IMMIGRATION, SCIENCE AND INVENTION.
LESSONS FROM THE QUOTA ACTS[*]

PETRA MOSER, NYU, NBER, AND CEPR
SHMUEL SAN, NYU

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Immigration quotas in the 1920s targeted "undesirable" nationalities to stem the inflow of low-skilled Eastern and Southern Europeans (ESE). Detailed biographical data for 91,638 American scientists reveal a dramatic decline in the arrival of ESE-born scientists after the quotas. Under the quotas, an estimated 1,165 ESE-born scientists were lost to US science. To identify effects on invention, we use k-means clustering to assign scientists to unique fields and then compare changes in patenting by US scientists in the pre-quota fields of ESE-born scientists with changes in other fields where US scientists were active inventors. Baseline estimates imply a 68 percent decline in invention. Decomposing this effect, we find that the quotas reduced both the number of US scientists working in ESE fields and the number of patents per scientist. Firms that employed ESE-born scientists experienced a 53 percent decline in invention. The quotas' effects on invention persisted into the 1960s.

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

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In the 1920s, the United States implemented nationality-based immigration quotas to keep out low-skilled immigrants from Eastern and Southern Europe and preserve the "Nordic" character of its population. This paper examines the effects of these nationality-based immigration rules on US science and invention. Did the quotas discourage foreign-born scientists from coming to the United States? And how did they affect US invention?

Until the late 19th century, most immigrants to the United States had come from the British Isles and the German-speaking regions of Europe. By 1890, changes in pull and push forces shifted the main sources of immigration to Italy and Eastern Europe. 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. A 1921 editorial in the *New York Times* warned that "American institutions are menaced; and the menace centres (sic) in the swarms of aliens whom we are importing as 'hands' for our industries."

Intended to stem the inflow of low-skilled immigrants from Eastern and Southern Europe, the 1921 Emergency Quota Act (Ch. 8, 42, Stat 5) restricted the number of immigrants per year to three percent of the number of residents from that country 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 percent, while immigration from Britain and Ireland dropped by a mere 19 percent (Murray 1976, p.7).

Strengthened during the Cold War, the quotas ruled US immigration until President Lyndon B. Johnson abolished them with the Immigration Act of 1965. In his "Remarks on Signing the Immigration Bill," Johnson (1965) called the quota system a "cruel and enduring wrong […] 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 […] We can now believe that it will never again shadow the gate to the

American Nation with the twin barriers of prejudice and privilege."

This paper uses rich biographical data on 91,638 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 of more than 90,000 American scientists, along with naturalization records, education and employment histories, as well as their research topics.

Using information on the age, full name, and discipline of each scientist, we establish a high-quality match between scientists and their patents. Starting from a standard Levenshtein (1966) distance measure, we use information on the scientist's age in the year of the patent application to filter out false positives. Through this improved matching process, which we describe in more detail below, we are able to reduce the rate of false positive matches from more than 80 percent for the most naïve Levenshtein matching (ignoring middle names, disciplines, and name frequencies) to less than 5 percent.

Naturalization data reveal 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 decline 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 1,165 ESE-born scientists were lost to US science as a result of the quotas. 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. In the physical sciences alone, an estimated 553 ESE-born scientists were lost to US science.

To estimate the effects of changes in immigration on US inventions, we compare changes in patenting per year after 1924 in the pre-quota fields of ESE-born US scientists with changes in patenting in other fields in which US scientists were active inventors before the quotas. This identification strategy allows us to control for changes in invention by US scientists across fields, for example, as a result of changes in research funding. Year fixed effects further control for changes in patenting over time that are shared across fields. Field fixed effects control for variation in the intensity of patenting across fields, e.g., between basic and applied research.

Methodologically, we apply *k*-means clustering to scientist-level data on research topics to assign each scientist to a unique research field. Intuitively, *k*-means clustering works like a multi-dimensional least square algorithm, which groups together data points (here, scientists) that are most similar in terms of their observable characteristics (here, research topics). We first apply *k*-means clustering to the topics of American scientists in 1956 to assign each scientist to a unique field. We then use the topics of American scientists in 1921 to assign each of them to one of the fields defined by topics in 1956. This assignment allows us to compare changes in US patents per year in the pre-quota fields of ESE-born US scientists with changes in the pre-quota fields of other US scientists.

Baseline estimates show a large and persistent decline in invention by US scientists in the pre-quota fields of ESE-born scientists. After the quotas, US scientists produced 68 percent fewer additional patents in the pre-quota fields of ESE-born scientists compared with the pre-quota fields of other US scientists. Time-varying effects reveal a large decline in invention by US scientists in the 1930s, persisting into the 1960s. Importantly, there is no evidence for pre-existing differences in patenting for ESE and other fields before the quotas.

This decline in invention is robust to controlling for pre-trends in patenting, excluding the largest fields or fields with the largest share of ESE-born scientists, and to including new fields. Alternative regression models, including quasi-maximum likelihood (QML), Poisson, and negative binomial regressions, further confirm the decline in invention. Results are also robust to our choice of the number of research fields, the *k* in *k*-means clustering. Alternative matchings between scientists and patents introduce noise, but show that our results do not depend on choices we make about the matching.

To examine the mechanism by which the quotas reduced US invention, we first distinguish changes at the intensive and extensive margin. These analyses show that invention declined *both* at the intensive margin (from more to fewer patents) and at the extensive margin (from some patents to no patents at all): After 1924, US scientists produced 45 percent fewer patents in the pre-quota fields of ESE-born scientists, and they produced no patents at all in an additional 16 percent of ESE fields. Scientist-level regressions show that 40 percent *fewer scientists* were active in ESE fields after the quotas and that US scientists produced 33 percent *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.

Importantly, estimates for US-born US scientists are only slightly smaller than estimates for all US scientists, including the foreign-born. After the quotas, US-born US inventors produced 62 percent fewer inventions in ESE fields compared with other fields, just slightly below the baseline estimate of 68 percent for all US scientists. This suggests that native US scientists benefitted more from the presence of their ESE-born colleagues than they were hurt by competing with the ESE-born.

A case study of co-authorships for the prolific Hungarian-born mathematician Paul Erdős illustrates how restrictions on immigration can reduced collaborations between foreign-born and native US scientists. As a Hungarian citizen, Erdős was denied a re-entry visa by the US immigration services in 1954, and not granted re-entry until 1963. Data on Erdős' top 100 collaborations document how these collaborations shifted away from the United States: Between 1954 and 1963, just 24 percent of Erdős' new co-authors were US scientists, compared with 60 percent until 1954. These patterns are confirmed in a broader analysis of patents by co-authors and co-authors of co-authors of ESE-born scientists, indicating a 26 percent decline in invention by scientists who were connected to ESE-born scholars.

A potential alternative explanation for our findings is that ESE-born scientists (before the quotas) may have selected into fields that became less productive after the quotas. To investigate selection we estimate placebo regressions for Canada, which did not implement restrictions on ESE-born immigrants in 1924. Time-varying estimates indicate no decline in Canadian invention in ESE fields after 1924. In fact, triple-differences regressions show that invention by Canadian scientists in ESE-fields increased compared with US scientists and other fields.

To further investigate underlying mechanisms, we investigate whether the aging of scientists can explain the decline in invention in ESE fields, as the quotas reduced the inflow of young immigrants. We find that the aging of ESE fields contributed to the decline in invention, without however, explaining the pronounced decline in invention which appears to be due to the great loss of ESE-born scientists.

A final section explores the broader effects of the quotas on invention in the United States and abroad. A firm-level analysis of changes in patenting reveals that firms which employed ESE-born scientists in 1921 created 53 percent fewer inventions after the quotas. Complementary text analyses of US patent titles suggest that invention declined more broadly in the fields of ESE-born scientists. After the quotas, 23 percent fewer US patents describe inventions 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 to this day. 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. 2019). Our research complements that work by investigating the quotas' *unintended effects on high-skilled immigrants* - which were not the target of the acts. Our research also implements a distinct identification strategy by comparing changes in innovation across research fields that were differentially affected

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[1] E.g., Kerr and Lincoln (2010); Hunt and Gauthier-Loiselle (2010), Moser, Voena, and Waldinger (2014), Bernstein, Diamond, McQuade, and Pousada (2019) and San (2020).

by the quotas, applying methods from text analysis to the topics of each scientist.[2]

1. HISTORICAL BACKGROUND

1.1. After 1890, Sources of Mass Migration Shift to Eastern and Southern Europe

Until 1880, 90 percent of immigrants to the United States came from the British Isles and the German-speaking parts of Continental Europe (Historical Statistics of the United States 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 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. To better understand the changed nature of immigration, the Federal Bureau of Immigration began to compile statistics on a new category "race" based on a person's "mother tongue." Using this new variable, in addition to "country of origin", the Bureau was

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[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: New waves of immigrants were more likely to move to counties that had recently been connected to rail.

able to distinguish “Poles” and “Hebrews” among immigrants from Russia and to separate “Poles” who came from Germany or Russia. The first tallies in 1899 showed that 26 percent of immigrants from Europe were Italians, 12 percent were “Hebrews” and 9 percent were Poles. These shares stayed roughly constant until the eve of World War I, with Italians averaging 24 percent and Jews and Poles 11 percent each.

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”). In 1915, the economics professor Arthur Salz described the role of Eastern Europeans in the United States

> “These men, employed in agriculture or as manual workers or day laborers in their home countries, fully supply the needs of American industry for unskilled labor. They not only supply that market, they oversupply it, and monopolize it: They are the sacred regiments of a reserve army drawn from the ranks of the willingly enslaved.” (Salz 1915, pp.110-1)

At the end of the 19th- century, nearly half of all workers in New York, Chicago, and Boston were foreign-born. Across the United States, one fifth of the labor force came from abroad. By 1910, half of all industrial workers, miners, and railroad employees were born outside of the United States. More than half of all garment-makers, and one quarter of all domestic servants were foreign-born (Rosenbloom 2002, p.16, Taylor 1971, pp.192-201).

1.2. A Nativist Response Reaching up to the Highest Levels

Cultural differences between the old and new immigrants triggered a nativist response reaching up to the highest levels of the executive (Jones 1992, p.176).[3] In 1911, Commissioner Williams (p.215) wrote in the Bureau of Immigration’s annual report that “We should…strive for quality rather than quantity.” In the same year, the 41-volume Dillingham report proposed the introduction of a literacy test. Yet, when it was introduced in 1917 this test failed to stem the inflow of Eastern Europeans because they could read remarkably well.

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[3] The distinction between “new” and “old immigration” was first made in the Dillingham Report (1911 vol.1, pp.12-14), named for its chairman Senator William P. Dillingham (R Vermont).

In February 1921, soon-to-be Vice President Calvin Coolidge warned that the United States "must cease to be regarded as a dumping ground," and 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…"

1.3. Quotas Target Eastern and Southern Europeans

In May 1921, the Emergency Quota Act (Ch. 8, 42, Stat 5) introduced limits on the total number of immigrants per year, for the first time in US history. The Act also established a quota system that restricted 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. When Warren G Harding died of a heart attack on August 2, 1923, Coolidge became President. In his first address to Congress President Harding argued 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 […] It is true that 75 per cent of our immigration will hereafter come from Northwestern Europe; but it is fair that it should do so, because 75 per cent of us who are now here owe our origins to immigrants from those same countries." (*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. With these changes, immigration fell precipitously from 357,803 in 1923-24 to 164,667 in 1924-25. Arrivals from Asia were banned, and arrivals from Italy fell by more than 90 percent, while immigration from Britain and Ireland declined by a mere 19 percent (Murray 1976, p.7).

During the Cold War, Congress strengthened the quotas in the 1952 Immigration and Nationality Act. The quotas only ended after September 1965, when Fidel Castro allowed Cubans with families in the United States to emigrate. On October 3, Lyndon B. Johnson (1965) gave his "Remarks on Signing the Immigration Bill" on New York's Liberty Island:

> "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. Under that system the ability of new immigrants to come to America depended upon the country of their birth. 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. Data on Scientists and Patents

The data for this study comprise detailed biographical information on 91,638 American scientists, matched with US patents between 1910 and 1970. These data cover each scientist's place of birth (which we use to identify foreign-born scientists), date of birth (which we exploit to create a high-quality match between scientists and their patents), as well as records on naturalizations, education, and employment (allowing us to investigate changes in the arrival of foreign-born scientists).

2.1. Biographies of American Scientists in 1921 and 1956

Detailed biographies are drawn from the *American Men of Science* (MoS, 1921 and 1956). Originally collected by 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 was the first US professor of psychology and served as the first editor of *Science* for 50 years. In the MoS, he used this expertise to establish a compendium of scientists for his own research. Cattell published the first edition in 1907, updating it until he passed the baton to his son Jacques who published the 1956 edition. Despite the name, the MoS include both male and female scientists in Canada and the United States.

To capture the state of American science immediately before the quota act, we hand-collected all 9,544 biographies in the MOS (1921). According to its editors, the 1921 edition is “tolerably complete for those in North America who have carried on research work in the natural and exact sciences” (Cattell and Brimhall 1921, p.v), which is the focus of our paper.

Detailed biographical data for 82,094 American scientists in 1956 make it possible to observe American scientists 20 years after the quotas.[4] Beyond the Physical Sciences (volume 1), and the Biological Sciences (volume 2), the 1956 edition also includes the Social & Behavioral Sciences (volume III, 15,493 scientists). We use this disciplinary division to improve the patent matching, as described below.

Both editions of the MoS (1921 and 1956) were 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 in the Directory." 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 Research Council “which acted in an "advisory capacity“ (Cattell 1956, Preface).

2.1.1. Date and Place of Birth

A major advantage of the MoS is that they list each scientist’s place of birth, allowing us to identify foreign-born scientists.[5] George Michael Volkoff, for example, was born in Moscow, Russia, on February 23, 1914, which makes him an ESE-born American scientist:

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[4] This count excludes 6,352 duplicate mentions of scientists who appear in multiple volumes of the MoS (1956), 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).

[5] While existing analyses have used names as a proxy for ethnicities (e.g., Moser 2012b), name-based ethnicity measure measure national origins with a considerable amount of noise and may be a biased.

> VOLKOFF, PROF. G(EORGE) M(ICHAEL), Dept. of Physics, University of British Columbia, Vancouver 8, B.C. Can. PHYSICS. Moscow, Russia, Feb. 23, 1914, Can. Citizen; m.40, c.3. B.A., British Columbia, 34. M.A. 36, hon D.Sc, 45: Royal Soc. Can. Fellow, California, 39-40, Ph.D. (theoretical physics), 40. Asst. prof. physics, British Columbia, 40-43; assoc. research physicist, Montreal lab, Nat. Research Council Can, 43-45, research physicist and head theoret. Physics branch, Atomic Energy Proj. Montreal and Chalk River, 45-46, PROF. PHYSICS, BRITISH COLUMBIA, 46- Ed.'Can. Jour. Physics.' 50- Mem. Order of the British Empire, 46. A.A; Asn. Physics Teachers; Physical Soc; fel. Royal Soc. Can; Can. Asn. Physicists. Theoretical nuclear physics; neutron diffusion; nuclear magnetic and quadrupole resonance.

Birth years are available for 99.2 percent of 82,094 American scientists in 1956. These data allow us to develop a high-quality matching between scientists and their patents, by helping to eliminate false positives (as described in section 2.3 below).

Birth places are known for 99.5 percent of all 82,094 American scientists (working at US or Canadian institutions) in 1956, and 99.5 percent of 79,507 US scientists working at US institutions in 1956. In 1956, 2,066 US scientists were ESE-born (2.5 percent). Another 4,029 US scientists (4.9 percent) were born in Northern or Western Europe, 70,927 (86.4 percent) were born in the United States, and another 3,117 (3.8 percent) were born in Canada (Table 1). The most common birthplaces for ESE-born US scientists were Russia, Poland, and Hungary with 613, 319, and 272 scientists, respectively, followed by Czechoslovakia (201) and Italy (173 scientists, Figure A2). In the MoS (1921), birth places are known for 99.0 percent of all 9,449 American scientists. Like in 1956, Russia, Poland, and Hungary were the most common birthplaces for ESE-born American scientists in 1921 (Figure A2).

2.1.2. Active Scientists Per Year and Field

To investigate changes in patenting *per scientist* and to investigate changes in the number of *new scientists* per field, we use scientists' employment and education histories to determine when they first became involved in US science. Elias Klein, for example, received his undergraduate degree from "Valparaiso" University in Indiana in 1911. Subtracting the median length of an undergraduate degree, we estimate that Klein entered US science as a student as early as 1909.[6] The average scientists in the MoS (1956) attended 2.9 educational

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[6] The median length for an undergraduate degree is two years. Start and end years are known for 1,643 undergraduate degrees, 6,530 Masters, and 15,273 PhDs (10.0 percent of our data).

institutions, yielding a total of 238,895 entries on educational institutions. We clean these entries by expanding and matching acronyms such as "N.Y." (New York) and "Univ." (University); this yields 7,174 unique institutions. By consulting publicly available sources, we manually assign 87.02 percent of these 7,174 institutions to a unique country. These data allow us to establish the country of a scientist's university education for 237,644 of 238,895 entries on educational institutions (99.5 percent), and we can determine the year of a scientist's first US degree for 77,551 of the 82,094 American scientists (94.5 percent).

Information on employment allows us to estimate when each scientist took their first job in the United States. Elias Klein, for example, started his first job in 1912, when he became a physics instructor at Valparaiso. MoS (1956) lists 465,918 institutions of employment for 82,094 American scientists. The average scientist held 5.7 unique jobs; these jobs yield 117,606 unique employment institutions. To identify employment institutions that are located in the United States, we develop a three-step algorithm. First, we create a cross walk to countries, based on our manual matching of universities and cities to countries, respectively. Second, we clean all strings of employment institutions and match these strings with strings in the cross walk. 319,477 institutions are matched in this step (68.6 percent), using either information on a university or a city in which a firm is located. For example, the string "Telefunken Co, Berlin" is separated into two strings "Telefunken Co" and "Berlin," The second string is matched to the city Berlin, which allows us to match the institution "Telefunken Co, Berlin" to Germany. Third, we revisit career institutions that remain unmatched and match words within the string of a career institution with birth cities and universities. For example, the string "Harvard Physics" is matched to Harvard and therefore to the United States. Another 84,288 institutions (18.1 percent of all career institutions) can be assigned to a unique country in this step. Using this three-step algorithm, we assign 403,955 of 465,918 institutions (86.7 percent) to a unique country, yielding the first year of US employment for 77,996 of 82,094 American scientists (95.0 percent).

To determine the year when a scientist first entered US science, we combine information on scientists' employment and education. The year of a scientist's first US job or their first US university enrollment is known for 80,965 of 82,094 American scientists (98.6 percent).

2.1.3. Arrival of Foreign-Born Scientists in the United States

To examine changes in rates of arrivals for foreign-born US scientists after the quotas, we combine data on naturalizations with information on education and employment histories (from section 2.1.2) to develop three alternative measures of changes in arrivals per year.

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 ESE-born US scientist Dr. Elias Klein, for example, was naturalized in 1912: "KLEIN, DR. ELIAS, Naval Research Lab…Wilno, Poland, Jan. 11, 90, nat. 12," which means that he must have been in the United States in 1907. The year of the scientist's naturalization is known for 2,775 foreign-born scientists, and 33.5 percent of all European-born scientists, including 745 ESE- and 1,296 WNE-born scientists (36.1 and 32.2 percent, respectively). Naturalizations indicate that the average ESE-born scientist was 32.9 years old when they arrived (with a standard deviation of 10.8 and a median of 33).

Second, we use information on each scientist's employment and education to identify the year in which a scientist first became involved in US science (as described in section 2.1.2). These data allow us to determine arrival years for 5,751 of 6,095 European-born scientists (94.4 percent), including 1,995 ESE- and 3,756 WNE-born scientists (96.6 and 93.2 percent 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 percent), including 2,005 ESE- and 3,781 WNE-born scientists (97.0 and 93.8 percent of ESE- and WNE-born scientists, respectively).

2.1.4. Research Topics

A unique feature of the MoS (1921 and 1956) is that scientists list their research topics along with their discipline. Volkoff, for example, lists "physics" as his discipline and describes his topics as "theoretical nuclear physics; neutron diffusion; nuclear magnetic and quadrupole resonance." Topics are known for 96.4 percent of all 82,094 scientists in the MoS (1956); disciplines are known for 99.97 percent. Implementing k-means clustering (as described in section 4.1), we use these data to assign each scientist to a unique research field.

2.2. US Patents, 1910-1970

Changes in inventive output are measured by changes in the number of US patents per field and application year. Patent data include 2,748,078 successful applications for patents between 1910 and 1970. We collect patent identification numbers, the full name of inventors and assignees, titles, as well as application and publication (issue) years from Google Patents. We use the application, rather than patent issue (or publication or grant) year to define the timing of invention, because the application date is closer to the date of the invention, while issue dates are can be delayed by several years. For instance, Thomas Edison's last patent, US patent 1,908,830 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 between 1910 and 1970 (96 percent). For patents with missing application dates, we subtract the median lag between application and publication (2.4 years) from the publication date.[7]

To match scientists with patents, we start from a standard Levenshtein (1966) measure (allowing one letter to differ between the name of the scientist and the inventor) and use the scientist's age to filter out false positives. First, we exclude all patents whose application predates the scientist's birth or postdates their 80th birthday.[8] This leaves 1,897,128 patents by 82,094 scientists between 1910 and 1970 (92.5 percent of the original matches). Next, we exploit the fact that patents by children are truly exceptional to use patents "filed" when the inventor would have been between 0 and 17 years old, as a proxy for false positives.[9]

Appendix A describes this matching process. The most naïve Levensthein matching yields an error rate of 83.3 percent false positives. Using information on scientists' disciplines, their first, last, and middle names, and dropping the top quintile of frequent

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[7] We also considered citations from later patents as a measure for the quality of patents. For example, field trial data on hybrid corn show that citations are a good predictor for improvements in yields and other characteristics of patented varieties (Moser, Ohmstedt, and Rhode 2018). Yet, citations are not systematically recorded on patent documents until 1947, which means that citation-based measures are extremely noisy for the period that we study.

[8] Even the most successful inventors, like Thomas Edison, slow down after 80. Edison's final patent lists an application date in 1923, when he was 76 years old.

[9] The middle-schooler Marissa Streng was invited on the Tonight Show with Jimmy Fallon when she patented a dog dryer (https://www.uspto.gov/kids/inventors-kids.html).

names reduces the error rate to 4.2 percent for the physical sciences. With 32.8 and 67.9 percent false positives, respectively, error rates remain high for the biological and physical sciences. This is consistent with the fact that advances in both of these disciplines were not patentable until recently. To circumvent these issues, our analyses of patents focus on the physical sciences. Within the physical sciences, we are able to 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.

In a final step of our data collection, we construct data on the assignee (owner) 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.

3. EFFECTS ON ENTRY INTO US SCIENCE

Proponents of the quotas, like President Coolidge, aimed to clear the United States from "diseases of ignorance" by restricting the inflow of Eastern and Southern Europeans. We now examine whether the quotas had the opposite effect by depriving US science of foreign-born talent. While it is impossible to say with certainty how many ESE-born scientists would have come without the quotas, comparisons with scientists from Western and Northern Europe (WNE) are informative. WNE-born immigrants were attracted by the same labor markets as the ESE-born, and they faced comparable costs of trans-Atlantic migration. Unlike ESE-born scientists, however, WNE-born scientists were not targeted by the quotas.

3.1. Nearly 1,200 Missing Scientists

Naturalization data reveal a sharp decline in the arrival of new ESE-born scientists after 1924 (Table 1, row 1). Using information on the year when foreign-born US scientists became naturalized, we estimate that 583 ESE-born US scientists were lost to US science among the naturalized US citizens alone.

The key assumption of this estimate is that the ratio of ESE-born and WNE-born scientists arriving in the United States would have remained stable without the quotas. Supporting this assumption, this ratio was steady around 250/244 for 1910-24. After the quotas, 962 WNE-born scientists arrived in the United States between 1925 and 1955. Given a constant ratio of naturalized ESE/WNE scientists, the number of ESE scientists arriving in 1925-1955 would have been 250/244 * 962= 986. Yet, less than half that number (only 403 ESE-born naturalized US scientists) arrived between 1925 and 1955, implying 583 missing scientists among the naturalized US citizens alone (Table 1, row 1, and Figure A3).

Data on education and employment histories confirm this enormous loss. Between 1910 and 1924, 428 ESE-born and 516 WNE-born US scientists arrived in the United States to attend university or work (Table 1, row 2). In the 30 years after the quotas, only 1,435 ESE-born scientists came to study or work in the United States, less than half compared with 2,891 WNE-born scientists. Had the ratio of ESE-born and WNE-born stayed at its pre-quota level, an additional 963 ESE-born scientists would have come to the United States.

Our preferred estimates combine information on naturalizations, university education, and employment to extend estimates to the population of US scientists in 1956 (Figure 1). The data show that 32.5 ESE-born scientists arrived in the United States per year between 1910 and 1924, not much less than the 37.0 WNE-born scientists arriving per year. After the quotas, arrivals from Eastern and Southern Europe declined dramatically relative to arrivals from the rest of Europe. Between 1925 and 1955, 42.9 ESE-born scientists came to the United States each year, less than half compared with 91.5 WNE-born scientists.

Had the ratio of ESE- to WNE-born scientist stayed at its pre-quota levels, another 1,165 ESE-born scientists would have entered US science between 1925 and 1955 (Table 1, row 3). This implies a loss of 38 ESE-born US scientists per year, equivalent to eliminating a major physics department each year. For the physical sciences alone, an estimated 553 ESE-born scientists were lost to US science (Table 1, last row).

4. EFFECTS ON INVENTION: EMPIRICAL STRATEGY

To investigate the causal effects of the quotas on US invention, we compare changes in patenting by US scientists after the quotas in the pre-quota fields of ESE-born American scientists with changes in patenting after the quotas in fields in which other American scientists were active inventors before the quotas. Under the assumption that changes in patenting after 1924 would have been comparable in ESE and other fields had the quotas not been implemented, this difference-in-difference comparison estimates the causal effects of the quotas on the inventive output of US scientists. Section 4.3 investigates the identifying assumption by comparing the pre-quota characteristics of ESE and other fields.

4.1. Defining Scientists' Research Fields Using K-Means Clustering

To assign each scientist to a unique field, we first apply k-means clustering to scientist-level data on research topics. ESE fields are defined by the topics of scientists in 1921, *before* the quotas. Detailed individual-level data on a scientist's discipline and research topics allow us to assign each scientist to a unique field. Volkoff, for example, lists "physics" as his discipline, but "physics" includes thousands of other scientists whose work is fundamentally different from Volkoff's research. To develop a more informative definition of fields, we exploit unique information on research topics. Volkoff, for example, describes his topics as "Theoretical nuclear physics; neutron diffusion; nuclear magnetic and quadrupole resonance." We use these topics along with his discipline to define Volkoff's "field."

Methodologically, we apply k-means clustering to a "bag of words" that includes both the scientist's discipline ("physics"), and their research topics ("Theoretical nuclear physics"). *K-means* is one of the most basic and intuitive unsupervised machine learning classification algorithms.[10] A "cluster" (here a field) refers to a collection of data points (scientists) that are grouped together because they include similar observable characteristics (here topics). The intuition of the k-means algorithm is similar to a multi-dimensional-least-squares. To group scientists into clusters, the k-means algorithm assigns researchers to one of k centroids by minimizing the distance between the observations and the centroid. The number of clusters k is a choice variable. We set k=100 and estimate robustness checks with other values of k.

To measure distance between topics, they are presented through a bag of words in Euclidian space. First, we concatenate topics into a list of words, removing punctuation and stop words. We then create a matrix in which a scientist's bag of words (document d) represents a row and words w in the corpus of document represents a column. An element in this "text frequency" *(tf)* matrix, $tf(d,w)$, is the frequency of word w in document d. For example, if "neutron" occurs once in a scientist's topics, the column for "neutron" equals 1.

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[10] Unsupervised classification algorithms make inferences from datasets about the best classification of the data points without referring to known (or labelled) classes.

Since frequent words like “theory” or “research” carry less information than rarer words like “neutron” or ”polymer”, we transform the matrix to assign less weight to words that are frequent in the corpus. In this “term frequency–inverse document frequency method” (*tf_idf*, implementing Baeza-Yates and Ribeiro 1999), an entry in the transformed matrix is $tf\_idf(d,w) = tf(d,w) \times idf(w)$, where $tf(d,w)$ is the frequency of word w in document d, $idf(w) = \log[(1+n)/(1+df(w))] + 1$, n is the number of documents, and *df(w)* is the number of documents that contain word *w.*

Similar to OLS, the k-means algorithm starts with a group of randomly selected centroids, and performs iterative calculations to minimize the mean of the sum of the squared distances between the centroids and the data. The algorithm stops when further changes to the location of the centroids yield no further decline in the minimized sum of squared distances.

Despite its simplicity, k-means offers several key benefits over alternative methods of text analysis for our setting. First, the k-means algorithm is relatively stable, which implies that the assignments do stay substantially unchanged if we start from a different (random) choice of k initial centroids. Another benefit is that k-means delivers training results relatively quickly, even for large data sets. For the k-means algorithm to work, clusters are assumed to be spherical and evenly sized. In our data, fields are fairly evenly distributed (Figure A4), which suggests that this assumption is not a major problem. The median cluster (number 58) holds 303 scientists, and the average cluster has 410.9 with a standard deviation of 514.7.[11] Comparisons of fields in 1921 and 1956 indicate a strong persistence in the relative size of fields. The correlation between the number of scientists per field in 1921 and 1956 is 0.89 (significant at 1 percent) and 0.50 for logs (p-value < 0.01, Appendix Figure A5).

To check the content of the cluster assignments, we use Google to “name” our fields. Specifically, we enter the 10 most frequent words in each field into Google and name the field with the first result of that search. Cluster 59, for example, is named “aircraft,” and the words are a good fit: aeronautical, aircraft, engineering, structures, design, control, flight, research, stability, and guided.

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[11] A residual cluster (number 25) includes 4,881 scientists, whose research is described by “chemistry”, “organic”, “geology”, “engineering”, “analysis”, “development”, “research”, “methods”, “oil”, and “chemical.” We drop this cluster in robustness checks.

Compared with the disciplines that are listed in the MoS, fields defined by *k*-means clustering do better at capturing the essence of a scientists' research topics.[12] Caesar Fragola, for example, states his discipline as engineering, while Elder de Turk lists physics. Fragola describes his research topics as "aircraft instrumentation engineering; development of aircraft flight and navigation instruments; individual components and complete system components for stabilized remotely located aircraft compasses and flight directors." De Turk worked on "design and development of aircraft instruments; test of gravity meters; test, development and evaluation of aircraft armament systems." The *k*-means algorithm recognizes the similarity in their research and assigns both scientists to field "aircraft."

4.2. ESE Fields are Pre-Quota Research Fields of ESE-born American Scientists

ESE fields are defined as the pre-quota research fields of ESE-born American scientists: An ESE field is a field in which at least one ESE-born American scientist was active in 1921. No ESE-born scientists were active in Volkoff's field "neutron radiation" in 1921, and "neutron radiation" is assigned to the control. Klein's field "radiation", however, is an ESE field because it included 4 ESE-born among 325 American scientists in 1921.

Among 100 research fields, 36 are ESE fields; 59 "other" fields form the control; and 5 had no scientists in 1921. The average share of ESE-born scientist in 1921 was 1.3 percent, with a standard deviation of 2.4; the median field includes no ESE scientists. Five "new" fields had no scientists in 1921: "Solid-state chemistry" (field 27), "Electronic engineering" (field 53), "Aircraft" (field 59), "Polymer" (field 74) and "Nylon" (field 97). We exclude these new fields in the main specifications and include them in robustness checks.

4.3. Investigating the Identifying Assumption

The identifying assumption of our main estimates is that – in the absence of the quotas - changes in patenting after the quotas would have been comparable in the pre-quota fields of ESE-born American scientists and in other fields in which other American scientists where

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[12] Using topics and disciplines offers several additional advantages over using disciplines alone: In addition to Volkoff, another 4,882 scientists list "physics" as their discipline, but the topics of their research are dissimilar. "Chemistry" is even larger and more diverse, with 7,091 scientists. Other disciplines have just one or two scientists (384 and 119 of 781 "disciplines" in the physical sciences).

active inventors before the quotas.

To investigate this assumption, we first compare the observable pre-quota characteristics of ESE and other fields. These comparisons show that ESE and other fields had similar counts of scientists per field (Figure A4) and demographic characteristics. The average age of scientists was 44.7 in ESE fields and 44.4 in other fields, and the share of female scientists was 1.1 percent and 1.2 percent, respectively. ESE and other fields also had a comparable share of other European scientists, with a share of 5.4 percent WNE-born scientists in ESE fields and 5.1 percent in other fields. Moreover, there is no evidence that ESE-born fields were less "hot" before the quotas: The share of "star" scientists was comparable, with 11.5 percent start scientists in ESE fields and 10.4 in the control.[13] The most significant difference between ESE and other fields lies in the share of ESE-born scientists (Table A2).

Robustness checks below present additional tests of our identification strategy, including time-varying effects, alternative specifications of pre-trends, and placebo tests for Canada.

5. EFFECTS ON INVENTION: RESULTS

Patent data indicate a decline in inventions by US scientists in the pre-quota fields of ESE-born scientists relative to other fields (Figure 2). Between 1910 and 1924, US scientists filed 255 successful patent applications per year in the fields of ESE-born scientists, 83 percent more than the 139 annual patents in other fields. By 1929, five years after the quotas, US scientists produced fewer patents in ESE fields compared with other fields.

Invention remained low level through WWII and into the 1960s. Across all years, US scientists produced 14 percent fewer patents in ESE fields between 1925 and 1970 compared with other fields. Figure A6 plots the ratio of pre-and post-quota patents per field to compare changes in patenting across ESE and other fields of American science. This comparison shows that ESE fields (such as geometry and radiation) experienced a much smaller increase in patenting after 1924 than other fields (such as differential equations and steroids).

5.1. Effects on Invention by US Scientists

To investigate the quota's causal effects on US invention, we estimate OLS regressions:

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[13] MoS (1921) placed stars next to scientists who were voted to be superstars by their peers.

$$\ln(y_{it}) = \beta \cdot ESE_i \cdot post_t + \gamma_i + \delta_t + \epsilon_{it} \quad (2)$$

where the dependent variable $\ln(y_{it})$ represents the natural logarithm of the number of US patents by US scientists in field i and year t. The variable ESE_i indicates fields in which ESE-born scientists pursued research before the quotas. The indicator $post_t$ denotes years after 1924. Field fixed effects γ_i control for differences in patenting across fields that stay constant over time. Scientists may patent more in an applied field, such as "radio waves (63.1 patents per year) than in a theoretical field like the "calculus of variations" (0.18 patents), and inventors may be more likely to rely on patents in some industry than others (Cohen, Nelson, and Walsh 2000, Moser 2012a). Field fixed effects control for these differences. In addition, year fixed effects δ_t control for variation in patenting over time that is shared across fields, e.g., as a result of a variation in funding or increased secrecy.[14] Under the identifying assumption that, in the absence of the quotas, changes in patenting would have been comparable across ESE and other field (controlling for year and field fixed effects), the coefficient β estimates the causal effects of the quotas on invention.

OLS estimates indicate a substantial decline in US invention after the quotas: After 1924, US scientists produced 68 percent fewer additional patents in the pre-quota fields of ESE-born American scientists compared with other fields (with an estimate of -1.134 for β on $ESE \times Post$, 1-exp(-1.134)=1-0.32=0.68. significant at 1 percent, Table 2, column 1).

This decline is robust to controlling for field-specific pre-trends. Estimates with field-specific pre-trends indicate that US scientists produced 66 percent fewer additional patents after 1924 in the pre-quota fields of ESE scientists (Table 2, columns 2, significant at 5 percent). Results are also robust to excluding the five largest fields (column 3, with a percentage change of 69), to excluding fields with the highest share of ESE-born scientists (column 5, with a percentage change of 72), and to including new fields that did not have any scientists in 1921 (column 7, with a percentage change of 72).

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[14] Gross (2019) shows that secrecy orders for 11,000 patent application during WWII succeeded in keeping sensitive technologies out of public view and discouraged follow-on invention. De Rassenfosse et al. (2020) find that patents under the US Invention Secrecy Act of 1951 were less likely to become the foundation for new cumulative knowledge, measured by citations and the textual similarity between patents.

5.2. Time-varying Estimates, 1910-1970

To examine whether the decline in US invention in ESE fields started *before* the quotas, and, more generally, to investigate the timing of the decline, we estimate:

$$\ln(y_{it}) = \beta_t ESE_i + \gamma_i + \delta_t + \epsilon_{it} \quad (3)$$

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 as defined above in equation (2).

Time-varying estimates are close to zero before the quotas and yield no evidence for pre-existing differences in trends (Figure 3). After the quotas, time-varying estimates decline to 66 percent fewer additional patents in the pre-quota fields of ESE-born scientists for 1933-1935. Estimates remain consistently large and negative between 69 and 83 percent throughout World War II, the Cold War, and into the 1960s, with an estimated decline of 79 percent in 1969-70. These results suggest that the quotas may have led to a permanent reduction in US invention in the fields of ESE scientists.

5.3. Robustness to Alternative Matching Rules and Definitions of Fields

All results are robust to alternative rules for matching scientists with patents. Re-estimating the baseline specification with the full data set, including the most common names, yields an estimated 72 percent decline in patenting (Table A3, column 2, significant at 1 percent). Allowing for scientists and patentees to have different middle name increases the estimate to 75 percent (column 3, significant at 1 percent). Including common names and allowing for different middle names reduces the estimate to 60 percent (column 4, significant at 1 percent, compared with 63 percent in the baseline, column 1). Overall, these changes introduce more noise, but leave the estimates fundamentally unchanged.

Results are also robust to alternative choices for the numbers of clusters k. Regressions with 50 fields implies a 61 percent decline in invention (k=50, Table A4, column 1). Estimates with 75 fields imply a 64 percent decline (column 2), and 125 fields imply 68 percent decline (column 4), compared with 68 percent in the baseline (k=100, column 3).

5.4. Robustness to Alternative Econometric Models

About one fifth of all field-year pairs (18.3 percent) have zero patents; to keep them in the regressions, the baseline estimates add 0.01 to all observations. Results are robust to alternative choices of this small number (0.1, 0.001, and 0.0001 Table A5, columns 3-6).

Results are also robust to alternative regression models. Quasi-maximum likelihood (QML) Poisson estimates indicate a 53 percent decline in invention (Table A5, column 1, significant at 1 percent). Negative binomial regressions imply a 60 percent decline (Table A5, column 2, significant at 1 percent).

5.5. *Intensity: Invention Declines more in Fields with Higher Shares of ESE Scientists*

Intensity regressions examine whether fields with a larger pre-quota share of ESE-born scientists experienced a larger decline in invention after the quotas. We estimate

$$\ln(y_{it}) = \beta \cdot \%ESE_i post_t + \gamma_i + \delta_t + \epsilon_{it} \quad (4)$$

where the explanatory variable $\%ESE_i$ represents the share of ESE-born scientists in field i in 1921 the last year before the quotas.

OLS estimates confirm that fields that were more exposed to the national origin quotas experienced a larger decline in patenting after the quotas. Fields that had a 1 percent higher share of ESE-born scientists in 1921 experienced a 11 percent larger decline in patenting after the quotas (Table A6, column 1, significant at 5 percent).

In sum, all of these robustness checks confirm that US invention declined in ESE fields after the quotas. The following section explores alternative mechanisms for this decline.

6. MECHANISMS

How did the quotas discourage US invention? To investigate this question, we first decompose the decline in patenting into changes at the intensive and extensive margin. We then examine changes in patenting by US-born scientists who may have benefitted from reduced competition with immigrants after the quotas. Next, to explore the influence of co-authorship networks we examine the co-authors of a prolific ESE-born mathematician. Finally, we estimate placebo regressions for Canada to examine the influence of selection into research fields and examine the effects of aging on ESE fields.

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

To begin our analysis of the mechanisms that drove this decline in invention, we first decompose the baseline estimates into changes at the extensive and intensive margin.

Extensive margin regressions test whether the quotas reduced the number of ESE fields in which US scientists were active inventors. Specifically, we estimate regressions in which the outcome variable equals one if American scientists produced at least one patent in field i and year t. OLS estimates imply a 16 percent decline in the number of ESE fields in which US scientists were active inventors (Table 4, column 1, significant at 1 percent).

To investigate changes at the intensive margin we re-estimate the baseline model excluding field-year pairs with zero patents. This specification ignores changes at the extensive margin and instead estimates only the effect of the quotas on the intensive margin (fewer patents per field). Intensive margin regressions show that, after the quotas, US scientists created 45-percent fewer patents in ESE fields compared with other fields in which they were active inventors (Table 4, column 2, significant at 1 percent).

6.2. Less Entry, Fewer Scientists per Field, and Fewer Patents per Scientists

Did the quotas discourage US scientists from entering the fields of ESE-born scientists? To examine this question, we re-estimate equation (2) with the logarithm of the number of *new* US scientists entering field i in year t as the outcome variable. (New scientists are defined based on their education and career and histories, as described in section 2.1.2). Estimates indicate that 46 percent fewer new US scientists entered ESE fields in the physical sciences (Table 3, column 1). Across all fields, including the biological and social sciences, 23 percent fewer scientists entered ESE fields (Table 3, column 2).

Next, we decompose the change in invention at the scientist level into 1) the change in the *number of US scientists* working in ESE fields and 2) the change in patents *per scientist.* First, we estimate equation (2) for the logarithm of the count of US scientists working in field i in year t up to 1955, the last year for which we observe employment. OLS estimates imply a 40-percent decline after the quotas in the number of US scientists working in ESE fields compared with other fields (Table 4, column 4, significant at 1 percent).

To examine changes in patents *per scientist*, we estimate equation (2) with the logarithm of patents per scientist as an outcome variable. OLS estimates show that US scientists produced 33 percent fewer patents per scientist in ESE fields after the quotas (Table 4 column 5, significant at 5 percent). Time-varying estimates confirm that the quotas inflicted persistent damage on US invention. Inventions per scientist declines after the quotas, with

30 percent fewer patents in 1928, and invention remains low until the 1950s (Figure 4). As in the baseline, there is no evidence for differential changes before the quotas. Scientist-level regressions that combine effects at the extensive and intensive margin imply a 60-percent decline in patenting in ESE fields (Table 4, column 6, significant at 1 percent).

6.3. Effects on Native, US-Born Scientists

A central and contentious question in the rich literature on immigration relates to the effects of immigration (and restrictions on immigration) on native workers. Much of this work has focused on unskilled jobs. A historical analysis of the American bracero program by Clemens, Lewis, and Postel (2018) examines the exclusion of nearly half a million Mexican (bracero) farm workers from the United States in 1964. Clemens et al (2018) finds that restrictions on immigration created no tangible benefits for natives: the abrogation of the bracero program failed to increase the wages or the employment of native farm workers.

Analyzing effects across occupations, Burstein, Hanson, Tian, and Vogel (2019) examine how the tradability of occupations shaped the effects of immigration on native workers in the United States between 1980 and 2012. They show that a local influx of immigrants crowds out native workers from non-tradeable occupations that are more intensive in immigrant labor, but has no such effect on occupations whose output is tradable, such as science. In an analysis of high-skilled mathematicians, Borjas and Doran (2012) document that US mathematicians published less and in worse journals once they had to compete with Russian immigrant scientists after 1990. An empirical analysis of German Jewish émigrés, however, shows that the arrival of German Jewish émigrés raised the productivity of US inventors (Moser, Voena and Waldinger 2014).

Re-estimating our analysis for US-born US scientists (excluding any foreign-born scientist) reveals a substantial decline in US invention in response to the quotas, only slightly below the baseline estimates. After the quotas, US-born scientists produced 62 percent fewer inventions in the fields of ESE-born scientists compared with other fields (Table 5, column 1, significant at 5 percent). Results are robust to excluding the largest fields, excluding fields with the largest share of ESE scientists, and including new fields (Table 5, columns 2-4).

We also decompose the change in invention into a change in the *number of US-born scientists* working in ESE fields and a change in the number of patents *per US-born scientist.*

Invention declined at both margins. After the quotas, 40 percent fewer US-born scientists worked in ESE fields (Table 5, columns 5, significant at 1 percent), and the number of patents *per US-born scientist* declined by 31 percent (Table 5, columns 6, significant at 5 percent).

Compared with the full sample, these estimates imply that the quotas *reduced* the productivity of US-born scientists. With a 31 percent decline, the estimated change in patenting per scientist is only slightly smaller for US-born scientists than for all US scientists (including both US- and foreign-born, 33 percent, Table 4, column 5). Intuitively, invention is not subject to capacity constraints (like, for example, scientific journals), which allows the benefits from knowledge spillovers to outweigh the costs of increased competition.

6.4. Reduced Collaborations between ESE-born Scientists and US Scientists

How did the quotas reduce the productivity of US-born scientists? One candidate explanation is reduced knowledge flows through mentorships and collaborations. The case of the prolific Hungarian mathematician Paul Erdős illustrates how such collaborations were hindered by the quota acts. After Austria's Anschluss in 1938, Erdős had come to Princeton as a post-doctoral fellow. Soon dismissed from his first job as "uncouth and unconventional," Erdős worked at other US universities, writing most of his 1,500 papers with co-authors.[15] In 1954, the US Citizenship and Immigration Services denied Erdős a re-entry visa, citing his Hungarian citizenship. Erdős returned to Hungary, repeatedly, but unsuccessfully requesting reconsideration. When his request was finally granted in 1963, Erdős resumed to visit US universities.

Data on the locations of Erdős coauthors indicate that Erdős' influential network of coauthors shifted away from the United States after he was denied entry (Appendix Figure A7).[16] Between 1935 and 1954, 60 percent of Erdős most prolific coauthors were based in

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[15] A scientist's Erdős number counts the coauthors required to link her to Erdős (Goffman, 1969, p.791). In mathematics, the median Fields Medalist has an Erdős number of three (with a range from two to six). In economics, the median Erdős number for a Nobel Laureate is four (with a range from two to eight*)*. In computer science, influential people with low Erdös numbers include Bill Gates whose Erdös number is four (https://oakland.edu/enp/erdpaths/ accessed July 31, 2019).

[16] We asked students to search for coauthors' locations when they published their first paper with Erdős. They identified locations for 92 of Erdős' top 100 coauthors.

the United States. After 1954, this share declined to 24 percent. The share of Americans among Erdős co-authors only recovered after 1963, when Erdős was allowed to enter the United States again. When Erdős died in 1966, the *New York Times* wrote that he had "founded the field of discrete mathematics, which is the foundation of computer science."

An analysis of co-inventor networks in the MoS (1921 and 1956) confirms that the quotas reduced patenting by US-born co-inventors of ESE-born scientists, as well as the co-inventors of co-inventors (Figure A8). Before the quotas, between 1910 and 1924, scientists in the professional network of ESE-born and WNE-born scientists produced a comparable number of patents (with 948 and 1,167 patents, respectively). After the quotas, US-born collaborators of ESE-born scientists produced many fewer patents than collaborators of WNE scientists (20,316 and 34,323 between 1925 and 1970, respectively). A comparison of patents per year by the collaborators of ESE-and WNE-born scientists suggest that the quotas reduced invention by US collaborators of ESE-born scientists by 7,566 patents, equivalent to a decline of 27.1 percent.[17]

6.5. Selection into ESE Fields: Placebo Estimates for Canada

A potential alternative explanation for the decline in invention is that ESE-born scientists may have selected into fields that generated fewer inventions after 1924 - independently of the quotas. To investigate this mechanism, we estimate placebo regressions for Canadian scientists. Since Canada did not adopt comparable quotas in 1924, a decline in invention by Canadian scientists in ESE fields after the quotas would indicate selection.

Placebo estimates yield no evidence for selection. Canadian scientists did not produce fewer patents in ESE fields after 1924 (Table A7). Estimates for time-varying effects are close to zero and not statistically significant between 1910 and 1970 (Appendix Figure A9).

In fact, triple-differences estimates indicate that Canadian scientists became *more* productive relative to US scientists in ESE fields after 1924 (Table A8 and Figure 5). Triple differences estimates compare changes in patenting after 1924 by US scientists with

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[17] The key assumption for this estimate is that the ratio of patents per year by coauthors of WNE- and ESE-born scientists would have stayed stable without the quotas. Holding that ratio constant, US collaborators of ESE-born scientists would have produced 27,882 patents, 1925-1970, 37 percent more than the 20,316 observed patents with the quotas.

Canadian scientists after 1924 in ESE fields compared with other fields:

$$\ln(y_{ict}) = \beta\, ESE_i\, US_c\, post_t + \gamma_{ic} + \delta_{it} + \theta_{ct} + \epsilon_{ict} \quad (5)$$

where y_{ict} measures patents by scientists in field i and country c in the application year t. The indicator US_c equals 1 for scientists working in the United States in 1956 and 0 for scientists working in Canada. $\gamma_{ic}, \delta_{it}, and\ \theta_{ct}$ are field-country, field-year and country-year fixed effects. Compared with Canadian scientists and other fields, US scientists produced 69 percent fewer patents in ESE fields after 1924 (Table A8, column 1). These results are robust to controlling for country-field pre-trends, excluding the five largest fields, fields with highest ESE share, and to including new fields (Table A8, column 2-8). Time-varying estimates are close to zero before 1924 (Figure A10). Yet, by 1933-35, US scientists produced 72 percent fewer patents in ESE fields compared with Canadian scientists and other fields. Estimates remain large between -62 and -86 percent through the 1960s, suggesting a permanent relative decline in US invention relative to Canada.

6.6. Effects of an Ageing Work Force

Another candidate mechanism for declining invention is that restrictions on immigration may influence the age structure of the workforce (e.g., Anelli et al 2019).[18] In 1956, scientists in ESE fields were about 3.4 years older than scientists in other fields, with a mean age of 51.3 and 47.9 years, respectively. While small, this difference may have contributed to the decline in patenting, especially since patenting peaks around age 38 (Figure A1).

To investigate whether the quotas reduced invention by ageing ESE fields, we re-estimate the baseline specification with additional interaction terms for age:

$$\ln(y_{it}) = \beta_1 \cdot ESE_i \cdot post_t + \beta_2 \cdot ESEAge_i \cdot post_t + \gamma_i + \delta_t + \epsilon_{it} \quad (6)$$

The variable $ESEAge_i$ represents three alternative measures for the aging of ESE scientists: first, the share of ESE scientists in field i who are above 40 in 1956 (Table A9, column 1), second, the share of ESE scientists who are above 65 in 1956 (column 2), and third, the average age of ESE scientists in field i. All other variables are as defined in equation (2).

Estimates indicate that only a small share of the decline in patenting was due to age.

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[18] Anelli et al (2019) find that, for each 1,000 emigrants, Italy creates 10 fewer young-owned firms; 60 percent is generated by the emigration of young Italians.

Estimates for all three measures of $ESEAge_i$ are negative but not statistically significant. Importantly, controlling for age leaves the estimate for ESE_i between 63 and 66 percent (Table A9, Columns 2-4), only slightly below the baseline estimate of 68 percent.

7. AGGREGATE EFFECTS ON INVENTION IN THE UNITED STATES AND ABROAD

We have found that the quotas greatly reduced the number of ESE-born US scientists and discouraged innovation by all US scientists, including those who had been born in the United States. To complement these results, we now investigate the broader effects of the quotas on US firms and aggregate invention.

7.1. Effects on Firms Employing Immigrants

How do restrictions on immigration affect the research productivity of firms that employ immigrant inventors? This question is difficult to answer with modern data because such data cannot capture long-run effects. Here, we can examine the question by estimating the effects of the quotas on firms that had employed immigrant inventors before the quotas.

US firms that had employed at least one ESE-born scientists before the quotas produced fewer inventions after the quotas compared with other firms that had employed other US scientists (Figure 5). Before the quotas, US firms with ESE-born American produced nearly the same number of patents per year compared with other US firms that employed no ESE-born scientists. Between 1910 and 1924, inventors in ESE firms filed 1,119 successful patent per year compared with 1,114 in other firms. After the quotas, patenting declined for firms that had employed ESE-born immigrant scientists. Between 1925 and 1970, ESE firms produced 2,449 patented inventions per year, 53 percent less compared with the 5,146 patents generated by other firms. Confirming our main estimates, this relative decline in invention persisted throughout the 1960s.

7.2. Estimating Aggregate Effects through a Text Analysis of Patent Titles

Next, we perform a text analysis of patent titles to examine whether ESE fields experienced an overall decline in invention. We extend the predictions of the *k*-means model in the main analysis, fitted on the research topics of scientists in 1956, to assign each titles to fields, and compare changes in patenting for ESE fields and other fields after the quotas.[19]

This analysis corroborates the decline in invention in ESE fields. Before the quotas, US inventors patented at the same rate in ESE and other fields. Between 1910 and 1924, US inventors filed 1,130 successful patent applications per year in the fields of ESE-born scientist compared with 1,137 in other fields. After the quotas, US inventors patented significantly less in ESE fields, with 2,353 patents per year in ESE fields compared with 3,056 in other fields (Figure A11).

7.3. 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 invention outside of the United States? While the number of those saved was "pitifully small" (Abella and Troper 2012) some scientists managed to move to other countries.

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 A12). 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, shortly after the Johnson-Reed immigration act, when 15 ESE-born scientists arrived in the future Israel. In the same year, only 1 ESE-born Jewish scientist moved to the United States.[20] 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

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[19] Between 1910-1970, US inventors filed 2,748,078 patents. The corpus of patent titles is much larger than the topics in our main analysis; 89 percent of titles are allocated to a residual cluster. We focus on 301,206 patents that *k*-means assigns to other clusters.

[20] This scientist was the Hungarian-born Ernst Borek (1921-1986), a future Guggenheim fellow pursuing research on intermediate and bacterial metabolisms.

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).

8. 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 invention. Designed to keep out "undesirable" low-skilled immigrants, the quotas caused a dramatic decline in the arrival of ESE-born scientists. Using comparisons with arrivals from Western and Northern Europe (which were on comparable trends before the quotas) we estimate that nearly 1,200 ESE-born scientists were lost to US science.

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. Yet,

> "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." (Abella and Troper 2012, first edition, 1983)

In the United States, the immigration quotas of the 1920s, prevented ESE-born scientists from moving to the United States until the 1960s. 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 percent of that population. While German-born scientists were allowed to flee to the United States, the quotas limited the inflow of Eastern Europeans.

Beyond the immeasurable loss of human lives, the quotas damaged US science and invention well into the 1960s. Our analyses imply that, as a result of the quotas, US scientists produced roughly two thirds fewer inventions 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 scientists, whose invention declines almost as much as aggregate invention. Firm-level analyses further show that firms which had employed ESE-born scientists before the quotas experienced a 53 percent decline in invention relative to other firms.

Do these estimates over- or underestimate the quota's aggregate effects on US invention? This project has focused on foreign-born scientists, omitting the children of immigrants. Yet, many of the US-born 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 – MISSING ESE-BORN US SCIENTISTS

	US Scientists				Counterfactual ESE-born scientists post 1924	**Missing # ESE-born scientists post 1924**
	ESE-born		WNE-born			
	pre 1924	post 1924	pre 1924	post 1924		
All disciplines						
Arrivals by year of scientist's						
naturalization	250	403	244	962	986	**583**
start year of US job or enrollment in US university	428	1,435	516	2,891	2,398	**963**
naturalization, US job, or US university enrollment	488	1,330	555	2,837	2,495	**1,165**
Physical sciences only						
Arrivals by year of scientist's						
naturalization	148	250	144	624	641	**391**
start year of US job or enrollment in US university	189	692	273	1,569	1,086	**394**
naturalization, US job, or US university enrollment	235	637	304	1,539	1,190	**553**

Notes: Estimates of the number of missing ESE-born US scientists after the quota act of 1924, under the assumption that the ratio of ESE-born to WNE-born scientists arriving in the United States would have been constant after 1924 without the quotas. This assumption is supported by data on arrivals in Figure 1. Estimates based on the year of naturalization use the year when a scientist became a naturalized US citizen to determine the year when a scientist must have been present in the United States (five years before the year of naturalization). Estimates based on naturalization, US job, or US university enrollment measure arrivals by the first year based on the scientist's year of naturalization, the start year of their first US job, and the year when they first enrolled in a US university.

TABLE 2 – EFFECTS ON INVENTION BY US SCIENTISTS

	ln(patents)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESE x post	-1.134***	-1.089**	-1.183***	-1.231**	-1.277***	-1.346**	-1.280***	-1.278**
	(0.360)	(0.536)	(0.380)	(0.559)	(0.379)	(0.561)	(0.359)	(0.533)
	Baseline		Excl. 5% largest fields		Excl. fields w top 5% ESE share		Incl. new fields	
Percentage change	-0.68	-0.66	-0.69	-0.71	-0.72	-0.74	-0.72	-0.72
Mean patents per field and year in 1910-24	4.15	4.15	3.47	3.47	4.22	4.22	3.97	3.97
N (fields x years)	5,795	5,795	5,490	5,490	5,551	5,551	6,100	6,100
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Field-specific pre-trends	No	Yes	No	Yes	No	Yes	No	Yes
Standard errors are clustered at the level of research fields								

Notes: OLS estimates compare changes in the log of US patents by US scientists per year and field in the pre-quota fields of ESE-born American scientists with changes in the pre-quota fields of other American scientists. The variable *ESE* indicates the pre-quota research fields of ESE-born American scientists, defined using their research topics in the MoS (1921). The variable *post* indicates years after 1924. Columns 2, 4, 6, and 8 control for field-specific linear pre-trends in patenting

$$\ln(y_{it}) = \beta_t ESE_i + t \cdot \eta_i \cdot \mathbb{I}(t \leq 1924) + \gamma_i + \delta_t + \epsilon_{it},$$

Columns 3 and 4 exclude the top five percent of fields with the largest number of scientists. Columns 5 and 6 exclude the top five percent of fields with the highest share of ESE-born scientists. In columns 7 and 8 the control includes three new fields in which no scientists were working in 1921.

TABLE 3 – EFFECTS OF THE QUOTAS ON ENTRY INTO US SCIENCE

	ln(new scientists)	
	Physical sciences	All disciplines
	(1)	(2)
ESE x post	-0.623***	-0.260**
	(0.204)	(0.130)
Percentage change	-0.46	-0.23
Mean new scientists per field and year 1910-24	5.65	12.47
N (fields x years)	3,800	3,600
Year FE	Yes	Yes
Field FE	Yes	Yes
Standard errors are clustered at the level of research fields		

Notes: OLS estimates compare changes in the number of *new* scientists working in field *i* per year *t* between 1910 and 1949 in the pre-quota fields of ESE-born American scientists with changes in the pre-quota fields of other American scientists. The variable *ESE* indicates fields in which at least one ESE-born scientist was an active inventor in 1921, and *post* indicates years after the passage of the Johnson-Reed immigration act in 1924. A scientist's year of entry into science is defined by their employment history and education history (as described in section 2.1.2). Column (1) presents estimates for the physical sciences alone, while column (2) includes data for the biological and social sciences (including medicine, economics, and psychology). Estimates for the physical sciences exclude three new fields that have no scientists in 1921; estimates for all disciplines exclude ten new fields.

Table 4 – Effects of the Quotas on Patents By US Scientists, Extensive vs Intensive Margin

	Fields			Scientists		
	$\mathbb{I}$(patents>0)	ln(patents>0)	ln(patents)	ln(scientist)	ln(patents/ scientist)	ln(patents)
	(1)	(2)	(3)	(4)	(5)	(6)
ESE x post	-0.158***	-0.593***	-1.134***	-0.515***	-0.394**	-0.923***
	(0.049)	(0.196)	(0.360)	(0.102)	(0.156)	(0.326)
Percentage change	-0.16	-0.45	-0.68	-0.40	-0.33	-0.60
Mean outcome before 1924	0.53	7.78	4.15	66.32	0.05	3.84
N (fields x years)	5,795	4,742	5,795	4,275	4,275	4,275
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes	Yes	Yes
Standard errors are clustered at the level of research fields						

Notes: Columns 1-2 decompose the baseline regression (reported for comparison in column 3) into changes at the extensive and intensive margin of invention. Column 1 estimates the extensive margin effect of the quotas on the number of fields in which US scientists produced at least one patent in year *t.* The outcome variable in column 1 is an indicator for field-year pairs with at least one patent by a US scientist. Column 2 presents the intensive margin effect of the quotas on the number of patents in fields with patents; it re-estimates the baseline excluding field-year pairs without patents. Columns 4 to 6 present the analogous decomposition at the level of scientists working in field *i* and year *t* until 1955—the last year for which we can observe scientists' employment records in the MoS (1956). Specifically, we decompose the effect in terms of number of scientists per field and year (extensive margin) and number of patents per scientist (intensive margin). In column 4 the outcome variable is the natural log of the number of scientists who were active in the United States in field *i* and year *t*, based on the start year of the scientist's first job or university enrollment in the United States. Column 5 estimates the effects of the quotas on the number of patents per scientist in field *i* and year *t*, counting only patents by scientists who had entered US science by year *t*. Column 6 estimates the quota's aggregate effect on patenting for the same data.

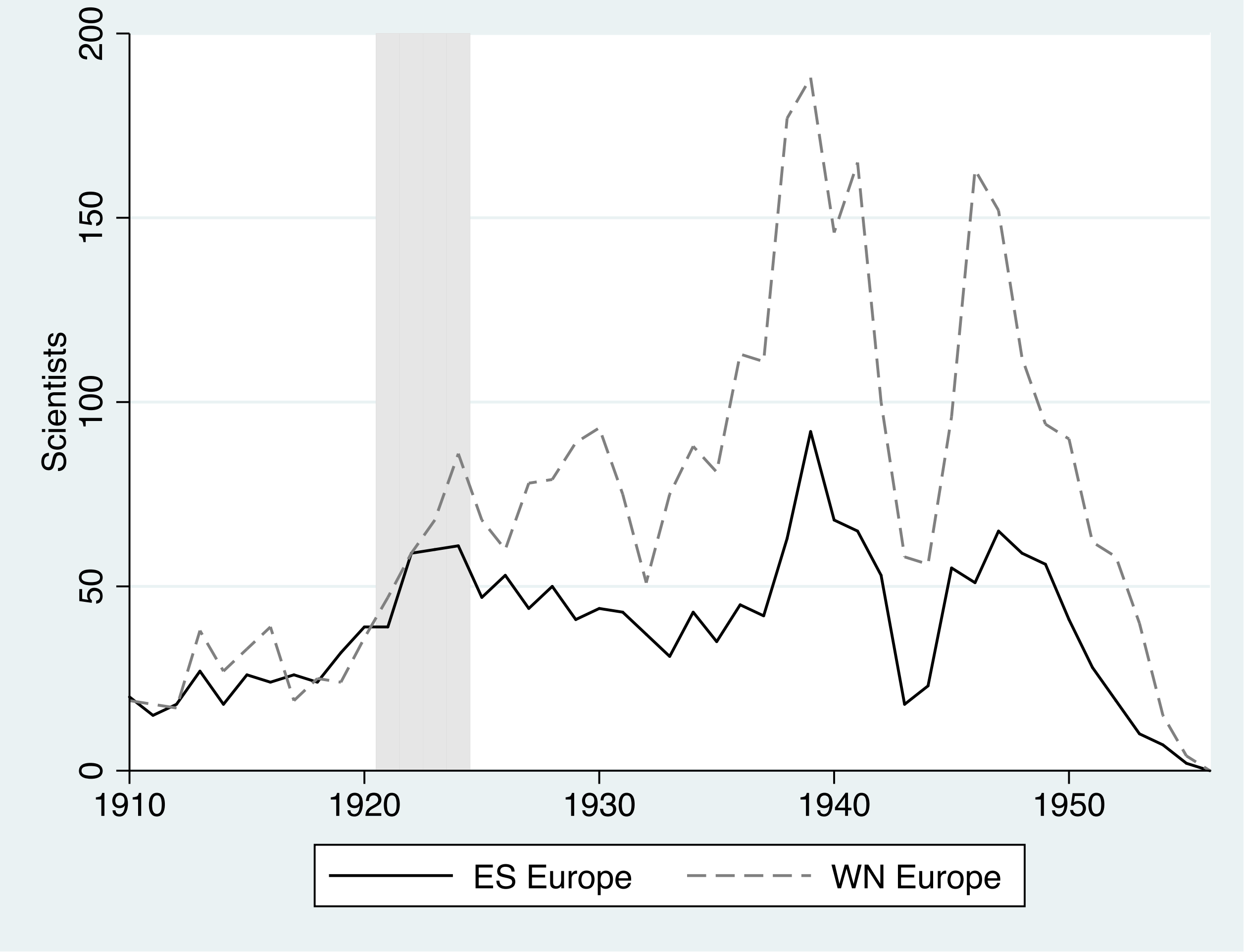
TABLE 5 – EFFECTS OF THE QUOTAS ON INVENTION BY US-BORN SCIENTISTS

	ln(patents)				ln(scientists)	ln(patents/ scientist)	ln(patents)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ESE x post	-0.971**	-1.020**	-1.094***	-1.111***	-0.506***	-0.367**	-0.819**
	(0.374)	(0.397)	(0.397)	(0.372)	(0.101)	(0.164)	(0.344)
	Baseline	Excl. 5% largest fields	Excl. fields w top 5% ESE share	Incl. new fields	OLS	OLS	OLS
Percentage change	-0.62	-0.64	-0.67	-0.67	-0.40	-0.31	-0.56
Mean patents before 1924	3.61	3.04	3.68	3.45	61.61	0.05	3.52
N (fields x years)	5,795	5,490	5,551	6,100	4,275	4,275	4,275
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors are clustered at the level of research fields

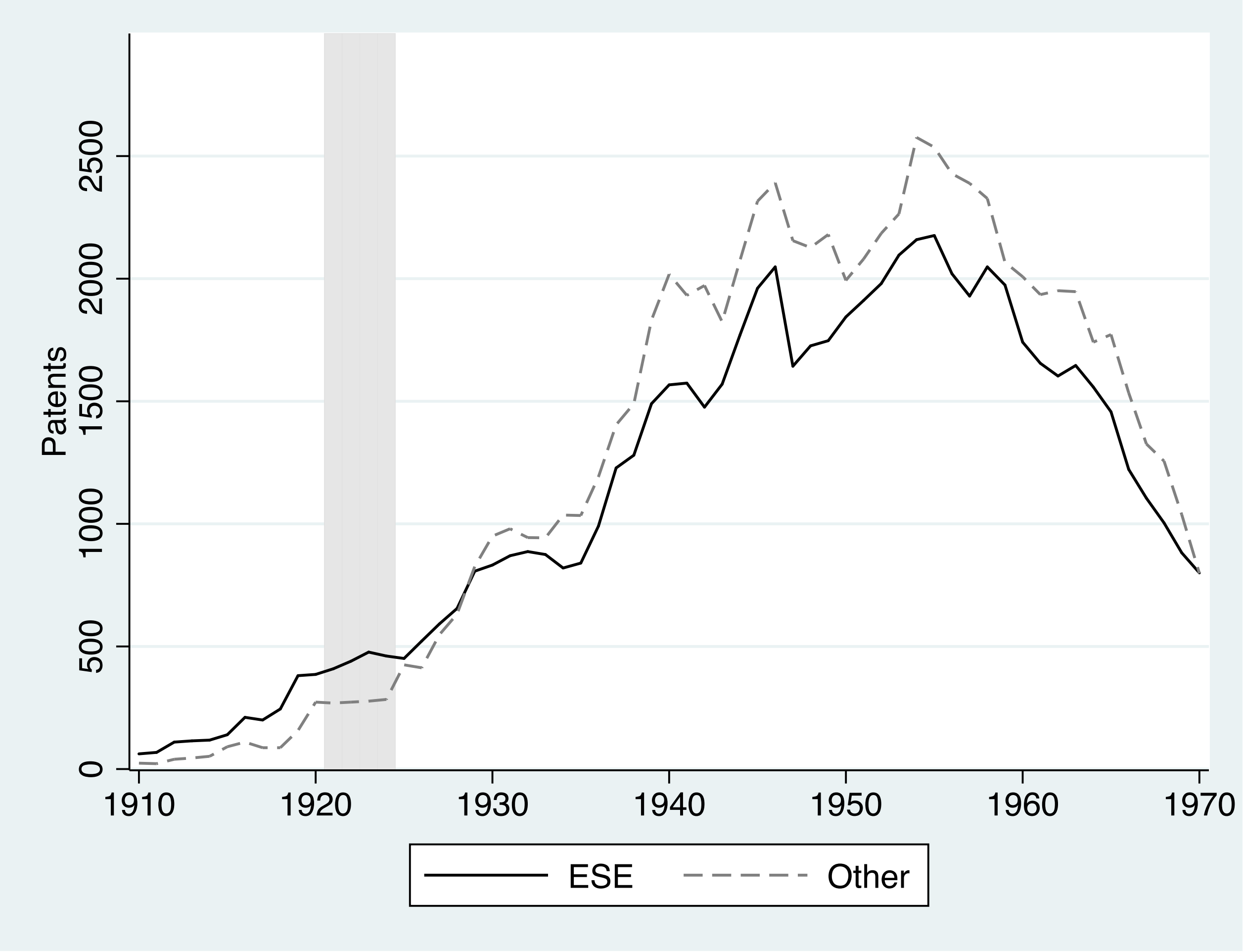
Notes: Columns 1-4 re-estimate the baseline specifications (in Table 2) for US scientists who were born in the United States (excluding all foreign-born scientists and their patents). Columns 5-7 re-estimate scientist-level regressions in columns 4-6 of Table 4 for US-born scientists. As above, the variable *ESE* indicates research fields in which ESE-born scientists were active in 1921, and *post* indicates years after 1924. Columns 4 to 6 decompose the effect on invention at the level of scientists working in field *i* and year *t* until 1955 (the last year for which we can observe scientists' employment records in the MoS 1956). Specifically, we decompose the effect in terms of number of scientists per field and year (extensive margin) and number of patents per scientists (intensive margin). In Column 5 the outcome variable is the natural log of the number of scientists who were active in the United States in field *i* and year *t*, based on the start year of the scientist's first job or university enrollment in the United States. Column 6 estimates the effects of the quotas on the number of patents per scientist in field *i* and year *t*, counting only patents by scientists who had entered US science by year *t*. Column 7 estimate the quota's aggregate effect on patenting for the same data.

FIGURE 1 – ARRIVALS OF ESE- AND WNE-BORN IMMIGRANT SCIENTISTS IN THE US



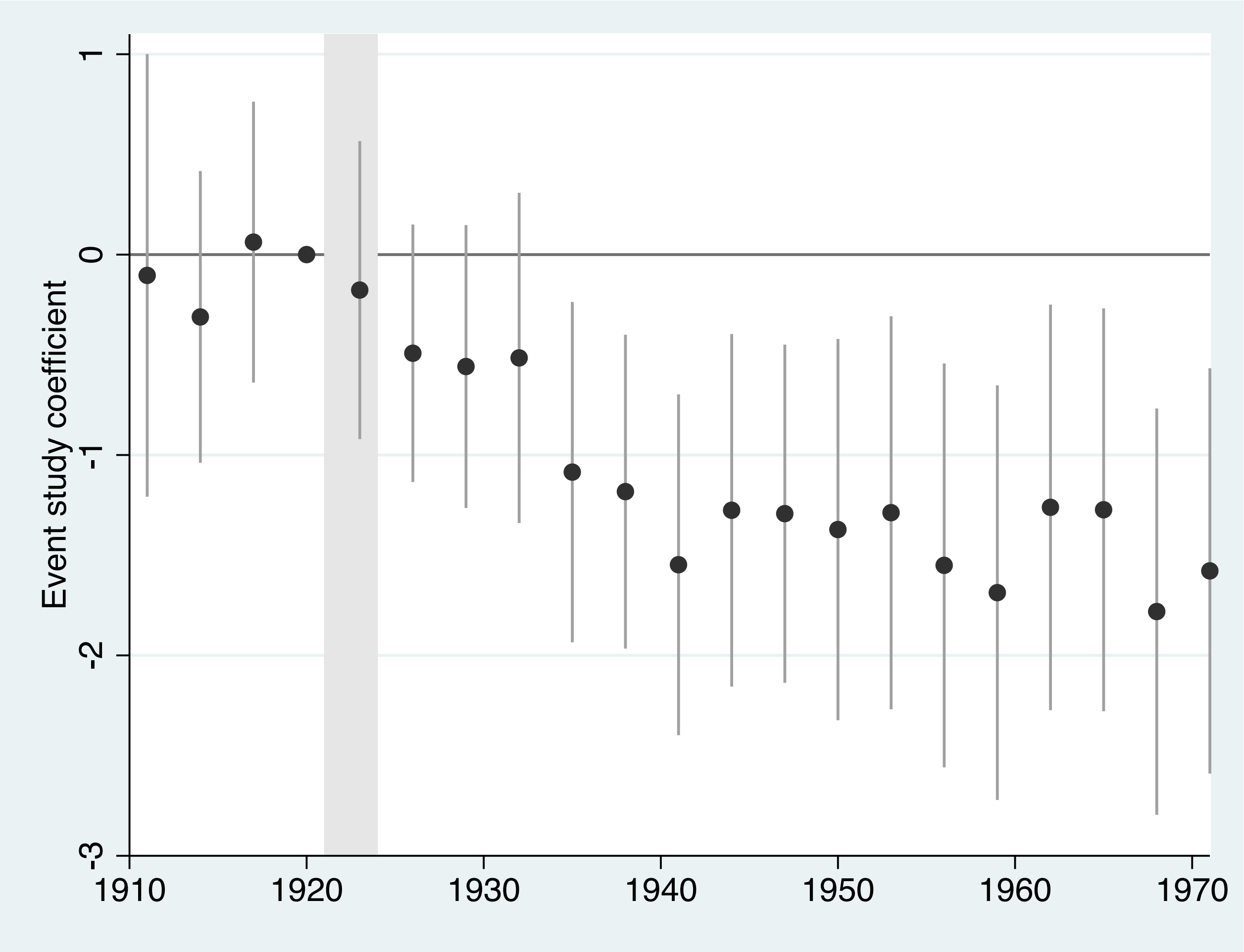
Notes: To examine changes in arrivals per year, we use the earliest year when each scientist was present in the United States, based on their naturalization, education, and employment histories. Data include arrival years for 5,786 of 6,095 ESE- and WNE-born scientists, 94.9 percent of all European-born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

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



Notes: Patents by US scientists per year. *ESE* fields are the pre-quota research fields of ESE-born American scientists. *Other* fields are the pre-quota research fields of other American scientists. US scientists are scientists who worked at a US firm, university, or other research institution in 1956. Scientists are assigned to *ESE* fields and *other* fields based on their research topics; to perform this assignment, we use *k*-means clustering to assign each scientist to a unique field.

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

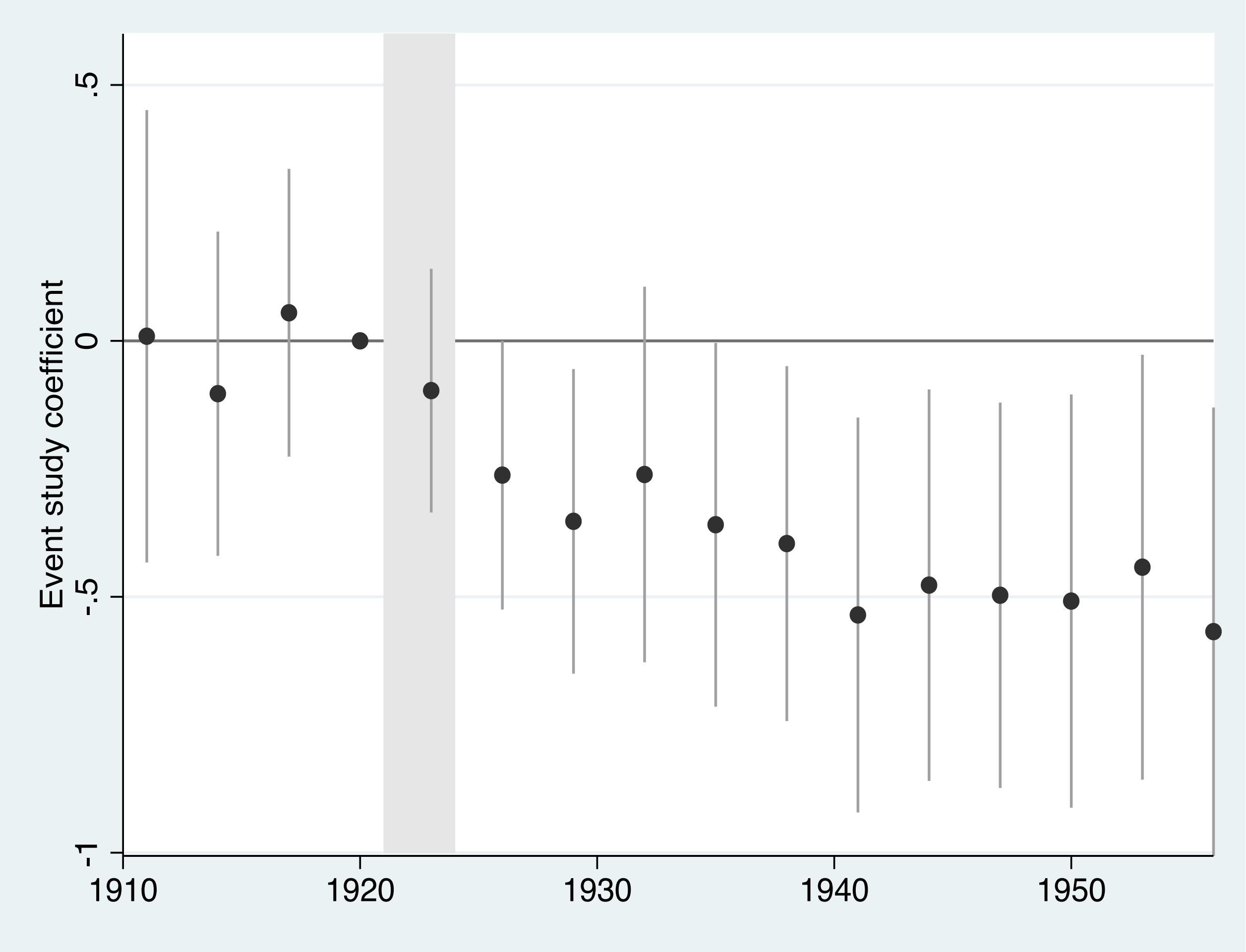


Notes: OLS estimates and 95 percent confidence interval of β_t in the regression

$$\ln(y_{it}) = \beta_t ESE_i + \gamma_i + \delta_t + \epsilon_{it}$$

where $\ln(y_{it})$ is the natural logarithm of the number of US patents by US scientists in field i and year t. The variable ESE_i indicates the pre-quota fields of ESE-born American scientists, and γ_i and δ_t are field and year fixed effects, respectively, and 1918-1920 is the excluded period. Standard errors are clustered at the level of research fields.

FIGURE 4 –TIME-VARYING EFFECTS OF THE QUOTAS ON PATENTS PER SCIENTIST

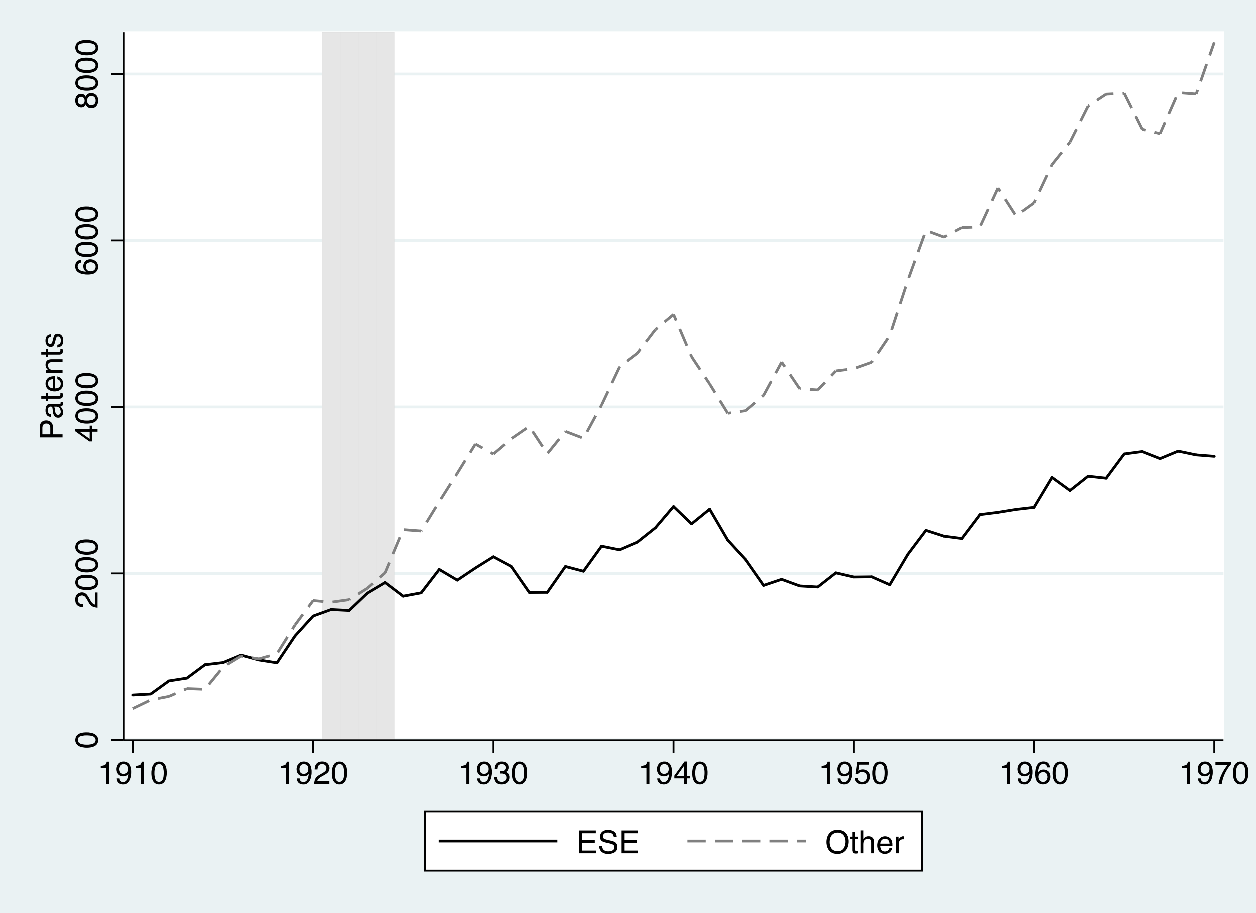


Notes: OLS estimates and 95 percent confidence interval of β_t in the regression

$$\ln(y_{it}) = \beta_t ESE_i + \gamma_i + \delta_t + \epsilon_{it}$$

where $\ln(y_{it})$ is the natural logarithm of the number of US patents per scientist in field i and year t. The variable ESE_i indicates the pre-quota research fields of ESE-born American scientists; γ_i and δ_t are field and year fixed effects, and 1918-1920 is the excluded period. Standard errors are clustered at the level of research fields.

FIGURE 5 – PATENTS BY FIRMS THAT EMPLOYED ESE-BORN SCIENTISTS BEFORE THE QUOTAS COMPARED WITH PATENTS BY OTHER US FIRMS



Notes: ESE firms are firms who employed at least one ESE-born American scientist before the quotas. Other firms are firms with at least one patent by an American scientist in 1921 but no patents by ESE-born American 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.

ONLINE APPENDIX

APPENDIX A: MATCHING SCIENTISTS WITH PATENTS

To match scientists with patents, we start from a standard Levenshtein (1966) measure (allowing one letter to differ between the name of the scientist and the inventor) and use the scientist's age to filter out false positives. First, we exclude all patents whose application predates the scientist's birth or postdates their 80th birthday. This leaves 1,897,128 patents by 82,094 scientists between 1910 and 1970 (92.5 percent of the original matches). Next, we use patents that the inventor would have filed between the ages of 0 and 17 as a proxy for false positives, and develop a matching procedure that reduces the error rate.

Under the assumption that false positive matches are distributed uniformly across the age profile of an inventor, we can use patent applications by children to estimate the rate of false positive (type I) errors

$$Error\ Rate = \frac{False\ Positives_{18-80}}{Total\ Matches_{18-80}} \quad \text{(A1)}$$

where $False\ Positives_{18-80}$ counts false positive matches between scientists and patents for scientists between the ages of 18 and 80 and $Total\ Matches_{18-80}$ is the total number of matches between scientists and patents for scientists of the same age.

$Total\ Matches_{18-80}$ are observable in the data, and we need to estimate $False\ Positives_{18-80}$. Let m_{ia} be the number of matched patent scientist pairs for scientist i at ages a and let e_{ia} be the number of false positive matches between scientists and patents. Then,

$$False\ Positives_{18-80} = \sum_{a\,=\,18}^{80} \sum_{i\,=\,1}^{N_a} e_{ia} \quad \text{(A2)}$$

where N_a is the total number of scientists of age a in the data. Because our sample is restricted to patents between 1910-1970, we only keep scientist-age observations (a, i) for which $1910 \leq b_i + \mathrm{a} \leq 1970$ where b_i is the birth-year of scientist i.

Next, we use patents that the inventor would have filed between the ages of 0 and 17 as a proxy for false positives. While there is no age restriction on patents, applications by children are exceptional. Under the assumption that false positive matches are distributed uniformly across different ages of an inventor, we can use patent applications by children to estimate the rate of false positive.

Specifically, for each age between 18-80, we assume that the average error matchings per scientist is equal to the average number of matchings per scientist that we observed for scientists between the ages of 0 and 17. If the average number of matchings per scientist at age a is lower than the average for ages 0 to 17, we assume that all matched patent-scientists pairs at that age are false positive matches. Defining

$$\bar{e}_a = \frac{1}{N_a}\sum_{i=1}^{N_a} e_{ia}, and\ \bar{m}_a = \frac{1}{N_a}\sum_{i=1}^{N_a} m_{ia} \quad \text{(A3)}$$

our assumptions imply

$$\bar{e}_a = \min\left(\frac{1}{18}\sum_{\tilde{a}=0}^{17} \bar{m}_{\tilde{a}}, \bar{m}_a\right) \quad \text{(A4)}$$

Substituting into equation (B2), we obtain

$$False\ Positives_{18-80} = \sum_{a=18}^{80} \bar{e}_a N_a \quad \text{(A5)}$$

and the error rate is

$$Error\ Rate = \frac{\sum_{a=18}^{80} \bar{e}_a N_a}{\sum_{a=18}^{80} \bar{m}_a N_a} \quad \text{(A6)}$$

Using this measure, a naïve Levenshtein matching yields an error rate of 83.3 percent across all disciplines, suggesting that more than four in five "matches" are false positive (Table A1, Panel A). Notably, the error rate is much lower in the physical sciences (75.0 percent) than in the biological and social sciences (with 96.2 and 92.9 percent, respectively).

To reduce error, we first match scientists with patents using their middle name or middle initial, defining two conditions for a scientist-inventor pair to be a middle name match. First, the scientist and the inventor must have the same number of names (e.g., three names including one middle name or two names without any middle name). Second, if the scientist and the inventor both have a middle name, their middle name must have the same initial or the same middle name. For example, Aarons W. Melvin" and "Aarons Wolf Melvin" are middle name matches, while "Robert A. Lester," "Robert Lee Lester" or "Arthur Dwight Smith" and "Arthur Dean Smith" are not. With middle name matching, the rate of false positives declines from 75.0 to 14.2 percent in the physical sciences but stays high for the biological and social sciences at 72.3 and 81.6 percent, respectively (Table A1, Panel B).

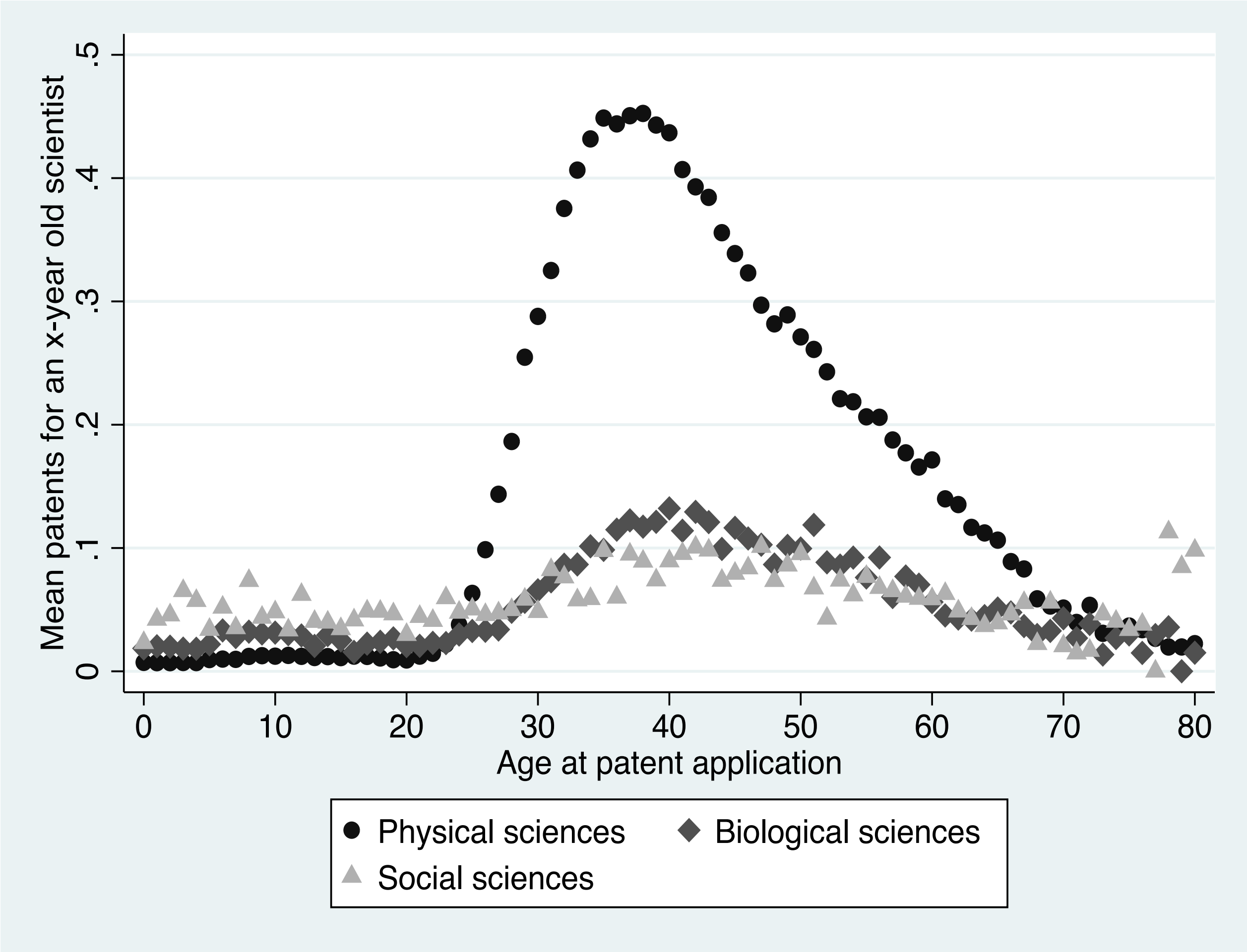
In the final step of the matching, we exclude the top quintile of common names, like John Smith. (To calculate the frequency of a scientist's name, we multiply the probability of their first name in social security records 1880-2013 by the probability of their last name in the US Census 2000.) Excluding common names further reduces the error rate from 22.1 to 6.3 percent. Controlling for middle names and dropping the top quintile of frequent names reduces this rate to 4.2 percent for the physical sciences. Error rates for the biological and social sciences remain high at 32.8 and 67.9 percent (Table A1, Panel C, and Figure A1), which is consistent with inter-industry differences in the propensity to patent (Cohen, Nelson and Walsh 2000, Moser 2012a).

TABLE A1 – MATCHING SCIENTISTS WITH PATENTS

	All	Physical Sciences	Biological Sciences	Social Sciences
Scientists in MoS (1956)	82,094	41,096	25,505	15,493
A. Patent applications made when scientists are 18-80 years old				
Scientists with at least 1 patent	43,929	27,527	10,777	5,625
Patents	1,496,170	887,658	384,058	224,454
Patents per scientist	18.23	21.60	15.06	14.49
Error rate	83.3%	75.0%	96.2%	92.9%
B. Scientists and patentees have matching middle names				
Scientists with at least 1 patent	27,030	20,743	4,506	1,781
Patents	250,707	216,475	23,113	11,119
Patents per scientist	3.05	5.27	0.91	0.72
Error rate	22.1%	14.2%	72.3%	81.6%
C. Matching middle name & excluding frequent names				
Scientists with at least 1 patent	18,035	15,146	2,311	578
Patents	164,892	154,883	8,064	1,945
Patents per scientist	2.01	3.77	0.32	0.13
Error rate	6.3%	4.2%	32.8%	67.9%

Notes: Panel A reports statistics on patents for which scientists would have applied between the age of 18 and 80, excluding applications between the ages 0 and 17 and above 80. Panel B reports scientists-patent pairs with a matching middle name. Panel C excludes the top five percent of common names.

FIGURE A1 – PATENTS PER YEAR ACROSS A SCIENTIST'S LIFE CYCLE



Notes: Patents per scientist for scientists who are x-years old in the year of the patent application. Scientists are matched to their patents using information on first, middle and last names and excluding the top quintile of common names. For the physical sciences, patenting peaks at age 38, for the biological sciences at age 40.

Most advances in the biological sciences were not patentable until the 1980s (when the USPTO granted the first patent for oil-eating bacteria). In the social and psychological sciences, scientific advances have not been patentable until recently.

Focusing on the physical sciences, we are able to 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.

APPENDIX B: SUPPLEMENTARY ANALYSES AND ROBUSTNESS CHECKS

TABLE A2 – BALANCING TABLE. ESE VS. OTHER FIELDS IN 1921

	Fields			
	ESE	Other	Difference	p-value
Share ESE-born scientists	0.035	0.000	0.035	0.000
Share WNE-born scientists	0.054	0.051	0.003	0.823
Age	44.72	44.41	0.313	0.854
Female	0.011	0.012	-0.001	0.832
Share star scientists	0.115	0.104	0.011	0.660

Notes: ESE fields are 36 research fields in which ESE-born American scientists were active in 1921. "Other" fields are 59 research fields in which other American scientists were active at the same time. *Share ESE-born scientists* reports the share of scientists who were born in Eastern and Southern Europe among all scientists in field *i*. *Share WNE-born scientists* reports the analogous share for scientists who were born in Western or Northern Europe. Age reports the average age of scientists in field *i* in 1921. Star scientists are scientists whom their peers identified as leaders in their fields in 1921.

TABLE A3 – EFFECTS OF THE QUOTAS ON INVENTION BY US SCIENTISTS, ROBUSTNESS TO ALTERNATIVE RULES TO MATCH SCIENTISTS WITH PATENTS

	ln(patents)			
	(1)	(2)	(3)	(4)
ESE x post	-1.134*** (0.360)	-1.283*** (0.345)	-1.402*** (0.276)	-0.927*** (0.220)
	Baseline	Incl. common names	Incl. different middle names	Incl. common names and different middle names
Percentage change	-0.68	-0.72	-0.75	-0.60
Mean patents before 1924	4.15	6.38	7.24	39.51
N (fields x years)	5,795	5,795	5,795	5,795
Year FE	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes
Standard errors are clustered at the level of research fields				

Notes: This table checks the sensitivity of our results to alternative rules to match scientists with their patents. Excluding the top quintile of common names and restricting the data to patent-scientist pair with a matching middle name greatly increases the accuracy of our data (see Appendix Table A1). Here, we examine whether results are robust to alternative matching rules. Column 2 re-estimates the baseline specification, including common names. Column 3 keeps patent-scientist pairs with different middle names. Column 4 keeps all patent-scientist pairs for which the scientists is at least 18 years old but no older than 80 at the time of the patent application. Data for the biological and social sciences are mostly noise. Our main analysis focuses on the physical sciences.

TABLE A4 – EFFECTS ON INVENTION BY US SCIENTISTS, ROBUSTNESS TO THE CHOICE OF *K*

	ln(patents)			
	(1)	(2)	(3)	(4)
ESE x post	-0.932**	-1.022***	-1.134***	-1.141***
	(0.429)	(0.382)	(0.360)	(0.341)
K clusters (here fields)	50	75	100	125
Percentage change	-0.61	-0.64	-0.68	-0.68
Mean patents before 1924	8.37	5.50	4.15	3.51
N (field x years)	2,867	4,392	5,795	6,832
Year FE	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes
Standard errors are clustered at the level of research fields				

Notes: A "cluster" (here a research field) is a collection of data points (here scientists) that are grouped together because they include similar observable characteristics (here research topics). To group scientists into clusters, the *k*-means algorithm assigns researchers to one of *k* centroids by minimizing the distance between the observations and the centroid. The number of clusters *k* is a choice variable. In the baseline specifications, we set *k*=100 (column 3). Here, we investigate whether our results are robust to alternative choices of *k,* setting k to 50, 100, and 125.

TABLE A5 – EFFECTS ON INVENTION BY US SCIENTISTS, ROBUSTNESS TO ALTERNATIVE ECONOMETRIC MODELS

	patents		$\ln(\text{patents} + \epsilon)$			
	(1)	(2)	(3)	(4)	(5)	(6)
ESE x post	-0.756***	-0.910***	-0.771***	-1.134***	-1.498***	-1.861***
	(0.272)	(0.237)	(0.278)	(0.360)	(0.454)	(0.555)
	Poisson	Negative Binomial	$\epsilon = 0.1$	$\epsilon = 0.01$	$\epsilon = 0.001$	$\epsilon = 0.0001$
Percentage change	-0.53	-0.60	-0.54	-0.68	-0.78	-0.85
Mean patents before 1924	4.15	4.15	4.15	4.15	4.15	4.15
N (fields x years)	5,795	5,795	5,795	5,795	5,795	5,795
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes	Yes	Yes
Standard errors are clustered at the level of research fields						

Notes: In the baseline specifications (column 4) we estimate OLS regressions with the natural logarithm of patents as the outcome variable. About one fifth of all field-year pairs (18.3 percent) have zero patents; to keep them in the regressions, the baseline estimates add 0.01 to all observations. This table investigates whether our results are robust to alternative econometric models. Columns 1-2 report estimates of quasi-maximum-likelihood (QML) Poisson and negative binomial models

$$\mathbb{E}\left[\ln(y_{it})\right] = \beta \cdot ESE_i \cdot Post_t + \gamma_i + \delta_t,$$

where the operator $\mathbb{E}[\cdot]$ represents the mean conditioned on all the variables in the right-hand side of the equation. Columns 3, 5 and 6 change the small number ϵ that we add to the outcome variable in OLS log regressions to 0.1, 0.001, and 0.0001.

TABLE A6 – EFFECTS OF THE QUOTAS ON INVENTION BY US SCIENTISTS, INTENSITY REGRESSIONS

	ln(patents)			
	(1)	(2)	(3)	(4)
% ESE x post	-0.119**	-0.139**	-0.261**	-0.143**
	(0.057)	(0.061)	(0.116)	(0.060)
	Baseline	Excl. 5% largest fields	Excl. fields w top 5% ESE share	Incl. new fields
Percentage change	-0.11	-0.13	-0.23	-0.13
Mean patents before 1924	4.15	3.47	4.22	3.97
N (fields x years)	5,795	5,490	5,551	6,100
Year FE	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes
Standard errors are clustered at the level of research fields				

Notes: $\%ESE_i$ represents the share of ESE-born American scientists (in percentage points) among all American scientists working in field *i* in 1921. Column 2 excludes the top five percent of fields with the largest number of scientists. Column 3 excludes the top five percent of fields with the highest share of ESE-born scientists. In column 4 the control group includes three new fields in which no scientists were working in 1921.

TABLE A7 – PLACEBO: EFFECTS ON INVENTION BY CANADIAN SCIENTISTS

	ln(patents)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESE x post	0.049	-0.019	-0.103	-0.176	0.061	-0.025	0.081	0.021
	(0.151)	(0.171)	(0.131)	(0.148)	(0.158)	(0.180)	(0.148)	(0.167)
	Baseline		Excl. 5% largest fields		Excl. fields w top 5% ESE share		Incl. new fields	
Percentage change	0.05	-0.02	-0.10	-0.16	0.06	-0.02	0.08	0.02
Mean patents before 1924	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
N (fields x years)	5,795	5,795	5,490	5,490	5,551	5,551	6,100	6,100
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Field-specific pre-trends	No	Yes	No	Yes	No	Yes	No	Yes
Standard errors are clustered at the level of research fields								

Notes: A potential alternative explanation for the decline in invention is that ESE-born scientists may have selected into fields which generated fewer inventions after1924 independently of the quotas. To investigate this mechanism, we estimate placebo regressions for Canadian scientists who were not subject to the US quotas. Since Canada did not adopt comparable quotas in 1924, a decline in invention in ESE field after the quotas would be an indicator of selection. Here, OLS estimates compare changes in the log of US patents by Canadian scientists per year and field in the pre-quota fields of ESE-born American scientists with changes in the pre-quota fields of other American scientists. Canadian scientists are scientists in the MoS (1956) who worked in Canada in 1956. The variable *ESE* indicates fields in which at least one ESE-born scientist was an active inventor in 1921. The variable *post* indicates years after 1924. Columns 2, 4, 6, and 8 control for field-specific linear pre-trends in patenting. Columns 3 and 4 exclude the top five percent of fields with the largest number of scientists. Columns 5 and 6 exclude the top five percent of fields with the highest share of ESE-born scientists. In columns 7 and 8 the control group includes three new fields in which no scientists were working in 1921.

TABLE A8 – TRIPLE DIFFERENCES: EFFECTS OF THE QUOTAS ON INVENTION BY US SCIENTISTS COMPARED WITH CANADIAN SCIENTISTS

	ln(patents)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ESE x Canada x post	-1.183***	-1.070**	-1.080***	-1.056**	-1.337***	-1.321**	-1.362***	-1.299**
	(0.357)	(0.509)	(0.364)	(0.520)	(0.372)	(0.535)	(0.358)	(0.509)
	Baseline		Excl. 5% largest fields		Excl. fields w top 5% ESE share		Incl. new fields	
Percentage change	-0.69	-0.66	-0.66	-0.65	-0.74	-0.73	-0.74	-0.73
Mean patents before 1924	2.08	2.08	1.74	1.74	2.12	2.12	1.99	1.99
N (clusters x countries x years)	11,590	11,590	10,980	10,980	11,102	11,102	12,200	12,200
Year-field FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-field FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-field-specific pre-trends	No	Yes	No	Yes	No	Yes	No	Yes
Standard errors are clustered at the level of research fields								

Notes: Triple-differences regressions compare changes in patenting by Canadian with American scientists after 1924 in the pre-quota fields of ESE-born American scientists with changes in the pre-quota fields of other American scientists

$$\ln(y_{ict}) = \beta\, ESE_i\, US_c\, Post_t + \gamma_{ic} + \delta_{it} + \theta_{ct} + \epsilon_{ict}$$

where $\ln(y_{ict})$ is the natural logarithm of the number of US patents by scientists worked in country c (Canada/US) in 1956 in field i 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. The variable *ESE* indicates fields in which at least one ESE-born scientist was an active inventor in 1921. The variable *post* indicates years after 1924. Columns 2, 4, 6, and 8 control for field-specific linear pre-trends in patenting. Columns 3 and 4 exclude the top five percent of fields with the largest number of scientists. Columns 5 and 6 exclude the top five percent of fields with the highest share of ESE-born scientists. In columns 7 and 8 the control group includes three new fields in which no scientists were working in 1921.

Table A9 – Effects of the Quotas on Invention by US Scientists, Controlling for the Age of ESE-Born US Scientists

	ln(patents)				
	(1)	(2)	(3)	(4)	(5)
ESE x post	1.145***	-1.045***	-1.073***	-0.985***	-1.014***
	(0.371)	(0.363)	(0.384)	(0.367)	(0.377)
Share above 40 x post		-0.011			-0.016
		(0.007)			(0.013)
Share above 65 x post			-0.006		-0.009
			(0.015)		(0.017)
Average age x post				-0.034	0.029
				(0.027)	(0.055)
Percentage change	-0.68	-0.65	-0.66	-0.63	-0.64
Mean patents pre-1924	4.22	4.22	4.22	4.22	4.22
N (fields x years)	5,551	5,551	5,551	5,551	5,551
Year FE	Yes	Yes	Yes	Yes	Yes
Field FE	Yes	Yes	Yes	Yes	Yes

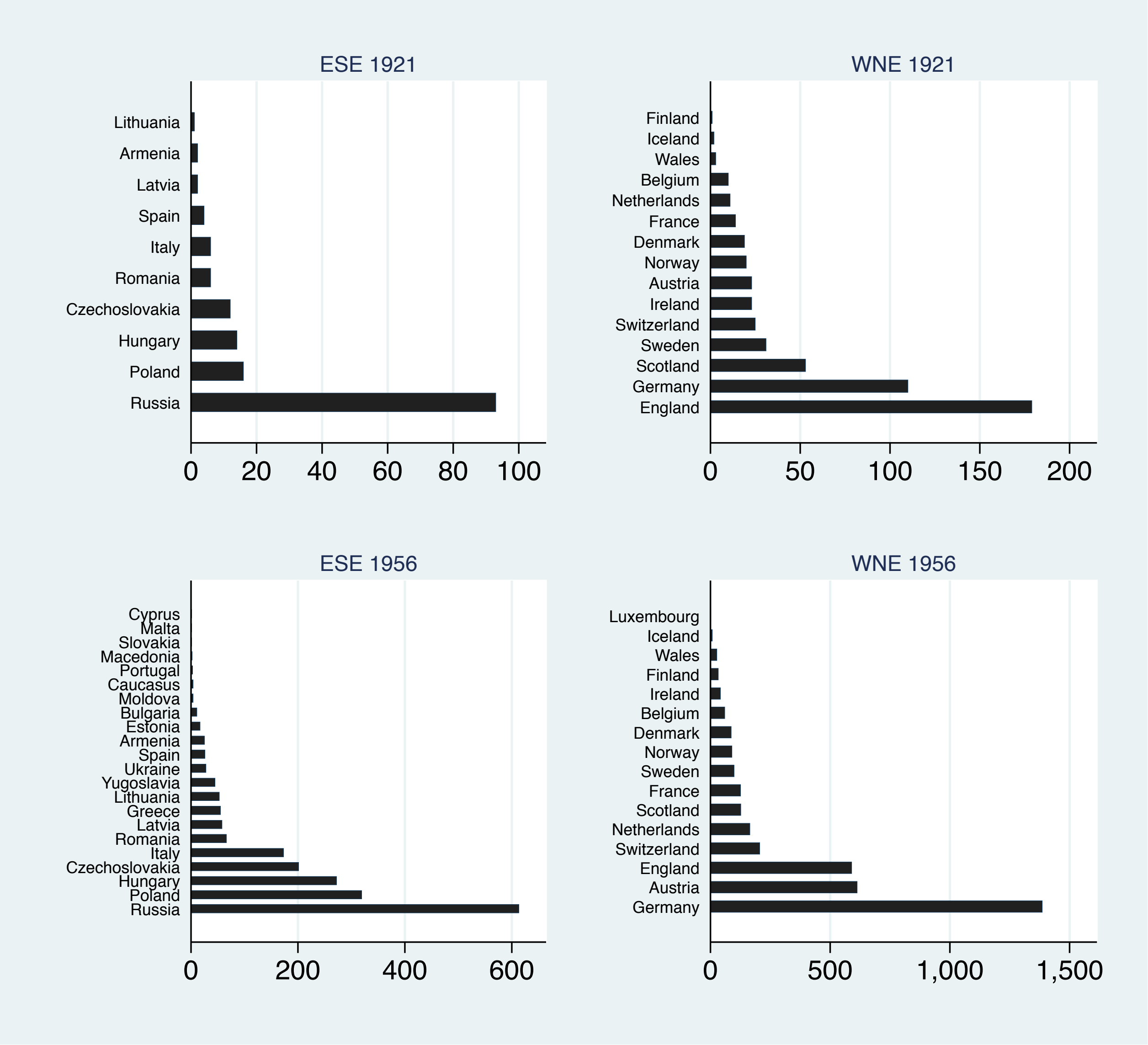
Standard errors are clustered at the level of research fields

Notes: To investigate whether the quotas reduced invention by contributing to the ageing of ESE fields, we re-estimate the baseline specification with additional interaction terms for age:

$$\ln(y_{it}) = \beta_1 \cdot ESE_i \cdot post_t + \beta_2 \cdot ESEAge_i \cdot post_t + \gamma_i + \delta_t + \epsilon_{it}$$

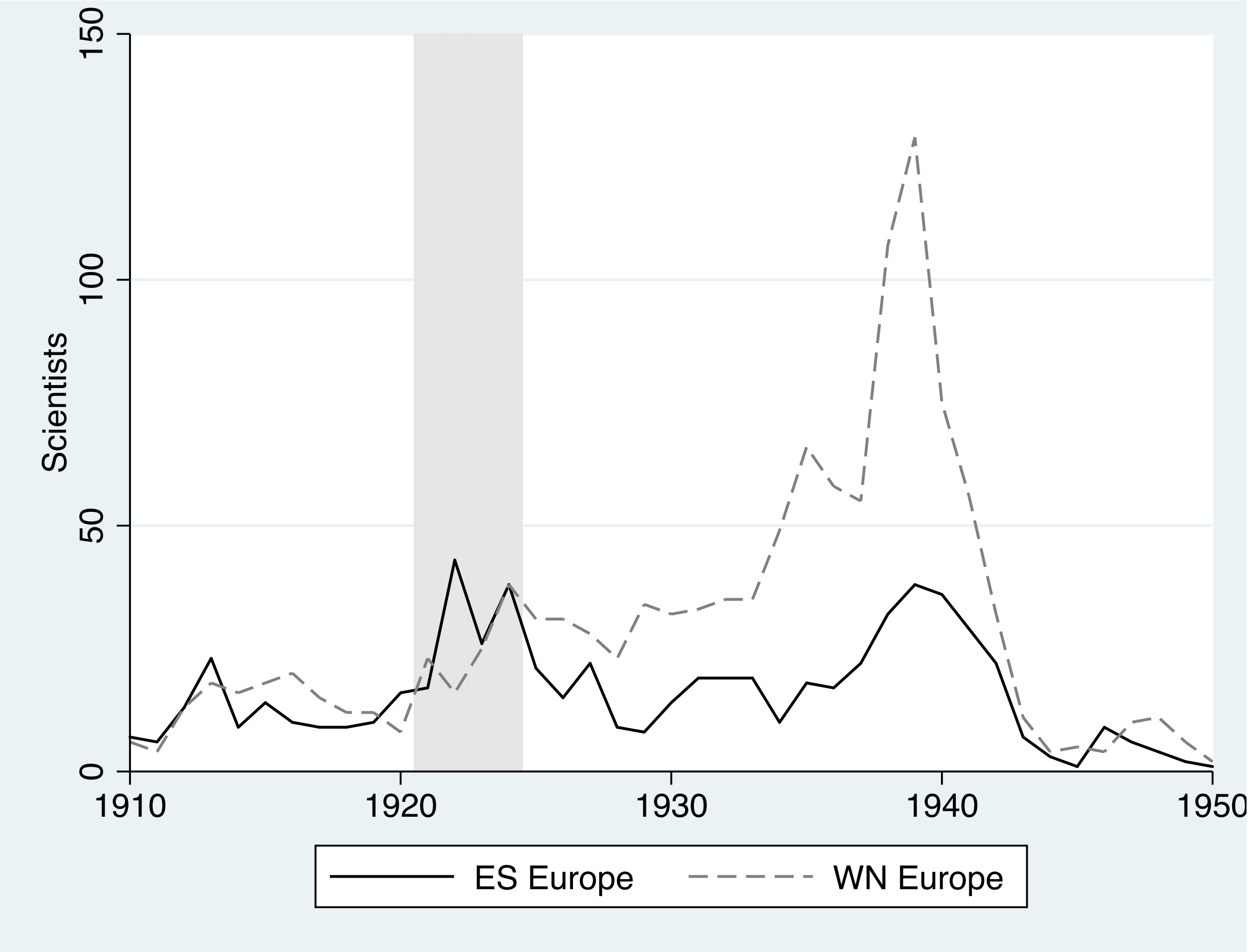
The variable $ESEAge_i$ represents three alternative measures for the aging of ESE scientists: first, the share of ESE scientists in field *i* who are above 40 in 1956 (column 2), second, the share of ESE scientists who above 65 in 1956 (column 3), and third, the average age of ESE scientists in field *i*. As above, the variable *ESE* is an indicator for the pre-quota fields of ESE-born American scientists, and *post* is an indicator for years after 1924.

FIGURE A2 - BIRTH PLACES OF AMERICAN SCIENTISTS IN 1921 AND 1956



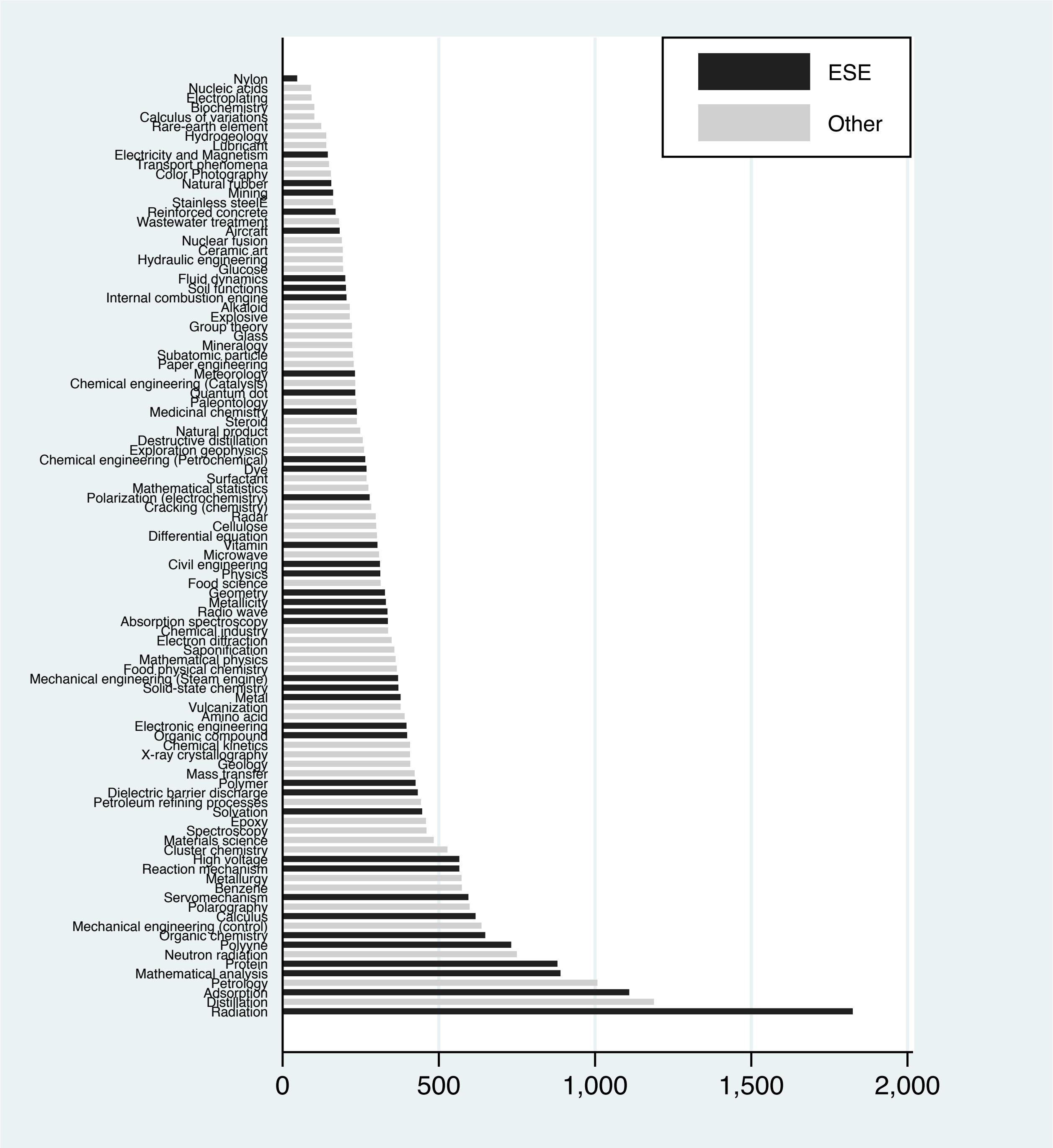
Note: Countries of birth of European-born scientists in MoS (1921) and MoS (1956). Eastern-Southern Europe (ESE) includes Armenia, Bulgaria, Caucasus, Cyprus, Czechoslovakia, Estonia, Georgia, Greece, Hungary, Italy, Latvia, Lithuania, Macedonia, Malta, Moldova, Poland, Portugal, Romania, Russia, Slovakia, Spain, Ukraine and Yugoslavia. Western-Northern Europe (WNE) includes Austria, Belgium, Denmark, England, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Scotland, Sweden, Switzerland, and Wales.

FIGURE A3 – ARRIVALS OF ESE- AND WNE-BORN AMONG NATURALIZED US SCIENTISTS



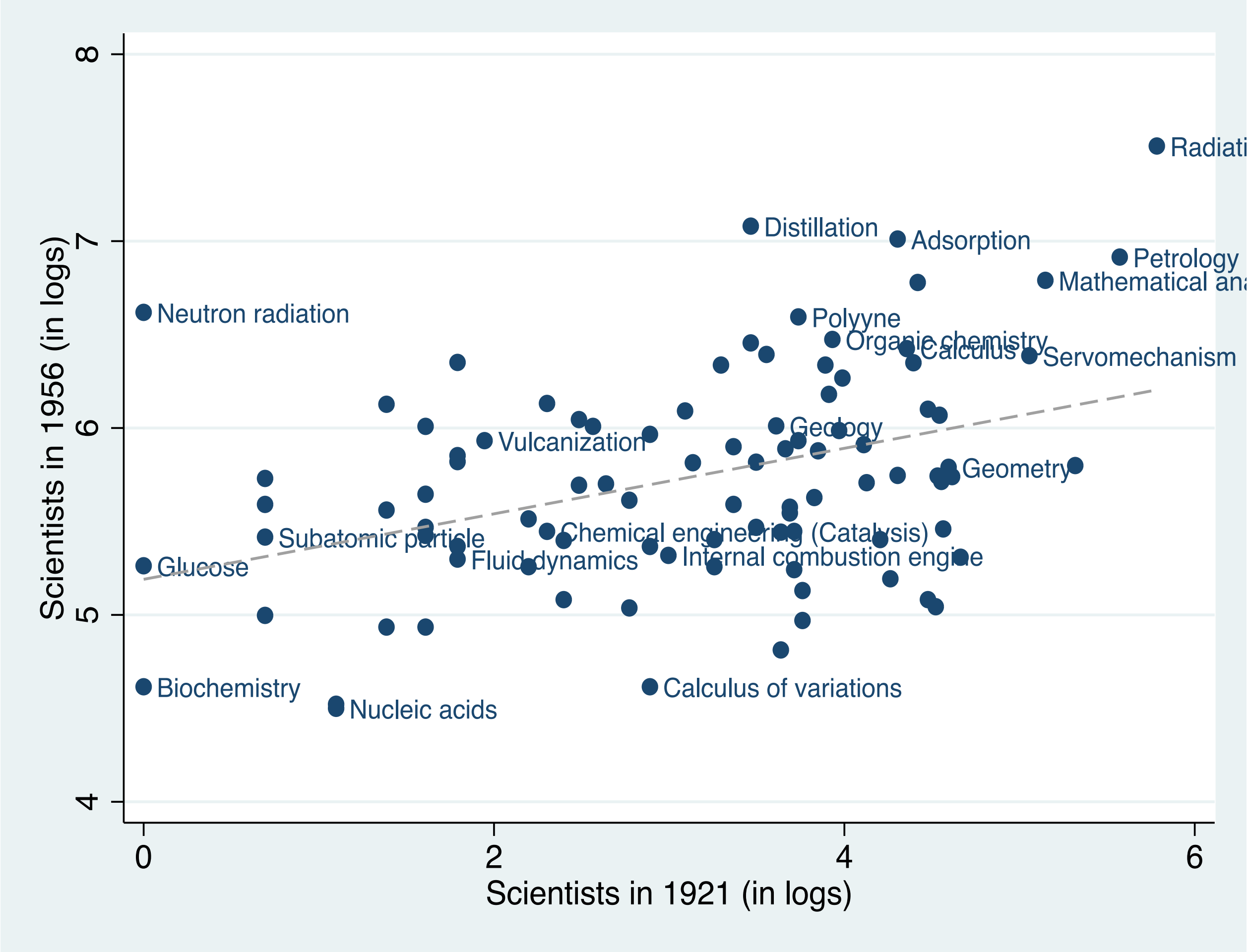
Notes: Arrivals per year of US scientists who became naturalized citizens of the United States. Under US law, immigrants are eligible for naturalization after five years. The ESE-born US scientist Dr. Elias Klein, for example, was naturalized in 1912: "KLEIN, DR. ELIAS, Naval Research Lab…Wilno, Poland, Jan. 11, 90, nat. 12," which means that he must have been in the United States in 1907. The year of the scientist's naturalization is known for 2,775 foreign-born scientists, and 33.5 percent of all European-born scientists, including 745 ESE- and 1,296 WNE-born scientists.

FIGURE A4– NUMBER OF SCIENTISTS IN ESE AND OTHER FIELDS



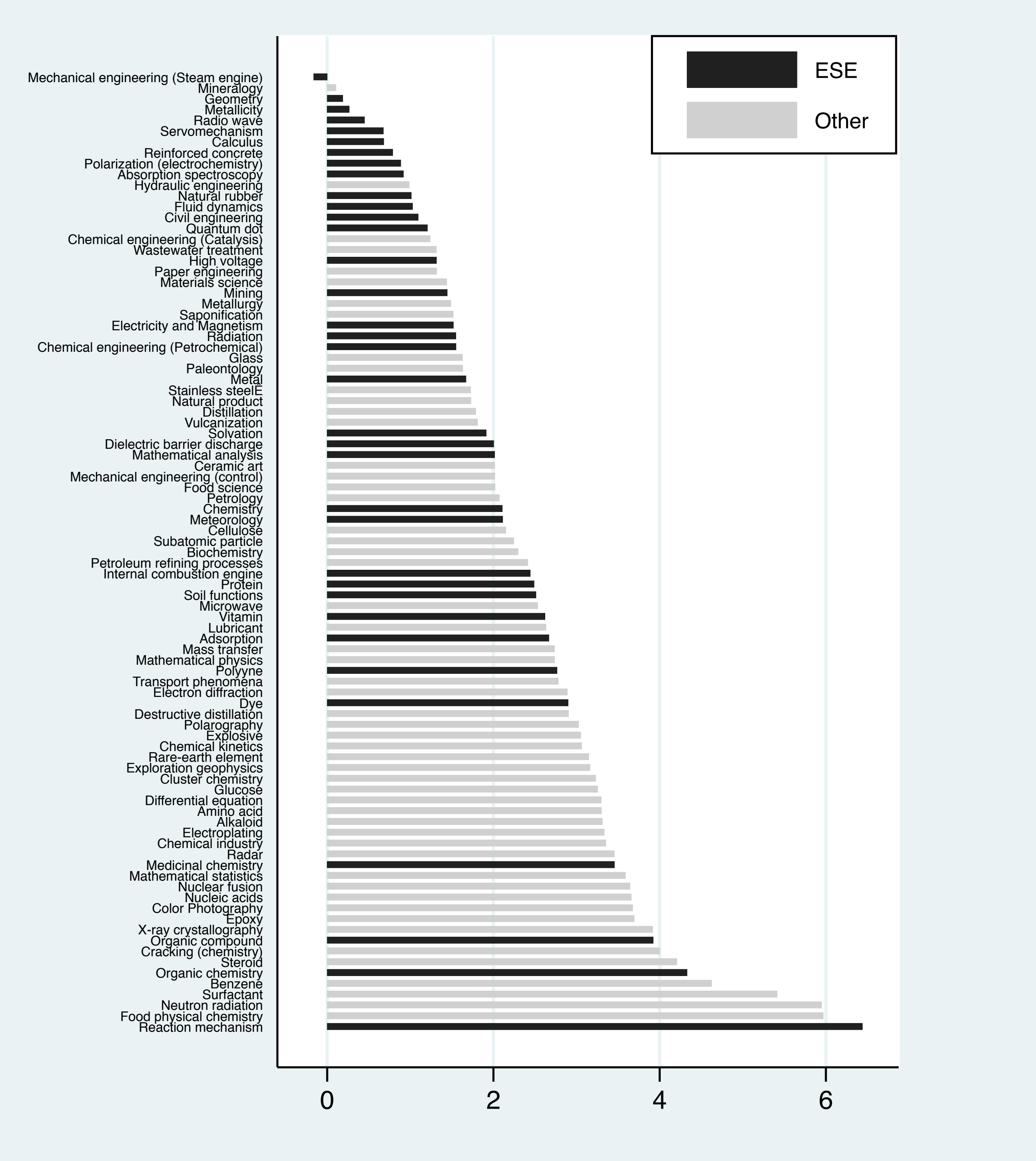
Notes: We apply *k*-means clustering to data on research topics to assign each scientist to a unique research field. For the *k*-means algorithm to work, clusters are assumed to be spherical and evenly sized, which we check with this figure. The median cluster (number 58) holds 303 scientists, and the average cluster has 410.9 with a standard deviation of 514.7.

Figure A5- Scientists per Field in 1921 and 1956



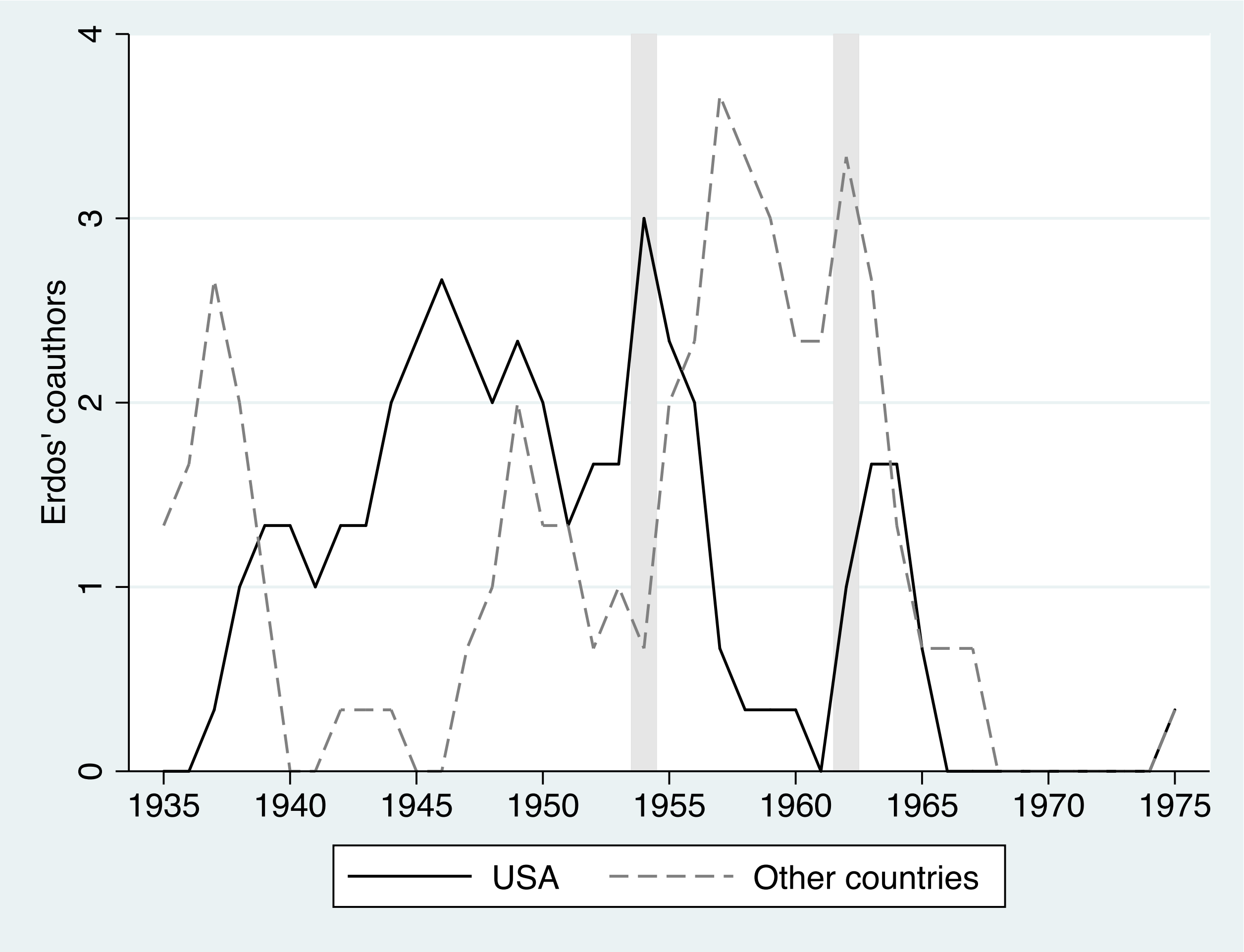
Note: Scientists per field in 1921 and 1956 (in logs excluding the residual cluster). The interrupted line plots the linear fit between the two variables. Clusters are names using a Google search for the most frequent words in each field and name each cluster with the first result of that search.

FIGURE A6 –RATIO OF PRE-AND POST-QUOTA PATENTS PER FIELD



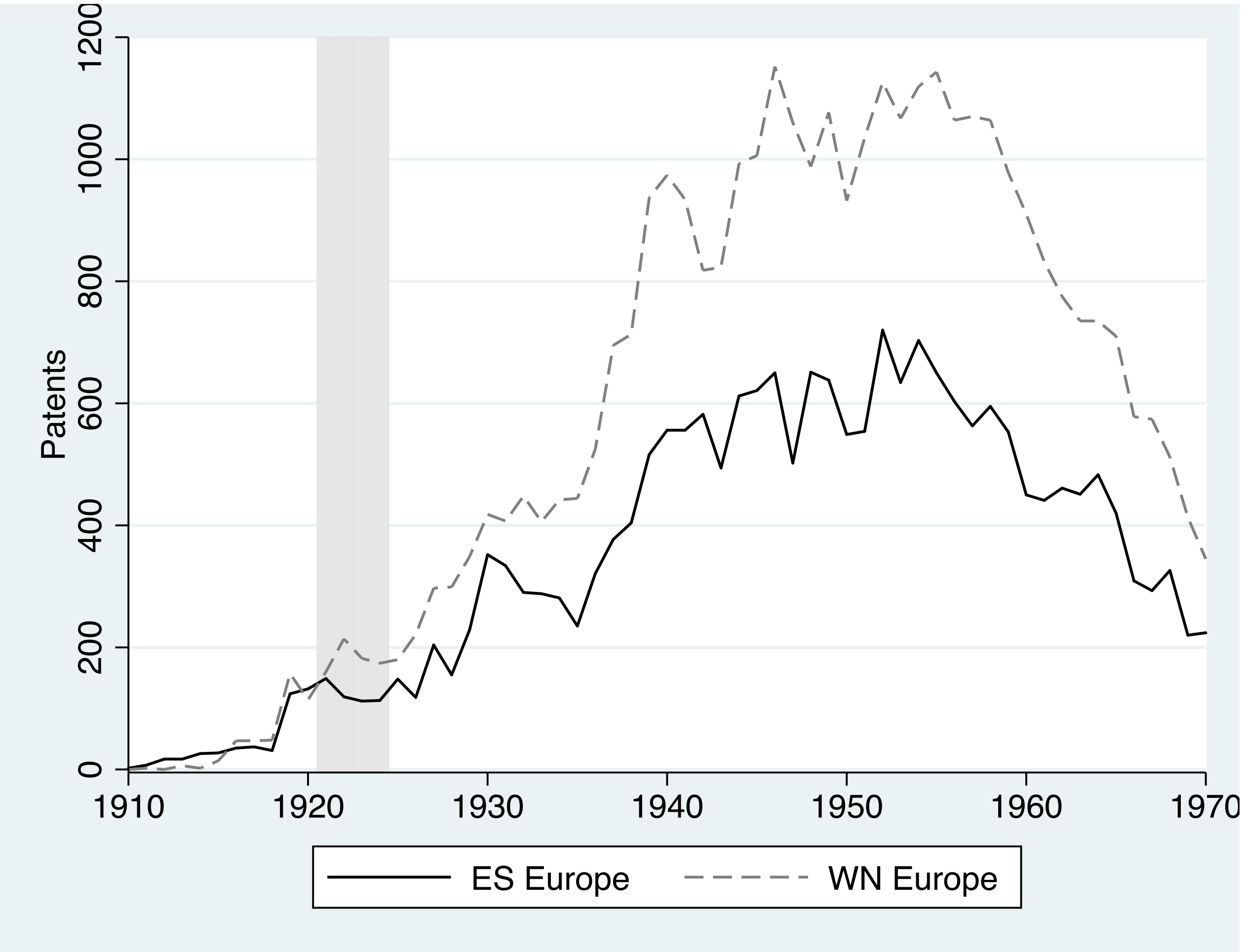
Notes: To examine visually whether patenting increased less in *ESE*-fields compared with other fields, this figure plots the natural logarithm of the ratio between the number of patents by US scientists after the quotas (1925-1970) and the number of patents by US scientists before the quotas (1910-1924). *ESE* fields are the pre-quota research fields of ESE-born American scientists. *Other* fields are the pre-quota research fields of other American scientists.

FIGURE A7– ERDÖS' COAUTHORS BY YEAR AND COUNTRY OF FIRST JOINT PUBLICATION



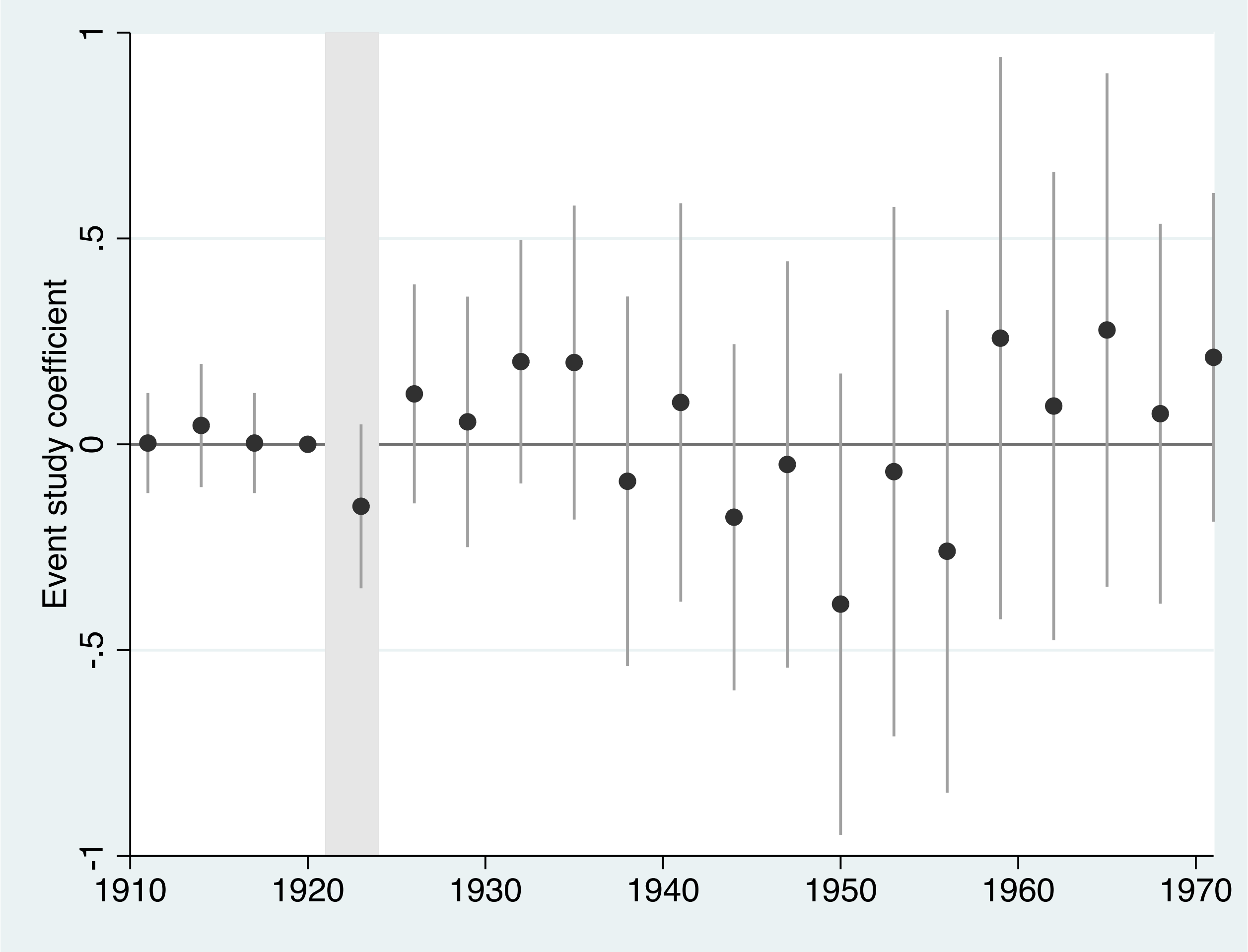
Notes: Co-authors by the mathematician Paul Erdős by the publication year of their first joint publication, for co-authors who were based in the United States (USA) in the year of their first publication, compared with co-authors who were based in other countries (dotted line). Data include 92 of Erdős' top 100 coauthors, smoothed to show the three-year moving average.

FIGURE A8– PATENTS BY CO-INVENTORS AND
CO-INVENTORS OF CO-INVENTORS OF ESE-BORN AND WNE-BORN US SCIENTISTS



Notes: Patents by US-born co-inventors of ESE-born and WNE-born scientists and by the co-inventors of co-inventors. Before the quotas, between 1910 and 1924, scientists in the professional network of ESE-born scientists produced a comparable number of patents as did scientists in the network of WNE-born scientists (with 948 patents for ESE and 1,167 for WNE). After the quotas, US-born collaborators of ESE-born scientists produced many fewer patents than collaborators of WNE scientists (20,316 and 34,323 between 1925 and 1970, respectively). A comparison of patents per year by the collaborators of ESE-and WNE-born scientists suggest that the quotas reduced the patenting of US collaborators of ESE-born scientists to forego 7,566 patents, equivalent to a decline of 27.1 percent.

FIGURE A9 – PLACEBO: TIME-VARYING EFFECTS OF THE QUOTAS ON CANADIAN INVENTION

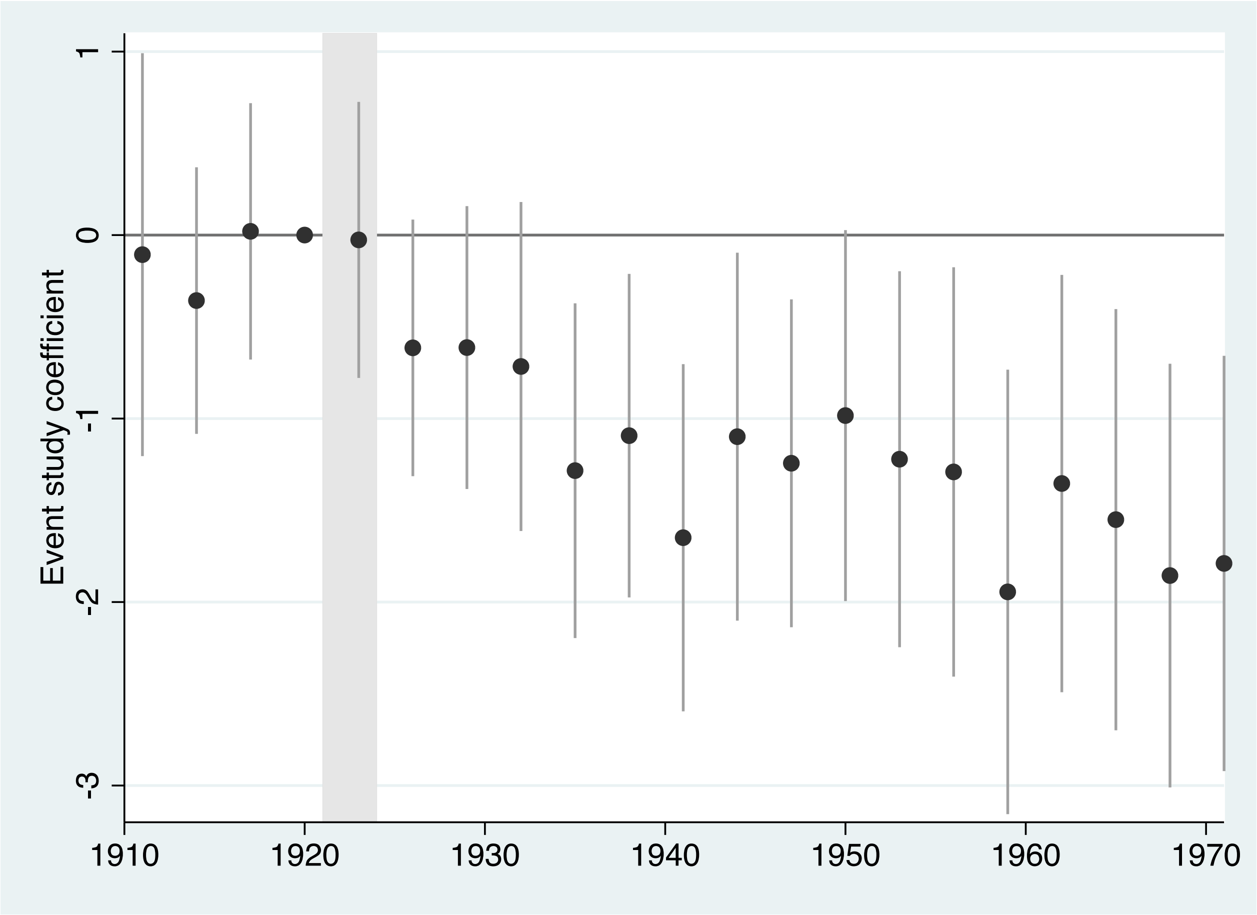


Notes: OLS estimates and 95-percent confidence interval of β_t in the placebo regression

$$\ln(y_{it}) = \beta_t ESE_i + \gamma_i + \delta_t + \epsilon_{it}$$

by scientists working in Canada in 1956. A potential alternative explanation for the decline in invention is that ESE-born scientists may have selected into fields which generated fewer inventions after 1924 independently of the quotas. To investigate this mechanism, we estimate placebo regression for Canadian scientists who were not subject to the US quotas. Standard errors clustered at the level of research fields.

FIGURE A10– TRIPLE DIFFERENCES. EFFECTS OF THE QUOTA ON INVENTION BY CANADIAN SCIENTISTS COMPARED WITH US SCIENTISTS

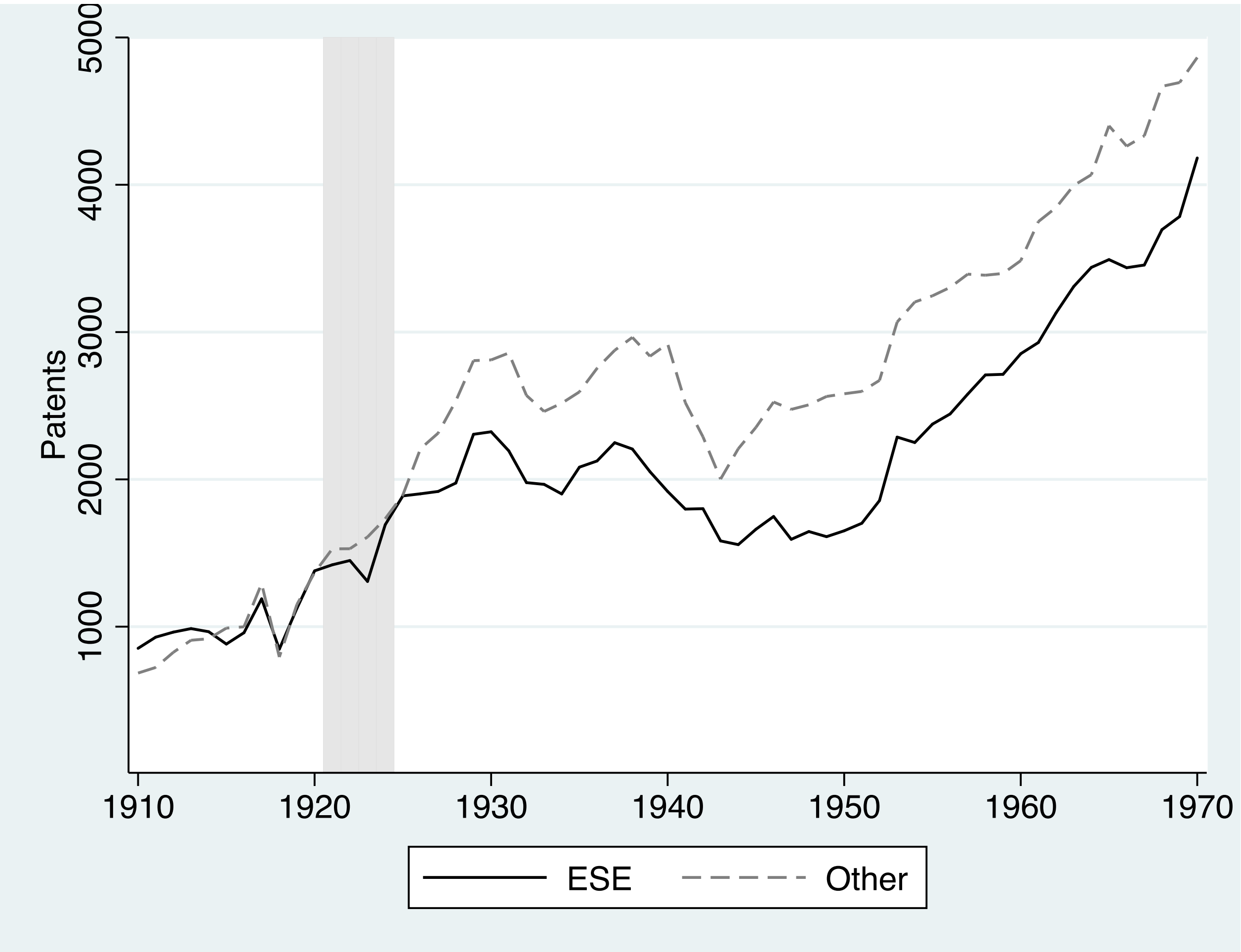


Notes: OLS estimates and 95 percent confidence interval of β_t in the regression

$$\ln(y_{ict}) = \beta_t \, ESE_i \, US_c + \gamma_{ic} + \delta_{it} + \theta_{ct} + \epsilon_{ict}$$

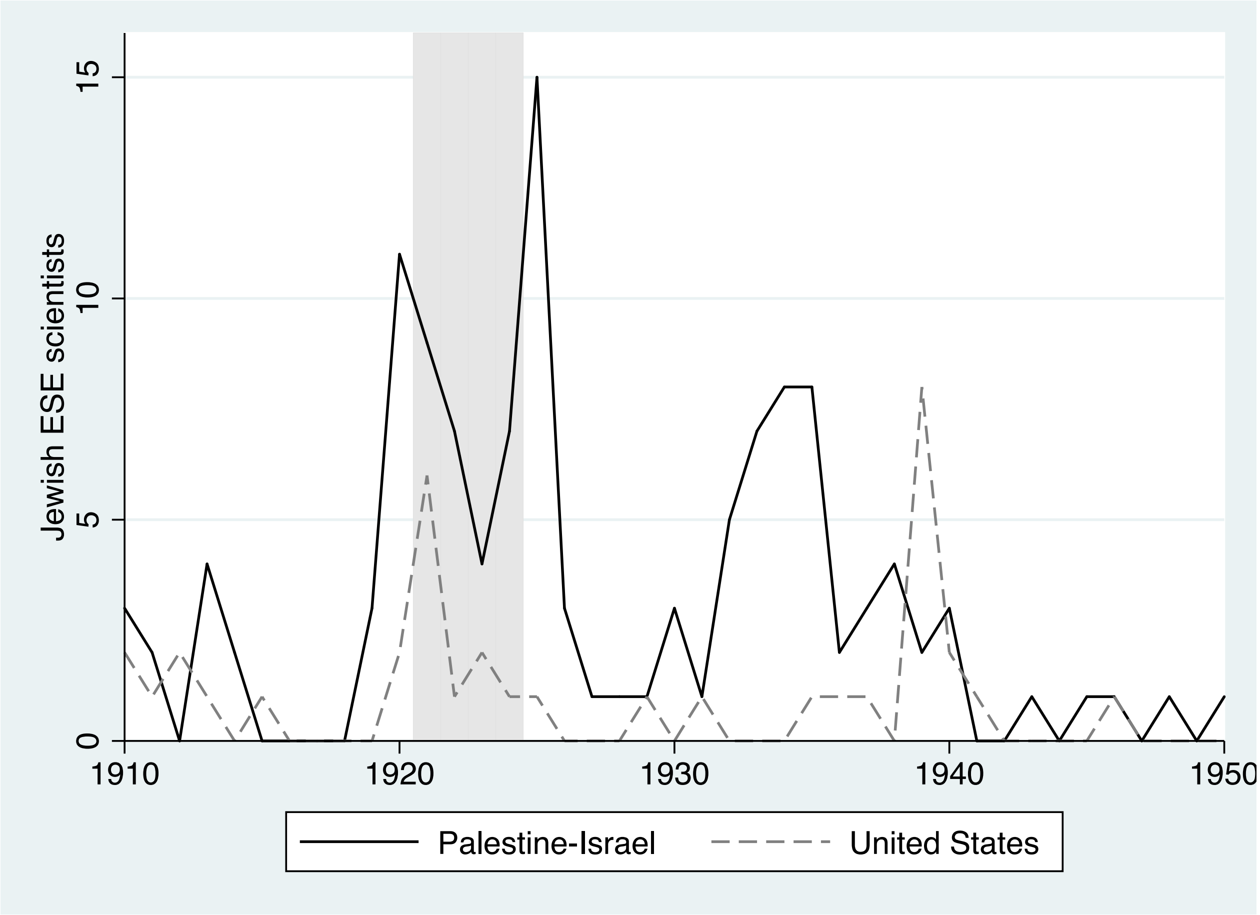
where ln (y_{ict}) is the natural logarithm of the number of US patents by scientists working in field i, year t and country c (Canada or the United States). ESE fields are the pre-quota fields of ESE-born American scientists. The indicator US_c equals 1 for scientists working in the United States in 1956 and 0 for those working in Canada. The variables $\gamma_{ic}, \delta_{it}, and\ \theta_{ct}$ are field-country, field-year and country-year fixed effects, respectively. 1918-1920 is the excluded period. Standard errors are clustered at the level of research fields.

Figure A11 — Patents per Year in ESE and Other Fields, Aggregate US Invention



Notes: Patent per year in the pre-quota fields of ESE-born American scientists compared with the fields of other American scientists. To assign patents to ESE and other fields, we extend the predictions of the *k*-means model in the main analysis, fitted on the research topics of scientists in 1956, to assign each patent title to a field of science, and then compare changes in patenting for ESE fields and other fields after the quotas. Before the quotas, US inventors patented at the same rate in ESE and other fields. Between 1910 and 1924, US inventors filed 1,130 successful patent applications per year in the fields of ESE-born scientist compared with 1,137 in other fields. After the quotas, US inventors patented less in ESE fields with 2,353 patents per year in ESE fields compared with 3,056 in other fields.

FIGURE A12– JEWISH ESE SCIENTISTS TO US AND PALESTINE-ISRAEL BY YEAR OF IMMIGRATION



Notes: Counts of ESE-born Jewish scientists per year who immigrated to the Palestine (or Israel after 1948) and the United States. We have collected these data using the birth country of entries in the Science section of the *World Jewish Register* (1955). 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. During this time immigration to the United States increased much less, 0.7 ESE-born scientists in 1910-1919 to 2.2 in 1920-1925. Immigration peaked in 1925, shortly after the second quota act, when 15 ESE-born scientists arrived in the future Israel. In the same year, only 1 ESE-born Jewish scientist 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 immigrants to Palestine/Israel included the Polish-born Aharon Katzir (1914-72), who became the founder of the polymer research department at Israel's Weizmann Institute of Sciences, and the Italian-born Giulio Racah (1919-65) who established theoretical physics as a discipline in Israel.