficult to match with their patents. Hermann was the 6th

[12] Other scholars left voluntarily in response to the 1933 law. Fritz Haber, for example, who won a Nobel Prize in chemistry for his contribution to the Haber-Bosch process of nitrogen fixation, fled to Switzerland in 1933. Haber was exempt from the 1933 law because his research on combat gases had been instrumental to Germany during World War I (Aftalion, 1991, p.121, Ambrose 2001, p. 181). He would have lost his position under the Reich Citizenship of 1935, but died of heart failure in 1934.
[13] Funded by donations of large companies, landed gentry, and contributions from the federal government and the state of Prussia, the Kaiser-Wilhelm-Institutes (KWI) allowed researchers to focus on basic research. Most KWI researchers did not have civil servant status and were therefore exempt from the Law of 1933. After WWII, most KWIs reopened as Max-Planck Institutes.

most popular name when Fischer was born and Fischer is the 4th most common last name in Germany today (Duden, 2000 and www.beliebte-vornamen.de).[14] Only 8 of the dismissed professors have both a first and last name that is among the 50 most common German names. We are able to match all of these scientists with their U.S. patents by using information on their employment history and research fields from the *Dictionary.* This matching process yields a total of 1,120 patents between 1900 and 1970, including 316 patents by dismissed German chemists and 161 by émigrés.

Data on patents for émigrés and other German chemists show that émigrés began to patent substantially more in the United States in the late 1930s, and continued to patent large numbers of inventions until the early 1950s, while the patenting activity of all German chemists peaks in the mid 1930s (Figure 1). The average émigré patented 0.16 inventions per decade before 1933, compared with 1.71 after 1933.[15] Arnold Weissberger, for example, is listed as an inventor on 62 patents between 1938 and 1953, and a total of 7 patents after 1955. Ernst Berl is listed as an inventor on 26 patents between 1933 and 1950.

C. Identifying U.S. patents that cite the patents of German chemists

In the third step of the data collection we extract citations to these patents by other U.S. patents between 1920 and 1970 from the full text of historical patent documents.[16] For example, Weissberger's patent 2,350,127 was cited by

> USPTO 2,680,731, granted on June 8, 1954, application filed July 5, 1950, Inventor: Elmore Louis Martin, Wilmington Del., Assignor to E. I. du Pont de Nemours and Company,

[14] Hermann Fischer was a *privatdozent* for at the University of Berlin when he was dismissed in 1933.
[15] This increase in patenting cannot be explained by variation in the age of émigrés. In the regression *Number of US patents*$_{sci,t}$ $= \alpha + \beta\, Dismissed_{sci} * Post1933_t + \gamma\, Post\ 1933_t + \delta\, Dismissed_{sci} + f(age_{sci,t}) + \varepsilon_{sci,}$ the coefficient for *Dismissed* * *post-1933* is 0.095 with a standard error of 0.07; coefficients for age and age square are significant, with coefficients of 0.008 and 0.000 respectively.
[16] The full text of USPTO patents between 1920 and 1979 is available in Google's database *Patent Grant OCR Text (1920-1979)* at http://www.google.com/googlebooks/uspto-patents-grants-ocr.html.

Wilmington Del., for "acetals containing a cyanoacetyl group."

A total of 4,905 U.S. patents between 1920 and 1970 cite the 1,120 U.S. patents that were granted to German chemistry professors; 1,148 patents cite a patent by an émigré, and 3,757 patents cite a patent by another German chemistry professor. The first citation to a patent by a German chemistry professor occurs in 1921, the first citation to a patent by an émigré occurs in 1935. Total citations to patents by German chemistry professors (including émigrés and other professors who were allowed to stay) increase steadily after 1920. In comparison, citations to patents by émigré professors start increasing in the 1940s, with a particularly strong increase in the 1950s (Figure 2).

D. Matching patents with USPTO subclasses

In the fourth step, we extract information on all primary and secondary subclasses of the patents that cite earlier patents by émigrés and other German chemists. USPTO subclasses are narrowly defined technology areas. For example, subclass 548-422 includes

"Organic compounds wherein one of the benzene rings and an additional carbocyclic ring bonded directly to the same acyclic nitrogen"

Patents by émigrés and other German chemists span a total of 4,873 USPTO subclasses, 1,092 of these subclasses are treated, and 3,781 are in the control.

E. Patents per subclass and year

In the fifth step, we collect data on the outcome variable: 614,538patents by U.S. inventors between 1900 and 1970 across the 4,873 subclasses. To separate patents by domestic and foreign inventors we search the inventors' country of origin and the full text of each patent for country names such as "Argentina," "Australia," and "Austria." U.S. patents between 1900 and

1920 are searchable in the *Lexis Nexis Chronological Patent Files*, and patents between 1920 and 1970 are available in Google's *Patent Grant OCR Text (1920-1979)* database.[17] Distinguishing patents by foreign inventors in this manner makes it possible to focus on the effects of émigrés to the United States on U.S. invention rather than estimating a broader effect on U.S. patents. The timing of invention is measured at the date of the patent grant.[18] Improvements in the quality of OCR are captured by annual fixed effects. Differences in breadth and in the propensity to patent across subclasses are captured by subclass fixed effects.[19] Differences in the growth paths of technological change across subclasses are addressed in regressions that control for subclass-specific time trends.

Summary statistics indicate that patenting increased disproportionately more in subclasses that received an émigré chemist. In subclasses that cite émigré professors, patents increase from 0.64 per year before 1933 to 2.64 per year after 1933. In subclasses that cite the inventions of other German professors, patents increase from 0.86 per year before 1933 to 2.69 after 1933. Across the entire data set, subclasses produced 1.83 patents per year between 1900 and 1970, and 2.71 patents per year after 1933 (Table 4).

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[17] Because this search is based on optical character recognition, it is subject to measurement error. To address it, we have hand-checked a data set of 625 dye patents between 1900 and 1943. In the hand-collected data, 241 patents are assigned to the United States, 226 to Germany, and 159 to other countries. In the algorithm-collected data, 290 patents are assigned to the United States, 197 are assigned to Germany, and 138 to other countries. An additional test compares the distribution of patents across nationalities across 18 main USPTO classes of chemical innovations (Moser and Voena 2010). This test reveals no significant differences between the two data sets. To identify as many foreign inventors as possible, we search for the name of a foreign country anywhere in the document. This overestimates the number of foreign inventors, if patent applications use the country name in a different context. For example, we wrongly assign USPTO patent 1,674,085 to Britain, because its inventors (who came from Massachusetts) also applied for a patent in Britain and mentioned this in their patent document. Several cross-checks of the data, however, indicate that such errors are rare. As an additional check of the nationality data, we compare the nationality data that we are able to collect from Google's *Patent Grant OCR Text (1920-1979)* database with nationality data in the NBER patent data between 1963 and 1970 (available at http://elsa.berkeley.edu/~bhhall). This comparison further confirms the quality of our data. For example, 98 percent of patents that our algorithms assign to U.K. inventors are also U.K. inventors in the NBER data..

[18] In a sample of 493 patents between 1930 and 1933 the average patent is granted 3 years after the application date, with a 25th percentile of 2, a mode of 3, and a 75th percentile 4 (Moser and Voena 2010).

[19] Empirical studies of 20th-century inventions in biotechnology and 19th-century exhibition records show that inventors' propensity to patent varies across technologies (Lerner 1995, Moser 2007).

Comparisons of patenting over time suggest that U.S. émigrés were active in research areas that produced fewer patents compared with research areas of other German chemists before the émigrés became professionally active in the United States. Between 1900 and 1932, subclasses that cite the work of an émigré produce xx U.S. patents by domestic inventors, compared with xx patents in subclasses that cite the work of another German professor (Figure 3). In terms of patents per year, this is equivalent to xx patents per year in subclasses that cite an émigré compared with xxx patents per year in subclasses that cite other German chemists (Table xx, Figure 3). Historically, this gap in patenting activity may be suggestive of discrimination against Jewish scientists in Germany before 1932, for example, if Jewish graduate students and post-docs or even professors were assigned to less productive research areas.

The gap in patenting by U.S. inventors begins to close after the émigrés arrive in the United States. By 1937 U.S. patents by domestic inventors have begun to increase at a higher rate in research fields that receive an émigré professor (Figure 3). Between 1940 and 1943, the gap in patenting nearly closes. Between 1943 and 194x (in terms of grant date, equivalent to 1941 and 194xx in terms of application dates) U.S. patents by domestic inventors decline in both types of research fields, possibly as a result of the war.

D. Attenuation Bias

Most importantly, the USPTO classification system may cause us to underestimate the effect of émigrés on invention because we assume that the arrival of an émigré only affects domestic invention in subclasses that cite an émigré patent. Given the relatively narrow definition of subclasses, however, knowledge spillovers from émigré inventions are likely to benefit inventions in other subclasses, which are included in the control.

II. EFFECTS OF ÉMIGRÉS ON U.S. INVENTION

Our empirical strategy is to compare changes in U.S. invention in fields of chemistry that benefitted from the arrival of a Jewish émigré with fields where other German chemists, who were allowed to stay in Germany, were active inventors. The dependent variable is the number of patents by U.S. inventors per USPTO subclass and year between 1900 and 1970:

$$(1)\ \textit{Patents by U.S. inventors}_{c,t} = \alpha_0 + \beta\ \textit{émigré patents}_c \cdot \textit{post}_t + \gamma \cdot X_{c,t} + \delta_t + f_c + \varepsilon_{c,t}$$

where *émigré patents*$_c$ counts the number of patents by émigrés that are cited by other U.S. patents in subclass *c*, and *post*$_t$ equals 1 after 1933 for subclasses with citations to German patents, and after 1938 for subclasses with citations to Austrian patents. Subclasses in the control group include patents that cite patents by other German chemistry professors, but do not cite patents by émigrés. The variable *X* measures the total number of patents by inventors from countries that did not receive any dismissed chemists; it controls for unobservable factors, such as differences in the speed of invention or in the propensity to patent within subclasses over time; δ indicates year fixed effects and *f* subclass fixed effects.[20]

A. Effects of émigré professors on U.S. invention

Subclasses that include citations to one more émigré patent produce 0.09 additional patents after 1933, compared with subclasses that cite other chemists (Table 5, column 2, significant at 1 percent). Compared with a mean of 1.83 patents per subclass and years across all

[20] We exclude patents by inventors from countries that received émigré chemists, such as the United Kingdom, Switzerland, or Palestine/ Israel, because inventive activity in those countries may have also benefitted from the arrival of dismissed German chemists. If the arrival of dismissed chemists had a positive effect on patenting in those countries, including them in the control variable Z would lead us to underestimate the effect of tacit knowledge in the United States.

years, this implies a 15 percent increase in domestic invention; compared with the post-1933 mean of 2.7 patents per subclass and year, it implies an increase of 6.4 percent.[21]

B. Time-varying treatment effects of émigrés

To assess the timing of effects, we estimate time-specific treatment effects β_t

$$(2)\ Patents\ by\ U.S.\ inventors_{c,t} = \alpha_0 + \beta_t \cdot \text{émigré patents} \cdot Year_t + \gamma \cdot X_{c,t} + \delta_t + f_c + \varepsilon_{c,t}$$

where β_t measures the differential change in two-year bins t in patenting between subclasses that cite émigré patents and subclasses that cite other German chemists, and $Year_t$ measures biannual intervals, with 1931 to 1932 as the excluded control period. Importantly, the variable $Year_t$ is not restricted to equal 0 before 1933, so that the coefficient β_t can be estimated for years before 1933. This allows us to investigate the standard assumption of differences-in-difference tests that treatment and control groups would follow a common time trend in the absence of treatment.

Estimates of time-specific treatment effects confirm that the arrival of émigré chemists brought substantial benefits for U.S. invention. Before 1933, estimates are close to zero, suggesting that differential pre-trends cannot explain the increase after 1933. Estimates become statistically significant in the late 1930s, and remain relatively constant until the late 1960s, with a further increase in the 1970s (Figure 3). Allowing for three-year lag between patent applications and grants, this implies that the benefits for U.S. invention set in around 1936, after many German chemists had settled and became professionally active in the United States.

[21] Conditional on citing any patents by U.S. émigrés, subclasses cite an average of 1.94 émigré patents. This implies that the average subclass that cites any patents by U.S. émigrés experiences an increase in patenting of 0.0885*1.94 = 0.17. Compared with an average of 2.67 patents per subclass and year after 1933 this implies an effect of 0.17/2.67 = 0.064.

D. Controlling for subclass-specific time trends

An additional test controls for variation in the time trends of patenting at the level of individual subclasses. For example, patenting may increase because a subclass becomes a "hot" technology fields independently of the contributions of an émigré chemist, or patenting may decrease because the field that is covered by a specific subclass becomes obsolete. Alternatively, patenting may increase because two firms engage in strategic patenting within a subclass (e.g. Hall and Ziedonis 2002). To control for these factors, we estimate time-varying effects including a separate linear time trend for each subclass. Estimates with subclass-specific time trends confirm a significant increase in patenting after 1938 that persists until 1957 (Figure 4).

D. Robustness checks

The first robustness check replaces the continuous explanatory variable *émigré patents* with a binary variable that distinguishes subclasses that cite an émigré patent from subclasses that only cite patents by other German chemists. Most subclasses include only one citation to an émigré patent; the median and average number of citations in treated subclasses is 1 and 1.17, respectively, but a small number of subclasses include up to 5 citations. Estimating the regressions with a binary treatment variable restricts these additional patents to have no additional benefits for invention:

$$(3)\ \textit{Patents by U.S. inventors}_{c,t} = \alpha_0 + \beta\ \textit{subclass citing emigre}_c \cdot \textit{post}_t + \gamma \cdot X_{c,t} + \delta_t + f_c + \varepsilon_{c,t}$$

where *subclass citing émigré*$_c$ equals 1 if the subclass cites any émigré patents, and all remaining variables are defined as above.

Coefficient estimates with the binary treatment variable imply a comparable effect to estimates with the continuous variable. Subclasses that cite at least one émigré patent produce 0.18 additional patents per year after 1933 compared with subclasses that cite other German chemists (Table 6, column 2, significant at 1 percent).

A second robustness check estimates Poisson regressions to allow for the fact that patents are count data.   In these tests, the coefficient estimates for the difference-in-difference estimator is 0.105 for $\textit{patents citing émigrés}_c \cdot \textit{post}_t$ and significant (Table 6, column 3, significant at 1 percent). Estimates of incidence ratios imply a xx percent increase in invention.

D. Using Swiss chemists as an alternative control

Another potential concern is that the research of chemists who stayed in Germany may have suffered from the adverse effects on working conditions in German chemistry departments. For example, the research of chemists who stayed in Germany may have been hindered by war-time destruction and post-war shortages (e.g., Aftalion 1991) or compulsory licensing of German-owned U.S. patents (Lee and Moser 2011, Moser and Voena 2011). Mechanically, our results cannot be driven by this change because we include citations to both pre-and post-war patents to measure knowledge flows. We do, however, also use technology fields that cite patents by Swiss chemistry professor, who were less affected by the war, as an alternative control.

Using the research fields of Swiss chemists as a control, the estimated effect of the émigrés on U.S. invention is in fact slightly larger, with a coefficient of 0.09 (Table 6, column 2, significant at 5 percent). Four of the dismissed German chemists in our sample moved to Switzerland, 2 of them patented a total of 11 patents in the United States; their patents were cited in 13 USPTO subclasses. Dropping data for these subclasses yields a coefficient of 0.09 (Table 6, column 4, significant at 1 percent).

E. Did émigrés to United Kingdom increase U.K. chemical inventions?

Twenty-six dismissed German chemists were active in the United Kingdom for some time after 1933 (Table 2). Data on U.S. patents by U.K. inventors allows us to test whether émigrés to U.K. had a comparable positive effect on U.K. invention.

$$\textit{U.S. Patents by U.K. inventors}_{c,t} = \alpha_0 + \beta \cdot \textit{U.K. émigré patents}_c \cdot \textit{post}_t + \gamma \cdot X_{c,t} + \delta_t + f_c + \varepsilon_{c,t}$$

where *U.S. patents by U.K. inventors*$_{c,t}$ measures the number of U.S. patents by U.K. inventors per subclass and year and *U.K, émigré patents*$_c$ counts the number of cited patents by U.K émigrés in subclass *c* and year *t*.

Estimates indicate a significant effect of émigrés to the U.K. on U.K. invention. In subclasses that include an additional patent by a U.K. émigré, U.K, inventors patent an additional 0.0013 inventions in the United States after 1933 (Table A3, column 2, significant at 1 percent). Due to the relatively low level of U.S. patents by inventors in the United Kingdom, the size of these coefficients is relatively small. Estimates, however, imply a substantial increase in patenting relative to the small number of U.S. patents by British inventors.[22] Between 1900 and 1970, U.K. inventors patent an average of xx inventions per subclass and year in the United States; after 1932, U.K. inventors patent an average of xx patents per subclass and year. This

[22] Most importantly, U.K. inventors may only patent the most valuable inventions in the United States, or U.K. inventions that are patented in the United States may be tailored to the American market.

implies an xx percent increase in patenting by U.K. inventors in subclasses that cite the work of an émigré to the United Kingdom.

III. Instrumental Variable Estimates

Historical records indicate that chemists who worked on the "hottest" technologies may not have come to the United States, which was a less desirable destination for Jewish émigrés due to its greater geographic and cultural distance from Germany. In comparison, Britain, which was the first refuge for many émigrés in the early and mid 1930s (Ambrose 2001, p. 215)[23] had established universities, such as Oxford and Cambridge and offered opportunities for prominent scientists who pursued the most attractive topics to continue their careers. Twelve of 250 émigrés to Britain won a Nobel Prize and 53 became Fellows at the Royal Society (Ambrose 2001, pp. 182-185).

Evidence from the patent histories and biographies for the chemists in our sample confirms that the United States attracted chemists who were less prominent in 1932 and whose research was less promising. Chemistry professors who moved to the United States were on average xx years younger than émigrés to Britain and other German chemistry professors (Table 1) and had produced fewer U.S. patents by the time they were dismissed (with xx patents compared to xxx, Table 1). Arnold Weissberger, for example first moved to Oxford on a three-year fellowship, and only continued to the United States when this fellowship expired in 1936, and he English firms deemed him "unsuitable for industry" (Deichmann 2005, p.585-586). Another example, is Gertrud Kornfeld who had been a *privatdozent* and assistant to Max Bodenstein at the University of Berlin, where her work focused on photochemistry and reaction

[23] Émigré Nobel laureates include Hans Krebs, the first refugee to be appointed to a university chair in Britain, and Ernst Chain, whose discovery of the molecular structure of penicillin made it possible to cheaply and reliably manufacture the drug (Ambrose 2001, pp. 182-185).

kenetics. When Kornfeld was dismissed in 1933, she first tried to find a position in England, and only when she could not find a position there, went to Vienna on a fellowship of the American Association of University Women. From there, Kornfeld continued to the United States (Deichman 2005, p. 585).

A. Did the U.S. attract the most productive scientists?

The fact that all professors of Jewish origin were dismissed allows us to use dismissals as an instrument to measure selection in the emigration decisions of dismissed professors. Specifically, we use the number of cited patents by dismissed chemists as an instrument for the number of cited patents by émigré chemists. The first stage regression is

$$(4)\ \textit{émigrés patents}_c \cdot post_t = \alpha_0 + \beta\ \textit{dismissed patents}_c \cdot post_t + \gamma \cdot X_{c,t} + \delta_t + f_c + \varepsilon_{c,t}$$

where the dependent variable measures the number of cited émigré patents in subclass c interacted with the post-dismissal variable and the instrumental variable $\textit{dismissed patents}_c \cdot post_t$ measures the number of cited patents in subclass c by dismissed chemists interacted with the post-dismissal variable. An F-statistic of 13,583 for the excluded instrument (Table 7) suggests that the number of cited patents by dismissed chemists in a given subclass is a strong predictor for the number of cited patents by émigré chemists in the same subclass.

Instrumental variable results confirm that Jewish émigrés had a significant positive effect on U.S. invention. Subclasses that include an additional cited patent by an émigré produce 0.12 additional patents per year after 1933 (Table 8), implying a larger effect than OLS. Although some of the difference between OLS and IV estimates may be due to measurement error attenuating the OLS coefficients, this result is consistent with historical evidence suggesting that the most productive professors found positions at English universities.

B. How important was knowledge that the émigrés had brought from Germany?

We use citations to pre-1933 patents by émigrés to analyze the importance of knowledge that émigrés brought from Germany. For that reason, we restrict the sample to only include subclasses with at least one pre-1933 patent by any of the German chemists. To address selection we use cited pre-1933 patents of dismissed chemists as an instrument for cited pre-1933 patents by émigrés. The first stage regression is

$$(5)\quad \textit{pre-1933 émigré patents}_c \cdot \textit{post}_t = \alpha_0 + \beta\ \textit{pre-1933 dismissed patents}_c \cdot \textit{post}_t$$

$$+ \gamma \cdot X_{c,t} + \delta_t + f_c + \varepsilon_{c,t}$$

where the dependent variable measures the interaction between the number of cited patents by émigrés in subclass c before 1933 and the post-dismissal variable, and the instrumental variable measures the number of cited patents before 1933 by dismissed chemists in subclass c interacted with the post-dismissal variable. An F-statistic of 157 for the excluded instrument (Table 9) suggests that the number of cited patents by dismissed chemists in subclass c before 1933 is a good predictor for the number of cited émigré patents in that subclass before 1933. OLS estimates suggest that subclasses that include an additional cited pre-1933 patent by an émigré chemist produce 0.3 *fewer* patents per year after 1933, compared with subclasses that cite pre-1933 patents by other German chemists. This is consistent with the fact that Jewish scientists worked on less promising research fields in the early decades of the 20th century and negative selection of less prominent, younger dismissed professors into migration to the United States. At xx, instrumental variable estimates are comparable in size to OLS estimates (xx, Table xx) but they are less precisely estimated, due to the small number of U.S. patents by German chemists before 1933.

C. Including chemists below privatdozent

Although the comparison of Jewish and other German professors offers a particularly clean test for the effects of Jewish émigrés, it is likely to estimate a lower bound for the total effect of Jewish émigrés on U.S. invention by focusing on patented inventions and limiting the analysis to chemistry professors, rather than private sector chemists. Our main tests also do not capture the effects of younger academics, who had not yet reached the rank of a *privatdozent* in 1933. These scientists had a larger number of productive years ahead of them, and may have been more likely to move to industry, where the propensity to patent may have been higher. On the other hand, they were also less prominent and had fewer opportunities to acquire knowledge in Germany before they were dismissed.

As a first cut to evaluate the potential effects of younger scientists, we extract the names of all 139 chemists who were at least 18 years old in 1933 and are listed in the *Dictionary of Central European Emigrés*, and collect data their U.S. patents, citations to these patents and thus additional subclasses that were treated by German émigrés. This process yields an additional 67 émigrés to the United States, whose average age in 1933 was 35 years, compared with 45 years for émigré professors. Younger chemists produced on average 0.47 patents between 1900 and 1970, compared with 0.29 patents for émigré professors; their patents span 651 subclasses, expanding the sample to a total of 1,524 subclasses with a total of 183,837 patents (Table 1, columns 6-8).

Extending the sample of émigrés to include younger chemists reduces the size of the OLS estimate to 0.04 (Table 11), roughly one sixth of the estimate for professors. Instrumental variable results confirm emigrants to the United States were negatively selected. These results suggest that older, and more prominent Jewish scientists had the largest impact on U.S. invention.

IV. Conclusions

How much did the arrival of Jewish émigrés benefit U.S. innovation? Our analysis of differential changes in U.S. patents by domestic inventors in chemistry suggests that the émigrés effects were substantial: Subclasses that cite an additional patent of an émigré chemist produced an additional 0.24 patents per year after 1933, compared with subclasses that cite other German chemists. Compared with the average number of patents per subclass and year after 1933, this is equivalent to a 10 percent increase.

The timing of estimated effects suggests that the benefits to U.S. invention were gradual and persistent learning effects. In research fields that cite émigrés rather than other Germans, patent grants to domestic inventors begun to increase around 1938 and peaked in the early 1950s. This suggests that émigrés had the strongest effects on patent applications in the mid and late 1940s, after they had reestablished themselves in the United States, their ideas had spread and they begun to train students and collaborators. These results are robust to various controls for pre-trends in patenting. Regressions that use Swiss chemists instead of German stayers as a control group, to account for adverse research conditions in Germany after 1933, yield similar estimates.

The data also indicate that émigrés to the United States were negatively selected. Britain was the first stop for many émigrés and many of the most prominent scientists were able to continue their careers at Oxford and Cambridge. In our data émigrés to the United States were about 5 years younger and less experienced. Instrumental variable regressions, which address selection by using patents by dismissed scientists as an instrument for patents by émigrés, yield larger estimates than OLS. Equivalent analyses for the United Kingdom suggest a similar effects, although estimates are imprecise due to a small number of observations.

What are the mechanisms by which émigrés benefitted U.S. invention? One prominent candidate explanation is the knowledge that émigrés had acquired in Germany and brought with them to the United States. Some of this knowledge could have been transferred without their arrival in the United States, but a significant portion may have been tacit, non-codified knowledge that is most easily transferred by the physical presence of the people who know. Instrumental variable regressions that use the émigrés pre-1933 patents to measure the effect of such knowledge yield no significant effects, suggesting that it was what the émigrés did in the United States, rather than what they had learned in Germany, that benefitted U.S. innovation. Our data also indicate that older, and more prominent researchers carried the most significant benefits for U.S. innovation. Expanding the professor sample to include chemists who had not yet reached the rank of a *privatdozent* in 1933 lowers the estimated effects by about 70 percent, even though younger chemists had more productive years ahead of them in the United States and were more likely to enter private sector employment, where they could have patented more.

Our findings suggest the following extensions for future work. What were the contributions of émigrés outside of the patent system? How did émigrés affect the publications of their peers? Can their contributions be measured through the discovery and developments of new chemical compounds? And what are the mechanisms by which the émigrés benefitted U.S. innovation? Were their effects localized geographically or within firms and research departments or did they affect U.S. innovation at a larger scale? And what were their effects on inspiring and training future generations of scientists?

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