IMMIGRATION AND INNOVATION: LESSONS FROM THE QUOTA ACTS [*]

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In the 1920s, the United States introduced immigration quotas to limit arrivals from Eastern and Southern Europe (ESE). Intended to discourage low-skilled immigration, the quotas exempted scientists and students. We use biographical data on more than 80,000 American scientists to investigate the quotas' effects on innovation. These data show that the quotas discouraged ESE-born scientists from studying and working in the United States. To investigate effects on innovation, we use the world-wide universe of publications to identify research fields in which ESE-based science was prominent before the quotas. Difference-in-difference analyses show that, after the quotas, US innovation experienced a large and persistent decline in ESE fields. A decomposition exercise reveals that the quotas reduced innovation by lowering the productivity of incumbent scientists and by replacing immigrants with less productive natives. As US scientists produced fewer innovations in ESE fields, Canada gained relative to the United States.

KEY WORDS: IMMIGRATION, SCIENCE, INNOVATION, *K*-MEANS, AND TEXT ANALYSIS

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Between 1921 and 1965, immigration to the United States was ruled by a quota system, which encouraged immigration from Germany and the British Isles, while heavily restricting arrivals from Eastern and Southern Europe, Asia, and other parts of the world. Intended to stem the inflow of "undesirable" low-skilled non-Nordic immigrants, the quotas explicitly excluded scientists and students. Yet, by declaring certain nationalities unwanted, the quotas may have discouraged high-skilled immigrants from these countries from coming the United States, harming US innovation.

We examine the quotas' effects on US science and innovation using rich data on the birth places, education, and career histories of more than 82,000 US-based scientists. Applying tools of natural language processing (NLP) to the universe of publications in the United States and abroad, we identify research fields in which ESE-based science was prominent *before the quotas.* Linking scientists with US patents, we investigate the quotas' effects on US innovation.

Until the late 19th century, most US immigrants arrived from the British Isles and the German-speaking regions of Europe. By 1890, however, most immigrants came from Eastern and Southern Europe (ESE). These "new" immigrants met with a surge of nativist sentiment, reaching to the highest levels. Writing in the popular magazine *Good Housekeeping*, soon-to-be Vice President, Calvin Coolidge (1921, pp.13-14) argued that the United States "must cease to be regarded as a dumping ground," and asked for an "ethnic law" to change the nature of immigration.

Intended to preserve the existing ethnic composition of the United States and stem the inflow of low-skilled ESE immigrants, the 1921 Emergency Quota Act (Ch. 8, 42, Stat 5) restricted the number of immigrants per year to three percent of the number of people from that country who were in the US Census of 1910. When these rules proved ineffective, the 1924 Johnson-Reed Act further reduced the quota to two percent and changed its reference population to the Census of 1890 (pub. L. 68-139, 43, Stat. 153). Immigration fell precipitously from nearly 360,000 in 1923-24 to less than 165,000 the following year. Beyond merely reducing the number of immigrants, the 1924 quota act adjusted the ethnic mix of immigration. Arrivals from Asia were banned. Immigration from Italy fell by more than 90%, while immigration from Britain and Ireland dropped by a mere 19% (Murray 1976, p.7). This nationality-based quota system ruled US immigration until President Lyndon B. Johnson abolished it with the passage of the 1965 Immigration Act.

This paper uses rich biographical data on 82,094 American scientists in 1921 and 1956, matched with their patents, to examine the quotas' effects on US science and invention. A major strength of our data is that they include the precise date and place of birth for 99.5% of

82,094 American scientists, along with naturalization records, education and employment histories, as well as their research topics.

Examining the immigration and career histories of US-based scientists, we uncover a dramatic decline in the arrival of new ESE-born scientists after the quotas. Until 1924, arrivals of new ESE-born immigrant scientists were comparable to arrivals from Northern and Western Europe (WNE), who were subject to comparable pull and push factors of migration. After the quotas, arrivals of ESE-born scientists declined significantly while arrivals from Northern and Western Europe continue to increase. Combining data on naturalizations with information on scientists' education and career histories, we estimate that 1,164 ESE-born scientists were lost to US science after the quotas, including 568 scientists in the physical sciences. At an annual level, this implies a loss of 38 scientists per year, equivalent to eliminating a major physics department each year between 1925 and 1955.

Even though professors and students were explicitly exempted from the restrictions of the quota acts, US universities lost an estimated 122 ESE-born professors as well as 670 ESE-born scientists who would have moved to the US as students. In addition to professors and students, the United States lost an estimated 402 ESE-born industry scientists, who (unlike academic scientists) were subject to the quotas. Using the MoS (1921) to identify scientists who were already in the United States at the passage of the quota acts, we investigate whether the quotas also encouraged established ESE-born scientists to leave. This analysis indicates that the large majority (95%) of ESE-born scientists who were already in the United States chose to stay.

To estimate the causal effects of the quotas on US science and innovation, we compare changes in patenting by US scientists in fields in which many ESE-based scientists were active before the quotas with changes in other fields with fewer ESE-based scientists. Methodologically, we use the universe of publications in Microsoft Academic Graph (MAG, Sinha et al. 2015) to create a dictionary of scientific terms and apply a Word2Vec algorithm (Mikolov et al. 2013) to learn 100-dimensional vector embeddings for each term. These embeddings capture the semantic relationships between scientific keywords in a dictionary, which we use to construct the landscape of research fields. Using this dictionary we apply a k-means clustering algorithm to the vector representation of key words of publications in the MAG to assign every MAG author to a unique research field. Information on the institutional affiliations of MAG authors allows us to identify fields in which many ESE-based scientists published before the quotas. Keywords that describe the research of each scientist in the MoS (1956) allow us to assign scientists to ESE and control fields, using the pre-quota definitions of fields which we built from the MAG.

To create a high-quality match between scientists and their patents, we develop a matching algorithm that incorporates rich information on each scientist's date of birth, full name, and discipline. This improved matching algorithm allows us to reduce false positive matches from more than 80% for the most naïve Levenshtein matching (ignoring middle names, name frequencies, and differences in match quality between the physical, biological, and social sciences) to less than 5% for the physical sciences. We focus our empirical analyses of patenting on 646 research fields in the physical sciences, where patents are a good measure for innovation.

Comparing changes in patenting after the quota, we document a strong and persistent decline in US innovation in the pre-quota fields of ESE scientists. After 1924, US scientists patented 30% less in ESE fields in relative to other fields. Time-varying estimates show that innovations by US scientists in ESE fields declined in the 1930s and stayed low through the 1950s. Importantly, there is no evidence for pre-existing differences in patenting for ESE and other fields before the quotas. Estimates for US-born scientists are nearly identical to estimates for all US scientists (including the foreign-born). All estimates are robust to alternative regression models, including quasi-maximum likelihood (QML) Poisson and inverse hyperbolic sine. Estimates are also robust to controlling for alternative specifications of pre-trends in patenting, and to excluding the largest fields.

A potential alternative explanation for the decline in innovation in the fields of ESE-based scientists is that ESE-based scientists may have pursued research in fields that declined relative to other fields after 1924, independently of the quotas. To investigate this alternative channel, we estimate placebo regressions for Canada, which did not implement restrictions on ESE-born immigrants. These estimates reveal no decline in Canadian innovation in ESE fields after 1924. Triple-differences regressions show that Canadian scientists produced more patents in ESE-fields after 1924 compared with US scientists and other fields.

To investigate the mechanisms by which the quotas reduced US innovation, we first separate effects at the extensive and at intensive margin. These estimates show that US scientists produced 45% fewer patents in the pre-quota fields of ESE-born scientists and produced no patents after 1924 in an additional 5% of ESE fields. Next, we investigate whether the decline in innovation in ESE fields was linked to the loss of ESE-born immigrants. Specifically, we decompose the overall effect on innovation into a loss due to the missing contributions of ESE-born scientists and a loss due to reduced spillovers to US-born inventors. To perform this analysis, we interact the number of patents per ESE-born scientists before the quotas with the estimated count of 568 missing ESE-born scientists in the physical sciences after the quotas to gauge the counterfactual contributions that missing ESE-born scientists would have made to US innovation. These estimates suggest that a loss of 1,331 patents between 1921 and 1950 is due directly to missing patents by ESE-born scientists, just 6.3% of 21,674 total missing US patents, suggesting that most of the decline was due to reduced spillovers to US-born inventors.

Further decomposing the decline in innovation by US-born scientists, we identify two possible channels: a decline in patents per scientist and a decline in the number of US-born scientists in ESE fields. 17.56% fewer scientists were active in ESE fields after the quotas; these scientists produced 47.87% fewer patents per scientist. Time-varying estimates, which compare the number of active scientists in ESE fields with other fields, show that the timing of this decline closely matches the timing of the observed decline in patenting. Estimates with scientist fixed effects indicate that incumbent US-born scientists who were active in ESE fields before the quotas produced fewer patents after the quotas, relative to incumbents who were active in other fields. This decomposition exercise indicates that immigration quotas reduced innovation by lowering the productivity of incumbent scientists and by replacing immigrants with less productive non-immigrants.

US-born scientists may have produced fewer patents because they had fewer opportunities to collaborate with ESE-born scientists after the quotas. The example of the Hungarian-born mathematician Paul Erdős illustrates this mechanism. Erdős was denied a re-entry visa by in 1954, and not allowed to return to the United States until 1963. Examining Erdős' top 100 collaborations we find Erdős' collaborations shifted away from the United States during this time: Between 1954 and 1963, just 24% of Erdős' new co-authors were US scientists, compared with 60% until 1954. These patterns are confirmed in our broader analysis of patents by co-authors (and co-authors of co-authors): After 1924, there was a 25.6% decline in innovation by scientists who were connected to at least one ESE-born scholars.

A final section explores the broader effects of the quotas on innovation in the United States and abroad. Firm-level analyses of changes in patenting reveals that firms which employed ESE-born scientists in 1921 created 33.1% fewer innovations after the quotas. Complementary text analyses of US patent titles suggest that innovation declined more broadly in the fields of ESE-born scientists. After the quotas, 23% fewer US patents describe innovations in ESE fields compared with other fields. Some of the missing scientists moved to the future Israel, where they helped to build the foundation for universities that fuel innovation. Migration data for Jewish scientists, which we collect from the World Jewish Register (1955), reveal a dramatic increase in the migration of Jewish scientists to Palestine, around the time of the quotas. Many moved to the Technion, which had been founded in Haifa in 1912, and grew dramatically during this time. Today, the Technion is Israel's premier university for technology and science.

Thematically, our findings relate to research on the effects of immigration on innovation[1] and to the broader literature on the effects on immigration in the US economy (Clemens, Lewis, and Postel 2018; Burstein et al. 2019). In a historical analysis of restrictions on immigration under the US Bracero program, Clemens, Lewis, and Postel (2018) find that restrictions on the inflow of unskilled Mexican workers created no benefits in terms of higher wages or improved employment for native workers. Using recent data on US commuting zones between 1980 and 2012, Burstein, Hanson, Tian, and Vogel (2019) show that in non-tradable jobs, an influx of immigrants' crowds out native workers in jobs that are "immigrant-intensive," while there is no such effect in tradable occupations (like science).

Several recent papers examine the effects of the quota acts on low-skilled immigration (Tabellini 2020, Doran and Yoon 2019, Abramitzky et al. 2022). Our research complements that work by investigating the quotas' unintended effects on high-skilled immigrants - which were not the target of the acts. To pursue this analysis, we implement a distinct identification strategy by comparing changes in innovation across research fields that were differentially affected by the quotas, using NLP techniques to define the pre-quota fields of ESE scientists.[2]

1. The 1920s Quota Acts

Before 1890, 90 percent of immigrants to the United States came from the British Isles and the German-speaking parts of Continental Europe (US Census 1975, pp.106-09). Towards the end of the 19th century, a combination of push and pull factors triggered a new wave of mass migration from Eastern and Southern Europe. Rapid industrialization increased demand for unskilled workers in the United States (Rosenbloom 2002). Improvements in rail and steamship links facilitated immigration from Eastern and Southern Europe (Keeling 2012, p.23), while increased competition with American grain reduced rural incomes (O'Rourke 1997, pp.775-76). Jews from Russia's Pale of Settlement came to the United States to escape violence and oppression. The hardship of military service motivated people of all religious

[1] E.g., Kerr and Lincoln (2010); Hunt and Gauthier-Loiselle (2010), Moser, Voena, and Waldinger (2014), Bernstein, Diamond, McQuade, and Pousada (2022) and San (2023).

[2] Following Card (2001), other papers have used geographic variation in pre-existing immigrant flows to identify the effects of immigration. Using pre-existing settlement patterns to instrument for the location decisions of new immigrants, Tabellini (2020) finds that immigration triggered support for anti-immigrant legislation even where it increased employment. Doran and Yoon (2019) find that restrictions on unskilled immigration reduced innovation, while Abramitzky et al. (2019) show that the loss of immigrant workers encouraged farmers to shift toward capital-intensive agriculture. Sequeira, Nunn, and Qian (2020) examine the effects of European immigration before the quotas by interacting variation in arrivals over time with variation in the expansion of the rail network.

backgrounds to leave Russia, Poland, and Austria-Hungary.

As a result of these factors, the share of Eastern Europeans and Italians among all US immigrants exploded from 8 percent in the 1870s and 18 percent in the 1880s to 49 percent in the 1890s, 76 in the 1900s, and 80 percent in the 1910s. Three countries alone - Russia, Austria-Hungary, and Italy - accounted for nine in ten immigrants from Southern and Eastern Europe. None of these countries had made up more than ten percent of European migration before 1890. Most Italian immigrants were "propertyless peasants" from the rural South. Roughly two thirds of Polish immigrants were "landless peasants and the agrarian proletariat" (Nugent 1992, p.94). Jewish immigrants, three quarters of them coming from Russia, were artisans, professionals, and urban workers from medium-sized towns ("shtetls").

Cultural differences between the old and new immigrants triggered a nativist response reaching the highest levels of the executive (Jones 1992, p.176). In February 1921, soon-to-be Vice President Calvin Coolidge asked for an "ethnic law" to regulate migration. The *New York Times* (February 9, 1921, p.7) weighed in arguing that: "American institutions are menaced; and the menace centres (sic) in the swarms of aliens whom we are importing as 'hands' for our industries, regardless of the fact that each hand has a mind and potentially a vote. With the diseases of ignorance and Bolshevism we are importing also the most loathsome diseases of the flesh. Typhus, the carrier of which is human vermin, has already been scattered among us…"

For the first time in US history, in May 1921, the Emergency Quota Act (Ch. 8, 42, Stat 5) introduced limits on the total number of immigrants per year, by restricting immigrants per year to three percent of the number of residents from that country in the US Census of 1910. Yet, due to the dramatic inflows from Southern and Eastern Europe between 1890 and 1910, the 1921 Act had little bite. After Coolidge became President in 1923, he used his first address to Congress to argue for restrictions on immigration: "New arrivals should be limited to our capacity to absorb them into the ranks of good citizenship. America must be kept American. For this purpose, it is necessary to continue a policy of restricted immigration."

In May 1924, the Johnson-Reed Act (pub. L. 68-139, 43, Stat. 153) reduced the quotas to two percent and pushed their reference population back to the Census of 1890. Senator Reed, a Republican from Pennsylvania, argued for "Our New Nordic Immigration Policy"
"There has come about a general realization of the fact that the races of men who have been coming to us in recent years are wholly dissimilar to the native-born Americans; that they are untrained in self-government – a faculty that it has taken the Northwestern Europeans many centuries to acquire. […] From all this has grown the conviction that it was best for America

that our incoming immigrants should hereafter be of the same races as those of us who are already here, so that each year's immigration should so far as possible be a miniature America, resembling in national origins the persons who are already settled in our country" (*Literary Digest*, May 10, 1924, pp.12-13)

To ensure enforcement, Congress appropriated funding and instructed courts to deport nationals from countries that had exceeded their quotas.

Scientists and students were explicitly exempt from the restrictions of the quota acts:

"An immigrant who continuously for at least two years immediately preceding the time of his application for admission to the United States has been, and who seeks to enter the United States solely for the purpose of, carrying on the vocation of minister of any religious denomination, or professor of a college, academy, seminary, or university; and his wife, and his unmarried children under 18 years of age, if accompanying or following to join him" (Section 4d), and

"An immigrant who is a bona fide student at least 15 years of age and who seeks to enter the United States solely for the purpose of study at an accredited college, academy, seminary, or university" (Section 4e). Section 2 examines whether these exceptions were effective.

Strengthened by the 1952 Immigration and Nationality Act, the quotas governed US immigration until 1965 when President Lyndon B. Johnson signed a new immigration bill: "This bill that we will sign today […] corrects a cruel and enduring wrong in the conduct of the American Nation […] Yet the fact is that for over four decades the immigration policy of the United States has been twisted and has been distorted by the harsh injustice of the national origins quota system. […] Only 3 countries were allowed to supply 70 percent of all the immigrants. […] Men of needed skill and talent were denied entrance because they came from southern or eastern Europe or from one of the developing continents. […] Today, with my signature, this system is abolished. We can now believe that it will never again shadow the gate to the American Nation with the twin barriers of prejudice and privilege."

2. Effects on Arrivals

To investigate the quotas' effects on innovation, we first examine whether they reduced the number of ESE-born immigrant scientists in the United States – even though scientists and students were explicitly exempted from the quotas.

Data: Birth Places and Immigration Histories of American Scientists

Our main data set covers rich biographical information for 82,094 American scientists in the *American Men of Science* (MoS 1956). These data include each scientist's place of birth (allowing us to identify ESE-born scientists), date of birth (enabling us to create a high-quality match between scientists and patents), as well as records on naturalizations, education, and employment (allowing us to investigate changes in the arrival of foreign-born scientists in the United States). Originally collected by a long-time editor of *Science*, James McKeen Cattell (1860-1944), the "chief service" of the MoS was to "make men of science acquainted with one another and with one another's work" (Cattell 1921). Cattell, who was the first psychology professor in the United States, collected these data for his own research on intelligence. James Cattell published the first edition in 1907; his son Jacques published the 1956 edition.

Assuring data quality, the MoS 1956 was subject to comprehensive input and review from "scientific societies, universities, colleges, and industrial laboratories." Jacques Cattell thanks them for having "assisted in supplying the names of those whom they regard as having the attainments required for inclusion." He also thanks "thousands of scientific men who have contributed names and information about those working in science" and "acknowledges the willing counsel of a special joint committee of the American Association for the Advancement of Science and the National Academy of Science National Despite the name, the MoS include both male and female scientists in Canada and the United States. Research Council, which acted in an "advisory capacity" (Cattell 1956, Preface). Entries are divided into the Physical Sciences (volume I, 41,096 scientists), Biological Sciences (volume II, 25,505 scientists), and the Social & Behavioral Sciences (volume III, 15,493 scientists).[3]

A major advantage of the MoS is that it lists each scientist's place of birth, allowing us to identify foreign-born scientists. Birth places are known for 99.5% of all 82,094 scientists at US and Canadian institutions and 79,507 scientists at US institutions, respectively. In 1956, 2,066 US scientists were ESE-born (2.5%), 4,029 US scientists (4.9%) were born in Northern or Western Europe, 70,927 (86.4%) were born in the United States, and another 3,117 (3.8%) were born in Canada. The most common birthplaces for ESE-born US-based scientists were Russia, Poland, and Hungary, with 613, 319, and 272 scientists, respectively, followed by Czechoslovakia (201) and Italy (173 scientists).

To examine changes in the number scientists after the quotas, we combine data on naturalizations, education, and employment histories. First, we examine changes in the number of foreign-born scientists who became naturalized US citizens per year. Under US law, immigrants are eligible for naturalization after five years. The year of the scientist's

[3] In total the MoS (1956) has 91,638 American scientists, including 6,352 scientists who appear in multiple volumes, 2,015 scientists whose entry consists only of a reference to another MoS edition and 534 scientists whose entry is a reference to Cattell's Directory of American Scholars (1957).

naturalization is known for 2,775 foreign-born scientists, and 33.5% of all European-born scientists, including 745 ESE- and 1,296 WNE-born scientists (36.1% and 32.2%, respectively). Next, we use the locations of the universities that scientists attended to identify scientists who came to the United States as students and determine when they arrived. These data are available for 77,551 American scientists (94.5%).

In addition to university attendance, information on employment allows us to estimate when each scientist took their first job in the United States. 82,094 American scientists in the MoS (1956) lists 465,918 institutions of employment. To identify employment institutions in the United States, we develop a three-step algorithm (Appendix C), which allows us to assign first year of US employment for 77,996 of 82,094 American scientists (95.0%).

Combining data on education and employment histories, we determine the arrival year for 5,751 of 6,095 European-born scientists (94.4%), including 1,995 ESE- and 3,756 WNE-born scientists (96.6% and 93.2% of ESE- and WNE-born American scientists, respectively). Our preferred measure combines naturalizations with employment and education histories to estimate the earliest year when each scientist was present in the United States. This method allows us to estimate the year of arrival for 5,786 of 6,095 European-born US scientists (94.9%), including 2,005 ESE- and 3,781 WNE-born scientists (97.0% and 93.8% of ESE- and WNE-born scientists, respectively).

Fewer ESE-Born Scientists Come to the US as Students and to Work in Industry after 1924

We use information on naturalization, education, and employment histories to estimate the number of ESE-born scientists that were lost to US science due to the quotas. Combining information on naturalizations, university education, and employment, we estimate that 1,164 ESE-born scientists were missing from US science by 1956 (Table 1, row 1, and Figure 1). This implies a loss of 38 ESE-born US scientists per year, roughly the size of a major physics department each year. For the physical sciences alone, an estimated 568 ESE-born scientists were lost to US science (Table 1, row 7).

Even though professors and students were explicitly exempted from the quotas, US universities lost an estimated 122 ESE-born professors after 1921 (Table 1, row 4)[4] as well as 670 ESE-born scientists who would have come to the United States as students (Table 1, row 3).[5] In addition to professors and students, the United States lost an estimated 426 scientists

[4] To estimate the number of missing scientists, we calculate the counterfactual number of ESE-born scientists under the assumption that the ratio of ESE-born to WNE-born scientists arriving in the United States after 1924 would have remained stable at pre-quota levels and subtract the observed count of ESE-born scientists.
[5] Only three European-born scientists arrived as dependents of professors and ministers between 1910 and 1956. Among them was Ernest Courant, the son of Richard Courant. To examine dependents, we match all 334 scientists who arrived in the US as minors (below the age of 18) with their childhood home in the US census

who were subject to the restrictions of the quota acts (Table 1, row 6). 402 of these non-exempted scientists were industry scientists; the remaining 24 scientists were university employees who had not yet been professors for two years, as required by the provisions of the quota acts.

In addition to discouraging arrivals, the quotas may have motivated established ESE-born US-based scientists to leave the United States. To measure potential outflows, we collect the names, research fields, birth places, birth dates, and career histories of all 121 ESE-born and 380 WNE-born scientists from the MoS (1921) and search university directories, obituaries, and ancestry to determine whether these ESE-born US-based scientists left the United States after 1921. We find that nearly all scientists who were already in the United States stayed: 95.0% of ESE-born and 93.6% WNE-born scientists in the MoS (1921) remained in the United States for the remainder of their lives.

3. Using NLP Methods to Assign Scientists to Fields

A key advantage of the MoS is that it reports scientists' research topics and disciplines, allowing us to assign scientists to research fields that were differentially affected by the restrictions of the quota acts. Research topics are known for 96.4% of all 82,094 scientists; disciplines are known for 99.97%. We apply NLP methods to textual data on research topics and disciplines to assign each scientist to a unique research field. To measure variation in exposure to the quota acts, we apply NLP tools to the universe of publications in Microsoft Academic Graph (MAG, Sinha et al. 2015) and identify fields in which ESE-based research was prominent *before the quotas*.[6] Specifically, we use the keywords that describe the corpus of publications in Microsoft Academic Graph (MAG) between 1900 to 1956 to define research fields and use author affiliations in the MAG (e.g., with an ESE-based university in Prague) to identify fields in which ESE-based researchers were active before the quotas.[7]

Identifying the Pre-Quota Fields of ESE-based Scientists

First, we use keywords for 6,150,512 publications (including journal articles, books, and patents) to construct a comprehensive dictionary of 36,094 scientific terms that represent the

and check whether the occupations of the parents qualified for exemptions. Census records on parents' occupation are available for 269 scientists (80.50% of the 334 scientists arriving as minors). For the remaining 65 scientists we collect data on parents' occupation from obituaries, faculty records, and other sources.

[6] Existing research on immigration (e.g., Moser and Voena 2012; Moser, Waldinger, and Voena 2014) has used the assignment of patents to USPTO technology subclasses to define technology fields. This strategy, however, fails to capture knowledge in key fields, such as physics or mathematics, in which knowledge is not typically patented. To address this issue, we use the text that describes the content of *publications* to define fields.

[7] MAG was updated until December 2021 (Wang et al. 2019), we use the version from August 1, 2020.

state of science in the first half of the 20th century. Specifically, we use the Word2Vec algorithm to learn 100-dimensional word embeddings for all keywords in MAG between 1900 and 1956.[8] This embedding technique (implemented in *Python's Gensim* library) converts keywords into a machine-readable vector that captures semantic similarities between related terms (Mikolov et al. 2013). These word embeddings make it possible to characterize the work of individual scientists by computing the average of the embeddings for keywords describing their research.

Next, we apply a *k*-means clustering algorithm to group the authors of these publications into fields. A "cluster" (here, a field) refers to a collection of data points (here, authors) with similar observable characteristics (here, the keywords that describe their research). To group authors into clusters, the *k*-means algorithm assigns them to one of *k* centroids by minimizing the distance between the observations and the centroid, starting with *k* randomly selected centroids. The algorithm performs iterative calculations to minimize the mean of the sum of the squared distances between the centroids and the vectors representing the research of each author. It stops when moving the centroids yields no further decline in the minimized sum of squared distances.

To determine the optimal number of clusters *k* we apply three complementary diagnostics: the elbow method (a decision rule using kinks or "elbows" in the plot of within-clusters sum-of-squared errors), the silhouette score (a metric that measures how similar a point is to its own cluster – cohesion - compared to other clusters - separation), and the gap statistic (the natural logarithm of the within-cluster dispersion). These measures jointly indicate that the optimal number of clusters is *k*=1,500 (see Appendix E for details).

To identify fields in which ESE-based scientists were active before 1924, we use the institutional affiliations of authors who published between 1900 and 1924. For example, we classify the mathematician Friedrich (Frigyes) Riesz as an ESE-based author in the pre-quota period because he lists Budapest as his place of work on a 1910 paper ("Untersuchungen über Systeme Integrierbarer Funktionen," *Mathematische Annalen*, Vol. 69, Issue 4, pp. 449-497).

In a final step, we apply the field classification that we created using publications to the text that describes the research of each scientist in the MoS (1956); this allows us to assign each scientist in the MoS (1956) uniquely to one of the 1,500 MAG fields. 41,096 scientists in the physical sciences work in 646 fields; 332 of these fields are *ESE* fields – research fields in which ESE-based scientists were active before the quotas. Section 4 describes the *ESE*

[8] We use 100-dimensional word embeddings as a balance between capturing semantic information and computational efficiency. This dimensionality helps mitigate issues associated with high-dimensional spaces in k-means clustering and falls within the range of 100 to 300 dimensions commonly used in practical applications.

variable in more detail and presents two complementary measures of exposure to the quotas.

Matching Scientists with Patents

To measure changes in innovation, we count successful patent applications by American scientists per field and year. We construct these data through an improved matching process that links all 82,094 American scientists with their US patents between 1910 and 1970 from Google Patents, using information on the scientist's full name, age, and discipline. This allows us to reduce the rate of false positives from 83.3% (without considering the inventor's age, middle name, or disciplines) to 4.2% for the physical sciences. For the biological and social sciences error rates remain high, with 32.8% and 67.9%, respectively.[9] Within the physical sciences, we match 154,883 successful patent applications between 1910 and 1970 with 15,146 unique American scientists, including 445 ESE-born and 997 WNE-born American scientists (see Table A1 and Appendix D).

To measure the timing of innovation, we use application (rather than issue) dates because issue dates can be delayed by years. For instance, Thomas Edison's final patent for a "holder for article to be electroplated" was issued on May 16, 1933, two years after Edison's death, even though Edison filed this patent on July 6, 1923. Application dates are available for 2,509,425 of 2,604,834 patents issued 1910-70 (96%). For patents with missing application dates, we subtract the median lag between application and publication (2.4 years).[10]

We use the assignee of each patent to identify firms that employed foreign-born scientists. For patents issued after 1926, these data are available from Kogan et al. (2017). We extend their data to include patents issued before 1926 and add information on application years.

4. Effects on Innovation

To capture variation in exposure to the quotas across fields, we define three complementary measures of exposure. First, a binary measure ESE_j, indicates fields in which ESE-based scientists were active before the quota acts. Among 646 fields with MoS scientists, 332 fields are ESE fields; 314 other fields form the control. In the average *ESE* field, 0.32 ESE-born scientists did research in the United States, 4 times as many compared with 0.08 ESE-born scientists in the control fields. *ESE* fields had the same number of WNE-born US-based

[9] Biological organisms became patentable after 1980, when the U.S. Supreme Court in Diamand v. Chakrabartyupheld a patent for a bacterium engineered to digest crude oil. In the social sciences, business methods became patentable after 1998 when the U.S. Court of Appeals for the Federal Circuit (in *State Street Bank & Trust Co. v. Signature Financial Group, Inc.*) allowed patents for innovations in business methods.

[10] Citations are a useful control for the quality of patents (e.g., Moser, Ohmstedt, and Rhode 2018), but they are not systematically recorded in patents before 1947.

scientists, with an average of 0.49. Further comparing the pre-quota characteristics of *ESE* fields and the control, we find that scientists in ESE fields are more likely to hold PhDs (with 64% compared to 57% in non-ESE fields), while all remaining differences between ESE fields and the control group are small (Table A2).

Second, we use the number of ESE-based scientists in field *j before the quotas*, relative to the sum of ESE- and US-based scientists to define a continuous measure of exposure

$$\%ESE_j = \frac{N^{ESE}(j)}{N^{US}(j)+N^{ESE}(j)} \quad (1)$$

where $N^{ESE}(j)$ is the number of scientists in field j in Eastern and Southern Europe in 1900-24, and $N^{US}(j)$ is the number of scientists in field j in the US in 1900-24. For instance, field 409, which covers research in "combinatorics" includes 162 ESE-based scholars (including the Hungarian mathematician Frigyes Riesz) and 22 US-based scholars (e.g., the mathematician Edward Wilson Chittenden at the University of Iowa), yielding a quota share $\%ESE_j$ = 0.86. $\%ESE_j$ spans the full support between 0 and 1, with a median of 0.01, a mean of 0.14 and a standard deviation of 0.24 (Figure A3).

Third, we separate the continuous measure into three categories to distinguish high, low and no exposure. High ESE fields are those in which most scientists are ESE-based ($\%ESE_j \in [0.5,1]$), low ESE fields are fields in which most scientists are US-based ($\%ESE_j \in (0,0.5)$), and control fields are those without any ESE-based scientists ($\%ESE_j$ = 0).

Changes in Innovation in ESE Fields Relative to Control Fields without ESE-based Scientists

Before the quotas, US inventors produced 165.1 patents per year between 1910 and 1924 in ESE fields, just slightly less than the 187.7 patents in the control group (Figure 2). Five years after the quotas, however, however, US scientists produced just 446 patents ESE fields in 1929, 58% fewer compared with 1,056 patents in control fields. Across all post-quota years, between 1925 and 1954, US scientists created just 847 patents per year in ESE fields, 53% fewer than the 1,784 patents per year in control fields.

OLS regressions control for variation across fields and over time:

$$ln(patents_{jt}) = \beta \cdot ESE_j \cdot post_t + \gamma_j + \delta_t + \epsilon_{jt} \quad (2)$$

where the dependent variable $ln(patents_{jt})$ is the natural logarithm of US patents (+0.01) by US scientists in field *j* and year *t*. The indicator $post_t$ denotes years after 1924. Field fixed effects γ_j control for variation in patenting across research fields (e.g., Cohen, Nelson, and Walsh 2000; Moser 2012a), and year fixed effects δ_t control for variation in patenting over time. Standard errors are clustered at the field level. Under the identifying assumption that, in the absence of the quotas and controlling for year and field fixed effects, changes in US innovation after 1924 would have been comparable in ESE fields and control fields, β estimates the causal effects of the quotas on US innovation. =

OLS estimates of equation (2) confirm the decline in US innovation: After the quotas, US scientists produced 29% fewer additional patents in ESE fields compared with control fields (with an estimate of -0.346 for β, significant at 1 percent, Table 2, column 1).

Event Studies of Changes in Innovation in ESE fields after the Quota Acts

To investigate the timing of this decline in innovation, we estimate:

$$ln(patents_{jt}) = \beta_t ESE_j + \gamma_j + \delta_t + \epsilon_{jt} \quad (3)$$

where β_t is a vector of time-varying estimates for the quotas' effect on US science, 1918-1920 is the excluded period, and all other variables are defined in equation (2).

Supporting the identifying assumption, time-varying estimates are close to zero before the quotas (Figure 3). Estimates first become statistically significant in 1930-32, when US inventors produce 27% fewer additional patents in ESE fields relative to control fields. Estimates reach a low of 38% in 1948-50 and remain statistically significant until 1953.

Using the continuous measure for exposure to the quotas, we estimate

$$ln(patents_{jt}) = \beta \cdot \%ESE_j \cdot post_t + \gamma_j + \delta_t + \epsilon_{jt} \quad (4)$$

where $\%ESE_j$ captures the pre-quota share of ESE-based scientists in field j based in ESE countries. Under the identifying assumption that, in the absence of the quotas and controlling for year and field fixed effects, changes in US innovation after 1924 would have been comparable in fields with a larger share of ESE-based scientists before the quotas, β measures the impact of increased exposure to the quotas on US innovation. To interpret coefficients as the effects of a one-standard-deviation increase in exposure to the quotas, we divide the treatment measure by its standard deviation (0.24).

OLS estimates indicate that increasing exposure to the quotas by one standard deviation (0.24) reduces innovation by 15% (Table 2, columns 2, significant at 1 percent). Event study estimates indicate no significant differences before the quotas and become first significant in 1927-29, with an estimate of 12% for a one standard deviation increase in exposure to the quotas. Estimates reach a low of 17% in 1948-50 (Figure A4).

A third specification separates exposure into *High ESE* (defined as $\%ESE_j \in [0.5,1]$), *Low ESE* (defined as $\%ESE_j \in (0,0.5)$), using fields without exposure as the control.

$$ln(patents_{jt}) = \beta_{Low} \cdot LowESE_j \cdot post_t + \beta_{High} \cdot HighESE_j \cdot post_t + \gamma_j + \delta_t + \epsilon_{jt} \quad (5)$$

Estimates are negative for fields with *Low ESE* and *High ESE* exposure and significantly larger for fields with *High ESE* exposure. After 1924, US scientists in *High ESE* fields produced 51% fewer patents compared with fields without exposure, while US scientists in

Low ESE fields produced 22% fewer patents (Table 2, column 3, significant at 10 and 1%, respectively). Event study estimates show no significant effects before the quotas. After the quotas, innovation in high-ESE fields declines by 42% in 1927-29; this decline reaches a low of 59% in 1948-50 and remains large and statistically significant until 1953, with a decline of 54% (Figure A5).

To check our empirical strategy, we plot the relationship between exposure and the relative number of patents before and after 1924 across research fields (Figure 4). These comparisons show a clear negative correlation across the entire distribution of exposure, indicating that our results are not driven by outliers or by a group of fields in a specific part of the distribution of exposure.

Placebo and Triple-Difference Estimates for Canada

A potential alternative explanation for the decline in innovation is that scientists who worked in ESE countries before the quotas may have worked in fields which generated fewer US innovations after 1924 - independently of the quotas. For instance, ESE-based scientists may have been more likely to work in older fields with fewer remaining recoveries, which would violate the identification assumption. Above, we estimate event studies to evaluate changes in innovation before the quotas; these estimates show no differences in the speed of innovation in ESE and other fields leading up to the quotas.

Here, we perform an additional set of tests by re-estimate equation (2) as a placebo regression for Canadian scientists – Canada-based scientists in the MoS 1956 – who were not subject to the quota. Since Canada did not pass its own quota acts in 1924, a decline in innovation in ESE fields after 1924 would indicate selection and suggest that our identification assumption is invalid. To investigate this possibility, we estimate placebo regressions that compare changes in innovation by Canadian scientists per year and field in ESE fields with changes in other fields.

Supporting the identification assumption, placebo estimates show that there was no significant decline in innovation in ESE fields by Canadian scientists after the quota acts (Table 2, column 4). Moreover, there was no significant decline in fields with a higher share of ESE-based scientists (column 5). The only significant estimate (for High-ESE fields in column 6), is marginally significant and much smaller (at 0.08 log points) than the corresponding estimate for the United States (0.72 log points). Estimates for time-varying effects are close to zero, and not significant except for 1954-56, with an estimate of 13% (Figure 5, Panel A).

Triple-differences regressions estimate:

$$ln(patents_{jct}) = \beta\, ESE_j\, US_c\, Post_t + \gamma_{jc} + \delta_{jt} + \theta_{ct} + \epsilon_{jct} \quad (6)$$

where $\ln(patents_{jct})$ is the natural logarithm of the number of US patents (+0.01) by scientists working in country c (Canada/US), field j, and year t. The indicator US_c equals 1 for scientists working in the United States in 1956 and 0 for those working in Canada. γ_{jc}, δ_{jt} and θ_{ct} are field-country, field-year and country-year fixed effects.

Triple-differences estimates confirm that US innovation declined in ESE fields relative to other fields and relative to innovation by Canadian scientists after the quotas. Compared with Canadian scientists and other fields, US scientists created 32% fewer patents in ESE fields after 1924 (Table 2, column 7). Time-varying triple differences estimates are close to zero before 1924 (Figure 5, Panel B). After the quotas, in 1927-29, US scientists produced 29% fewer patents in ESE fields compared with Canadian scientists and other fields.

Triple-differences estimates remain large between -24% and -41% until 1953, suggesting a permanent relative decline in US innovation. These estimates are close to the baseline estimate for the United States of 29% (Table 2, column 1), which suggests that the change is driven primarily by a decline in US innovation, rather than an increase in Canadian innovation. Estimates with alternative exposure measures confirm these results (Table 2, columns 8-9). In addition, results are robust to controlling for field-level pre-trends (Table A3, column 2), to adding alternative values to the log-transformation (0.1, 0.001, and 0.0001, columns 3-5) and to specifications as Inverse Hyperbolic Sign or Quasi Maximum Likelihood Poisson (columns 6-7).

US Scientists were Active in Fewer Fields and Produced Fewer Patents per Field

We estimate extensive margin regressions to examine whether the quotas reduced the number of ESE fields in which US scientists were active inventors. In these regressions, the outcome variable equals one if US-based scientists produced at least one patent in field i and year t. Estimates with the binary exposure variable for ESE fields imply a 3.5% decline in the number of ESE fields in which US scientists were active inventors (Table 3, column 1, significant at 10 percent). Estimates with the continuous exposure measure imply a 2.0% decline in invention at the extensive margin for one standard deviation increase in the exposure $\%ESE$ (0.24) (significant at 10 percent, column 3). Fields with high exposure experience a strong 8.3% decline in invention at the extensive margin (significant at 1 percent, column 5), while fields with low exposure experience no significant change.

To investigate changes at the intensive margin we re-estimate the baseline specification excluding field-year pairs without patents. Intensive margin estimates imply that US scientists created 49% fewer patents in ESE fields after the quotas compared with other research-active fields (Table 3, column 2, significant at 1 percent). Increasing exposure $\%ESE$ by one standard deviation (0.24) reduces innovation by 24% (column 4, significant at 1 percent). In fields with high ESE exposure US scientists produced 67% fewer patents after the quotas compared to fields with no exposure; fields with low ESE exposure created 47% fewer patents (column 6, significant at 1 percent).

Time-varying estimates of the extensive margin are close to zero before the quotas and decline to a minimum of -5.2% in 1948-50 (p-value of 0.08, Figure A6, Panel A). Intensive-margin estimates are also close to zero before the quotas in all years except 1912-1914, and decline significantly after to reach a low of 55% in 1948-50. Estimates remain statistically significant until 1956 (with an estimate of 49%, p-value<0.001, Figure A6, Panel B).

5. Mechanisms

How did the quotas harm US innovation? To answer this question, this section presents a decomposition exercise (separating lost innovations into the losses due to missing scientists and changes in productivity), scientist-level estimates for incumbent US-based scientists, and an analysis of changes in patterns of collaboration.

Decomposing the Decline in Innovation: Missing Scientists or Lost Productivity?

First, we decompose the decline in innovation (*Missing Patents*) into a decline due to *Missing Scientists* and *Lost Productivity*:

Missing Patents= Missing Scientists · Avg Productivity+ Lost Productivity · Avg Scientists (7)

where *Missing Patents (Scientists)* represents the difference between the observed number of patents in a field and the counterfactual number of patents (scientists) in that field had the ratio of patents (scientists) in ESE and other fields remained stable at pre-quota levels. *Lost Productivity* is the difference between the observed productivity in a field and the counterfactual productivity, defined as the counterfactual number of patents divided by the counterfactual number of scientists.[11] *Avg Scientists* is the average of actual and counterfactual scientists, and *Avg Productivity* is defined in the same way.[12] This decomposition suggests that the decline in invention is due primarily to *Lost Productivity* (79.7% of missing patents, Table 4, Panel A) rather than *Missing Scientists* (20.3%).

[11] To ensure that the number of missing scientists in this decomposition is identical to the number of missing scientists in the baseline estimates, we apply a constant multiplier to all estimates of missing patents.

[12] Let subscript 0 denote observed patents, productivity, and scientists, and let 1 denote counterfactuals. Then, Missing Patents = $\text{Patents}_1 - \text{Patents}_0 = \text{Scientists}_1 \cdot \text{Productivity}_0 - \text{Scientists}_1 \cdot \text{Productivity}_0$ = Missing Scientists$\cdot \text{Productivity}_0 + \text{Scientists}_1 \cdot$ Lost Productivity_0= Missing Scientists $\cdot (\text{Productivity}_1 + \text{Productivity}_0)/2$ + Lost Productivity $(\text{Scientists}_1 + \text{Scientists}_0)/2$ = Missing Scientists $\cdot$ Avg Productivity_1 + Lost Productivity $\cdot$ Average Scientists.

Decomposing *Missing Patents* further into changes in patenting by US-born, other foreign-born and ESE-born scientists, we find that most of the decline in innovation is due to a decline in the productivity of US-born scientists. 81.3% of *Missing Patents* are by US-born scientists; 65.7% (80.8% of this 81.3% decline) is due to a decline in the productivity of US-born scientists. Another 12.4% are *Missing Patents* by other foreign-born scientists; 10.7% (86.2% of this 12.4% decline) is due to a decline in the productivity of other foreign-born scientists (Table A4).

By comparison, just 6.3% of *Missing Patents* are due to a decline in patenting by ESE-born scientists; this decline is moderated by an increase in the productivity of ESE-born scientists after the quotas. 11.3% of Missing Patents are by ESE-born scientists. An increase in the productivity of ESE-born US-based scientists after the quotas, however, adds 5.1% of patents (Table A4, holding constant the number of ESE-born US-based scientists). Notably, the estimate of *Missing Patents by ESE-born scientists* implied by this decomposition is close to estimates implied by the comparison of ESE-and WNE-born scientists above (Figure 6).

Effects on Incumbent US-Based Scientists

Even if restrictions on immigration harm innovation overall, they may increase the productivity of incumbent scientists who face less competition for university appointments, laboratory space, or other scarce resources. To investigate effects on incumbents, we estimate scientist-level regressions with scientist fixed effects for scientists who were already working in the United States before 1924:

$$ln\ (patents_{it}) = \beta \cdot ESE_{j(i)} post_t + \gamma_i + \delta_t + \epsilon_{it} \quad (8)$$

where the dependent variable ln $(patents_{it})$ represents the number of US patents in year *t* by US-based scientist i who were either working in the United States or studying at a US college before 1924. The variable $ESE_{j(i)}$ equals one if scientist i works in an ESE field. The indicator $post_t$ denotes years after 1924. γ_i are scientist fixed effects and δ_t are year fixed effects. Standard errors are clustered at the scientist level.

These estimates imply a significant decline in innovation by incumbent US-based scientists in the fields of ESE scientists. After the quotas, incumbent US-based scientists patented 10.2% less in ESE fields (Table 5, column 1), indicating that the decline in positive spillovers outweighed the gains due to reduced competition from missing ESE-born scientists.

Innovation declined both at the extensive and the intensive margin. Extensive margin estimates indicate that US-based scientists became 2.0% less likely to create at least one patent in a given year after the quotas (Table 5, column 2). Intensity estimates show that incumbent scientists in fields that were more exposed to the quotas experienced a substantially larger decline in innovation: Increasing $\%ESE$ by one standard deviation (0.24) reduces innovation relative to incumbents in other fields by 4.8% (Table 5, column 3) and reduces incumbents' probability of patenting by 1.0% (column 4). Separating exposure into *high, low*, and *no exposure*, we find that incumbent scientists in fields with *high exposure* patent 11.3% less compared with incumbents in fields with *no exposure*, and incumbent scientists in fields with *low exposure* patent 10.0% less (column 5). Incumbent scientists are 2.3% less likely to have any patent in fields with *high exposure* and 2.0% less likely in fields with low exposure (columns 6).

Event study estimates indicate no differences in trends of patenting leading up to the quotas, followed by a large decline in patenting in ESE fields after the quotas (Figure 7). The decline in innovation becomes first significant in 1927-29, when US-based scientists patent 8.1% less in ESE fields relative to innovation in controls fields before the quotas. US-based innovation in ESE fields continues to decline to a low of 15.7% fewer innovations in 1936-38 and 14.8% in 1939-41. After this low, innovation recovers slowly to 7.7 % fewer innovations in 1948-50, the last period with a significant decline.

Reduced Spillovers as a Result of Missing Collaborations with ESE-born Scientists

Why did US-born scientists become less productive in ESE-based fields after the quota acts? A case study of Paul Erdős suggests a reduction in opportunities for collaboration and the resulting knowledge spillovers as a potential mechanism. After Erdős was denied a re-entry visa to the United States in 1954 (and blocked from returning to the United States until 1963), his collaborations shifted away from US coauthors. Between 1954 and 1963, just 24% of Erdős' new co-authors were US scientists, compared with 60% until 1954 (Figure A7).

To examine collaborations as a mechanism, we compare changes in patenting for the co-inventors (and co-inventors of co-inventors) of ESE-born scientists with changes in patenting for the co-inventors (and co-inventors of co-inventors) of WNE-born scientists. This analysis reveals a decline in patenting by US-born co-inventors (and co-inventors of co-inventors) of ESE-born scientists (Figure A8). Between 1910 and 1924, US-born scientists who collaborated with ESE-born and WNE-born scientists produced a comparable number of patents (946 and 1,167 patents, respectively). After the quotas, the collaborators of ESE-born scientists produced fewer patents than the collaborators of WNE scientists (14,527 and 24,092 between 1925 and 1956, respectively). Holding the ratio of patents per year by coauthors of WNE- and ESE-born scientists constant over time, US collaborators of ESE-born scientists would have produced 19,530 rather than 14,527 patents in 1925-1956, implying a 25.6% decline.

To investigate collaborations more systematically, we estimate:

$$ln(PatCoinventors_{it}) = \beta_t \cdot ESEborn_i \cdot post_t + \gamma_i + \delta_t + \epsilon_{it} \quad (9)$$

where $PatCoinventors_{it}$ counts patents by co-inventors and the co-inventors of co-inventors of scientists i. $ESEborn_i$ is an indicator equals 1 if scientist i is ESE-born (and 0 if she is WNE-born). The indicator $post_t$ denotes years after 1924. γ_i and δ_t are scientist and year fixed effects, respectively. Standard errors are clustered at the scientist level.

The results indicate a strong, significant, and persistent decline in innovation for the collaborators of ESE-born scientists (Figure 8). Before the quotas, US-born scientists who collaborate with ESE- and WNE-born scientists patent at similar rates. After the quotas, US-born collaborators of ESE-born scientists patent 10.6% less (11 log points) in 1927-29 (the first period with significant estimates). Patenting by US-born collaborators of ESE-born scientists continue decline to 45.3% less (60 log points) in 1954-56.

6. Aggregate Effects on Innovation in the United States and Abroad

In this final section, we investigate the broader effects of the quotas on US firms, on aggregate innovation, and on science in mandatory Palestine and Israel.

Effects on Firms Employing Immigrants

How do restrictions on immigration affect the research productivity of firms? We investigate this question by comparing changes in invention after the quotas for eight US firms in the MoS (1956) that employed ESE-born immigrant inventors before the quotas with changes in invention for 18 other firms that employed WNE-born inventors before the quotas.[13]

Before the quotas, US firms that employed ESE-born scientists produced nearly the same number of patents per year (1,119 patents per year) compared with other US firms that employed WNE-born scientists (1,237 patents per year, Figure A9). Across all years between 1910 and 1924, firms filed 16,788 successful patent applications compared with 18,548 by firms that employed WNE-born scientists. After the quotas, firms that had employed ESE-born scientists before the quotas create 2,144 new inventions per year, compared with 3,541 new inventions per year by firms that had employed WNE-born scientists before the quotas.

[13] We use assignee data to identify firms that employ foreign-born scientists. For patents issued after 1926, Kogan et al. (2017) list assignees. We add patents issued before 1926, as well as application years. Specifically, we use the original Kogan et al. (2017) patent to firm ID data and merge it with the assignee name from Google patents to build a dictionary that links the assignee name and firm ID. We then search for assignees' names in patents outside the original sample to link them to the firm ID. Firms that employed ESE (WNE)-born scientists are assignees of pre-1925 patents by ESE (WNE)-born scientists in the MoS (1921 or 1956).

A comparison of patents by ESE and WNE firms suggests that the quotas reduced innovation by ESE-firms by 33,947 patents, equivalent to a decline of 33.1%. Had these firms continued to patent at their pre-quota ratio of inventions per year, ESE firms would have produced 102,551 patents in 1925-56, 18.4% more than the 86,603 observed total patents.

OLS regressions of these changes control for firm and year fixed effects:

$$ln(Patents_{it}) = \beta_t \cdot ESE_i \cdot post_t + \gamma_i + \delta_t + \epsilon_{it} \quad (10)$$

where $Patents_{it}$ counts patents by firm i in year t. ESE_i is an indicator for firms that employed ESE-born scientists before the quotas. The indicator $post_t$ denotes years after 1924. γ_i and δ_t are firm and year fixed effects. Standard errors are clustered at the firm level. Time-varying estimates indicate no significant differences in patenting leading up the quota acts (Figure 9). After 1924, the estimates slowly decline, indicating a 98% (p-value 0.045) reduction in patenting at its lowest point in 1939-41.

Estimating the Aggregate Effects on Patenting Using Patent Titles

To estimate the quota's effects on aggregate invention in the United States, we use the text that describes the title of each patent to identify inventions in ESE fields and separate them from other types of inventions. For example, the US patent No. US2957903A for "Stabilization of organic isocyanates" is classified as a patent in an ESE-field because it references key words such as "stereochemistry," "crystallography," and "combinatorial," that are semantically close to the keywords that characterize cluster 772, which is an ESE-field.

This analysis indicates a significant decline in aggregate invention. Before the quotas, US inventors patented at the same rate in ESE and other fields. Between 1910 and 1924, inventors filed 232,295 successful patent applications in the fields of ESE-born scientists compared with 210,236 in other fields. After the quotas, US inventors patented significantly less in ESE fields, with 558,901 patents per year in ESE fields compared with 609,199 in other fields (Figure 10). Assuming the ratio of patents in ESE and Other fields would have stayed similar to the pre-quota ratio, the number of missing patents is as high as 114,218 patents, a decline of 17.0% in innovation (Figure A10).

Gains for the Future Israel

Nearly 1,200 ESE-born scientists were lost to US science. Were these scientists lost to the world or did they encourage science and innovation outside of the United States? According to Abella and Troper (2012), "measured against the millions who were murdered […] the number saved was pitifully small. During the twelve years of Nazi terror, from 1933 to 1945, the United Kingdom opened its doors to 70,000, and allowed another 125,000 into British-administered Palestine. Other states, with long histories of immigration, did even less.

Argentina took 50,000, Brazil 27,000 and Australia 15,000. Some Latin American states, where life-granting visas were bought and sold like any other commodity, admitted but the trickle of Jews who could pay for their salvation." Eastern Europe was hit especially hard. Poland, for example, had the largest Jewish population in 1933, with more than 3 million people. By 1950 Poland had lost 98% of that population. While German-born scientists were allowed to flee to the United States, the quotas limited the inflow of Eastern Europeans.

Still, with the support from relief organizations, like the Emergency Committee in Aid of Displaced Foreign Scholars, many ESE-born scientists found refuge in other countries. Israel, in particular, benefitted from the US quotas. Migration patterns for Jewish scientists (from the *World Jewish Register* 1955) reveal a dramatic increase in the migration of Jewish scientists to Palestine, around the time of the quotas (Figure A11). Between 1910 and 1919, only 1.4 ESE-born Jewish scientists moved to Palestine per year. In the early 1920s, arrivals increased by a factor of 6, to 8.8 ESE-born immigrant scientists per year between 1920 and 1925, while immigration to the United States increased much less, from 0.7 ESE-born scientists in 1910-1919 to 2.2 in 1920-1925.

Immigration peaked in 1925, just one year after the passage of the quota acts. In that year, 15 ESE-born scientists arrived in the future Israel. In the same year, only 1 ESE-born Jewish scientist, the Hungarian-born future Guggenheim Fellow Ernst Borek, moved to the United States. After 1925, rates of immigration remained high, with an average of 2.3 ESE-born scientists coming to Palestine/Israel between 1926 and 1950.

ESE-born immigrant scientists helped build major universities and research centers that are centers of innovation in Israel today. The Polish-born Aharon Katzir (1914-72), for example, moved to Palestine in 1925, and became a professor at the Hebrew University. A pioneer of the electrochemistry of biopolymers, he was the first head of the polymer research department at Israel's Weizmann Institute of Sciences. Another ESE-born immigrant, Italian-born Giulio Racah (1919-65) had been a professor of physics in Pisa. Racah emigrated to Palestine in 1939, after the Fascists' law (*regio decreto*) of November 17, 1938 excluded Jews from higher education. He was quickly appointed Professor of Theoretical Physics at the Hebrew University and established theoretical physics as a discipline in Israel. As professor in Israel, Racah developed mathematical methods based on tensor operators and continuous groups. These methods revolutionized spectroscopy and remain essential tools in atomic, nuclear and elementary particle physics to this day (Zeldes 2009, p.289).

7. Conclusions

This paper has used detailed biographical data on more than 90,000 American scientists in

1921 and 1956 to examine the effects of nationality-based immigration quotas on US science and innovation. Designed to keep out “undesirable” low-skilled immigrants, the quotas caused a dramatic decline in the arrival of ESE-born scientists in the United States. Using comparisons with arrivals from Western and Northern Europe (which were on similar trends before the quotas) we estimate that nearly 1,200 ESE-born scientists were lost to US science. Just a small number of these scientists were able to find refuge in other countries that welcomes Jewish immigrants. Some of the missing scientists moved to the future Israel, where they helped to build universities and research centers like the Technion that fuel innovation to this day.

Beyond the immeasurable loss of human lives, the quotas damaged US science and innovation well into the 1960s. Our analyses imply that, as a result of the quotas, US scientists produced roughly two thirds fewer innovations in the pre-quota fields of ESE-born scientists compared with other fields. These findings are robust to a broad range of alternative specifications, and they hold for US-born US scientists, whose innovation declines almost as much as aggregate innovation. Firm-level analyses further show that firms which had employed ESE-born scientists before the quotas experienced a 53% decline in innovation relative to other firms.

Do these estimates over- or underestimate the quotas’ aggregate effects on US innovation? This project has focused on foreign-born scientists, omitting the children of immigrants. Yet, many of the US-born US scientists in our data were the children of ESE-born immigrants to the United States. Our sample of native US scientists includes Dr. Richard Feynman of the California Institute of Technology, born in New York, NY on May 11, 1918. Feynman became a member of the National Academy and received the Einstein Award in 1954. Feynman’s father was born in Belarus and moved to the United States when he was 5 years old. His mother was born in Poland. Had the quotas been established earlier, both of Feynman’s parents would have been prevented from moving to the United States.

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TABLE 1 – CHANGES IN ARRIVALS - ESE-BORN SCIENTISTS ARRIVING IN THE UNITED STATES BEFORE AND AFTER 1924

		ESE-born		WNE-born		Counterfactual ESE-born	Missing ESE born
		pre-1924	post-1924	pre-1924	post-1924	post-1924	post-1924
Physical, biological, and social sciences							
1.	All scientists	489	1,331	557	2,842	2,495	1,164
2.	Exempt scientists	305	758	295	1,419	1,467	709
3.	Professors	5	38	2	64	160	122
4.	Students	299	720	291	1,353	1,390	670
5.	Dependents	1	0	2	2	1	1
6.	Subject to quotas	184	573	262	1,423	999	426
Physical sciences							
7.	All scientists	237	637	304	1,546	1,205	568
8.	Exempt scientists	138	347	131	728	766	419
9.	Professors	4	15	1	32	128	113
10.	Students	133	332	130	695	711	379
11.	Dependents	1	0	0	1	-	-
12.	Subject to quotas	99	290	173	818	468	178

Notes: Counterfactual ESE-born are estimated under the assumption that the ratio of ESE-born to WNE-born scientists arriving in the United States after 1924 would have remained stable at pre-quota levels after 1924. Missing scientists are calculated as the difference between the actual and counterfactual number of ESE-born scientists working in the United States in 1956.

TABLE 2 – BASELINE, PLACEBO, AND TRIPLE DIFFERENCES ESTIMATES COMPARING EFFECTS ON US-BASED AND CANADA-BASED SCIENTISTS

	Baseline: US Scientists			Placebo: Canadian Scientists			Triple Diff		
	ln(patents)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
ESE x post	-0.346***			-0.037			-0.381**		
	(0.133)			(0.032)			(0.149)		
%ESE x post		-0.168***			-0.023			-0.144**	
		(0.057)			(0.014)			(0.071)	
Low ESE x post			-0.245*			-0.027			-0.325**
			(0.143)			(0.033)			(0.159)
High ESE x post			-0.723***			-0.082*			-0.632***
			(0.190)			(0.046)			(0.237)
% change	-0.29	-0.15		-0.04	-0.02		-0.32	-0.13	
% change Low ESE			-0.22			-0.03			-0.28
% change High ESE			-0.51			-0.08			-0.47
Pre-1924 patents	0.55	0.55	0.55	0.00	0.00	0.00	0.41	0.41	0.41
N (fields x years)	28935	28935	28935	22724	22724	22724	45448	45448	45448
Field-Level Clustered Standard Errors									

Notes: Baseline estimates (columns 1-3) estimate OLS models of equation (2). ESE_j is an indicator for fields in which ESE-based scientists were active before the quota; $\%ESE$ measures the share of ESE-based scientists relative to the sum of all ESE- and US-based scientists in a field before the quotas 3) $High\ ESE$, is an indicator for field in which at least half of all scientists before the quotas were ESE-based, $Low\ ESE$ is an indicator for fields in which less than half of all scientists were ESE based. Columns 4 to 6 present placebo estimates for Canada, which did not adopt the quota system. Columns 7-9 present triple difference specification, comparing changes in patenting after the quotas for ESE-based and Canadian scientists. Difference-in-differences estimate (columns 1-6) control or year and field fixed effects; triple differences estimates (columns 7-9) control for year-field, year-country, and country-field fixed effects.

TABLE 3 – EFFECTS OF THE QUOTAS ON PATENTS BY US SCIENTISTS, EXTENSIVE VS INTENSIVE MARGIN

	Extensive	Intensive	Extensive	Intensive	Extensive	Intensive
	$\mathbb{I}$(patents > 0)	ln(patents)	$\mathbb{I}$(patents > 0)	ln(patents)	$\mathbb{I}$(patents > 0)	ln(patents)
	(1)	(2)	(3)	(4)	(5)	(6)
ESE x post	-0.035*	-0.677***				
	(0.020)	(0.135)				
%ESE x post			-0.018*	-0.271***		
			(0.009)	(0.075)		
Low ESE x post					-0.022	-0.638***
					(0.021)	(0.141)
High ESE x post					-0.083***	-1.030***
					(0.031)	(0.227)
% change	-0.04	-0.49	-0.02	-0.24		
% change Low ESE					-0.02	-0.47
% change High ESE					-0.08	-0.64
Pre-1924 mean/patents	0.13	4.19	0.13	4.19	0.13	4.19
N (fields x years)	28935	7974	28935	7974	28935	7974
Field-Level Clustered Standard Errors						

Notes: In extensive margin estimates (columns 1, 3 and 5) the outcome variable is an indicator for field-year pairs with at least one patent by a US scientist. In intensive margin estimates (column 2, 4, and 6), we keep only field-year pairs with a positive number of patents and use the log number of patents as an outcome. ESE is an indicator for fields in which ESE-based scientists were active before the quota; $\%ESE$ measures the share of ESE-based scientists relative to the sum of all ESE- and US-based scientists in a field before the quotas, 3) $High\ ESE$, is an indicator for field in which at least half of all scientists before the quotas were ESE-based, $Low\ ESE$ is an indicator for fields in which less than half of all scientists were ESE based.

TABLE 4 – DECOMPOSITION OF THE EFFECTS ON INNOVATION BY US-BASED SCIENTISTS

	N Scientists	Patents per scientists	Patents
Other fields - pre	45,359	0.062	2,816
ESE fields - pre	49,891	0.050	2,476
Other fields - post	434,430	0.123	53,534
ESE fields - post (actual)	422,303	0.060	25,408
ESE fields - post (counterfactual)	477,836	0.099	47,082
<u>Decomposition of Effects on Innovation</u>			
Missing patents	4,406	17,267	21,674
Missing patents (regression-adjusted)	2,136	8,368	10,504
Share in total	20.3%	79.7%	100.0%

Notes: We decompose the decline in innovation into a change in the number of scientists and change in productivity (patents per scientist):

$$Missing\ Patents = Missing\ Scientists \cdot Avg\ Productivity + Lost\ Productivity \cdot Avg\ Scientists$$

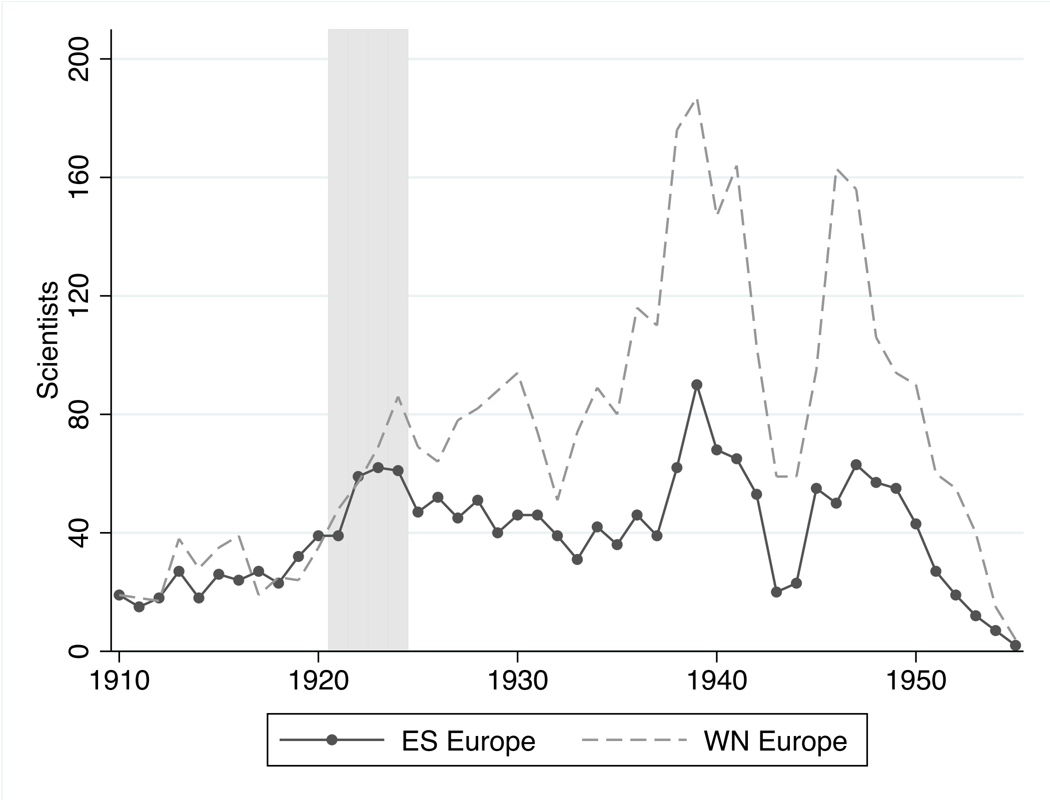
where $Missing\ Patents,\ Missing\ Scientists$, and $Lost\ Productivity$ are the differences between the counterfactual and actual number of patents, scientists and patents per scientists, respectively. $Avg\ Productivity$ and $Avg\ Scientists$ is the average between the number of actual and counterfactual productivity and scientists, respectively. The first four rows show the number of scientist-year observations, yearly productivity, and patents, by groups of fields (ESE/Other) and period (pre/post quotas). The counterfactual number of scientists and patents are calculated under the assumption that the ratio between ESE fields and other fields had remained stable at pre-quota levels, while the counterfactual productivity is the counterfactual patents divided by the counterfactual scientists. "Missing patents" shows the results of the decomposition: the column "Scientists" shows the change in patents due to the change in the number of scientists (the first term in the equation above), the column "Patents per scientist" reports the change in patents due to the change in productivity (the second term); the last column is the sum of the two. In the next row, we adjust the total decrease in patents to reflect the results of the baseline regression. The last row shows the share of missing patents due to each factor.

TABLE 5 – SCIENTIST-LEVEL ESTIMATES OF THE EFFECTS OF THE QUOTAS ON INNOVATION

	ln(patents)	𝕀(patents > 0)	ln(patents)	𝕀(patents > 0)	ln(patents)	𝕀(patents > 0)
	(1)	(2)	(3)	(4)	(5)	(6)
ESE x post	-0.107***	-0.020***				
	(0.025)	(0.005)				
%ESE x post			-0.049***	-0.010***		
			(0.012)	(0.002)		
Low ESE x post					-0.106***	-0.020***
					(0.026)	(0.005)
High ESE x post					-0.120***	-0.024***
					(0.027)	(0.005)
% change	-0.102	-0.020	-0.048	-0.010		
% change Low ESE					-0.100	-0.020
% change High ESE					-0.113	-0.023
Pre-1924 patents	0.047	0.020	0.047	0.020	0.047	0.020
N (fields x years)	442591	442591	442591	442591	442591	442591
Field-Level Clustered Standard Errors						

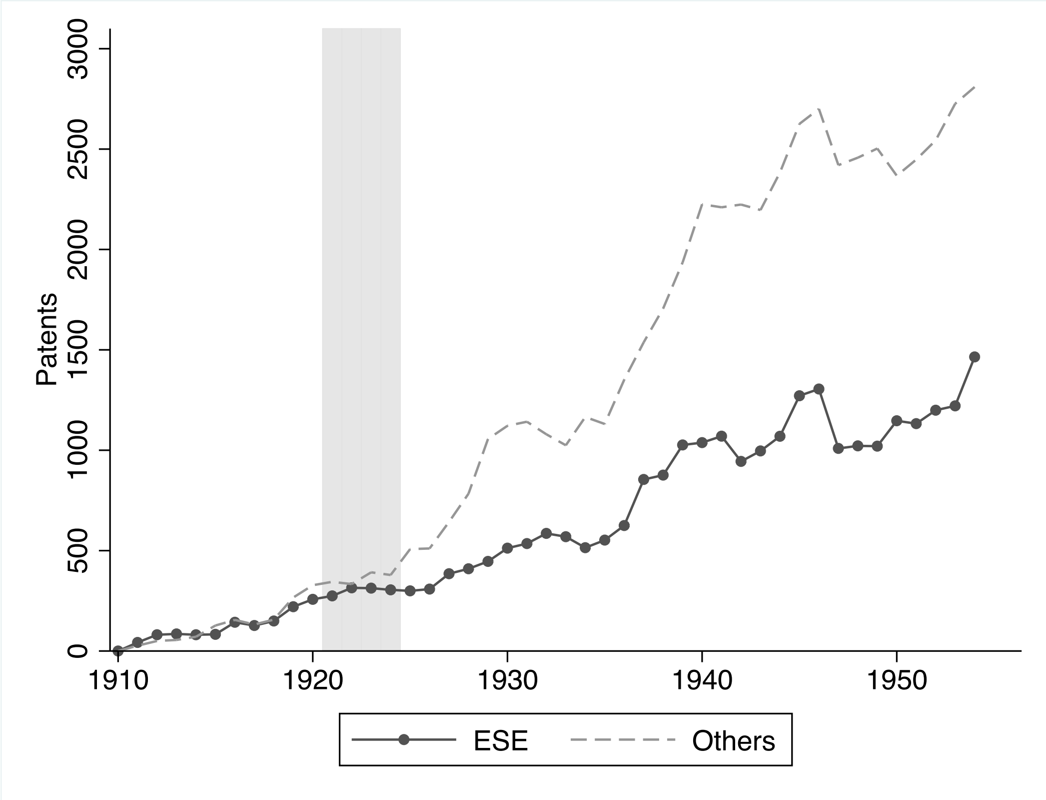
Notes: The first column shows the OLS estimate of β in the regression $\ln(patents_{it}) = \beta \cdot ESE_{j(i)}post_t + \gamma_i + \delta_t + \epsilon_{it}$ where $\ln(patents_{it})$ is the natural logarithm of the number of US patents (+0.01) by US scientist i and year t. ESE is an indicator for fields in which ESE-based scientists were active before the quota; $\%ESE$ measures the share of ESE-based scientists relative to the sum of all ESE- and US-based scientists in a field before the quotas 3) $High\ ESE$, is an indicator for field in which at least half of all scientists before the quotas were ESE-based, $Low\ ESE$ is an indicator for fields in which less than half of all scientists were ESE based.

FIGURE 1 – ARRIVALS OF ESE- AND WNE-BORN SCIENTISTS IN THE UNITED STATES



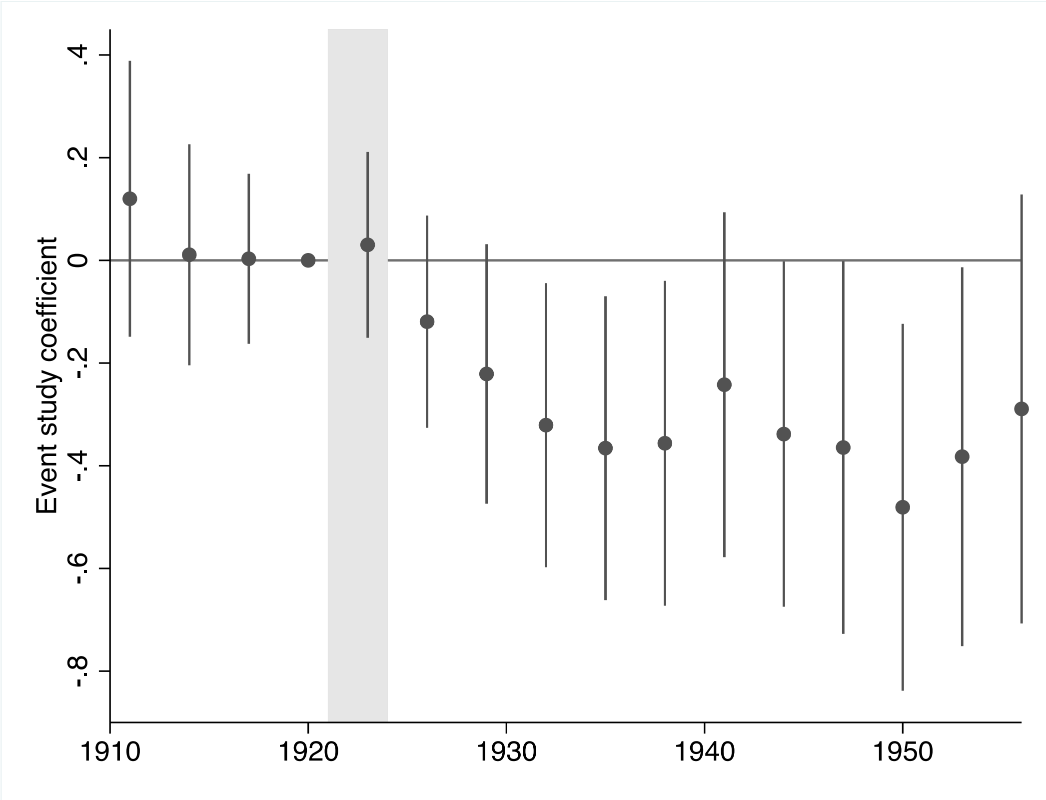
Notes: To examine changes in arrivals per year, we use the earliest year when each scientist was present in the United States, based on their naturalization, university education, and employment histories. Data include arrival years for 5,786 of 6,095 ESE- and WNE-born scientists, 94.9% of all European-born US scientists in 1956.

FIGURE 2 – PATENTS BY US SCIENTISTS AND YEAR IN ESE VS OTHER FIELDS



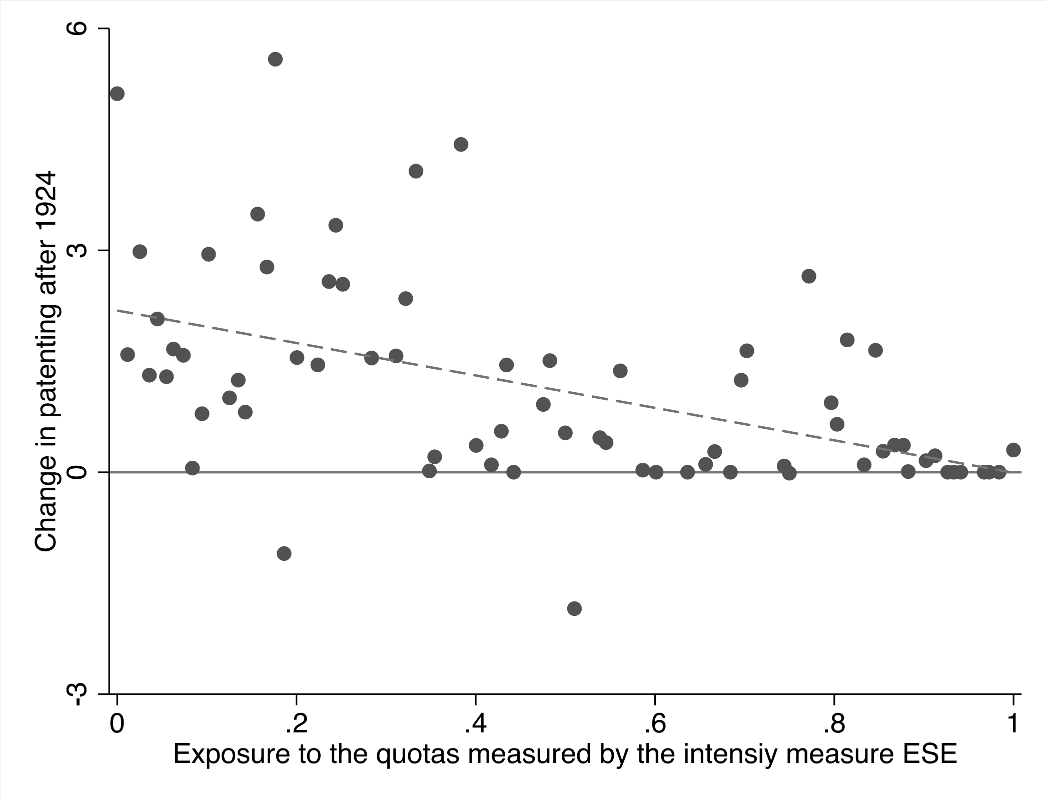
Notes: Patents by US-based scientists per year. ESE fields are the research fields with pre-quota ESE based scientists. Other fields are fields with no pre-quota ESE based scientists. US-based scientists are scientists who worked at a US firm, university, or other research institution in 1956.

FIGURE 3 –TIME-VARYING EFFECTS ON INNOVATION BY US SCIENTISTS



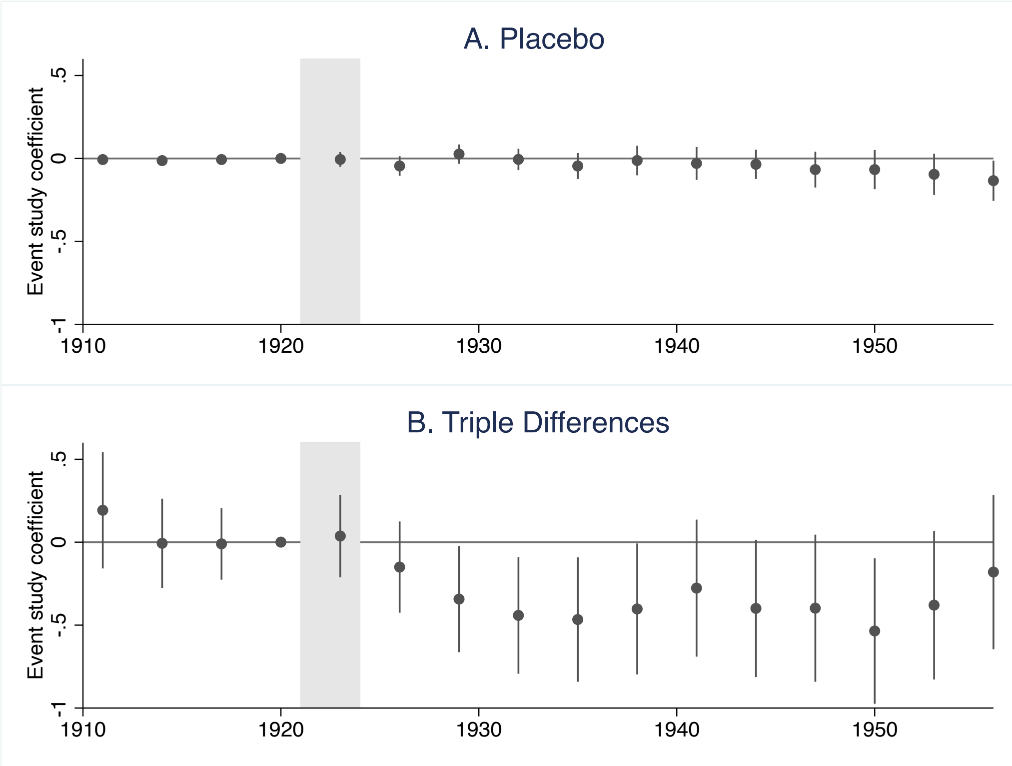
Notes: OLS estimates and 95 percent confidence interval of β_t in the regression $\ln(patents_{it}) = \beta_t ESE_i + \gamma_i + \delta_t + \epsilon_{it}$ where $\ln(patents_{it})$ is the natural logarithm of the number of US patents (+0.01) by US scientists in field i and year *t.* The indicator variable ESE_i equals 1 for 332 research fields in which ESE scientists published papers *before the quota*. γ_i and δ_t are field and year fixed effects, respectively. 1918-1920, the last period before the first quota law in 1921, is the excluded period. Standard errors are clustered at the level of research fields.

FIGURE 4 –CHANGE IN INNOVATION AFTER THE QUOTAS
ACROSS FIELDS WITH DIFFERENT LEVELS OF EXPOSURE TO THE QUOTA



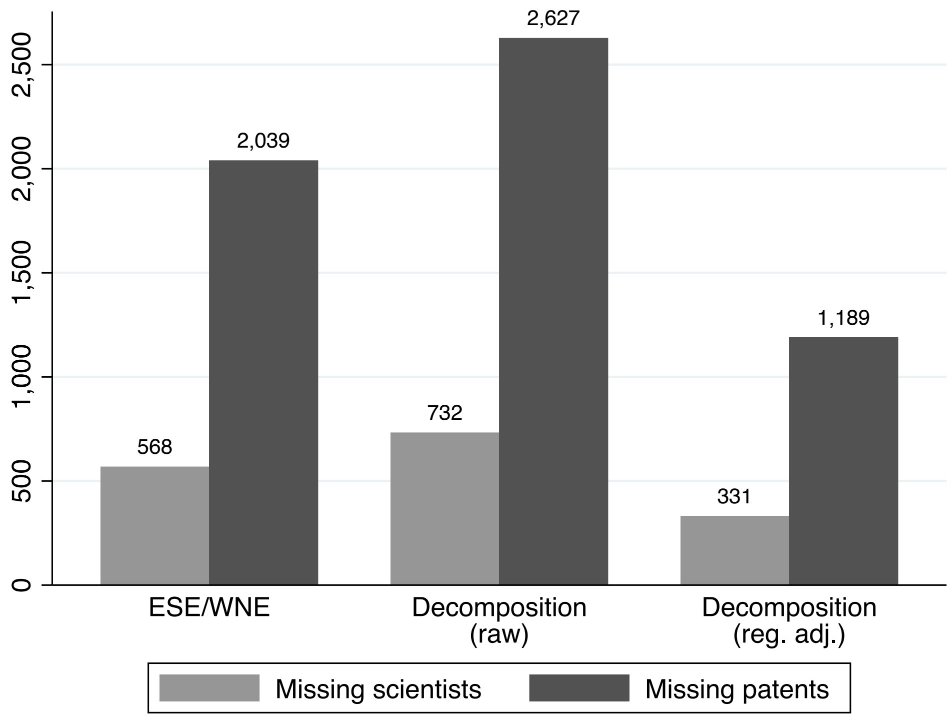
Notes: To capture variation in exposure to the quotas across fields, we use the number of ESE-based scientists in field j *before the quotas*, relative to the sum of ESE- and US-based scientists (as defined in equation 1). The change in innovation is measured as the difference in annual patents by US-inventors after 1924. The dashed line plots the linear regression between the intensity of exposure and the change in innovation.

FIGURE 5 – PLACEBO ESTIMATES OF THE EFFECTS OF THE QUOTAS ON CANADIAN SCIENTISTS AND TRIPLE DIFFERENCES ESTIMATES OF CHANGES IN INNOVATION BY US AND CANADIAN SCIENTISTS



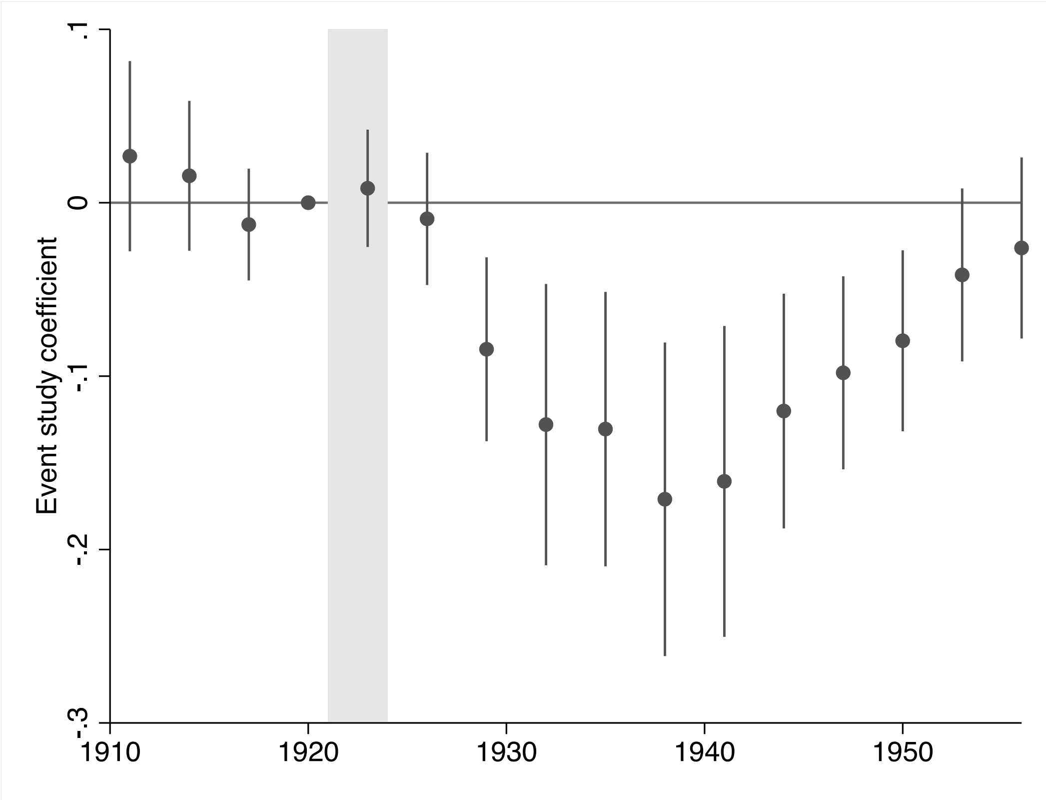
Notes: Panel A shows OLS estimates and 95 percent confidence interval of β_t in the regression $\ln(patents_{it}) = \beta_t ESE_i + \gamma_i + \delta_t + \epsilon_{it}$ where $\ln(patents_{it})$ is the natural logarithm of the number of US patents (+0.01) by scientists working in Canada in 1956. Panel B shows the estimate for the triple differences regression $ln(patents_{jct}) = \beta\ ESE_j\ US_c\ Post_t + \gamma_{jc} + \delta_{jt} + \theta_{ct} + \epsilon_{jct}$ where $\ln(patents_{jct})$ is the natural logarithm of the number of US patents (+0.01) by scientists worked in country c (Canada/US) in field j and year t.

FIGURE 6 – ESTIMATES OF MISSING ESE-BORN SCIENTISTS AND THEIR PATENTS



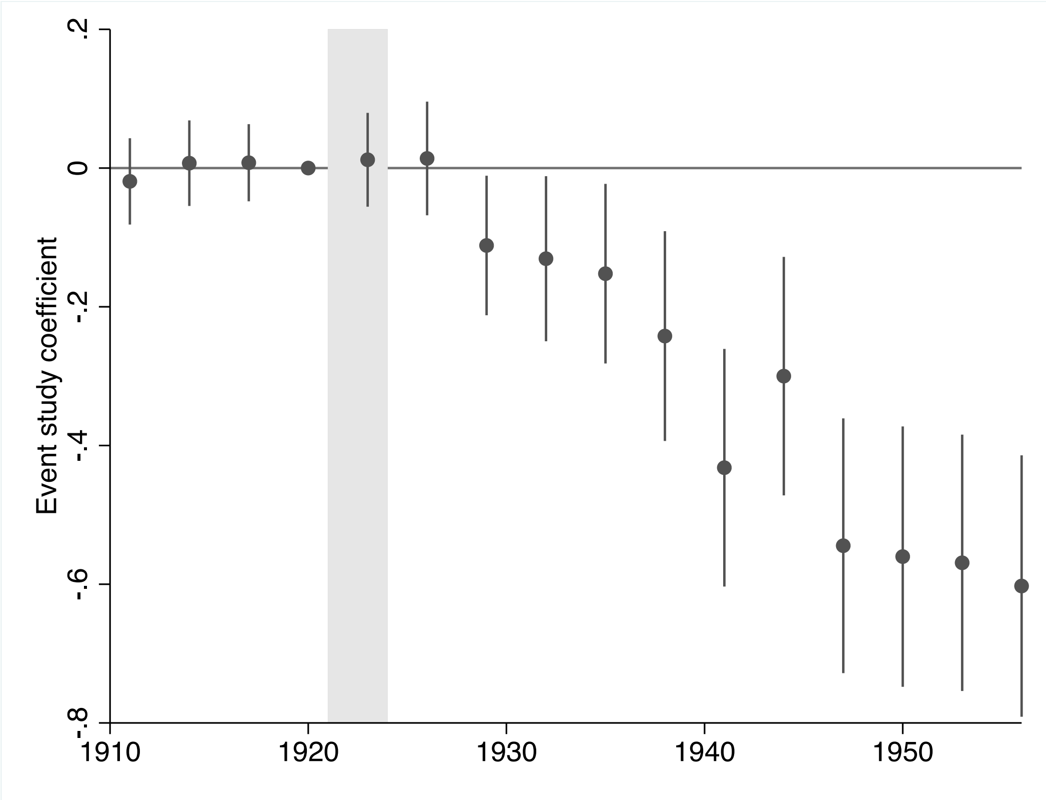
Notes: This figure shows alternative estimates of the number of missing ESE scientists and missing patents. The graph on the left (ESE/WNE) uses the comparison between ESE- and WNE-born scientists to calculate the number of missing ESE scientists, and the implied missing patents: There are 568 missing ESE-born scientists in the physical sciences (Table 1). If each of these scientists produces 3.59 patents (3,138 US patents by ESE-born scientists divided by 874 ESE-born scientists, Table A4) 568 missing ESE-born scientists would have produced an additional 2,039 patents. The middle graph reports missing patents by ESE-born scientists and the number of missing ESE-born scientists implied by the decomposition exercise by origin of birth in Table A4. The graph on the right adjusts the estimates in Table A4 of total missing patents to reflect the number of missing patents in the baseline regression (Table 2).

FIGURE 7 – TIME-VARYING EFFECTS ON INNOVATION BY US SCIENTISTS
WITH SCIENTISTS FIXED-EFFECTS



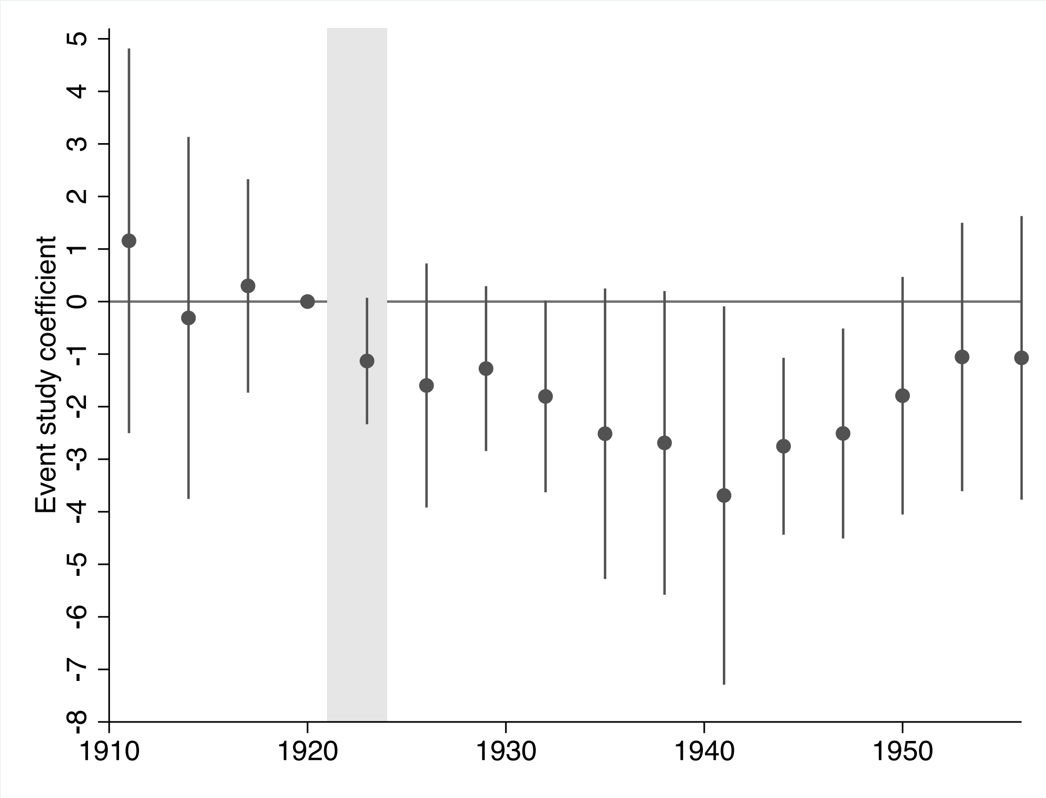
Notes: OLS estimates and 95 percent confidence interval of β_t in the regression $\ln(patents_{it}) = \beta_t \cdot ESE_{j(i)} + \gamma_i + \delta_t + \epsilon_{it}$ where $\ln(patents_{it})$ is the natural logarithm of the number of US patents (+0.01) by US scientist i and year *t*. The variable $ESE_{j(i)}$ is an indicator equals one if the field of scientist i is an ESE field. γ_i and δ_t are scientists and year fixed effects, respectively. Standard errors are clustered at the scientist level.

FIGURE 8 – TIME-VARYING EFFECTS ON INNOVATION BY CO-INVENTORS OF ESE-BORN SCIENTISTS COMPARED TO CO-INVENTORS OF WNE-BORN SCIENTISTS



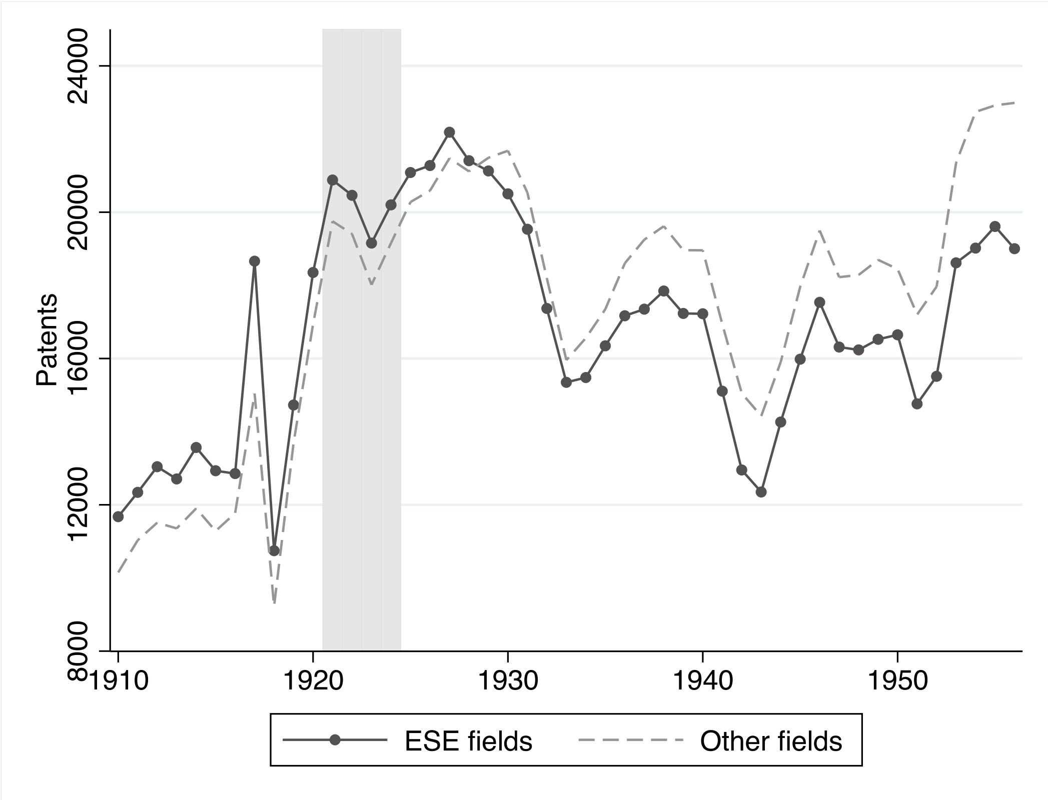
Notes: OLS estimates and 95 percent confidence interval of β_t in the regression $ln(PatCoinventors_{it}) = \beta_t \cdot ESEborn_i \cdot post_t + \gamma_i + \delta_t + \epsilon_{it}$ where $PatCoinventors_{it}$ are the number of patents by the co-inventors and the co-inventors of co-inventors of scientists i. $ESEborn_i$ is an indicator equals 1 if scientist i is ESE-born (and 0 if she is WNE-born). The indicator $post_t$ denotes years after 1924. γ_i and δ_t are scientist and year fixed effects, respectively. Standard errors are clustered at the scientist level.

FIGURE 9 – TIME-VARYING EFFECTS ON INNOVATION BY FIRMS WITH PRE-QUOTA ESE-BORN SCIENTISTS COMPARED TO FIRMS WITH PRE-QUOTA WNE-BORN SCIENTISTS



Notes: OLS estimates and 95 percent confidence interval of β_t in the regression $ln(Patents_{it}) = \beta_t \cdot ESE_i \cdot Post_t + \gamma_i + \delta_t + \epsilon_{it}$ where $ln(Patents_{it})$ is the natural logarithm of the number of patents (+0.01) by firm i in year t. ESE_i is an indicator equals 1 if firm i has at least one ESE-born scientist before the quotas (and 0 if she has a WNE-born scientist). For patents after 1926, cross-file between patents and firms is available from Kogan et al. (2017). We develop a matching algorithm to extend these data to include patents issued before 1926. If an assignee string is matched to more than one firm, the cross-file assigns that string to the firm that is the most frequent match. The indicator $Post_t$ denotes years after 1924. γ_i and δ_t are scientist and year fixed effects, respectively. Standard errors are clustered at the firm level.

FIGURE 10 – EFFECTS ON THE UNIVERSE OF US PATENTS



Notes: US patents per year in fields in which ESE scientists published papers *before the quota* compared with other fields. To assign the universe of USPTO patents to ESE and other fields, we apply the *k*-means model to the title of US patents.