International Knowledge Flows: Evidence from the Collapse of International Science in the Wake of WWI

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Abstract

We analyze international knowledge flows as measured by citations in scientific papers. To separate knowledge flows from other cross-country differences, we investigate a large and sudden shock during WWI and the subsequent boycott of scientists from Central countries. The boycott increased citation penalties against enemy countries by around 100%, indicating a substantial reduction in international knowledge flows. Additional results show that our findings are not driven by discrimination against enemy papers but rather by a genuine reduction in knowledge flows, and that some knowledge that was produced during the boycott never reached the enemy camp. We also provide suggestive evidence that the collapse of international science affected the world-wide production of Nobel Prize worthy ideas.

Introduction

Ideas are key in advancing technological progress and economic growth (e.g., Romer, 1990). Many technological breakthroughs follow from ideas that have been developed by scientists engaged in

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basic research. While scientists are keen to disseminate knowledge and claim priority through publication (Merton 1957, Dasgupta and David, 1994, and Stephan, 2010), knowledge diffusion only occurs if scientists are aware of prior knowledge and if the costs of accessing it are not prohibitive (Mokyr, 2002). Borders can act as substantial barriers to knowledge flows because scientific networks are often national and knowledge diffusion depends on face-to-face interactions that are more common across shorter distances.

We measure international knowledge flows with citations in scientific papers. Cross-country differences in citation patterns, however, do not only reflect differences in access to knowledge but also other forms of cross-country heterogeneity, such as a differential specialization of scientists. To isolate knowledge flows from these other differences, we rely on a sudden and sharp change to international knowledge flows that affected the entire scientific community in the wake of World War I (WWI).

WWI was the first war that was waged on an industrial scale and all major war participants enlisted some of their most prominent scientists to help with the war effort. Scientists developed poisonous agents for gas warfare, new explosives, and trench mortars. Chemical warfare, in particular, attracted some of the best minds. The German chemical war effort was led by Nobel Laureate Fritz Haber, who enlisted some of the most prominent chemists and physicists to develop new poisonous gases. His team included, among others, the seven Nobel Laureates: James Franck, Gustav Hertz, Otto Hahn, Walter Nernst, Emil Fischer, Heinrich Wieland, and Richard Willstätter (Van der Kloot, 2004). The French chemical war effort was led by Victor Grignard, who had received the chemistry Nobel Prize in 1912. The U.S. effort also enlisted a number of prominent scientists including the future president of Harvard University James Bryant Conant.

During the war, many scientists, in particular from Germany, issued statements in support of their home country's military actions. In the most infamous document, the so-called "Manifesto of the 93," 93 German intellectuals, including many Nobel Laureates, declared their support for Germany's military actions. The manifesto provoked a strong reaction from Allied scientists, including a letter published in *Nature* by British Nobel Laureate William Ramsay, who suggested "restrictions of the Teutons" for the post-war period (Ramsay, 1914).

The brutality of the war, the involvement of scientists in weapons development, and the public support of the war by many scientists, created bitter feelings between the scientific camps in Allied (USA, UK, France, Canada, Japan, and others) and Central countries (Germany, Austria, Hungary, Bulgaria, and the Ottoman Empire). To punish the scientific community in Central countries for its aggressive support of the war, Allied scientists organized a boycott against Central scientists.[1] In 1918, during a conference held at the London premises of the world's oldest scientific academy,

[1]The scientific boycott was not the only measure against the Central countries. U.S. patents of Central firms, for example, were licensed at lower than market rates to U.S. firms and increased patenting of U.S. firms in technology areas with licensing (Moser and Voena, 2012).

the Royal Society, prominent scientists from Allied countries announced that:

> "…the Allied Nations are forced to declare that they will not be able to resume personal relations in scientific matters with their enemies until the Central Powers can be readmitted into the concert of civilized nations." [Quoted in Lehto, 1998, p. 18.]

The boycott lasted from the end of the war until 1926. Scientists from Central countries were no longer allowed to attend international conferences, many Allied scientific associations excluded members from Central countries, fewer scientists published their findings in journals of the opposing camp, and international efforts to reference the world-wide scientific literature (International Catalog of Scientific Literature) were discontinued (Reinbothe, 2006).

The boycott interrupted knowledge flows between Allied and Central nations. Scientists from Allied countries suddenly faced higher barriers to access knowledge from Central countries; in particular from Germany, a country whose scientists had received more than 40 percent of Nobel prizes in physics and chemistry in the pre-war period. Similarly, scientists from Central countries faced higher barriers to access knowledge from Allied countries; in particular from the UK (20 percent of Nobel prizes), France (15 percent of Nobel prizes), and the rising scientific power United States. Neutral countries (e.g., Switzerland, Netherlands, and the Scandinavian countries) were invited to join the Allied scientific organizations in the post-war period and accepted the invitation to avoid scientific isolation. The Neutrals immediately started to lobby for the re-admittance of Central scientists into the international scientific community. While these proposals were initially rejected by the Allies, the boycott was officially terminated in June 1926. Two years later, the eminent German mathematician David Hilbert was honored to deliver the opening address of the International Congress of Mathematicians in Bologna, Italy. He proclaimed:

> "It makes me very happy that after a long, hard time all the mathematicians of the world are represented here. This is as it should be and as it must be for the prosperity of our beloved science. It is a complete misunderstanding of our science to construct differences according to peoples and races… For mathematics, the whole cultural world is a single country." [Quoted in Reid, 1970, p. 188.]

We estimate how much WWI and the boycott reduced international knowledge flows by analyzing citation patterns in five scientific fields: medicine, biology, chemistry, physics, and mathematics. Readily available publication and citation data lack address information for authors and cited references for the historical period studied in this paper. As country information is essential to study international citation flows, we construct a new dataset of all university scientists in the world in 1900 and 1914. These data contain names, scientific specializations, universities, and thus country affiliations for all university scientists. We combine the scientist data with data on more than 260,000 articles citing almost 2 million references from over 150 journals from the ISI Web of Science.

The data allow us to construct two measures of international knowledge flows. For our main results we focus on changes in citations to recent work by enemy authors, compared to recent work by authors from the home camp. As we compare citations to the different camps within papers, we can include paper-level fixed effects in our regressions. The fixed effects control for a large number of potential confounders, such as differences in citation conventions across fields, differential changes in the number of citations over time across fields, and even author-specific changes in citation behavior over time.

Independently of the time period, papers from all scientific camps are significantly less likely to cite recent papers from enemy camps, indicating a substantial "home bias" (or equivalently "citation penalty" against enemy papers). The citation penalty against enemy papers increases during WWI, and in particular during the early boycott years, when international scientific collaborations of Centrals and Allies were most severely interrupted.

Central papers increase their citation penalty against recent Allied work by more than 140% during the early boycott years (1919-1921), compared to the pre-WWI period. During the late boycott years (1922-1925), the citation penalty towards Allied work is still 47% higher than in the pre-period. After the end of the boycott, the citation penalty against Allied work reverts back to its pre-war levels.

Allied papers increase their citation penalty against recent Central work by more than 30% during WWI and by almost 80% during the early boycott years. During the later boycott years the citation penalty against Central work is still more than 50% higher than in the pre-period. After the end of the boycott, the citation penalty against Central work reverts back to its pre-war levels.

These changes in citation patterns are robust to using different measures of knowledge flows and alternative methods of assigning countries to authors and references. We also show that Neutrals are indeed "neutral". During the War and the boycott they increase citation penalties to both camps to a similar extent.

Additional results indicate that these changes in citation patterns during WWI and the boycott are not driven by discrimination against enemy papers, but rather by increased costs of accessing knowledge from the enemy camp. To differentiate knowledge flows from discrimination, we study citations to enemy papers that were published before WWI. We show that citation penalties against *pre-war* enemy papers do not increase during the War and the boycott.

We also explore the long-run effects of reduced knowledge flows between enemy camps. We find evidence that the reduction in knowledge flows during WWI and the boycott had long-run effects, even after the end of the boycott. In particular, some Allied knowledge produced during the early boycott period, never reached the Central camp.

We also provide suggestive evidence that the interruption of knowledge flows affected the world-wide production of Nobel Prize worthy ideas. We use data from Jones and Weinberg (2011), who report the years when Nobel laureates worked on their prize winning research. The data indicate that fewer Nobel Prize worthy ideas were produced during WWI. This drought of Nobel Prize worthy ideas continued until four years after the war. Of course, this pattern may just be driven by the physical destruction during WWI. We find, however, that the post-war drought following WWI lasted for longer than the drought following WWII. These findings suggest that the interruption of knowledge flows during WWI and the boycott indeed affected world-wide scientific progress.

Prior work has shown that patent citations are more likely to come from the same country, state, and city as the cited patent (Jaffe, Trajtenberg, and Henderson, 1993). These barriers to receiving patent citations are particularly strong at country borders (Thompson and Fox-Kean, 2005), suggesting that such borders are indeed important barriers to knowledge flows. Country borders, however, can become more or less permeable over time. While Western-to-Communist book translations were very rare during the Cold-War period, they increased massively after the Collapse of the Soviet Union (Abramitzky and Sin, 2014). We investigate international knowledge flows measured by citations in academic papers. Despite the fact that academic publishing is geared towards a free exchange of scientific knowledge, we find strong barriers to international knowledge flows that become less permeable in the wake of WWI.

Our findings highlight the effect of scientific institutions (such as conferences and referencing archives) on international knowledge flows. Related work has shown that intellectual property rights, such as copyrights and patents, affect knowledge flows (Scotchmer, 1991). A fall in copyrights of German scientific books during WWII increased U.S. citations to these books (Biasi and Moser, 2015). Patent protection for certain human genes reduced follow-on innovation building on these genes (Williams, 2013). Similarly, patent protection of genetically engineered mice reduced follow-on work based on these mice (Murray, Aghion, Dewatripont, Kolev, and Stern, 2009). More generally, patent protection affects follow-on work in computers, electronics, and medical instruments, but not in drugs, chemicals, or mechanical technologies (Galasso and Schankerman, 2015).

1 WWI and Scientific Collaboration

Science became increasingly international during the second half of the 19th century. The pre-WWI period was time of important scientific discoveries, which was characterized by ever increasing international scientific collaboration. Scientists published their most important contributions in international scientific journal, international conferences were attended by an increasing number of scientists, and scientific societies started to collaborate more extensively. In 1899 the leading scientific nations (Germany, UK, USA, France, Austria, Italy, and Russia) founded the International Association of Academies to "facilitate scientific intercourse between the different countries" (Greenaway, 1996).

Scientists and Weapons Development in WWI

The increasing internationalization of the scientific enterprise was abruptly interrupted by the outbreak of WWI, at the end of July, 1914. WWI became the first major war that was waged on an industrial scale and all major countries enlisted some of their most prominent scientists to support the war effort, in particular the development of poisonous agents for gas warfare.

In the first gas attack of WWI, the French used tear gas filled shells and hand grenades to attack the German troops in August 1914 (Trumpener, 1975). Gas warfare moved to a different scale, when the Germans deployed chlorine gas against the French near Ypres, Belgium, on April 22^{nd}, 1915. The greenish poison-cloud killed around 5,000 French soldiers and wounded 15,000. Until the end of the war in 1918, both Allies and Centrals deployed existing poisonous agents and developed new agents such as phosgene (introduced in 1915) and mustard gas (introduced by the Germans in 1917). Overall, gas killed around 91,000 soldiers. Compared to a total of 16 million war casualties, the number of gas victims was relatively low. Nonetheless, the "mysterious" nature of gas spread great fear among soldiers and made this new weapon a symbol of a war that became dependent on scientific discoveries.

Public documents in support of war

As soon as the war had started, scientists of both camps issued statements that showed their support for their national war effort. In the most infamous document, the so-called "Manifesto of the 93," 93 German intellectuals declared their support for Germany's military actions, including the killing of Belgian civilians and the destruction of Leuven with its famous university library. The document was widely distributed on October 4^{th}, 1914, and translated into 14 languages (see Professors of Germany,1919, for an English translation of the document). The signatories included 14 current or future Nobel Laureates, such as the chemist Fritz Haber, the inventor of chemotherapy Paul Ehrlich, and the inventor of X-rays Wilhelm Röntgen. Two weeks later, 3,000 German university teachers endorsed a declaration that "…Europe's culture depends on the victory of the German military" (Reinbothe, 2006, p. 99). In a reply that was published in *Nature,* the British chemistry Nobel Laureate William Ramsay wrote that "their ideal […] is to secure world supremacy for their race, […] 'Deutschland über Alles in der Welt"' (Ramsay, 1914). A similar reply was published by the French Académie des Sciences.

Exclusion of Central Scientists from Allied Scientific Associations

Already during the war, many Allied scientific associations excluded (honorary) members from Central countries. Eminent scholars, such as Nobel Laureates Adolf von Baeyer, Walter Nernst, and Richard Willstätter were excluded from the American Chemical Society, the British Chemical Society, and the French Societé Chimique. Many other Allied scientific associations followed suit (Reinbothe, 2006).

The Boycott of Scientists from Central Countries

The participation in the war effort of scientists from all countries embittered the international scientific relations. As early as October, 1914, William Ramsay suggested "restrictions of the Teutons" (Ramsay, 1914) in a *Nature* letter. In the following years, Allied scientists continued to discuss potential sanctions against Central scientists. In correspondence with Arthur Schuster, the Secretary of the Royal Society, Gaston Darboux and his successor Émile Picard, the Permanent Secretaries of the French Académie des Sciences, suggested to cut all scientific links with Central scientists (Letho, 1998, p. 16).

In October 1918, even before the Armistice of November 1918 that ended WWI, scientists from Allied countries called a conference at the premises of the Royal Society in London, which paved the way for the boycott of Central scientists.

At a follow-up conference in Brussels, over 200 scientists from 12 Allied countries founded the International Research Council (IRC).[2] The IRC replaced the International Association of Academies that had overseen international scientific relations in the pre-war era. The IRC statutes explicitly excluded the former Central countries, but some formerly Neutral countries were invited to join as members (Kevles, 1971, p. 58). While the Neutrals were initially put off by the strong anti-Central bias of the IRC, they accepted the invitation to avoid scientific isolation (Lehto, 1998, p. 21). As voting rights in the IRC depended on population counts (including colonies), the IRC was effectively controlled by the large Allied countries: the United States, the United Kingdom, and France.

Because international scientific relations were now organized under the auspices of the IRC, the international scientific community was divided into three major camps (Table 1): Allies, Centrals, and Neutrals. To facilitate international relations in each scientific field, a number of subject-specific Unions were established under the IRC.[3] Central scientists were excluded from most Allied

[2] In the humanities and social sciences the equivalent of the IRC, the so-called International Union of Academies, was founded in 1919.

[3] The International Union of Biological Science, the International Union of Pure and Applied Chemistry, the International Astronomical Union, the International Union of Geodesy and Geophysics were founded in 1919, the International Mathematical Union in 1920, and the International Union of Pure and Applied Physics, and the International Geographical Union in 1922.

scientific associations and international scientific meetings, even if the associations or conference organizers were not officially affiliated with the IRC or its Unions (Schroeder-Gudehus, 1973).

The Neutrals immediately started to lobby for the deletion of political membership restrictions in the IRC statutes. At the next general assembly of the IRC in 1922, Sweden proposed to invite the formerly Central countries to the IRC. At that time, the proposal was rejected by a large majority of Allied countries (Letho, 1998, p. 38). In the following years, the position of the Allied countries softened, in particular in the United States and the United Kingdom. As a result of the more general policy of détente in the mid-1920s, with Germany being invited to join the League of Nations, for example, the boycott was officially terminated in June 1926 and Germany, Austria, Hungary, and Bulgaria were invited to join the IRC and its Unions (Letho, 1998, p. 40).

While the boycott officially lasted until 1926 its strength declined between 1919 and 1926. During the early years of the boycott, scientists from Central countries were effectively banned from attending all international conferences. In 1919, for example, German scientists did not attend a single international scientific conference. In 1920, around 85 percent of international conferences took place without German scientists. This fraction fell to 60 percent between 1921 and 1923, and to 50 percent between 1924 and 1925. From 1926 onwards, less than 15 percent of scientific conferences took place without German scientists (Kerkhoff, 1940).

Attendance records of the International Congresses of Mathematicians (ICMs), that we have collected from the International Mathematical Union, demonstrate the effects of the boycott (Table 2). In the pre-war period, mathematics became increasingly international as the conferences were attended by ever more mathematicians. As one of the leading countries in mathematics, Germany always sent large delegations to the ICMs in pre-war period. Because of the outbreak of the war, the 1916 congress that was supposed to be held in Stockholm was canceled. In a symbolic move, the 1920 congress was held in Strasbourg, in the Alsace region that Germany had annexed from France after the 1870/71 war and that France recaptured during WWI. German mathematicians were not invited. They were also not invited to the Toronto congress in 1924. By 1928, the boycott had ended and Germany sent the second largest delegation after the host nation to the congress in Bologna.

2 Data

2.1 Scientist Data

To measure international knowledge flows we collect a new dataset of all university scientists in the world. The data come from the 1900 and 1914 volumes of "Minerva–Handbuch der Gelehrten Welt." Minerva was published since 1889 and used to be the most comprehensive world-wide listing of university professors. To extract all university scientists we digitize all 1,000 pages in the 1900 volume and all 1,500 pages in the 1914 volume with the help of research assistants.

The data list 565 universities in the year 1900 and 966 universities in the year 1914, indicating the exceptional growth of the university sector during this period (Table 3, Panel A).[4] The data contain all full-time professors at any level of seniority (i.e., all university ranks from the equivalent of assistant professors to full professors, in the following we refer to all of these scholars as professors, see Appendix Figure A.1 for a sample page of Minerva). The entries are very comprehensive for all major universities. Across all fields, the data contain 24,090 professors in 1900 and 42,112 professors in 1914. A few universities, mostly smaller and less well-known institutions, only report the number of professors but not their names. The data therefore contain names of 23,841 professors in 1900 and 36,738 professors in 1914 (Table 3, Panel A). Figure 1.a shows the distribution of scientists across the world. The map illustrates the concentration of scientific activity in the United States and Western Europe. We focus our empirical analysis on five scientific fields: medicine, biology, chemistry, physics, and mathematics. During the time period studied in this paper, scientists in these fields already published the majority of their research in academic journals. The publishing process in the sciences closely resembled publishing in modern times. Our data contain 10,040 scientists in 1900 and 15,790 scientists in 1914 across the five fields (Table 3, Panel B).[5]

Already in 1900, U.S. universities boasted the largest number of scientists, followed by German universities which were still the main centers of scientific excellence (Table 3, Panel C). The total number of scientists increased in all countries between 1900 and 1914, with particularly pronounced growth in the United States.

2.2 Publication and Citation Data

To analyze changes in citation patterns we collect all 260,375 publications in 151 science journals from the ISI Web of Science for publication years 1905 to 1930. The Web of Science has better coverage of Western, and in particular Anglo-Saxon journals. Hence, our set of journals includes many journals edited in the United States, the United Kingdom, and Germany, but a smaller number of journals edited in France, Netherlands, Switzerland, and Russia (see Appendix Tables A.1.a

[4]Newly founded universities are usually listed with a delay of about 10-15 years unless the new universities start with large faculties. Newly founded universities do usually not employ many research active professors during their first years of existence.

[5]Minerva lists the exact specialization (often in native languages) for each scientist. So mathematicians would list "Algebra," "Number Theory," and several other specializations in many languages. We recode thousands of these exact specializations into 32 fields (such as the five scientific fields: medicine, biology, chemistry, physics, and mathematics; but also all other fields like: engineering, theology, law, and so on).

and A.1.b for the full list of journals).[6] As we analyze changes in citation patterns over time, and include camp fixed effects in our regressions, a larger set of U.S., U.K., or German journals does not bias our results.[7]

The 260,375 original papers cite almost 2 million references to work published after 1900. These references are reported in an abbreviated format. Instead of the full reference with all authors and complete journal information, each reference lists at most five items: the first author, the publication year of the reference, an abbreviation of the journal name, the volume of the journal, and the first page of the article. Many references do not even report these five items, either because the reference is incomplete or because the reference cites a non-standard publication such as a government record or a book. To obtain complete references, including a full list of referenced authors, we merge the 2 million cited references with our 260,375 original papers (that include the full list of authors for each paper), using the five items reported above.[8] To improve the quality of this match we first correct spelling inconsistencies in the abbreviated journal name. The references abbreviate journal names, such as the "Proceedings of the National Academy of Sciences of the United States of America" (PNAS) in various ways. The journal is sometimes abbreviated as "p natl acad sci usa", but in other references as "p nat ac us", or with dozens of other abbreviations. We manually correct around 2,000 of these inconsistencies that affect more than 300,000 references. After this match, the final reference data contain the full list of authors for each reference. For references that do not merge with any of the 260,375 original papers we still know the first author, the journal, the volume, and the first page of the article (but not the full list of authors).[9]

For the historical period studied in this paper, only few papers in the Web of Science list the precise address information for each author; primarily because historical science journals often reported authors without listing their university affiliation. As our analysis of international citation patterns crucially depends on knowing the country of both authors and cited references, we use the scientist data described above, and address information contained in some articles, to

[6] The Web of Science digitized journals from the historical period in the early 2000s. The digitization included all journals that had published at least five papers that had received more than 100 post-WWII citations, or journals that received more than 1,500 post-WWII citations overall (see http://wokinfo.com/products_tools/backfiles/cos/ for more details). As post-WWII citations were measured in a set of journals that concentrates on Western journals, the historical set of journals has a better coverage for U.S., U.K., and German journals.

[7] Some journals were founded after 1905. Re-estimating all our results for the set of journals that were present during the entire period does not affect our findings.

[8] We also merge references that only contain four of the five items if the four items uniquely identify one of the 260,375 papers in our data.

[9] References may not merge during this step for a number of reasons: 1. the reference was not published in one of the 151 journals in our data, 2. the reference was published before 1900 (as the Web of Science data only lists articles after 1900), 3. some items in the reference are misspelled. For reasons that we explain below, we focus our analysis on citations to work that was published in one of the 151 journals and thus to references that include the full list of authors after we matched them with the 260,375 papers.

assign countries to authors and cited references.

We construct two measures for the country of each author and cited reference. The first measure only uses information from our scientist data to assign countries. For this measure we merge our scientist data to each citing author and each author in the full list of references. The second country measure combines the country information from our scientist data with address information listed in one of the 260,375 original papers. For both measures, we then calculate the "nationality" of each paper and its references as the fraction of citing authors and referenced authors from each country. A paper (reference) exclusively written by authors from the United States, for example, counts as one U.S. paper (reference). A paper (reference) co-authored by one U.S. author and one Canadian author, counts as 0.5 U.S. papers and 0.5 Canadian papers (references). Tables 4.a and 4.b report the number of papers from each country. Column 1 shows the number of papers per country based on the scientist and address data and column 2 shows the number of papers based on the scientist data.[10] Compared to the assignment that only uses the scientist data, we assign about three times as many papers to the United States if we combine the scientist data with the address information (Table 4.a, first line of columns 1 and 2). For German papers, however, the two country assignments are very similar (Table 4.a, columns 1 and 2). This difference between countries is driven by U.S. journals that are much more likely to list addresses than other journals. If the probability of reporting addresses in journals (or relative propensities to publish in certain journals, or the composition of journals, or the number of authors in certain countries) changed differentially across countries, the country assignment that combines the scientist data with the address information may lead to biased estimation results. We therefore estimate our main results on the set of papers and references that only relies on the scientist data to assign countries. We also show that our results are robust to using the alternative country assignment.

Our data indicate that authors from countries with large scientific communities usually publish in journals from their own country. U.S. scientists predominantly publish in U.S. journals, U.K. scientists in U.K. journals, French scientists in French journals, and German scientists in German journals (Table 4.a, columns 3 to 8). As smaller scientific countries have few prestigious journals, scientists from these countries often publish their best papers in foreign journals.

We also present summary statistics for the set of papers and references that we use in our analysis. Of the 260,375 original papers, 246,469 report the name of the author, while the remain-

[10]In most cases, the assignment that combines the scientist data with the address information assigns countries to more papers. The assignment that only uses the scientist data only assigns more papers if the scientist data report multiple potential countries for a last name - first name combination (within a scientific field). In those cases, we assign the paper to only one country if we combine the address information with the scientist data (because the address information takes precedence over the scientist data) but to multiple countries if we use the scientist data. This only affects a small number of papers, because multiple potential countries for a certain last name - first name combination are very rare.

ing papers do not report author names (Table 5, Panel A). We are able to assign a country to at least one author for 139,482 papers if we combine the scientist data and the address information, or for 71,368 papers if we use only the scientist data. Of the papers for which we can assign a country to at least one author, we are able to assign the country to at least one reference for 68,969 (scientist and address data) or 22,576 (scientist data) papers. To measure actual knowledge flows, we remove papers for which we assign only self-cites. This leaves us with 66,741 (scientist and address data) or 21,940 (scientist data) papers. As we explain in more detail below, our final analysis uses papers that cite references that were published in one of the 151 journals for which we collect all 260,375 papers published between 1905 and 1930. With this sample restriction, we are left with 56,147 (scientist and address data) or 16,749 (scientist data) papers. Panel B of Table 5 summarizes the references (published after 1900) that are cited in these papers.

3 Measuring Knowledge Flows and Empirical Strategy

3.1 Measuring Knowledge Flows

We measure international knowledge flows as paper-level probabilities of citing work produced by different scientific camps. The production of papers builds on ideas and knowledge encapsulated in existing work. References to papers from different camps therefore measure how much a new paper relies on existing knowledge produced by domestic or foreign authors.

We propose two measures of knowledge flows that are based on citations to work from each camp, but use different normalizations. For simplicity, we limit our exposition to Allied and Central papers. The empirical results include Allied, Central, Neutral, and Rest papers.

The first measure of knowledge flows measures the probability that the focal paper cites work from a certain camp. For Central papers it is defined as:

$$\textbf{Citation Levels (CL)}: \quad \begin{array}{l} \Pr\left[\text{paper } ce, \text{ rand. sel. A paper}\right] = c_{ce\rightarrow A} \times \dfrac{1}{N_A} \\ \Pr\left[\text{paper } ce, \text{ rand. sel. CE paper}\right] = c_{ce\rightarrow CE} \times \dfrac{1}{N_{CE}} \end{array},$$

where $c_{ce\rightarrow A}$ measures the number citations to Allied work in Central paper *ce*. We normalize this measure with the number of potentially citeable articles from the Allied camp N_A. The normalization ensures that differential changes in the number of potentially citeable articles produced by each scientific camp do not bias our estimates of knowledge flows. The Citation Levels measure would be 1 if the central paper cited all potentially citeable articles from the Allied camp and 0 if it did not cite any Allied work. Similarly, $c_{ce\rightarrow CE}$ measures the number of citations to Central work in Central paper *ce*, and N_{CE} measures the number of potentially citeable Central articles.

We also calculate equivalent measures for Allied papers.

Our second measure of knowledge flows measures the probability that a *citation* from the focal paper cites work from a certain camp. For Central papers it is defined as:

$$\textbf{Citation Shares (CS)}: \begin{array}{l} \Pr\left[ce \text{ citation, rand. sel. A paper}\right] = c_{ce\to A} \times \dfrac{1}{C_{ce}} \times \dfrac{1}{N_A} \\ \Pr\left[ce \text{ citation, rand. sel. CE paper}\right] = c_{ce\to CE} \times \dfrac{1}{C_{ce}} \times \dfrac{1}{N_{CE}} \end{array} .$$

The citation shares measure adds a further normalization by the total number of citations (C_{ce}) of focal paper ce. This normalization ensures that changes in the total number of cites, do not bias our measure of knowledge flows. Changes in the total number of cites that do not reflect differences in knowledge flows occur because citation conventions changed over time. Albert Einstein's famous 1905 paper on electrodynamics, for example, explicitly mentions the contributions of James C. Maxwell seven times. Einstein, however, does not "cite" (i.e., includes them in his list of references) any of Maxwell's works (Einstein, 1905).

In our empirical analysis we study relative changes in citation levels and citation shares across scientific camps over time. Table 6 reports averages of the two measures for each combination of cit*ing*-cit*ed* scientific camp. Panels A1 and B1 show averages over the entire period of our data. The values in Table 6 are close to 0 because they represent probabilities of rare events. As there are thousands of potentially citeable articles published in medicine, biology, chemistry, physics, and mathematics, the probability of citing any one specific article is indeed "small." Table 6 also highlights strong cross-camp citation penalties (or equivalently strong home-bias): authors from each scientific camp are much more likely to cite work from their own camp than from other camps. Panels A2 and A3 report how average citation levels change between the pre-war period and the early boycott period. Allied, authors, for example, increase the probability of citing Allied work and also reduce the probability of citing Central work.

3.2 Empirical Strategy

We investigate changes in knowledge flows during WWI and the boycott by analyzing citations to papers from home and enemy camps. Specifically, we analyze how much Central papers cite the work of Central and Allied authors and how relative citations between these camps change over time. Similarly, we analyze changes in relative citations in Allied papers.

We illustrate our empirical methodology with a simplified two-camp, two-period example. In our example we focus on two focal papers from Central authors, one published before WWI (paper ce published in year t) and one published during the boycott (paper ce' published in year t'). In our example, the focal paper only cites work from Central and Allied authors. For Central papers the relative change in citation levels between t and t' is:

$$DiD_{CL} = \left(\frac{c_{ce'\to CE}}{N_{CE,t'}} - \frac{c_{ce'\to A}}{N_{A,t'}}\right) - \left(\frac{c_{ce\to CE}}{N_{CE,t}} - \frac{c_{ce\to A}}{N_{A,t}}\right). \tag{1}$$

A *positive* value of DiD_{CL} represents a *relative increase* in the use of Central knowledge, from period t to period t'. We construct the analogous DiD measure for citation shares. The following numerical example shows a situation in which both measures (citation levels and citation shares) indicate an increase in the use of Central knowledge by Central authors. To simplify the exposition, we assume that $N_{A,\tau} = N_{CE,\tau} = N$ for both time periods t and t', and thus ignore the normalization by the number of potentially citeable articles, N.

Example 1: Changes in Citation Levels and Citation Shares

	Citation Levels (CL)		*Citation Shares (CS)*	
	pre-WWI paper ce	boycott paper ce'	pre-WWI paper ce	boycott paper ce'
Cites to Centrals	$c_{ce\to CE} = 2$	$c_{ce'\to CE} = 3$	$\frac{c_{ce\to CE}}{C_{ce}} = \mathbf{0.5}$	$\frac{c_{ce'\to CE}}{C_{ce'}} = \mathbf{0.75}$
Cites to Allied	$c_{ce\to A} = 2$	$c_{ce'\to A} = 1$	$\frac{c_{ce\to A}}{C_{ce}} = 0.5$	$\frac{c_{ce'\to A}}{C_{ce'}} = \mathbf{0.25}$
Diff. paper ce'	$3 - 1 = \mathbf{2}$		$0.75 - 0.25 = \mathbf{0.5}$	
Diff. paper ce	$2 - 2 = \mathbf{0}$		$0.5 - 0.5 = 0$	
$N \times DiD$	$DiD_{CL} = (2 - 0) = \mathbf{2}$		$DiD_{CS} = (0.5 - 0) = \mathbf{0.5}$	

In this example, the total number of citations remains fixed but Central authors shift their citations from Allied to Central work. In this and similar cases, both measures indicate that Central authors increase their use of Central knowledge between t and t'. If the total number of citations (C_{ce}) changes over time, DiD_{CL} will not simply be a rescaled version of DiD_{CS}.[11]

In the following examples, we show situations in which the total number of citations changes over time. As a result, the two measures differ qualitatively. In Example 2, citation levels change but citation shares do not.

[11]More precisely, the relationship between DiD_{CL} and DiD_{CS} can be expressed as:

$$\begin{aligned} DiD_{CL} &= C_{ce'}\left(\frac{c_{ce'\to CE}}{C_{ce'}N_{CE,t'}} - \frac{c_{ce'\to A}}{C_{ce'}N_{A,t'}}\right) - C_{ce}\left(\frac{c_{ce\to CE}}{C_{ce}N_{CE,t}} - \frac{c_{ce\to A}}{C_{ce}N_{A,t}}\right) \\ &= C_{ce'}DiD_{CS} + (C_{ce'} - C_{ce})\left(\frac{c_{ce\to CE}}{C_{ce}N_{CE,t}} - \frac{c_{ce\to A}}{C_{ce}N_{A,t}}\right) \end{aligned}.$$

Thus if the total number of citations does not change over time (i.e., $C_{ce} = C_{ce'}$), the relative change in citation levels will simply be a rescaling of the relative change in citation shares. If $C_{ce} \neq C_{ce'}$, DiD_{CL} and DiD_{CS} may qualitatively disagree.

Example 2: Citation Levels change but Shares do not

	Citation Levels (CL)		*Citation Shares (CS)*	
	pre-WWI paper *ce*	WWI/boycott paper *ce′*	pre-WWI paper *ce*	WWI/boycott paper *ce′*
Cites to Centrals	$c_{ce\to CE} = \mathbf{3}$	$c_{ce'\to CE} = \mathbf{6}$	$\frac{c_{ce\to CE}}{C_{ce}} = \mathbf{0.75}$	$\frac{c_{ce'\to CE}}{C_{ce'}} = \mathbf{0.75}$
Cites to Allied	$c_{ce\to A} = \mathbf{1}$	$c_{ce'\to A} = \mathbf{2}$	$\frac{c_{ce\to A}}{C_{ce}} = \mathbf{0.25}$	$\frac{c_{ce'\to A}}{C_{ce'}} = \mathbf{0.25}$
Diff. paper *ce′*	$6 - 2 = \mathbf{4}$		$0.75 - 0.25 = \mathbf{0.50}$	
Diff. paper *ce*	$3 - 1 = \mathbf{2}$		$0.75 - 0.25 = \mathbf{0.50}$	
$N \times DiD$	$4 - 2 = \mathbf{2}$		$0.50 - 0.50 = \mathbf{0}$	

In this example, Central authors increase the number of citations to each scientific camp by the same proportion. As a result, the total number of citations also increases by the same proportion. The citation levels measure DiD_{CL} indicates that Central authors increasingly rely on Central knowledge, while the citation shares measure DiD_{CS} indicates that Central authors continue to rely on Central and Allied knowledge in the same proportions. The example highlights that the citation levels measure is sensitive to proportional changes in the number of citations, while the citation shares measure is not.[12]

The third example, shows a situation where citation shares change but citation levels do not.

Example 3: Citation Shares change but Levels do not

	Citation Levels (CL)		*Citation Shares (CS)*	
	pre-WWI paper *ce*	WWI/boycott paper *ce′*	pre-WWI paper *ce*	WWI/boycott paper *ce′*
Cites to Centrals	$c_{ce\to CE} = 4$	$c_{ce'\to CE} = \mathbf{5}$	$\frac{c_{ce\to CE}}{C_{ce}} = \mathbf{0.80}$	$\frac{c_{ce'\to CE}}{C_{ce'}} = \mathbf{0.71}$
Cites to Allied	$c_{ce\to A} = \mathbf{1}$	$c_{ce'\to A} = \mathbf{2}$	$\frac{c_{ce\to A}}{C_{ce}} = \mathbf{0.20}$	$\frac{c_{ce'\to A}}{C_{ce'}} = \mathbf{0.29}$
Diff. paper *ce′*	$5 - 2 = \mathbf{3}$		$0.71 - 0.29 = \mathbf{0.42}$	
Diff. paper *ce*	$4 - 1 = \mathbf{3}$		$0.80 - 0.20 = \mathbf{0.60}$	
$N \times DiD$	$3 - 3 = \mathbf{0}$		$0.42 - 0.60 = \mathbf{-0.18}$	

In this example, Central authors increase the number of citations to each scientific camp by one and the total number of citations by two. The example underlines that the citation shares measure is sensitive to additive transformations in the number of citations, while the citation levels measure is not. As examples 2 and 3 indicate, the two measures could lead to different conclusions regarding relative knowledge flows. In our data, however, the two measures lead to similar conclusions, indicating that our results are not sensitive to using a particular measure of knowledge flows.

[12]In other words, DiD_{CS} is homogeneous of degree 0 (or scale invariant) to the number of citations, while DiD_{CL} is not.

Our empirical strategy builds on the examples discussed so far, but generalizes the analysis to four scientific camps (i.e., Allies, Centrals, Neutrals, and Rest) and to a time period of 26 years, from 1905 to 1930. Specifically, we construct four observations for each paper i published in year $t(i)$: citation levels to Allied work ($y_{i,A} \equiv c_{i \to A}/N_A$), citation levels to Central work ($y_{i,CE} \equiv c_{i \to CE}/N_{CE}$), citation levels to Neutral work ($y_{i,NE} \equiv c_{i \to NE}/N_{NE}$), and citation levels to Rest work ($y_{i,R} \equiv c_{i \to R}/N_R$). Similarly, we construct four citation shares observations for each paper: $y_{i,camp} \equiv c_{i \to camp}/\left(N_{camp} C_i\right)$, $camp$ = Allied, Centrals, Neutrals, and Rest. For each of the two measures of knowledge flows, we estimate two main regressions: one for relative citations of Allied papers and one for relative citations of Central papers. We then estimate the following regression for Central papers:

$$
\begin{aligned}
y_{i,camp} &= \sum_{\tau=1905}^{1930} \alpha_\tau \times 1\left[camp = \text{Allied}\right] \times 1\left[t(i) = \tau\right] \\
&+ \sum_{\tau=1905}^{1930} \nu_\tau \times 1\left[camp = \text{Neutral}\right] \times 1\left[t(i) = \tau\right] \\
&+ \sum_{\tau=1905}^{1930} \rho_\tau \times 1\left[camp = \text{Rest}\right] \times 1\left[t(i) = \tau\right] \\
&+ \text{Paper}FE_i + \epsilon_{i,camp}
\end{aligned}
, \qquad (2)
$$

where $y_{i,camp}$ are citation shares (or levels) to each camp in paper i, $1[\cdot]$ is the indicator function, and PaperFE_i is a paper-specific fixed effect. Parameter α_τ represents the average difference in citations to Allied work, compared to Central work (the omitted category) in year $t(i) = \tau$. Similarly, ν_τ and ρ_τ represent average differences in citations to Neutral and Rest work in year $t(i) = \tau$. Our main results plot the evolution of α_τ over time. We also estimate the equivalent regression for citations in Allied papers. In the estimation of the standard errors, we cluster at the level the journal-field and country.

The paper-specific fixed effects control for a number of potential confounders that may bias our parameter estimates. First, they control for differences in citation conventions; such as chemists citing more pre-existing work than mathematicians. Second, they control for differential changes in the number of citations over time across fields. These changes may occur because some fields, such as quantum mechanics, move faster than other fields, such as technical physics. Third, they also control for author-specific changes in citation behavior over time, such as authors getting older and accordingly changing their citation patterns; for example, citing less novel work.

For the main results, we compute $y_{i,camp}$ over a time interval of 5 years: from $t(i)-4$, the fourth year before the publication year of paper i, until $t(i)$, the publication year of paper i. For example, in the citation shares regressions, where $y_{i,camp} \equiv c_{i \to camp}/\left(C_i N_{camp}\right)$, we compute $c_{i \to camp}$ as the number of citations in paper i to any work by authors from a certain *camp* published in the 5-year period $t(i)-4$ to $t(i)$. Similarly, C_i is computed as the total number of citations to work published in the 5-year period $t(i)-4$ to $t(i)$, and N_{camp} is the total number of potentially citeable articles published by authors from a certain *camp* in the five-year period $t(i)-4$ to $t(i)$.

The estimates of equation (2) show how citation patterns towards different camps change over time. To test whether the changes in citation patterns during WWI and the boycott are significantly different from the pre- and post-periods, we estimate a "testing regression" that is a variant of regression (2). As an example, the testing regression for Central papers is:

$$\begin{aligned} y_{i,camp} &= \alpha_1 \times 1\,[camp = \text{Allied}] + \alpha_2 \times 1\,[camp = \text{Allied}] \times 1\,[t(i) = \text{WWI}] \\ &+ \alpha_3 \times 1\,[camp = \text{Allied}] \times 1\,[t(i) = \text{Early BCT}] + \alpha_4 \times 1\,[camp = \text{Allied}] \times 1\,[t(i) = \text{Late BCT}] \quad . \quad (3) \\ &+ \text{Neutral Interactions} + \text{Rest Interactions} + \text{Paper}FE_i + \epsilon_{i,camp} \end{aligned}$$

Instead of yearly effects, regression (3) includes indicators for each camp that are interacted with indicators for WWI, early boycott (Early BCT), and late boycott (Late BCT).[13] The parameter α_1 measures persistent citation penalties of Central authors against Allied work over the whole 26-year period. Parameter α_2 measures whether WWI—on top of any persistent citation penalty—caused additional changes in relative citations. Analogously, α_3 and α_4 measure whether the boycott caused additional citation penalties against Allied work.[14] We then test whether α_2, α_3, and α_4 are significantly different from 0.

4 The Effect of WWI and the Boycott on International Knowledge Flows

4.1 Citation Patterns in Central and Allied Papers

We analyze the effect of WWI and the boycott on international knowledge flows by estimating variants of equation (2) using citation shares as dependent variable. All results reported below are based on regressions that estimate relative citation probabilities compared to the home camp (the omitted category in the underlying regressions).

[13] Thus regression equation (3) is a restricted version of regression equation (2).

[14] As these regressions estimate results relative to the home camp, the omitted category. The regressions do not allow a distinction between "home-bias" and "citation penalties". The summary statistics reported in Table 6 suggest that the changes during WWI and the boycott were primarily due to an increased "home bias" but also due to increased "citation penalties." To streamline the writing, and for an easier comparison to pre-war levels, we discuss results as increased citation penalties.

Citations in Central Papers

Figure 2 reports regression coefficients from estimating equation (2) for Central papers (see Appendix Table A.2 for the underlying regression results). The dependent variable counts normalized citations by Central papers (published in year t) towards Allied, Central, Neutral, and Rest work that has been published between years $t-4$ and t. As the Allied line lies below 0 for all years, Central papers cite significantly less Allied work, relative to Central work, during the whole time period. This indicates substantial citation penalties against Allied work. During WWI, citation penalties against Allied work start to increase and become particularly pronounced during the early boycott years. By 1922, citation penalties against Allied work start to decline and recover to pre-war levels by the end of the boycott in 1926.

We test whether the increase in citation penalties during WWI and the boycott are statistically significant by estimating equation (3). The coefficient on Allied papers (-0.00088) indicates that Central papers cite significantly less Allied work compared to Central work, independently of the time period (Table 7, column 1, significant at 1%). During the war, the citation penalty against Allied work does not significantly change.[15] In the early boycott years, the citation penalty increases by 0.000124, an increase of 141 percent compared to the pre-WWI period (Table 7, column 1, significant at 1%).[16] In the late boycott years, the citation penalty towards Allied work is still higher by 0.000041; an increase of 47 percent (Table 7, column 1, significant at 1%). Allowing the post-boycott coefficients to differ from the pre-war coefficients does not substantially change results (Table 7, column 2). Controlling for camp-specific linear trends does not substantially change point estimates but affects the significance of the late boycott coefficient in the specification that allows the post-boycott estimates to differ from pre-boycott levels (Table 7, columns 3 and 4).

Citations in Allied Papers

The next set of results investigates changes of citation shares in Allied papers. As the Central line lies below 0 for all years, Allied papers cite significantly less Central work, relative to Allied work (Figure 3 and Appendix Table A.3). This indicates substantial citation penalties against Central work, that are about half as large as citation penalties in Central papers against Allied work. During the war, citation penalties in Allied papers against Central work increase and become particularly pronounced during the early boycott years. By 1923, citation penalties against Central work start to decline and almost recover to pre-war levels by 1924 (Figure 3).

[15] Figure 2 indicates that the trend in citation shares starts to reverse as early as 1915. This trend break is not reflected in the regression results reported in Table 7 because the regression tests whether the pre-war average is different from the WWI average.

[16] The pre-WWI citation penalty against Allied papers is 0.000088 (see first coefficient of column 2 in Table 7. A coefficient of -0.000124 on the interaction of Allied $\times$ Early Boycott is thus an increase of $(0.000124/0.000088) \cdot 100 = 141\%$.

We test whether the increase in citation penalties during WWI and the boycott are significantly different by estimating the equivalent of equation (3), using Allied papers and the Allied camp as the omitted category. The coefficient on Central work (-0.000054) indicates that Allied papers cite significantly less Central work compared to Allied work, independently of the time period (Table 8, column 1, significant at 1%). During the war, the citation penalty against Central work increases by 0.000016, an increase of 30 percent compared to the pre-WWI period (Table 8, column 1, significant at 1%). In the early boycott years, the citation penalty increases by 0.000042, an increase of 78 percent compared to the pre-WWI period (Table 8, column 1, significant at 1%). In the late boycott years, the citation penalty against Central work is still higher than before the war by 0.000027, an increase of 50 percent (Table 8, column 1, significant at 1%). Allowing the post-boycott coefficients to differ from the pre-war coefficients, slightly magnifies the increase in citation penalties during WWI and the boycott. Controlling for camp-specific time trends leaves results almost unchanged (Table 8, columns 3 and 4).

Overall, the results indicate that WWI and the boycott significantly reduced knowledge flows to enemy camps. It is important to note that the results are unlikely to be driven by changes in the quality of WWI or boycott papers, because such changes should affect citations from all camps in the same direction. If Central work, for example, became relatively better, maybe as a result of a localized scientific breakthrough, it should attract relatively more citations from both Central and Allied papers. We do not find such patterns. Both Central and Allied papers cite relatively more within-camp papers during WWI and the boycott.

4.2 Sensitivity to Using Different Measures of Knowledge Flows and Different Country Assignments

Alternative Measure of Knowledge Flows

In additional results, we show that the increased citation penalties against enemy work are also reflected in the citation levels measure of knowledge flows. For these tests we re-estimate equations (2) and (3) using citation levels as dependent variable.

Figure 4 shows that citation penalties of Central authors against Allied work, as measured by citation levels, also increase during WWI, and particularly during the early boycott years. Relative to the pre- and post-periods, they citation penalties against Allied work increases by 93 percent during the early boycott years and by 45 percent during the late boycott years (Table 9, column 1, significant at the 1 percent level). Allowing the post-boycott coefficients to differ from the pre-war coefficients, or controlling for camp-level linear trends, does not substantially change results (Table 9, columns 2 to 4).

Figure 5 shows that citation penalties of Allied authors against Central work, as measured by citation levels, also increase during the war and the boycott. Relative to the pre- and post-periods, citation penalties against Central work increase by 40 percent during WWI, by 122 percent during the early boycott years, and by 40 percent during the late boycott years (Table 10, column 1, significant at the 1 percent level). Allowing the post-boycott coefficients to differ from the pre-war coefficients, or controlling for camp-level linear trends, does not substantially change results (Table 10, columns 2 to 4).

Using Alternative Country Assignment

The following tests indicate that our results are not driven by the method of assigning countries to authors. For the main results, we assign countries to authors and references using the scientist data, only. This country assignment minimizes potential biases that may be caused by differentially changing propensities to report addresses in papers. As an alternative, we can combine the information from the scientist data and the addresses reported in papers to assign countries, resulting in larger samples. As before, we can use citation shares or citation levels to measure knowledge flows.

The alternative way of assigning countries does not substantially change results for Central authors when we use citation shares to measure knowledge flows (Figure A.2). Relative to the pre- and post-periods, citation penalties against Allied work increase by 20 percent during WWI, by 128 percent during the early boycott years, and by 39 percent during the late boycott years (Table 9, column 5, significant at the 5, 1, and 1 percent level).

For Allied papers, the results also remain similar (Figure A.3).[17] Relative to the pre- and post-periods, citation penalties against Central work increase by 57 percent during WWI, by 128 percent during the early boycott years, and by 39 percent during the late boycott years (Table 10, column 5, significant at the 1 percent level).

Results that use the alternative country assignment are also similar when we use citation levels to measure knowledge flows (Tables 9 and 10, columns 9 to 12).

[17] In both the pre-WWI period and the post-boycott period citation penalties in Allied papers against Central work decline substantially. This decline in citation penalties is driven by a large increase in the number of papers published by an increasing number of U.S. scientists, that can be observed in the addresses of the papers but not in the scientist data, because the scientist data only consider scientists who hold a university position by 1914. As U.S. scientists are not able to keep up to date with every paper that gets published in the United States, the probability of citing any particular U.S. paper falls, relative to citing any particular Central paper. The large increase in the number of U.S. papers has a smaller effect on relative citation patterns in Central papers, because citations from foreign camps focus on a smaller number of influential papers.

4.3 Citation Patterns in Neutral Papers

We also analyze changes of citation patterns in Neutral papers. As we observe fewer Neutral papers than Central or Allied papers, results are less precisely estimated. During most pre-WWI years, Neutral papers cite as much Central work but less Allied work, than Neutral work. During the war and the boycott, citation penalties against Central work increase substantially (Figure 6 and Table 11, significant at 5 percent for the WWI period but not statistically significantly different from 0 during the boycott years). Citation penalties against Allied work also increase substantially during those years (Figure 6 and Table 11, significant at 1 percent for the WWI period, at the 5 percent level for the early boycott period, and at the 10 percent level for the late boycott years). The increase in citation penalties against Central and Allied work is similar for the two camps suggesting that Neutrals were indeed "neutral" and suffered from reduced knowledge flows from both Allied and Central countries.

These results further suggest that our previous findings are not driven by differential changes in the quality of papers, as these should have been reflected in Neutral citations.

5 Knowledge Flows or Discrimination?

The previous results show that relative citations of enemy work decreased during WWI and the boycott. This decrease may either be driven by a genuine disruption of knowledge flows or by "discrimination" against enemy work. Authors may still have known the relevant enemy work, but may have avoided citing it in order to punish scientists from enemy countries. As we cannot measure whether scientists knew certain papers, we test for discrimination against enemy work by investigating citation patterns towards pre-war work, published before the interruption of knowledge flows. If discrimination affected pre-war and WWI/boycott work to the same extent, we should find similar reductions in citations to pre-1914 work by enemy authors.

We investigate how citations to pre-war work change over time by estimating the equivalent of equation (2) but with a re-defined dependent variable. The dependent variable now measures relative citations to work published between 1900 and 1913.[18] In all years, Central papers cite significantly less pre-war Allied work, compared to pre-war Central work (Figure 7). Over time, Central author rely relatively more on pre-war Allied work compared to pre-war Central work,

[18]For our main results $c_{ce \rightarrow CE}$ measures Central citations to Central work that was published in the preceding five years. For the current section, in contrast, $c_{ce \rightarrow CE}$ measures Central citations to Central work that was published between 1900 and 1913. For 1905, for example, $c_{ce \rightarrow CE}$ counts the number of citations in Central papers quoting Central work published between 1900 and 1905. For 1906, $c_{ce \rightarrow CE}$ counts citations in Central papers quoting Central work published between 1900 and 1906, and similarly for all years until 1913. For all post-1913 years, $c_{ce \rightarrow CE}$ counts citations in Central papers quoting Central work published between 1900 and 1913. Citation measures towards other camps are defined accordingly.

and citation penalties against pre-war Allied work almost disappear. More importantly, we see no obvious dip in relative citations to pre-war Allied work during WWI and the boycott. Similarly, in all years Allied papers cite significantly less pre-war Central work than pre-war Allied work (Figure 8). There is not obvious dip in relative citations towards Central work during WWI and the boycott.

Overall, these findings suggest that discrimination against enemy papers does not drive the citation patterns in our main results.

6 Did Knowledge Eventually Reach the Enemy Camp?

In this section, we explore whether enemy knowledge produced during WWI and the boycott eventually reached the foreign camp. We investigate these long-run effects by analyzing long-term citation patterns to enemy work published in different periods of time (i.e., paper cohorts). Specifically, we plot long-run relative citations to the following paper cohorts: two pre-war cohorts (1905-1907 and 1908-1910), one WWI cohort (1916-1918), one early boycott cohort (1919-1921), and one post-boycott cohort (1926-1928). These cohorts are examples for each of the time periods covered by our data, adjacent cohorts exhibit similar patterns.

For each of the five cohorts, we estimate a variant of equation (2) with a dependent variable that measures citations to work published during the three years of the respective paper cohort.[19] To improve the clarity of the figures, we now estimate two-yearly (instead of yearly) coefficients of relative citations from the time the cited work was published until 1932.[20]

Central papers initially cite relatively less Allied work, compared to Central work, independently of the time period (Figure 9). In the pre-period, relative citation penalties against Allied work diminish a few years after the publication of the cited work and remain small thereafter. During WWI, the initial citation penalty is larger than during the pre-period, indicating that Central authors learn about Allied work with an increased delay. The relative citation penalty against WWI-Allied work diminishes after the first years, but relative citations to Allied work remain lower until the late 1920s. By the early 1930s, however, the relative citation penalty against Allied work, that had been published during WWI, has disappeared. The early-boycott cohort starts with even larger citation penalties that diminish after the first years, but do not recover until the

[19] As an example, consider the 1905-1907 cohort. In 1905, $c_{ce \to CE}$ counts the number of citations in Central papers (published in 1905) quoting Central work that was published in 1905. In 1906, $c_{ce \to CE}$ counts citations in Central papers (published in 1906) quoting Central work that was published between 1905 and 1906. In 1907, $c_{ce \to CE}$ counts citations in Central papers (published in 1907) quoting Central work that was published between 1905 and 1907. In 1908, $c_{ce \to CE}$ counts citations in Central papers (published in 1908) quoting Central work that was published between 1905 and 1907, and so on. Citations quoting work from other camps are defined accordingly.

[20] We end the analysis in 1932 because hundreds of German scientists, who were dismissed by the Nazi government, migrated to Allied countries starting in 1933 (Waldinger 2012, Moser, Voena, and Waldinger, 2014).

1930s. These results suggest that some early-boycott Allied work never reached Central authors. The post-boycott cohort, in contrast, shows very similar patterns to the pre-period cohorts.

In Allied papers relative citation penalties towards Central work are relatively low for pre-war work (Figure 10). During WWI, however, Allied citation patterns change substantially: initial citation penalties against Central work increase and remain high until the late 1920s. Citation penalties against Central work published during the early-boycott years are even larger and do not recover until the mid-1920s. These results suggest that WWI and the boycott affected knowledge flows from Central to Allied authors in the short- to medium-run, but possibly not in the long-run. The post-boycott cohort shows similar patterns to the pre-period cohorts.

7 Did the Interruption of Knowledge Flows Affect World Scientific Progress?

To conclude our analysis, we gather suggestive evidence of whether the interruption of knowledge flows influenced world-wide scientific progress. In particular, we investigate how WWI and the boycott affected the production of major scientific breakthroughs, as measured by Nobel Prize worthy discoveries. Jones and Weinberg (2011) report the years when physics, chemistry, and medicine/physiology Nobel Laureates produced their prize-winning discoveries.[21] While the Nobel Foundation chose not to award some science prizes in certain years, at least one prize continued to be awarded in every year throughout WWI. The statutes of the Nobel Foundation state that "[i]f none of the works under consideration is found to be of … importance … the prize money should be reserved until the following year …" (Nobel Foundation, 2014).[22] On average, Nobel Laureates received the Nobel Prize around 13 years after carrying out the Prize winning research.[23] Because prizes are usually awarded with a relatively long delay, we do not expect that fewer prizes awarded during WWI affect the timing of Prize winning research.

We plot histograms of the number of Nobel Laureates who work on their prize winning discoveries in two year bins to provide suggestive evidence of how the interruption of knowledge flows affected the production of award winning research (Figure 11, Panel A). The vertical line indicates the beginning of WWI in 1914. Because Nobel Prizes were first awarded in 1901, and because later prizes were often split between two or three scientists, the number of Nobel Lau-

[21] We thank Ben Jones and Bruce Weinberg for generously sharing their data. The data report the year of the most important work, or the midpoint if a range of years was identified, as the most important period (see Jones and Weinberg, 2011, for details).

[22] "The Nobel Foundation – Special regulations." Nobelprize.org. Nobel Media AB 2014. Accessed the 20^{th} of March 2015. <http://www.nobelprize.org/nobel_organizations/nobelfoundation/statutes-kva.html>

[23] This calculation is based on Jones and Weinberg (2011) data for Nobel Laureates who received their prize before 1960. The 25^{th} percentile received the Prize seven years after carrying out the research, while the 75^{th} percentile received it 17 years later.

reates who work on their prize winning work increases before 1914.[24] With the onset of the war begins a drought of path-breaking scientific ideas: fewer future Nobel Laureates produce their prize winning work in this period. The drought continues for three years after the end of WWI, exactly coinciding with the period where we find the largest interruptions of knowledge flows. After 1922, the number of scientists who work on their Nobel Prize worthy ideas starts to increase.

The reduction in Nobel Prize worthy ideas may have been caused by other factors, such as the general disruption during WWI. In an attempt to investigate how much the general disruption during the war may have affected world-wide scientific progress, we plot an additional histogram with an extended time period, until 1960 (Figure 11, Panel B). The vertical lines indicate the beginning and the end of WWI and WWII. Despite the fact that WWII caused much larger destruction and disruption than WWI, the drought in the production of Nobel Prize worthy ideas continued for longer after WWI than after WWII, suggesting that the interruption of knowledge flows in the wake of WWI indeed affected world-wide scientific progress.

8 Conclusion

We show that WWI and the subsequent boycott of scientists from Central countries reduced international knowledge flows, as measured by relative citations to recent foreign work. During WWI and the boycott, scientists from Central countries cite less Allied work, compared to Central work. Scientists from Allied countries cite less Central work. By the end of the boycott, international flows of recently produced knowledge were re-established. These results are robust to using different measures of international knowledge flows and different methods of assigning countries to authors and references. We also find that Neutral authors reduce citations to both Allied and Central work, indicating that Neutral countries were indeed "neutral."

By comparing the main results with citation patterns towards pre-1914 papers, we show that these changing citation patterns reflect true changes in knowledge flows and not just discrimination against the scientific output of enemy camps.

We also investigate the possibility that WWI and the boycott had further reaching, long-run effects. We show that some Allied knowledge produced during the boycott indeed never reached Central scientists, even several years after the end of the boycott. Central knowledge produced during the boycott did not reach Allied scientists for a long time, but eventually reached the Allied camp by the early 1930s.

Finally, to investigate whether the interruption of international knowledge flows affected world-wide scientific progress, we analyze data on science Nobel Laureates. We show that fewer

[24] Later prizes were more often shared because scientists became more specialized over time, which caused increases in the importance of teams for scientific production (e.g., Jones, 2009, and Wuchty, Jones, and Uzzi, 2007).

Nobel Laureates worked on their prize winning work during WWI and the early boycott years. This suggests that the interruption of international knowledge flows slowed down the production of scientific breakthroughs and highlights the importance of knowledge sharing for scientific progress.

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Figures

Figure 1.a: The World of Science in 1914

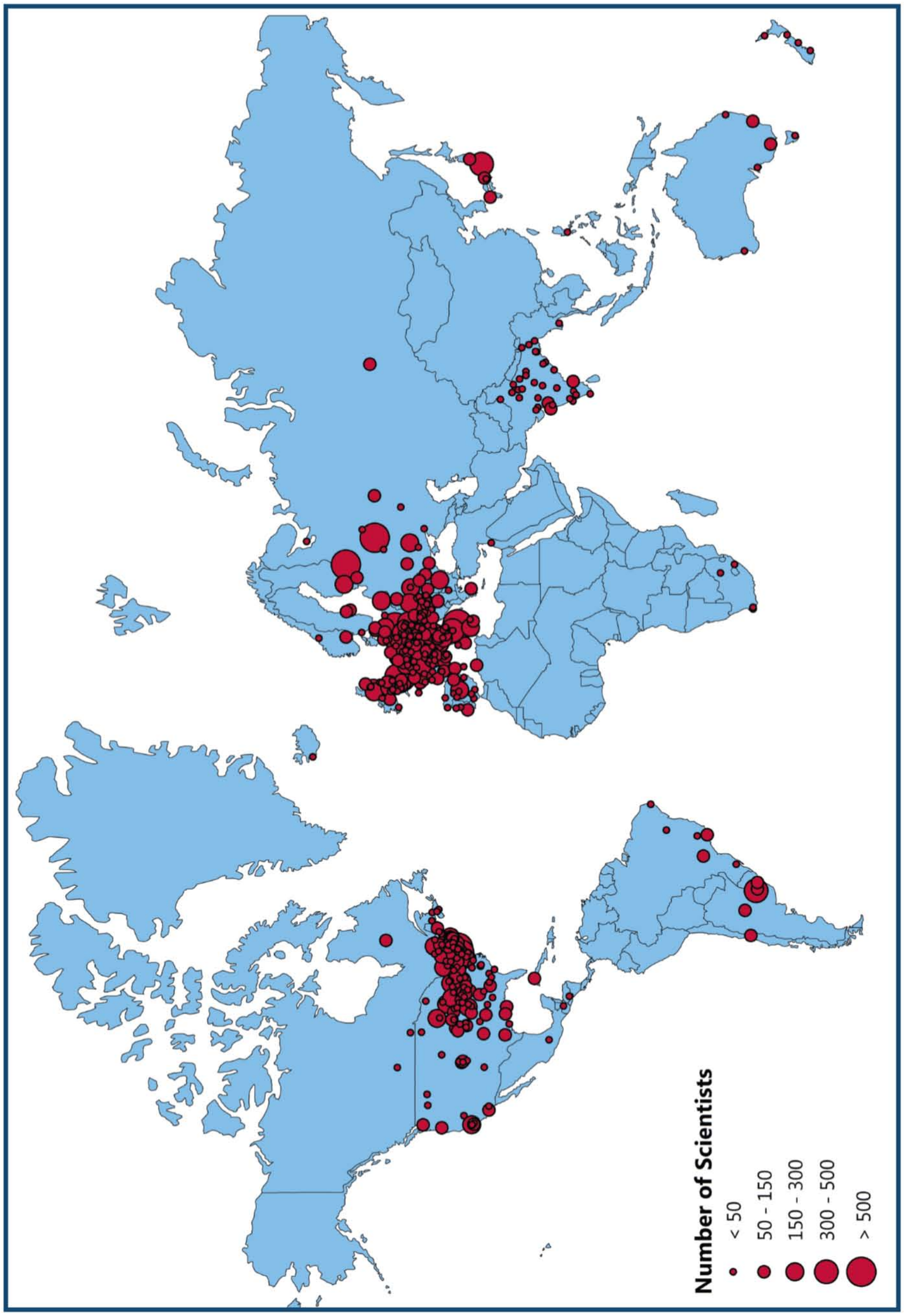
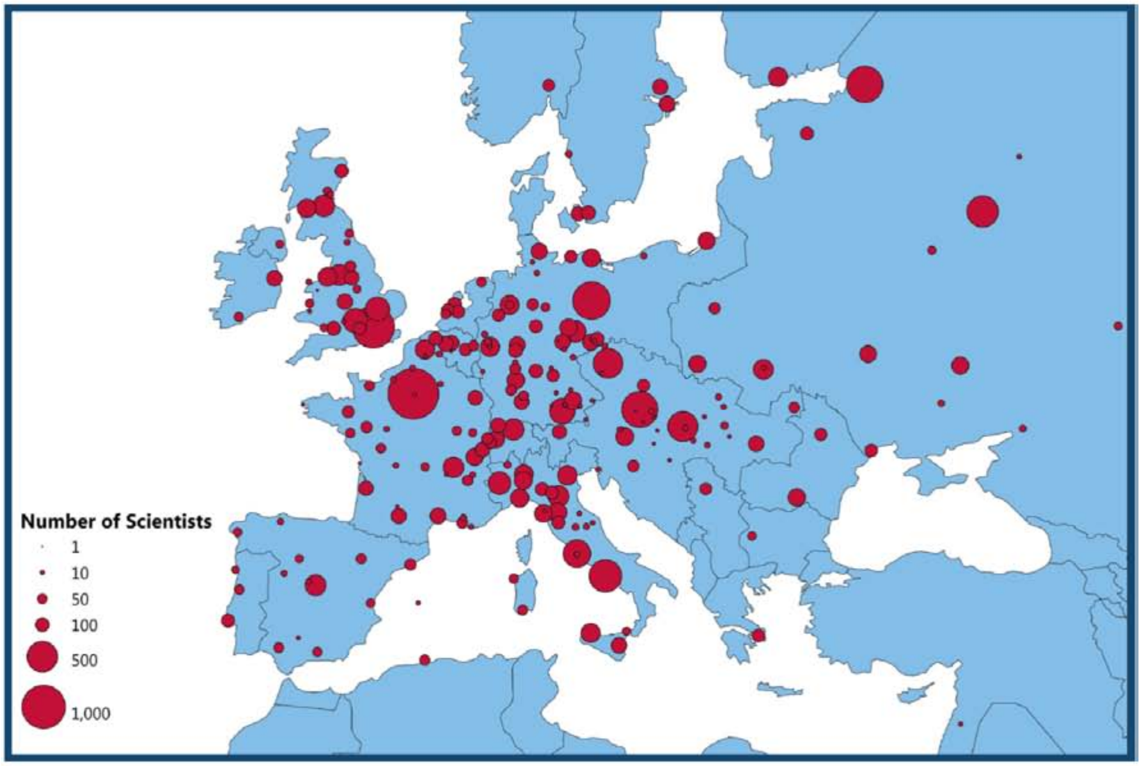
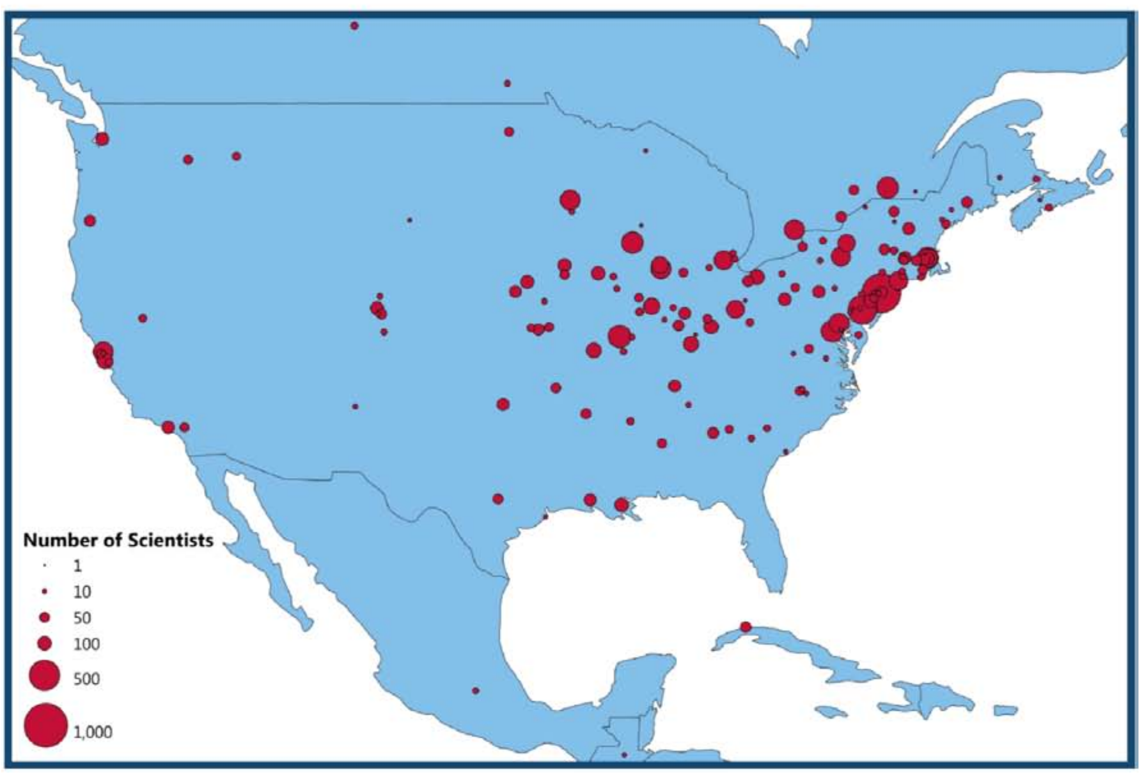


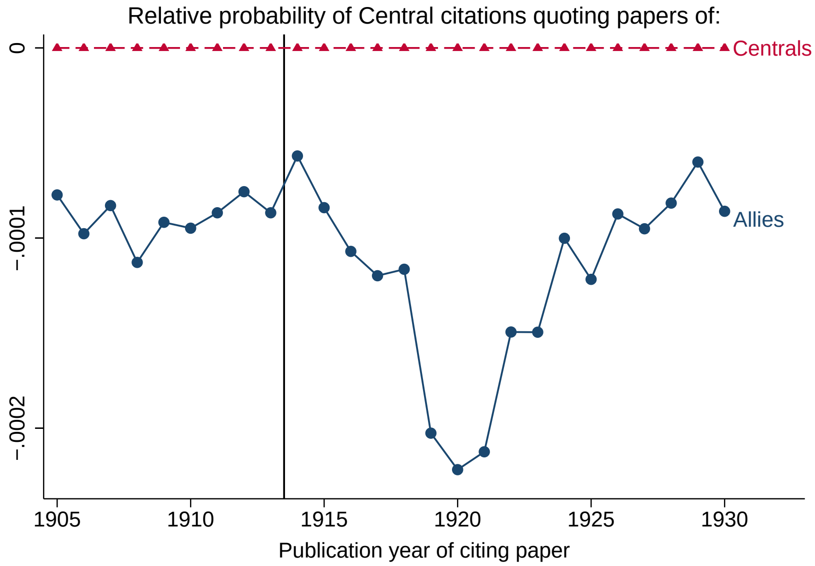
Figure 1.b: The World of Science in 1914





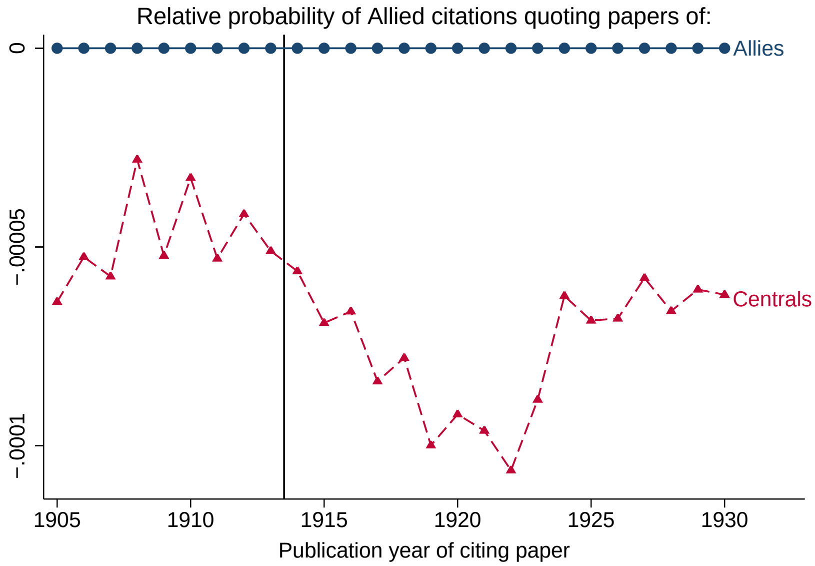
Notes: The map shows the total number of professors in all fields by city in 1914. Dot sizes are proportional to the number of professors. Data source: Minerva–Handbuch der Gelehrten Welt.

Figure 2: Central Papers: Relative Citations Measured by Citation Shares



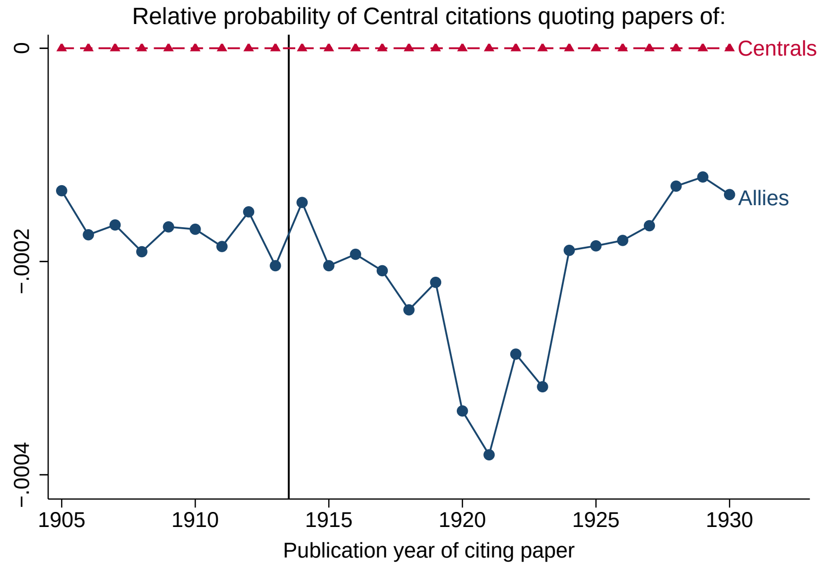
Notes: The Figure plots parameter estimates (α_τ) of regression (2) using citation shares as dependent variable. The Allied line reports point estimates (α_τ) that measure Central citations to work published in the preceding five years by Allied authors, relative to citations to work published in the same years by Central authors. For example, the first dot (1905) measures relative citations to work published by Allied authors between 1901 and 1905. The regression also controls for Central citations to work published in the preceding five years by Neutral and Rest authors. Point estimates and corresponding standard errors are reported in Appendix Table A.2. Point estimates (α_τ) are significantly different from 0 at the 1 percent level for all years between 1905 and 1930.

Figure 3: Allied Papers: Relative Citations Measured by Citation Shares



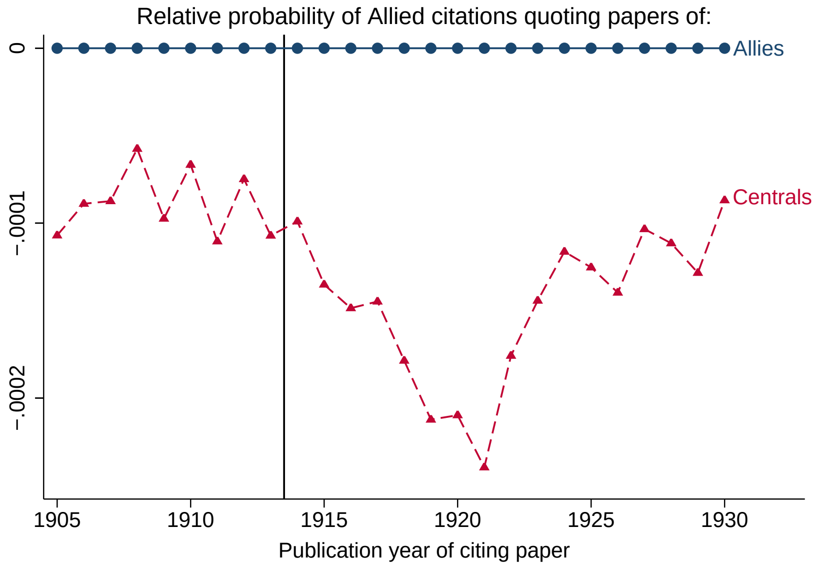
Notes: The Figure plots parameter estimates for the equivalent of regression (2) for Allied citations using citation shares as dependent variable. The Central line reports point estimates that measure Allied citations to work published in the preceding five years by Central authors, relative to citations to work published in the same years by Allied authors. For example, the first dot (1905) measures relative citations to work published by Central authors between 1901 and 1905. The regression also controls for Allied citations to work published in the preceding five years by Neutral and Rest authors. Point estimates and corresponding standard errors are reported in Appendix Table A.3. Point estimates are significantly different from 0 at the 1 percent level for all years but 1908 (significant at the 10 percent) and 1910 (significant at the 5 percent).

Figure 4: Central Papers: Relative Citations Measured by Citation Levels



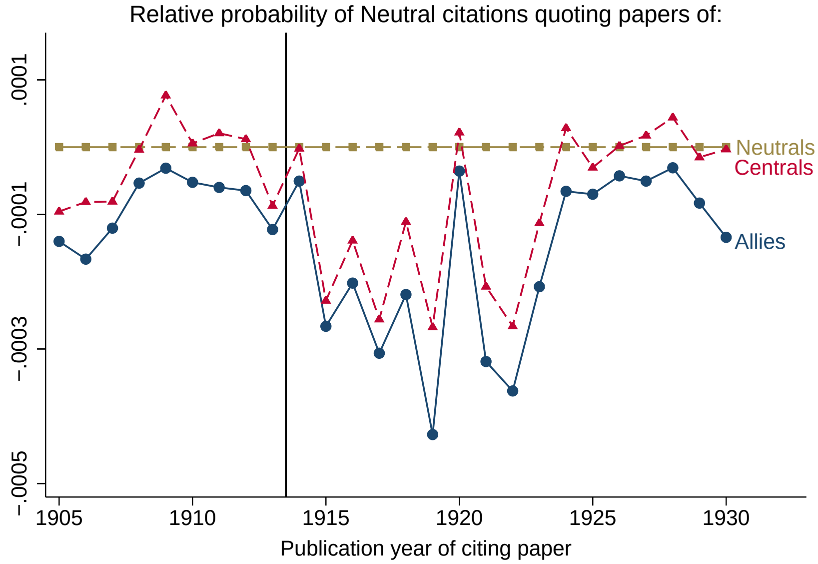
Notes: The Figure plots parameter estimates (α_τ) of regression (2) using citation levels as dependent variable. The Allied line reports point estimates (α_τ) that measure Central citations to work published in the preceding five years by Allied authors, relative to citations to work published in the same years by Central authors. For example, the first dot (1905) measures relative citations to work published by Allied authors between 1901 and 1905. The regression also controls for Central citations to work published in the preceding five years by Neutral and Rest authors. Point estimates (α_τ) are significantly different from 0 at the 1 percent level for all years between 1905 and 1930.

Figure 5: Allied Papers: Relative Citations Measured by Citation Levels



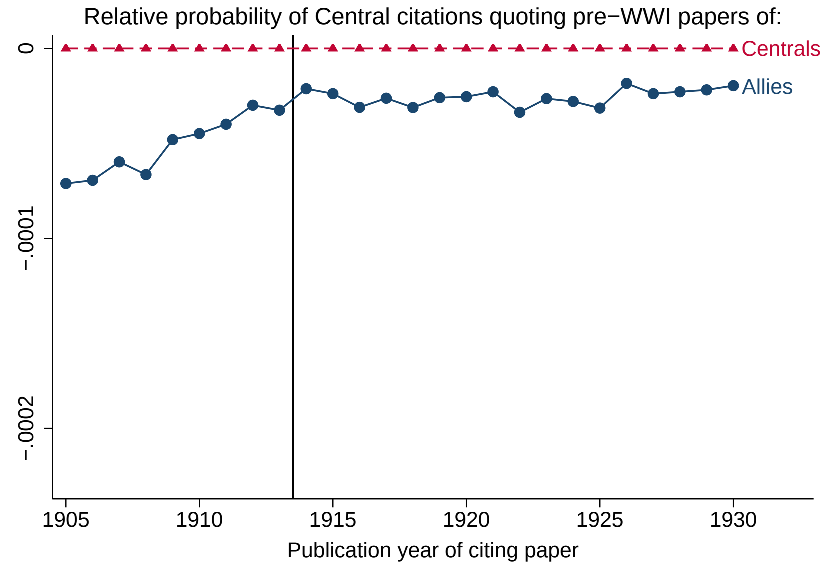
Notes: The Figure plots parameter estimates for the equivalent of regression (2) for Allied citations using citation levels as dependent variable. The Central line reports point estimates that measure Allied citations to work published in the preceding five years by Central authors, relative to citations to work published in the same years by Allied authors. For example, the first dot (1905) measures relative citations to work published by Central authors between 1901 and 1905. The regression also controls for Allied citations to work published in the preceding five years by Neutral and Rest authors. Point estimates are significantly different from 0 at the 1 percent level for all years but 1908.

Figure 6: Neutral Papers: Relative Citations Measured by Citation Shares



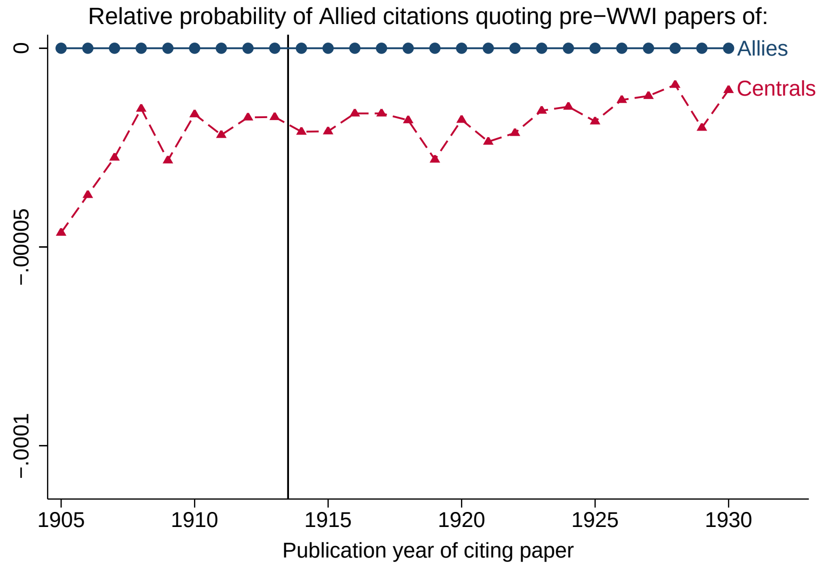
Notes: The Figure plots parameter estimates for the equivalent of regression (2) for Neutral citations using citation shares as dependent variable. The Central line reports point estimates that measure Neutral citations to work published in the preceding five years by Central authors, relative to citations to work published in the same years by Neutral authors. For example, the first dot of the Central line (1905) measures relative citations to work published by Central authors between 1901 and 1905. Similarly, the Allied line reports point estimates that measure relative Neutral citations to work published in the preceding five years by Allied authors. The regression also controls for Neutral citations to work published in the preceding five years by Rest authors.

Figure 7: Central Papers: Relative Citations of Pre–WWI Papers



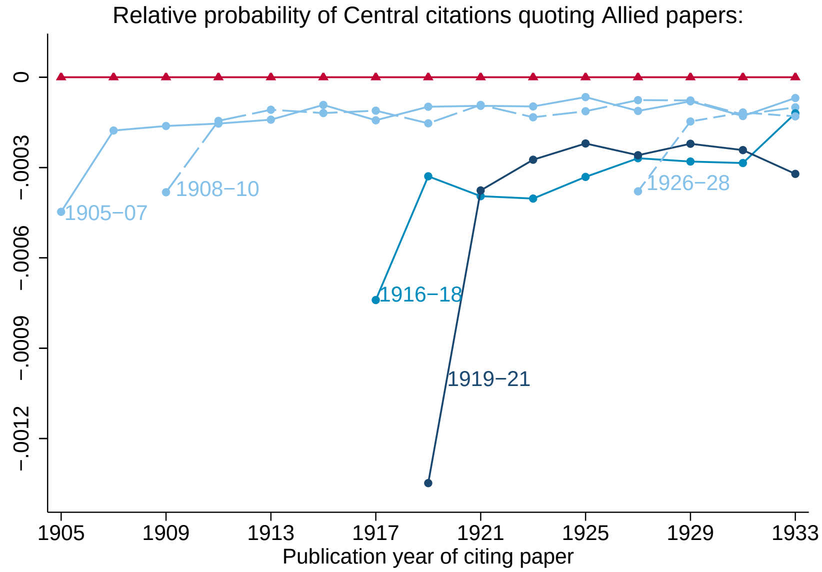
Notes: The Figure plots parameter estimates (α_τ) of regression (2) using citation shares as dependent variable. The Allied line reports point estimates (α_τ) that measure Central citations to 1900-1913 work published by Allied authors, relative to citations to 1900-1913 work published by Central authors. The regression also controls for Central citations to 1900-1913 work published by Neutral and Rest authors. To facilitate comparisons of relative magnitudes, the Figure is shown on the same scale as Figure 2.

Figure 8: Allied Papers: Relative Citations of Pre–WWI Papers



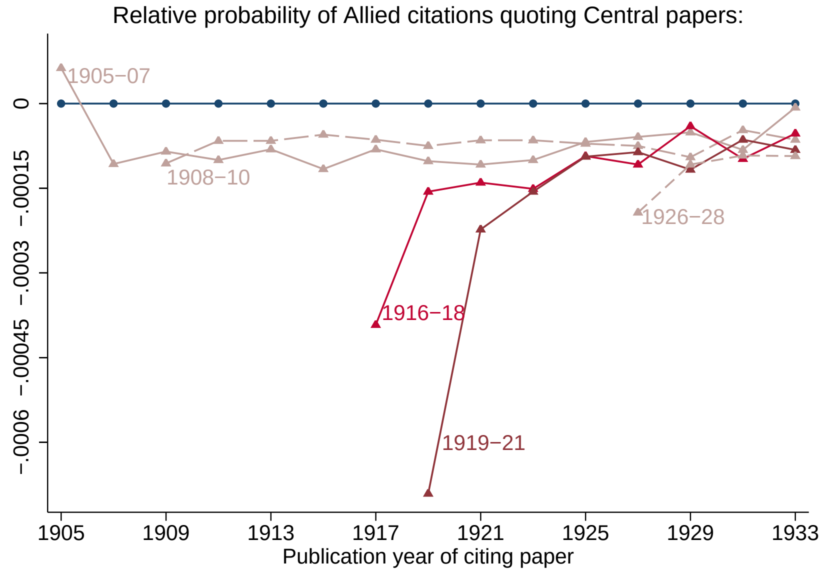
Notes: The Figure plots parameter estimates for the equivalent of regression (2) for Allied citations using citation shares as dependent variable. The Central line reports point estimates that measure Allied citations to 1900-1913 work published by Central authors, relative to citations to 1900-1913 work published by Allied authors. The regression also controls for Allied citations to 1900-1913 work published by Neutral and Rest authors. To facilitate comparisons of relative magnitudes, the Figure is shown on the same scale as Figure 3.

Figure 9:
CENTRAL PAPERS: RELATIVE CITATIONS OF ALLIED WORK PUBLISHED IN DIFFERENT COHORTS



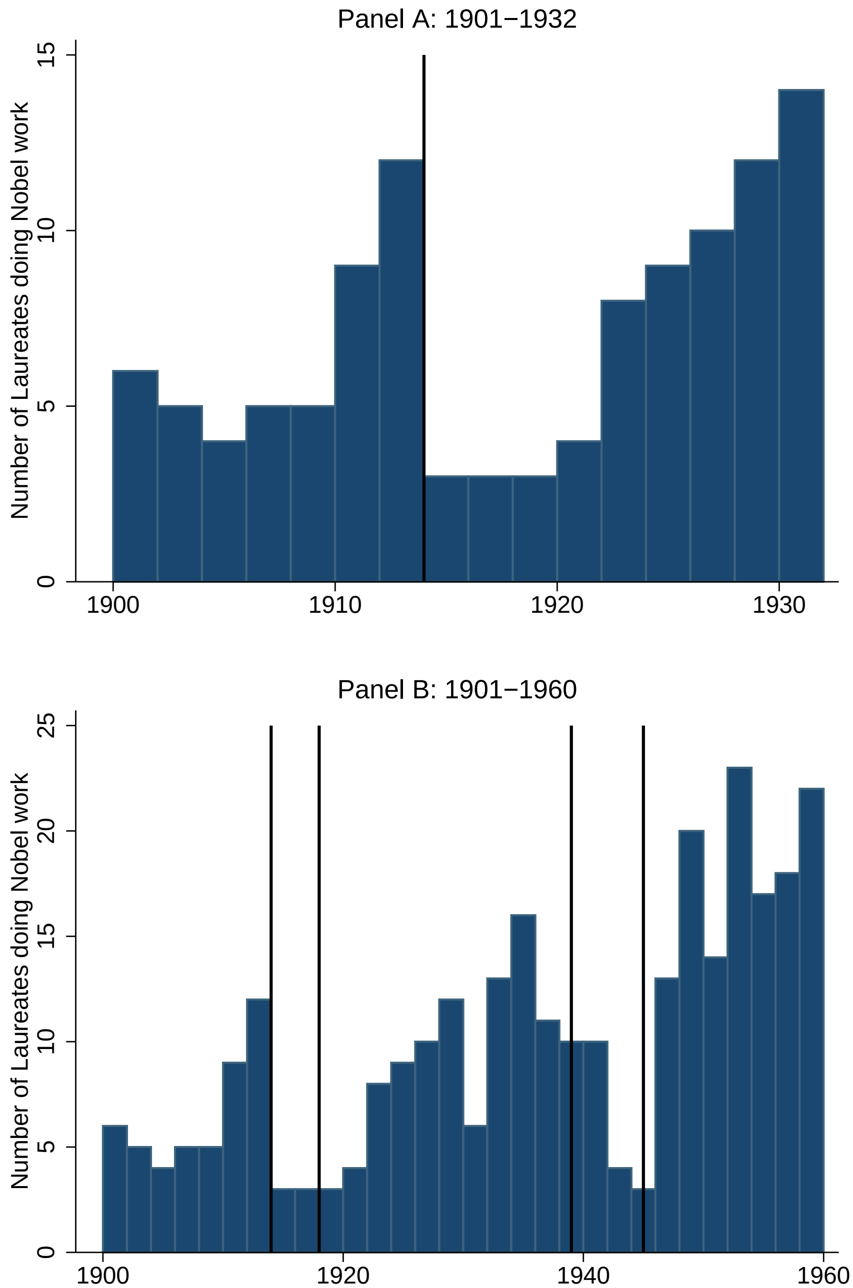
Notes: The Figure plots the estimates of the parameters from five separate regressions (2), each using citation shares as dependent variable. Each line plots the regression results corresponding to a cohort of work published in a three-year window (e.g., 1905-1907). The 1905-1907 line, for example, measures Central citations to 1905-1907 work published by Allied authors, relative to citations to 1905-1907 work published by Central authors. The other lines report results from analogous regressions for different cohorts. The regressions also control for Central citations to work published by Neutral and Rest authors in the same three year window.

Figure 10:
Allied Papers: Relative Citations of Central Work Published in Different Cohorts



Notes: The Figure plots the estimates of the parameters from five separate regressions equivalent to (2) for Allied citations, each using citation shares as dependent variable. Each line plots the regression results corresponding to a cohort of work published in a three-year window (e.g., 1905-1907). The 1905-1907 line, for example, measures Allied citations to 1905-1907 work published by Central authors, relative to citations to 1905-1907 work published by Allied authors. The other lines report results from analogous regressions for different cohorts. The regressions also control for Allied citations to work published by Neutral and Rest authors in the same three year window.

Figure 11: Timing of Science Nobel Laureates' Prize Winning Work



Notes: The Figures plot histograms of the number of Nobel Laureates who were working on their prize winning discoveries in two year bins. The vertical line in Panel A indicates the beginning of WWI. The vertical lines in Panel B indicate the beginning and end of WWI and WWII, respectively. Data source: Jones and Weinberg (2011).

Tables

Table 1: Scientific Camps during the Boycott

Allies	Centrals	Neutrals
U.S.A.	Germany	Switzerland
U.K. (incl. Ireland)	Austria	Netherlands
France	Hungary	Sweden
Canada	Bulgaria	Denmark
Japan	Ottoman E. / Turkey	Norway
Italy		Czechoslovakia
Belgium		Finland
Australia		Spain
Rumania		Monaco
Poland		
Brazil		
South Africa		
Greece		
New Zealand		
Portugal		
Serbia		

Notes: The Table reports the list of countries that constituted each scientific camp during the boycott. Countries are ordered in terms of scientific output.

Table 2: Attendance of International Congresses of Mathematicians

Year	*Location*	*Delegates from:*							
		Germany	*Switzerland*	*France*	*U.S.A.*	*Canada*	*U.K.*	*Italy*	*Others*
1897	Zurich	53	68	29	7	0	3	25	57
1900	Paris	26	7	93	19	1	12	23	69
1904	Heidelberg	204	13	29	19	1	8	14	108
1908	Rome	174	18	92	27	1	33	213	142
1912	Cambridge (U.K.)	70	10	45	87	5	270	41	181
1916	Stockholm				*Canceled*				
1920	Strasbourg	0	12	112	15	1	11	7	99
1924	Toronto	0	5	45	270	118	93	15	80
1928	Bologna	106	48	91	76	7	64	412	312
1932	Zurich	142	185	89	102	2	49	81	203

Notes: The Table reports the number of delegates at each International Congress of Mathematicians by country. Data source: *Proceedings of the International Congresses of Mathematicians.*

Table 3: Summary Statistics about Scientists

Panel A: Scholars from all fields	*Minerva 1900*	*Minerva 1914*
Total number of universities	565	966
Total number of university scholars	24,090	42,113
Scholars with name information	23,841	36,738

Panel B: Scientists from all fields	*Minerva 1900*	*Minerva 1914*
Total scientists (5 fields)	10,040	15,790
Medicine	5,341	8,762
Biology	1,489	2,339
Chemistry	1,309	2,058
Physics	1,147	1,630
Mathematics	1,067	1,435

Panel C: Scientists by country (largest countries)	*Minerva 1900*		*Minerva 1914*	
	#	*% of all*	*#*	*% of all*
U.S.A.	1,676	16.7	3,293	20.9
Germany	1,495	14.9	2,128	13.5
Italy	1,174	11.7	1,961	12.4
U.K.	865	8.6	1,381	8.8
France	1,021	10.2	1,309	8.3
Austria–Hungary	817	8.1	1,304	8.3
Russia	784	7.8	1,142	7.2
Switzerland	315	3.1	421	2.7
Spain	238	2.4	301	1.9
Japan	94	0.9	283	1.8
Canada	201	2.0	238	1.5

Notes: The Table reports the number of university professors in 1900 and 1914. In Panel B "Total scientists (5 fields)" is smaller than the sum of the 5 fields below because some scientists work in multiple fields. Data source: Minerva (1900 and 1914).

Table 4.a: Distribution of Allied and Central Papers by Journal Country

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Country information based on:		*Percent publications in journal country*					
Author country	*Address and Scientist data*	*Scientist data*	*U.S.A.*	*U.K.*	*France*	*Germany*	*Netherlands*	*Others*
Allies:								
U.S.A.	73,474	24,372	**81.6**	13.3	0.3	4.6	0.1	0.0
U.K.	19,505	12,409	16.9	**79.9**	0.3	2.6	0.1	0.1
France	3,275	2,401	3.2	2.5	**86.9**	5.7	0.4	1.3
Canada	1,746	1,044	**52.8**	43.1	0.0	4.0	0.0	0.0
Japan	830	339	24.4	13.4	0.6	**59.4**	0.4	1.8
Italy	714	679	9.1	12.9	5.0	**71.6**	0.6	0.9
Belgium	606	302	4.5	2.0	**65.2**	6.5	21.9	0.0
Australia	391	469	18.9	**79.0**	0.2	1.8	0.0	0.0
Rumania	208	142	0.7	0.7	**76.1**	22.5	0.0	0.0
New Zealand	204	95	**37.6**	57.1	4.2	1.1	0.0	0.0
Poland	172	0	-	-	-	-	-	-
Brazil	84	9	**41.2**	35.3	11.8	11.8	0.0	0.0
Portugal	42	30	3.3	13.3	80.0	3.3	0.0	0.0
South Africa	37	60	46.7	50.8	0.0	2.5	0.0	0.0
Greece	17	16	0.0	0.0	0.0	100.0	0.0	0.0
Serbia	0	0	-	-	-	-	-	-
Centrals:								
Germany	22,591	18,930	2.7	0.9	0.3	**95.0**	0.5	0.5
Austria	2,529	2,164	6.7	1.8	1.4	**88.0**	1.7	0.4
Hungary	1,300	1,102	10.1	0.9	0.6	**86.7**	0.3	1.4
Bulgaria	28	3	0.0	0.0	0.0	**100.0**	0.0	0.0
Ottoman E./Turkey	9	0	-	-	-	-	-	-

Table 4.b: Distribution of Neutral and Rest Papers by Journal Country

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Country information based on:		*Percent publications in journal country*					
Author country	*Address and Scientist data*	*Scientist data*	*U.S.A*	*U.K.*	*France*	*Germany*	*Netherlands*	*Others*
Neutrals:								
Switzerland	3,052	2,804	3.4	0.9	7.2	**71.4**	0.6	16.5
Netherlands	2,681	2,029	3.2	5.2	0.5	31.5	**59.5**	0.1
Sweden	1,255	794	6.1	2.6	2.8	**74.9**	1.3	12.3
Denmark	568	365	9.9	10.4	2.7	**62.7**	0.5	13.7
Finland	300	142	1.4	1.4	0.0	**48.1**	3.5	45.6
Norway	266	178	5.6	20.8	0.6	**70.2**	1.7	1.1
Czechoslovakia	212	0	-	-	-	-	-	-
Spain	53	6	0.0	0.0	72.7	**27.3**	0.0	0.0
Rest:								
Others	2,253	548	23.4	**63.6**	3.2	9.4	0.4	0.0
Russia	1,123	544	23.4	5.2	3.3	**66.3**	1.2	0.6
China	288	0	-	-	-	-	-	-
Argentina	191	132	10.6	0.8	13.6	**75.0**	0.0	0.0
Chile	113	4	30.8	**23.1**	0.0	46.2	0.0	0.0
Mexico	11	0	-	-	-	-	-	-
Thailand	0	0	-	-	-	-	-	-

Notes: The Table reports the number of papers by country based on two methods of assigning countries to authors. Column (1) reports the country assignment that combines the scientist data with address information in the paper and column (2) reports the country assignment that only uses the scientist data. Columns (3) to (8) report percentages of the journal country where scientists from each country publish. These calculations are based on the sample that uses the scientist data to assign countries to authors (column 2). Data sources: Scientist data digitized from Minerva (1900 and 1914). Publication data from the ISI Web of Science, collection "Century of Science" for publication years between 1905 and 1930.

Table 5: Summary Statistics about Papers and their References

Panel A: Papers published 1905–1930	*(1)* Country information based on: Address and Scientist data	*(2)* Scientist data
All papers	260,375	
+ author not anonymous	246,469	
+ country of citing author known	139,482	71,368
+ country of referenced author known	68,969	22,576
+ removing self cites	66,741	21,940
+ references in journal list	56,147	16,749
Panel B: References (published after 1900) in these papers		
All references	1,966,840	
+ author not anonymous	1,937,146	
+ country of citing author known	1,165,207	554,051
+ country of referenced author known	355,856	70,266
+ removing self cites	335,889	68,241
+ references in journal list	228,027	40,496

Notes: The Table reports the number of papers and the corresponding references in our analysis. Data sources: Scientist data digitized from Minerva (1900 and 1914). Publication data from the ISI Web of Science, collection "Century of Science" for publication years between 1905 and 1930.

Table 6: Summary statistics about Citation Levels and Citation Shares

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Panel A: Citation Levels								
	Panel A1: 1905-1930			Panel A2: 1905-1913			Panel A3: 1919-1921		
	Cited Work:			*Cited Work:*			*Cited Work:*		
Citing Papers:	Allied	Neutral	Central	Allied	Neutral	Central	Allied	Neutral	Central
Allied	**0.000185**	0.000066	0.000060	**0.000153**	0.000047	0.000065	**0.000261**	0.000073	0.000052
Neutral	0.000069	**0.000272**	0.000203	0.000072	**0.000208**	0.000186	0.000069	**0.000462**	0.000226
Central	0.000062	0.000181	**0.000250**	0.000059	0.000162	**0.000232**	0.000053	0.000200	**0.000363**
	Panel B: Citation Shares								
	Panel B1: 1905-1930			Panel B2: 1905-1913			Panel B3: 1919-1921		
	Cited Work:			*Cited Work:*			*Cited Work:*		
Citing Papers:	Allied	Neutral	Central	Allied	Neutral	Central	Allied	Neutral	Central
Allied	**0.000099**	0.000033	0.000033	**0.000087**	0.000031	0.000040	**0.000125**	0.000039	0.000030
Neutral	0.000039	**0.000153**	0.000109	0.000036	**0.000120**	0.000101	0.000047	**0.000279**	0.000148
Central	0.000033	0.000094	**0.000134**	0.000030	0.000086	**0.000120**	0.000031	0.000142	**0.000243**

Notes: The Table reports averages of the two measures of knowledge flows for each combination of citing-cited scientific camp. In Panels A1 and B1 averages are calculated over the entire period of our data, 1905 to 1930. In Panels A2 and B2 averages are calculated for the years 1905 to 1913, In Panels A3 and B3 averages are calculated for the period 1919 to 1921.

Table 7: Central Papers: Relative Citations as Measured by Citation Shares

Central citations to:	(1)	(2)	(3)	(4)
Allied work	-0.000088***	-0.000090***	-0.000893	-0.000871
	(0.000010)	(0.000009)	(0.000753)	(0.003480)
Allied × WW1	0.000000	0.000002	-0.000001	-0.000001
	(0.000010)	(0.000010)	(0.000010)	(0.000016)
Allied × Early Boycott	-0.000124***	-0.000122***	-0.000127***	-0.000127***
	(0.000018)	(0.000017)	(0.000018)	(0.000022)
Allied × Late Boycott	-0.000041***	-0.000039***	-0.000045***	-0.000045
	(0.000010)	(0.000011)	(0.000009)	(0.000031)
Allied × Post Boycott		0.000008		0.000000
		(0.000009)		(0.000039)
Neutral interacted with time periods	YES	YES	YES	YES
Rest interacted with time periods	YES	YES	YES	YES
Paper FE	YES	YES	YES	YES
Camp time trends			YES	YES
Observations	15,760	15,760	15,760	15,760
Number of papers	3,940	3,940	3,940	3,940
R-squared	0.011373	0.011926	0.011767	0.012024

Notes: The Table reports the estimation results from regression (3) using citation shares as dependent variable. The reference/omitted category is the citation share to work published by authors in the home camp. Standard errors are clustered at the camp times journal-field level. *** indicate a parameter estimate significantly different from 0 at the 1%, ** at the 5%, and * at the 10% level.

Table 8: Allied Papers: Relative Citations as Measured by Citation Shares

Allied citations to:	(1)	(2)	(3)	(4)
Central work	-0.000054***	-0.000047***	0.001422	-0.001679
	(0.000007)	(0.000010)	(0.001051)	(0.002895)
Central × WW1	-0.000016***	-0.000023**	-0.000018***	-0.000029***
	(0.000006)	(0.000009)	(0.000007)	(0.000009)
Central × Early Boycott	-0.000042***	-0.000049***	-0.000040***	-0.000058***
	(0.000007)	(0.000010)	(0.000007)	(0.000013)
Central × Late Boycott	-0.000027***	-0.000034***	-0.000022***	-0.000046***
	(0.000007)	(0.000010)	(0.000006)	(0.000017)
Central × Post Boycott		-0.000016*		-0.000032
		(0.000010)		(0.000024)
Neutral interacted with time periods	YES	YES	YES	YES
Rest interacted with time periods	YES	YES	YES	YES
Paper FE	YES	YES	YES	YES
Camp time trends			YES	YES
Observations	20,800	20,800	20,800	20,800
Number of Papers	5,200	5,200	5,200	5,200
R-squared	0.013435	0.013566	0.013651	0.013819

Notes: The Table reports the estimation results from the equivalent of regression (3) for Allied papers using citation shares as dependent variable. The reference/omitted category is the citation share to work published by authors in the home camp. Standard errors are clustered at the camp times journal-field level. *** indicate a parameter estimate significantly different from 0 at the 1%, ** at the 5%, and * at the 10% level.

Table 9: Central Papers: Robustness Checks

Central citations to:	*Citation Levels (Scientist Data)*				*Citation Shares (Address + Scientist Data)*				*Citation Levels (Address + Scientist Data)*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Allied work	-0.000167***	-0.000172***	-0.002060	0.004551	-0.000074***	-0.000080***	-0.001796*	-0.004440**	-0.000168***	-0.000167***	-0.000225	-0.004649
	(0.000012)	(0.000012)	(0.001501)	(0.006081)	(0.000007)	(0.000008)	(0.000973)	(0.002033)	(0.000014)	(0.000013)	(0.002457)	(0.003951)
Allied× WW1	-0.000019	-0.000014	-0.000021	0.000002	-0.000015**	-0.000009	-0.000014***	-0.000024***	-0.000031*	-0.000032	-0.000031*	-0.000047*
	(0.000028)	(0.000029)	(0.000028)	(0.000032)	(0.000005)	(0.000008)	(0.000005)	(0.000005)	(0.000018)	(0.000023)	(0.000018)	(0.000026)
Allied× Early Bct	-0.000155***	-0.000149***	-0.000161***	-0.000122**	-0.000095***	-0.000089***	-0.000099***	-0.000115***	-0.000155***	-0.000156***	-0.000155***	-0.000182***
	(0.000035)	(0.000036)	(0.000035)	(0.000058)	(0.000014)	(0.000017)	(0.000011)	(0.000008)	(0.000030)	(0.000036)	(0.000028)	(0.000025)
Allied× Late Bct	-0.000075***	-0.000070***	-0.000085***	-0.000034	-0.000029***	-0.000023**	-0.000035***	-0.000056***	-0.000069**	-0.000070*	-0.000069***	-0.000104***
	(0.000021)	(0.000022)	(0.000021)	(0.000044)	(0.000009)	(0.000011)	(0.000005)	(0.000010)	(0.000029)	(0.000038)	(0.000021)	(0.000034)
Allied× Post Bct		0.000024		0.000071		0.000015		-0.000028**		-0.000002		-0.000047
		(0.000016)		(0.000063)		(0.000009)		(0.000013)		(0.000024)		(0.000032)
Neutral interactions	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Rest interactions	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Paper FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Camp time trends			YES	YES			YES	YES			YES	YES
Observations	15,760	15,760	15,760	15,760	27,344	27,344	27,344	27,344	27,344	27,344	27,344	27,344
Number of papers	3,940	3,940	3,940	3,940	6,836	6,836	6,836	6,836	6,836	6,836	6,836	6,836
R-squared	0.010383	0.011853	0.011604	0.011893	0.018742	0.019218	0.019500	0.019976	0.018011	0.018169	0.018319	0.018673

Notes: The Table reports the estimation results from regression (3). Results reported in columns (1) to (4) use citation levels as dependent variable and the country assignment of authors and references is based on the scientist data. Results reported in columns (5) to (8) use citation shares as dependend variable and the country assignment of authors and references is based on the scientist and address data. Results reported in columns (9) to (12) use citation levels as dependend variable and the country assignment of authors and references is based on the scientist and address data. The reference/omitted category is the citation share to work published by authors in the home camp. Standard errors are clustered at the camp times journal-field level. *** indicate a parameter estimate significantly different from 0 at the 1%, ** at the 5%, and * at the 10% level.

Table 10: Allied Papers: Robustness Checks

Allied citations to:	*Citation Levels (Scientist Data)*				*Citation Shares (Address + Scientist Data)*				*Citation Levels (Address + Scientist Data)*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Central work	-0.000099***	-0.000088***	0.002495	0.001359	-0.000030***	-0.000047***	-0.002504***	-0.003706***	-0.000086***	-0.000114***	-0.004264***	-0.008067***
	(0.000016)	(0.000021)	(0.002510)	(0.005191)	(0.000002)	(0.000005)	(0.000491)	(0.000788)	(0.000006)	(0.000014)	(0.001405)	(0.002443)
Central× WW1	-0.000040***	-0.000051***	-0.000042***	-0.000046**	-0.000017***	-0.000000	-0.000008***	-0.000012***	-0.000042***	-0.000014	-0.000026***	-0.000041***
	(0.000013)	(0.000019)	(0.000014)	(0.000019)	(0.000001)	(0.000004)	(0.000002)	(0.000002)	(0.000007)	(0.000012)	(0.000008)	(0.000008)
Central× Early Bct	-0.000121***	-0.000133***	-0.000118***	-0.000125***	-0.000023***	-0.000006	-0.000019***	-0.000026***	-0.000075***	-0.000047***	-0.000068***	-0.000090***
	(0.000030)	(0.000033)	(0.000031)	(0.000039)	(0.000001)	(0.000004)	(0.000002)	(0.000002)	(0.000010)	(0.000015)	(0.000010)	(0.000015)
Central× Late Bct	-0.000040***	-0.000051**	-0.000032**	-0.000040	-0.000008***	0.000009**	-0.000008***	-0.000018***	-0.000027***	0.000002	-0.000027***	-0.000057***
	(0.000015)	(0.000022)	(0.000014)	(0.000028)	(0.000002)	(0.000004)	(0.000001)	(0.000003)	(0.000007)	(0.000014)	(0.000007)	(0.000015)
Central× Post Bct		-0.000026		-0.000012		0.000023***		-0.000012***		0.000038***		-0.000039**
		(0.000024)		(0.000041)		(0.000005)		(0.000004)		(0.000013)		(0.000016)
Neutral interactions	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Rest interactions	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Paper FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Camp time trends			YES	YES			YES	YES			YES	YES
Observations	20,800	20,800	20,800	20,800	127,800	127,800	127,800	127,800	127,800	127,800	127,800	127,800
Number of papers	5,200	5,200	5,200	5,200	31,950	31,950	31,950	31,950	31,950	31,950	31,950	31,950
R-squared	0.011511	0.011767	0.011812	0.011824	0.012602	0.013296	0.013312	0.013344	0.014444	0.014789	0.014821	0.014829

Notes: The Table reports the estimation results from the equivalent of regression (3) for Allied papers. Results reported in columns (1) to (4) use citation levels as dependent variable and the country assignment of authors and references is based on the scientist data. Results reported in columns (5) to (8) use citation shares as dependend variable and the country assignment of authors and references is based on the scientist and address data. Results reported in columns (9) to (12) use citation levels as dependend variable and the country assignment of authors and references is based on the scientist and address data. The reference/omitted category is the citation share with respect to work published by authors in the home camp. Standard errors are clustered at the camp times journal-field level. *** indicate a parameter estimate significantly different from 0 at the 1%, ** at the 5%, and * at the 10% level.

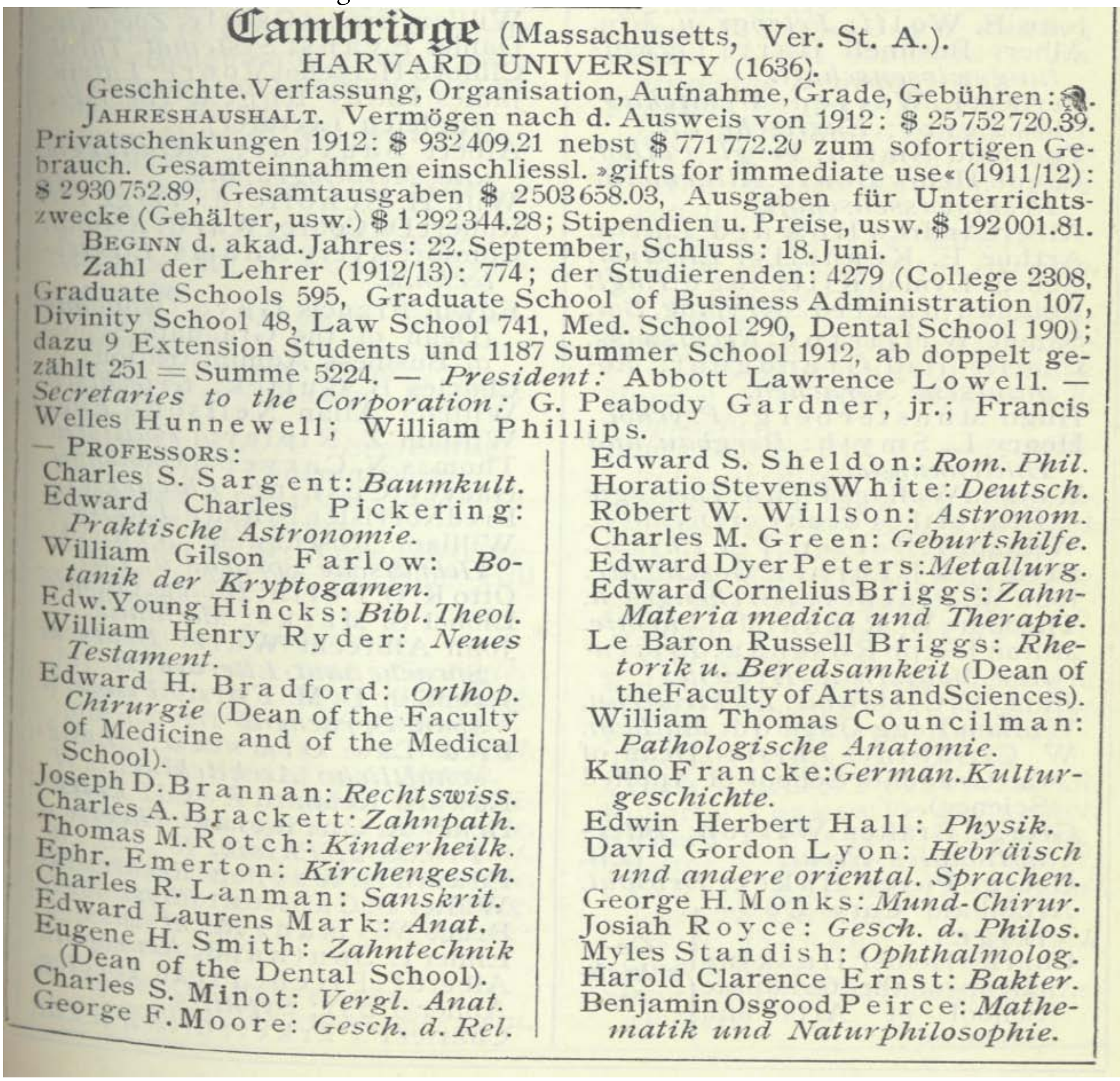
Table 11:
NEUTRAL PAPERS: RELATIVE CITATIONS AS MEASURED BY CITATION SHARES

Neutral citations to:	(1)	(2)	(3)	(4)
Central work	-0.000009	-0.000019	-0.003304	-0.007535
	(0.000014)	(0.000011)	(0.002610)	(0.015386)
Central × WW1	-0.000115**	-0.000106**	-0.000115**	-0.000130**
	(0.000044)	(0.000043)	(0.000044)	(0.000056)
Central × Early Boycott	-0.000121	-0.000111	-0.000129	-0.000153*
	(0.000081)	(0.000084)	(0.000078)	(0.000082)
Central × Late Boycott	-0.000061	-0.000052	-0.000075*	-0.000108
	(0.000046)	(0.000052)	(0.000041)	(0.000111)
Central × Post Boycott		0.000029		-0.000044
		(0.000022)		(0.000145)
Allied work	-0.000078***	-0.000084***	-0.002112	-0.004281
	(0.000018)	(0.000018)	(0.002416)	(0.014599)
Allied × WW1	-0.000106***	-0.000100**	-0.000106***	-0.000114**
	(0.000039)	(0.000038)	(0.000039)	(0.000045)
Allied × Early Boycott	-0.000154**	-0.000148*	-0.000158**	-0.000171**
	(0.000073)	(0.000076)	(0.000070)	(0.000066)
Allied × Late Boycott	-0.000070*	-0.000064	-0.000078**	-0.000095
	(0.000041)	(0.000044)	(0.000038)	(0.000100)
Allied × Post Boycott		0.000018		-0.000022
		(0.000020)		(0.000137)
Rest interacted with time periods	YES	YES	YES	YES
Paper FE	YES	YES	YES	YES
Camp time trends			YES	YES
Observations	3,768	3,768	3,768	3,768
Number of papers	942	942	942	942
R-squared	0.013759	0.013859	0.013893	0.015978

Notes: The Table reports estimation results from the equivalent of regression (3) for Neutral papers using citation shares as dependent variable. The reference/omitted category is the citation share to work published by authors in the home camp. Standard errors are clustered at the camp times journal-field level. *** indicate a parameter estimate significantly different from 0 at the 1%, ** at the 5%, and * at the 10% level.

Appendix Figures

Figure A.1: Sample page of Minerva



Cambridge (Massachusetts, Ver. St. A.).
HARVARD UNIVERSITY (1636).

Geschichte. Verfassung, Organisation, Aufnahme, Grade, Gebühren: [illegible].

Jahreshaushalt. Vermögen nach d. Ausweis von 1912: $ 25752720.39. Privatschenkungen 1912: $ 932409.21 nebst $ 771772.20 zum sofortigen Gebrauch. Gesamteinnahmen einschliessl. »gifts for immediate use« (1911/12): $ 2930752.89, Gesamtausgaben $ 2503658.03, Ausgaben für Unterrichtszwecke (Gehälter, usw.) $ 1292344.28; Stipendien u. Preise, usw. $ 192001.81.

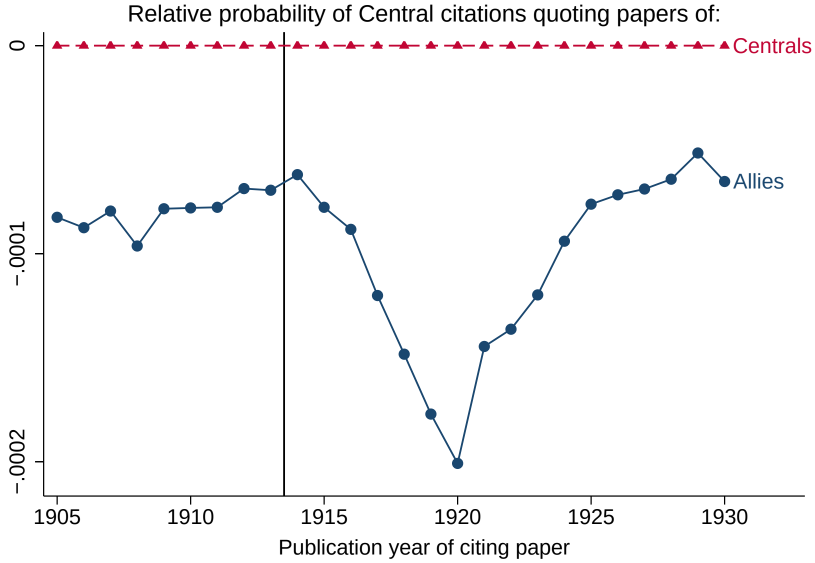
Beginn d. akad. Jahres: 22. September, Schluss: 18. Juni.

Zahl der Lehrer (1912/13): 774; der Studierenden: 4279 (College 2308, Graduate Schools 595, Graduate School of Business Administration 107, Divinity School 48, Law School 741, Med. School 290, Dental School 190); dazu 9 Extension Students und 1187 Summer School 1912, ab doppelt gezählt 251 = Summe 5224. — *President:* Abbott Lawrence Lowell. — *Secretaries to the Corporation:* G. Peabody Gardner, jr.; Francis Welles Hunnewell; William Phillips.

— Professors:
Charles S. Sargent: *Baumkult.*
Edward Charles Pickering: *Praktische Astronomie.*
William Gilson Farlow: *Botanik der Kryptogamen.*
Edw. Young Hincks: *Bibl. Theol.*
William Henry Ryder: *Neues Testament.*
Edward H. Bradford: *Orthop. Chirurgie* (Dean of the Faculty of Medicine and of the Medical School).
Joseph D. Brannan: *Rechtswiss.*
Charles A. Brackett: *Zahnpath.*
Thomas M. Rotch: *Kinderheilk.*
Ephr. Emerton: *Kirchengesch.*
Charles R. Lanman: *Sanskrit.*
Edward Laurens Mark: *Anat.*
Eugene H. Smith: *Zahntechnik* (Dean of the Dental School).
Charles S. Minot: *Vergl. Anat.*
George F. Moore: *Gesch. d. Rel.*
Edward S. Sheldon: *Rom. Phil.*
Horatio Stevens White: *Deutsch.*
Robert W. Willson: *Astronom.*
Charles M. Green: *Geburtshilfe.*
Edward Dyer Peters: *Metallurg.*
Edward Cornelius Briggs: *Zahn-Materia medica und Therapie.*
Le Baron Russell Briggs: *Rhetorik u. Beredsamkeit* (Dean of the Faculty of Arts and Sciences).
William Thomas Councilman: *Pathologische Anatomie.*
Kuno Francke: *German. Kulturgeschichte.*
Edwin Herbert Hall: *Physik.*
David Gordon Lyon: *Hebräisch und andere oriental. Sprachen.*
George H. Monks: *Mund-Chirur.*
Josiah Royce: *Gesch. d. Philos.*
Myles Standish: *Ophthalmolog.*
Harold Clarence Ernst: *Bakter.*
Benjamin Osgood Peirce: *Mathematik und Naturphilosophie.*

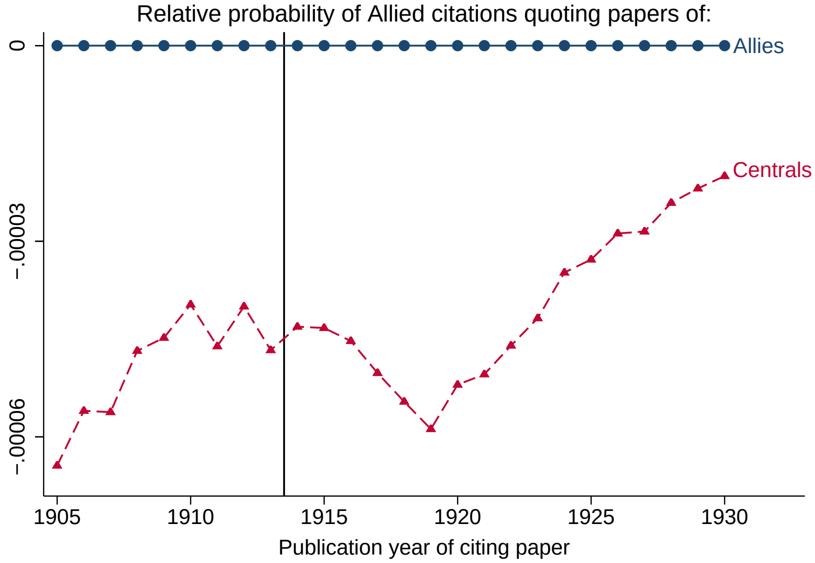
Source: Minerva–Handbuch der Gelehrten Welt.

Figure A.2: Central Papers: Relative Citations (Address + Scientist Data)



Notes: The Figure plots parameter estimates (α_τ) of regression (2) using citation shares as dependent variable. For these results we assign countries to authors and references by combining the scientist data with address information from the papers. The Allied line reports point estimates (α_τ) that measure Central citations to work published in the preceding five years by Allied authors, relative to citations to work published in the same years by Central authors. For example, the first dot (1905) measures relative citations to work published by Allied authors between 1901 and 1905. The regression also controls for Central citations to work published in the preceding five years by Neutral and Rest authors. Point estimates (α_τ) are significantly different from 0 at the 1 percent level for all years between 1905 and 1930.

Figure A.3: Allied Papers: Relative Citations (Address + Scientist Data)



Notes: The Figure plots parameter estimates for the equivalent of regression (2) for Allied citations using citation shares as dependent variable. For these results we assign countries to authors and references by combining the scientist data with address information from the papers. The Central line reports point estimates that measure Allied citations to work published in the preceding five years by Central authors, relative to citations to work published in the same years by Allied authors. For example, the first dot (1905) measures relative citations to work published by Central authors between 1901 and 1905. The regression also controls for Allied citations to work published in the preceding five years by Neutral and Rest authors. Point estimates are significantly different from 0 at the 1 percent level for all years between 1905 and 1930.

Appendix Tables

Table A.1.a: List of Scientific Journals (A–J)

Acta Mathematica	Chemical Reviews
American Journal of Anatomy	Comptes Rendus des Seances de la Societe de Biologie et de ses Filiales
American Journal of Botany	Comptes Rendus Hebdomadaires des Seances de L'Academie des Sciences
American Journal of Mathematics	Contributions to Embryology
American Journal of Pathology	Ecology
American Journal of Physiology	Endocrinology
American Journal of Science	Genetics
American Naturalist	Helvetica Chimica Acta
Anatomical Record	Hereditas
Annalen der Physik	Hoppe–Seylers Zeitschrift fur Physiologische Chemie
Annales de Chemie et de Physique	Industrial and Engineering Chemistry
Annales de Chimie France	Journal de Physique et le Radium
Annals of Applied Biology	Journal fur die Reine und Angewandte Mathematik
Annals of Botany	Journal fur Praktische Chemie–Leipzig
Annals of Eugenics	Journal fur Psychologie und Neurologie
Annals of Mathematical Statistics	Journal of Anatomy
Annals of Mathematics	Journal of Bacteriology
Archiv fur die Gesamte Physiologie des Menschen und red Tiere	Journal of Biological Chemistry
Archiv fur Entwicklungsmechanik der Organismen	Journal of Clinical Endocrinology
Archiv fur Experimentelle Pathologie und Pharmakologie	Journal of Ecology
Archiv fur Experimentelle Zellforschung	Journal of Economic Entomology
Archiv fur Mikroskopische Anatomie	Journal of Experimental Biology
Archiv fur Mikroskopische Anatomie und Entwicklungsgeschichte	Journal of Experimental Medicine
Archiv fur mikroskopische Anatomie und Entwicklungsmechanik	Journal of Experimental Zoology
Archives of pathology	Journal of General Physiology
Archives of Pathology and Laboratory Medicine	Journal of Genetics
Astrophysical Journal	Journal of Heredity
Beitrage zur Pathologischen Anatomie und zur Allgemeinen Pathologie	Journal of Immunology
Berichte der Deutschen Chemischen Gesellschaft	Journal of Infectious Diseases
Biochemical Journal	Journal of Medical Research
Biochemische Zeitschrift	Journal of Morphology
Biological Bulletin	Journal of Morphology and Physiology
Biological Reviews and Biological Proceedings of the Cambridge Philosophical Society	Journal of Pathology and Bacteriology
Biometrika	Journal of Pharmacology and Experimental Therapeutics
Botanical Gazette	Journal of Physical Chemistry
British Journal of Experimental Biology	Journal of the American Chemical Society
British Journal of Experimental Pathology	Journal of the American Medical Association

Table A.1.b: List of Scientific Journals (J–Z)

Journal of the American Statistical Association	Proceedings of the Royal Society of London, Series A, Math. and Physics
Journal of the Chemical Society	Proceedings of the Royal Society of London, Series B, Biology
Journal of the Franklin Institute	Proceedings of the Society for Experimental Biology and Medicine
Journal of the Optical Society of America	Proceedings of the Zoological Society of London
Journal of the Optical Society of America and Review of Scientific Instruments	Publications of the American Statistical Association
Journal of the Royal Statistical Society	Quarterly Journal of Experimental Physiology
Journal of Urology	Quarterly Journal of Medicine
Justus Liebigs Annalen der Chemie	Quarterly Journal of Microscopical Science
Kolloid Zeitschrift	Quarterly Publications of the American Statistical Association
Lancet	Recueil des Travaux Chimiques des Pays–Bas
Mathematische Annalen	Recueil des Travaux Chimiques des Pays–Bas et de la Belgique
Mathematische Zeitschrift	Review of Scientific Instruments
Medicine	Reviews of Modern Physics
Monthly Notices Of The Royal Astronomical Society	Science
Nature	Sitzungsberichte der Preussischen Akademie der Wissenschaften Physik.–Mathem. Klasse
Naturwissenschaften	Sitzungsberichte der Koniglich Preussischen Akademie der Wissenschaften
Naunyn–Schmiedebergs Archiv fur Experimentelle Pathologie und Pharmakologie	Skandinavisches Archiv fur Physiologie
New England Journal of Medicine	Stain technology
Organic Syntheses	Transactions of The American Institute of Chemical Engineers
Pflugers Archiv fur die Gesamte Physiologie des Menschen und der Tiere	Transactions of The American Mathematical Society
Philosophical Magazine	Transactions of the Faraday Society
Philosophical Transactions of the Royal Society of London, Series A, Math. and Physics	Virchows Archiv fur Pathologische Anatomie und Physiologie und fuer Klinische Medizin
Physical Review	Wilhelm Roux' Archiv fur Entwicklungsmechanik der Organismen
Physikalische Zeitschrift	Zeitschrift fur Angewandte Mathematik und Mechanik
Physiological Reviews	Zeitschrift fur Anorganische Chemie
Phytopathology	Zeitschrift fur Anorganische und Allgemeine Chemie
Plant Physiology	Zeitschrift fur Biologie
Proceedings of the American Academy of Arts and Sciences	Zeitschrift fur die Gesamte Neurologie und Psychiatrie
Proceedings of the American Academy of Arts and Sciences	Zeitschrift fur Elektrochemie und Angewandte Physikalische Chemie
Proceedings of the Cambridge Philosophical Society	Zeitschrift fur Kristallographie
Proceedings of the Cambridge Philosophical Society–Biological Sciences	Zeitschrift fur Krystallographie und Mineralogie
Proceedings of the IRE	Zeitschrift fur Physik
Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen te Amsterdam	Zeitschrift fur Physikalische Chemie Stochiometrie und Verwandtschaftslehre
Proceedings of the London Mathematical Society	Zeitschrift fur Physikalische Chemie, Abteilung A, Chem. Thermod. Kinetik Elektrochemie Eigensc.
Proceedings of the Physical Society	Zeitschrift fur Physikalische Chemie, Abteilung B, Chemie der Elementarpr. Aufbau der Materie
Proceedings of The Physical Society of London	Zeitschrift fur Wissenschaftliche Zoologie
Proceedings of the Royal Society of London	Zoologiska Bidrag fran Uppsala

Source: Publication data from the ISI Web of Science, collection "Century of Science" for publication years between 1905 and 1930.

Table A.2:
RELATIVE CITATION SHARES OF CENTRAL PAPERS – PARAMETER ESTIMATES FOR FIGURE 2

	Param. Est.	*Std. Err.*		*Param. Est.*	*Std. Err.*
Allied × 1905	-0.0000773	0.0000185	Neutral × 1905	0.0000052	0.0000186
Allied × 1906	-0.0000977	0.0000130	Neutral × 1906	-0.0000329	0.0000164
Allied × 1907	-0.0000829	0.0000147	Neutral × 1907	-0.0000328	0.0000203
Allied × 1908	-0.0001128	0.0000084	Neutral × 1908	-0.0000676	0.0000109
Allied × 1909	-0.0000917	0.0000101	Neutral × 1909	-0.0000303	0.0000131
Allied × 1910	-0.0000948	0.0000113	Neutral × 1910	-0.0000206	0.0000151
Allied × 1911	-0.0000867	0.0000113	Neutral × 1911	-0.0000714	0.0000145
Allied × 1912	-0.0000756	0.0000102	Neutral × 1912	-0.0000183	0.0000212
Allied × 1913	-0.0000867	0.0000104	Neutral × 1913	-0.0000317	0.0000238
Allied × 1914	-0.0000568	0.0000113	Neutral × 1914	-0.0000230	0.0000134
Allied × 1915	-0.0000840	0.0000196	Neutral × 1915	-0.0000260	0.0000338
Allied × 1916	-0.0001070	0.0000162	Neutral × 1916	-0.0000113	0.0000269
Allied × 1917	-0.0001198	0.0000282	Neutral × 1917	0.0000576	0.0000641
Allied × 1918	-0.0001164	0.0000352	Neutral × 1918	0.0000067	0.0000969
Allied × 1919	-0.0002026	0.0000461	Neutral × 1919	-0.0001173	0.0000721
Allied × 1920	-0.0002218	0.0000222	Neutral × 1920	-0.0001325	0.0000625
Allied × 1921	-0.0002124	0.0000183	Neutral × 1921	-0.0000685	0.0000821
Allied × 1922	-0.0001494	0.0000264	Neutral × 1922	-0.0000757	0.0000274
Allied × 1923	-0.0001495	0.0000146	Neutral × 1923	-0.0001015	0.0000190
Allied × 1924	-0.0001001	0.0000208	Neutral × 1924	0.0000088	0.0000401
Allied × 1925	-0.0001217	0.0000205	Neutral × 1925	-0.0000411	0.0000338
Allied × 1926	-0.0000873	0.0000232	Neutral × 1926	-0.0000374	0.0000172
Allied × 1927	-0.0000951	0.0000123	Neutral × 1927	-0.0000876	0.0000158
Allied × 1928	-0.0000816	0.0000220	Neutral × 1928	-0.0000537	0.0000267
Allied × 1929	-0.0000600	0.0000177	Neutral × 1929	0.0000001	0.0000198
Allied × 1930	-0.0000859	0.0000113	Neutral × 1930	-0.0000798	0.0000210
Rest interacted with years			YES		
Paper FE			YES		
Observations			15,760		
Number of papers			3,940		

Notes: The Table reports the estimation results from regression (2) using citation shares as dependent variable. The reference/omitted category is the citation share with respect to papers published by the home camp. Standard errors are clustered at the camp times journal-field level.

Table A.3:
RELATIVE CITATION SHARES OF ALLIED PAPERS – PARAMETER ESTIMATES FOR FIGURE 3

	Param. Est.	*Std. Err.*		*Param. Est.*	*Std. Err.*
Central × 1905	-0.0000638	0.0000225	Neutral × 1905	-0.0000413	0.0000300
Central × 1906	-0.0000525	0.0000146	Neutral × 1906	-0.0000564	0.0000190
Central × 1907	-0.0000574	0.0000166	Neutral × 1907	-0.0000612	0.0000243
Central × 1908	-0.0000280	0.0000162	Neutral × 1908	-0.0000536	0.0000127
Central × 1909	-0.0000522	0.0000141	Neutral × 1909	-0.0000787	0.0000097
Central × 1910	-0.0000326	0.0000150	Neutral × 1910	-0.0000546	0.0000095
Central × 1911	-0.0000529	0.0000091	Neutral × 1911	-0.0000578	0.0000119
Central × 1912	-0.0000417	0.0000095	Neutral × 1912	-0.0000428	0.0000161
Central × 1913	-0.0000510	0.0000102	Neutral × 1913	-0.0000569	0.0000116
Central × 1914	-0.0000561	0.0000091	Neutral × 1914	-0.0000565	0.0000125
Central × 1915	-0.0000691	0.0000047	Neutral × 1915	-0.0000503	0.0000150
Central × 1916	-0.0000662	0.0000102	Neutral × 1916	-0.0000746	0.0000110
Central × 1917	-0.0000838	0.0000118	Neutral × 1917	-0.0000734	0.0000208
Central × 1918	-0.0000779	0.0000087	Neutral × 1918	-0.0000965	0.0000117
Central × 1919	-0.0000999	0.0000125	Neutral × 1919	-0.0000875	0.0000231
Central × 1920	-0.0000921	0.0000121	Neutral × 1920	-0.0000953	0.0000158
Central × 1921	-0.0000962	0.0000116	Neutral × 1921	-0.0000761	0.0000114
Central × 1922	-0.0001062	0.0000095	Neutral × 1922	-0.0000896	0.0000129
Central × 1923	-0.0000884	0.0000096	Neutral × 1923	-0.0000698	0.0000133
Central × 1924	-0.0000623	0.0000134	Neutral × 1924	-0.0000626	0.0000190
Central × 1925	-0.0000685	0.0000136	Neutral × 1925	-0.0000761	0.0000138
Central × 1926	-0.0000680	0.0000089	Neutral × 1926	-0.0000630	0.0000100
Central × 1927	-0.0000578	0.0000095	Neutral × 1927	-0.0000712	0.0000128
Central × 1928	-0.0000661	0.0000088	Neutral × 1928	-0.0000408	0.0000151
Central × 1929	-0.0000607	0.0000083	Neutral × 1929	-0.0000760	0.0000085
Central × 1930	-0.0000620	0.0000085	Neutral × 1930	-0.0000618	0.0000121
Rest interacted with years			YES		
Paper FE			YES		
Observations			20,800		
Number of papers			5,200		

Notes: The Table reports the estimation results from regression (2) using citation shares as dependent variable. The reference/omitted category is the citation share with respect to papers published by the home camp. Standard errors are clustered at the camp times journal-field level.