EFFECTS OF COPYRIGHTS ON SCIENCE - EVIDENCE FROM THE WWII BOOK REPUBLICATION PROGRAM*

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This paper investigates how copyrights influence science, through their impact on the price of knowledge. In 1942, the US Book Republication Program (BRP) allowed US publishers to reprint German science books, leading to a 25-percent decline in price. Using two independent identification strategies, we show that this change increased citations to BRP books. Effects of price are more pronounced for human (rather than physical) capital-intensive disciplines. Geographic data on library holdings suggest that lower prices promoted science by enabling more and poorer libraries to buy BRP books. Two alternative measures of scientific output – new PhDs and patents – confirm the main results.

KEYWORDS: SCIENCE, COPYRIGHT, MEDIA, AND ECONOMIC HISTORY

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Copyrights establish intellectual property in books, music, and many other types of creative content. With the proliferation of digitization, policies that promote the creation of new content have become critical, yet systematic economic analyses of copyrights continue to be rare.[1] Recent empirical analyses have shown that basic levels of copyright protection can increase the profitability of authorship (MacGarvie and Moser 2013), and raise both the quantity and quality of creative output (Giorcelli and Moser 2015).

Yet, copyrights may cause extensive welfare loss by restricting access to existing work. For example, Heald (2014) and Reimers (2014) show that books that are slightly less than 95 years old (and therefore still on copyright) are less likely to be available for sale than slightly older books that are off copyright today. Analyses of Romantic Period books indicate that increasing the length of copyrights raises the price of books, by improving publishers' ability to price discriminate (Li et al. 2015). Higher prices can, however, discourage the *use* of copyrighted content in new work and thereby discourage future creativity.

The potential welfare effects of prices are especially great for science because the creation of new "cumulative" knowledge (Scotchmer 1991) depends critically on access to existing knowledge.[2] Based on this intuition, funding agencies increasingly require grant recipients to make articles available for free, essentially ignoring copyrights.[3] Although there is no systematic empirical evidence on the effects of prices, related research suggests that reductions in non-monetary access costs can encourage innovation. Furman and Stern (2011) show that the creation of biological research centers, which facilitate access to cancer cells, has promoted medical science. Murray et al. (2016) find that contracts, which improve access to genetically engineered mice, have encouraged follow-on research.[4] Empirical analyses of

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[1] A well-developed literature in legal studies reflects the importance of copyrights (e.g., Landes and Posner 1989, DiCola 2013, and Heald 2014). Economic analyses of copyrights face two major empirical challenges. First, the extreme length of modern copyrights (95 years in the United States) makes it difficult to observe all but extremely old cultural goods on and off copyrights. Second, experimental policy variation is rare, because modern laws are heavily influenced by lobbying from the owners of profitable and durable goods, which is reflected in nicknames such as the 1998 "Mickey Mouse Protection Act" and the 2011 UK "Cliff (Richard's) Law." For notable recent research in economics see Reimers (2014) and Nagaraj (2015). Analyses of piracy in popular music have explored quasi-experimental variation in copyright enforcement. Waldfogel (2012) shows that the quality of recorded music increased after the creation of Napster. Oberholzer-Gee and Strumpf (2007) find that an increase in file sharing had no statistically significant effects on record sales.

[2] Recent analyses use the term "cumulative" science interchangeably with "follow-on" science and innovation (e.g., Furman and Stern 2011; Galasso and Schankerman 2015).

[3] E.g., Howard Hughes Medical Institute Public Access Publishing (http://www.hhmi.org/about/policies#papp) and Bill & Melinda Gates Foundation Open Access Policy (http://www.gatesfoundation.org/how-we-work/general-information/open-access-policy, accessed December 3, 2015).

[4] At the same time, the incentive effects of stronger copyrights for scientists are likely to be limited. Stern (2004), for example, finds that scientists forego wages to pursue scientific discoveries. By comparison, authors of popular fiction may be more responsive to profits. Contracts for Romantic period novelists list payments equivalent to millions of dollars for the most successful authors (MacGarvie and Moser 2013).

patents have found that the existence of patents creates limited benefits for innovation (e.g., Moser 2005; Sampat and Williams 2016), and that invalidating patents (Galasso and Schankerman 2015) or allowing competitive entry into patented technologies (e.g., Moser and Voena 2012; Baten et al. 2016) can encourage downstream innovation.[5] Compared with copyrights, however, patents, establish much broader (and shorter-lived) intellectual property rights, so that these findings don't generalize to copyrights.

It has also proven difficult to identify how variation in the price of existing knowledge influences science. An inter-disciplinary literature on open access suggests that articles, which are available for free, are cited more (e.g., Eysenbach 2006, Evans and Reimer 2009). These findings are, however, compromised by selection if authors are more likely to pay open access fees for articles that are of greater general interest.[6]

To address these empirical challenges, we exploit an important historical episode of copyright licensing as a result of World War II. In 1942, the US Alien Property Custodian appropriated copyrights for German science books, along with all other enemy-owned US property. The Custodian issued temporary (6-month) licenses to US publishers, allowing them to reprint exact copies of German-owned science. At the end of the six-month period, copyrights reverted to the Custodian, who could license the book to another US firm, if there was additional demand.[7] During their license term, US publishers reproduced the original German text because most US scientists still spoke German (Ammon 2001).

A key effect of the BRP was a reduction in the price of German science books. Until 1941, the average BRP book sold for $43, equivalent to $1,160.00 in 2015.[8] Under the BRP, US publishers sold copies of BRP books with an average price decline of 25 percent. To investigate the effects of the BRP on science, we have constructed new data on more than 10,000 citations between 1920 and 1970 to BRP books in chemistry and mathematics, as well as a control group of Swiss books in the same disciplines.[9]

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[5] Moser (2005) finds that the existence of a patent system is not associated with more innovations (measured by exhibits at 19th century world fairs), but instead with a shift in the *direction* of innovation. Sampat and Williams (2015) use variation in the leniency of US patent examiners to show that the existence of a gene patent had no effect on follow-on research or product development. Galasso and Schankerman (2015) show that the invalidation of a patent is associated with a 50 percent increase in citations to the invalidated patents.

[6] McCabe and Snyder (2015) have shown that even basic controls for scientific quality reduce the correlation between open access and citations. To mitigate selection, Mueller-Langer and Watt (2014) examine hybrid open agreements, which assign open access based on authors, rather than articles.

[7] In practice, publishers supplied the market at a low enough price to discourage future entry.

[8] Using real wage conversions, based on the unskilled wage, as a conservative estimate (Williamson 2015).

[9] The Custodian (1944) also list 187 BRP books in physics. We exclude physics because much of the important research was done in complete secrecy, and these projects occupied many of the most prominent physicists. For example, Robert Oppenheimer and General Grove chose Los Alamos as the site of the Manhattan Project

We pursue two separate identification strategies to identify the effects of the BRP. The first strategy addresses the empirical challenge of selection into the BRP: US publishers selected books for the BRP program, so that changes in citations after 1941 may reflect pre-existing characteristics of BRP books, rather than an effect of the program. To address this issue, we compare changes in citations to *the same BRP book* from English-language authors (who benefitted directly from the US BRP) with changes in citations from authors publishing in other languages.

OLS estimates suggest that the BRP triggered a large increase in citations to BRP books. Citations to BRP books from English-language authors increased by an additional 80 percent after 1941 compared with citations by authors publishing in other languages. Consistent with results on the contributions of German-Jewish émigrés to US invention (Moser, Voena, and Waldinger 2014), we also find that citations to BRP books by émigrés increased more. Yet, citations to books by émigré scientists cannot explain the overall increase in citations to BRP books.

We then analyze the role of lower prices as a mechanism to drive citations. To motivate these estimates, we construct a simple model of cumulative science, which predicts that scientists produce more follow-on knowledge when existing knowledge is cheap. OLS estimates confirm this prediction: Each 10-percent decline in price is associated with an additional 38 percent increase in citations to BRP books by English-language authors compared with other languages.

Our simple model also yields an unexpected but intuitive prediction about differential price effects across disciplines: Under a general set of production functions, effects are greater for disciplines that are less intensive in physical capital. To test this, we estimate triple-differences regressions that compare the effects of price for mathematics (a discipline in which knowledge production depends primarily on human capital) and chemistry (which requires laboratory space and other types of physical capital). Triple-differences estimates confirm differential effects: A 10-percent decline in price is associated with an additional 88 percent increase in citations for mathematics compared with chemistry.

Citations by English-language authors may, however, have increased after World War I (both in absolute terms and relative to citations in other languages) due to an increase in the productivity of English-language scholars, for example, as a result of the expansion of the US economy. To address this issue we pursue an independent strategy to investigate the effects

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because it was a "site so isolated there was only a winding gravel road and one phone line into the place" (Bird and Sherwin 2006, p. 206), and researchers were not allowed to discuss their findings with the outside world.

of the BRP: It compares changes after 1942 in citations *by English-language authors* to BRP and Swiss books. Similar to their German colleagues, Swiss scientists were leaders in chemistry and math, and they also wrote primarily in German. Swiss books, however, could not be licensed under the BRP because Switzerland was a neutral country during the war. Results from this second identification strategy confirms all of the main findings from the first strategy. For example, OLS estimates for a matched sample of BRP and Swiss books indicate an additional 136 percent increase in citations to BRP books after 1941.

How did reductions in price increase citations? Archival sources suggest that libraries played a major part in amplifying the effects of the BRP. Before digitization, physical access to library copies was the main mechanism to access existing knowledge. For example, a major objection against Los Alamos as the site for the Manhattan Project was that "in the wilds of New Mexico" scientists lacked access to a decent library. [10] Records of the JW Edwards publishing company also suggest that research libraries were a major buyer of BRP books (Bokas and Edwards 2011, p.25).

To examine the role of libraries as a mechanism of knowledge diffusion we construct data on historical library holdings from the National Union Catalog (NUC). The NUC, which captures the stock of all books in US libraries by 1956, shows that BRP books had become substantially more evenly distributed compared with Swiss books by 1956: Many of the poorer libraries in the West and South held BRP books, while Swiss books remained concentrated in the holdings of two wealthy research libraries (the Crerar Library at the University of Chicago and the Yale University Library). The NUC data also show that BRP books with a larger price decline in 1942 had become more evenly distributed. To examine variation in the use of BRP books over time we collect information on loans of BRP books from lending cards that are in the back of library books. These data reveal a substantial increase in the first and overall use of BRP books around 1946, four years after the BRP. We then connect the locations of citing authors with the locations of libraries that held BRP books. This geographic analysis indicates that locations within commuting distance of BRP books experienced a disproportionate increase in citations.

Two alternative measures of scientific output confirm the main results. First, we examine variation in the number of new PhDs in mathematics across locations and over time. These data confirm the expansion in geographic scope, and indicate that locations within 25 miles of library with BRP books produced two times more new PhDs after 1942 compared

[10] John Manley, an experimental physicist, in Bird and Shirwin (2005, p. 207). Also Hargittai (2006, pp. 89-131).

with more distant locations. Importantly, there is no difference in the pre-trends of citations or PhDs per year between nearby and distant locations. Second, we link BRP books with US patents as a proxy for privately valuable, economically useful knowledge. These data indicate a 15 percent increase in inventions that build on BRP books.

I. The World War II Book Republication Program

In 1942, the US Book Republication Program issued involuntary copyright licenses for German-owned books to US publishers. Until then, German publishers had enjoyed the same copyright protection as US publishers, so-called "national treatment" as a result of a 1892 treaty between Germany and the United States.[11] This law granted German publishers exclusive rights to print and sell German-owned science books for a 56 years, as specified by the 1909 US Copyright Act.[12]

In 1939, the United States spent $1.5 million on foreign books and journals, mostly by German scientists (Richards 1981, p. 253). With the outbreak of the war, the President of the American Library Association (ALA) Ralph Munn wrote to Secretary of State Cordell Hull

> "Germany has made, and is making, many contributions to man's knowledge […] The world of scholarship can not afford to be deprived of the German contribution to this knowledge" (cited in Richards 1981, p. 254).

Initially, US libraries sourced books directly from Germany or through agents in Switzerland and other neutral countries. In 1940, Thomas Fleming of the Columbia Medical School Library explained that "the British have been confiscating no publications sent to American libraries, and that is about all there is to the situation" (Richards 1981, p. 254).

By mid 1941, however, the US Department of State prohibited money transfers to Germany, and the Nazis forbade German publishers to ship books unless the order had already been paid. Two independent organizations stepped in to secure a steady supply of European publications: the Federal Government's Interdepartmental Committee for the Acquisition of Foreign Publications (IDC, operated by the Office of Strategic Services), and Thomas Fleming's library-sponsored Joint Committee (chaired by Fleming since August

[11] April 15, 1892, United States Copyright Office, Circular 38A; Kawohl 2008, pp. 436-439. The 1892 treaty extended the 1891 International Copyright Act, which had granted copyrights to foreign books that had been typeset in the United States (*Manufacturing Clause*, Columbia Law Association 1950, p. 686).

[12] The 1909 Act extended copyrights to all works of authorship including music (Varian 2005, p. 124), and increased copyright length from 14 to 28 years, renewable for an additional 28 years. These terms remained in place until the 1976 Copyright Act increased copyrights to 50 years after the author's death and 75 years for corporate owners. The 1998 Copyright Term Extension Act further extended terms to 70 years after death and 95 years for corporate owners. See Goldstein (2003) for an enjoyable and informative history of copyright law.

1941). These organizations transferred German journals onto microfilm and distributed copies in the United States (Richards 1981, p. 255).

On July 6, 1942, President Roosevelt's Executive Order No. 9193 authorized the Office of the US Alien Property Custodian to "direct, manage, supervise, control or vest the following classes of property: […] Patents, patent applications, copyrights, copyright applications, trademarks, or trademark applications or rights" (Myron 1945, p. 76). In late 1942, a group of prominent librarians and professors urged the Custodian to exploit this directive to seize German-owned copyrights to reduce the amount of money sent to Germany and ensure the US supply of German books (Richards 1981, p. 255).

Between 1942 and 1944, the Custodian appropriated more than 100,000 books with enemy-owned copyrights (*Forty-sixth Annual Record of the Register of Copyrights* 1944, p. 8), and offered licenses for a non-extendable period of 6 months to US publishers (Myron 1945, p. 85). US publishers then submitted bids for these licenses (Bokas and Edwards 2011, p. 22). Along with Dover, J.W. Edwards Publisher, Inc. won the largest number of licensing bid, for 650 titles (Bokas and Edwards 2011, p. 23). The Custodian collected licensing revenues on behalf of German copyright owners:

> "According to the terms of the licenses…considerable royalties amounting to many thousands of dollars were accumulated and remitted to the U.S. Government for the benefit of the original copyright owner."[13]

Under the BRP US publishers received temporary licenses to German-owned books, allowing them to re-print copies for a period of six months. This ensured that publishers who charged too much would risk competition with a lower-priced competitor after their six-month turn. In practice, no book was licensed to more than a single publisher. Menu costs were also high enough to prevent publishers from adjusting prices dynamically, so that BRP publishers charged a single price for each book.

BRP books were reprinted as exact copies in editions between 200 and 500 copies (Bokas and Edwards 2011, p. 25). In 1943 J.W. Edwards published 700 titles of scientific books and 140 journals, "most of which have been published under license by the Alien Property Custodian Office."[14] Among Edwards' publications was Frederick Konrad Beilstein's (1918) *Handbuch der Organischen Chemie*, "a critical tool for every organic chemist working in a lab until the early 1970s." Until 1941, the German publisher Springer had sold the set for $2,000 (equivalent to a unskilled wage labor value of $54,200 in 2015,

[13] Bill Edwards, cited in Bokas and Edwards 2011, p. 25.
[14] Ernest Rynearson writing in the *Edwards Brother Newsletter,* cited in Bokas and Edwards (2011, p. 23).

Williamson 2015). Under the BRP, Edwards Brothers offered exact reproductions of Beilstein "for $400 a set, and the company sold more than 600 sets to laboratories, researchers, and academicians" (Bokas and Edwards, 2011 p. 25).

II. DATA

A. BRP Books and Price Data

In 1944, the Alien Property Custodian Office published a list of all BRP books in the *Book Republication Program: Titles Suggested for Republication, an Alphabetical List with a Subject Index*. For 334 books, including 274 in chemistry and 60 in mathematics, the Custodian (1944, pp. 1-102) lists the title, author, research field, publication year, and publication city.[15] For example, the first book in alphabetical order is

> Aberhalden, Emil, *Handbuch der Biologischen Arbeitsmethoden. Abt. 3: Physikalisch-chemische Methoden*. Berlin, Springer, 1928-30.3 vols. Field: Chemistry, Physical and Theoretical. Original price: $128.00. Reproduction: $84.50, set. Licensee: J.W. Edwards.

The average BRP book was 5.8 years old, and would have been covered by US copyrights for another 50 years.[16]

The Custodian lists the BRP price (charged by US publishers) for all 334 BRP books. For 319 of these books (96 percent), the Custodian also lists the original price that German copyright owners charged in the United States *before* the BRP. Thirteen of the remaining 15 books were published after 1941, and may not have been available in the United States before the BRP.[17] Under the pre-BRP copyright regime, German publishers sold 319 books for an average of $41.40 (equivalent to $1,120 in 2015, Appendix Figure A1).[18]

Under the BRP, book prices declined by an average of 24.97 percent ($\Delta p_i = 1 - BRP\ price/\ original\ price$, Appendix Table A1).[19] The book with the largest price decline, Saccardo's *Sylloge fungorum,* sold for an original price of $2,000 ($54,200 in 2015) and for $200 ($5,420) under the BRP. Beilstein's (1918) *Handbuch der Organischen Chemie* sold for

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[15] Most (323 of 334 BRP books) were published in German, and 5 were English-language translations. Prices declined less for these 5 books (by 16.9 percent), and citations increased more (from 0.388 to 0.838 per year).
[16] The 1909 Act offered 56 years (28 years initially plus the option to renew the copyright for another 28 years). One extremely old book, Pier Andrea Saccardo's (1881) *Sylloge Fungorum* presents a system for classifying mushrooms by spore color and form, which remained the standard until the field switched to analyzing DNA.
[17] Strohecker's *Taschenbuch für die Lebensmittelchemie,* had been published in 1938. English-language citations to books without a pre-BRP price increased from zero until 1941 to 0.155 per book and year after 1941.
[18] At an average price of $48.57 (Appendix Figure A1; roughly $1,320 in 2015, using relative wage conversions, Williamson 2015), chemistry books were more expensive than math books ($10.47, or $284 in 2015).
[19] Prices declined for 242 of 271 BRP books with an original BRP price. Another 20 books experienced no change in price; 15 of these books are in chemistry and 5 in mathematics. Nine chemistry books became more expensive under the BRP, by an average of 17.47 percent, increasing from an original price of $36.46.

an original price of $2,000 and for $400 ($10,840) under the BRP. Across disciplines, price declines were slightly smaller in chemistry (24.34 percent) than mathematics (27.44 percent).

B. Swiss Books in Chemistry and Mathematics

Our second identification strategy uses books that were published in Switzerland (and therefore not subject to the BRP) to control for unobservable factors that may have increased English-language citations to German-language books in chemistry and mathematics. To construct this control group, we extract all Swiss books in section 51 "Mathematik" and section 54 "Chemie" from the catalogs of the Swiss National Library. Founded in 1895, the Library's holdings include 1,683 books in chemistry that were published between 1921 and 1942, and 447 books in mathematics.

C. Citations to BRP and Swiss Books by New Scientific Publications, 1920-1970

To investigate the BRP's influence on science, we collect citations to BRP books by new scientific articles and books. We first search Google Scholar for each title (such as *Die Chemie des Pyrrols*) and author (such as "Fischer").[20] Google's algorithm searches "articles, theses, books, abstracts and court opinions from academic publishers, professional societies, online repositories, universities, and other web sites."[21] It is currently the most complete source of citations to foreign language books (Meho and Yang 2007),[22] even though its effectiveness may vary across cohorts of publications. To address this issue, we control for the publication year of citing articles and books.

To measure the effect of the BRP as conservatively as possible, we focus on citations to the original German-language version. If books became more popular as a result of the BRP, they were more likely to be translated, so that we may estimate a lower bound on the effects of citations for popular books. For example, new citations to Courant and Hilbert's (1931) *Methoden der Mathematischen Physik* declined after the publication of *Methods of Mathematical Physics* (vol. II, 1966). By 2016, *Methods* had received more than 16,000

[20] Fischer (1881–1945) received the Nobel Prize in chemistry for determining the structures of pigments in blood and bile as well as chlorophyll in leaves; these substances are derived from pyrrole.
[21] For books with multiple editions we collect citations to the edition whose publication year is closest to the publication year of the original book. Less than five percent of books have multiple editions in the same year; for these books we examine the edition with the largest number of citations.
[22] Meho and Yan (2007) compare citations to the work of 25 faculty members from three sources: the Institute for Scientific Information (ISI, or Web of Science), Scopus, and Google Scholars. Google Scholar stands out in its coverage of conference proceedings and international journals, but also requires a substantially greater effort of data collection (with a total of 3,000 hours compared with 1000 for the Web of Science and 200 for Scopus).

citations. Among 334 BRP books, 291 (87 percent) are cited at least once. Among 2,130 Swiss books, 486 books (23 percent) are cited at least once.

A potential drawback of citations is that they may be influenced by unobservable changes in tastes.[23] For example, Paris et al. (1998) document a region-based bias in citations, and Jannot et al. (2013) show that scientists are more likely to cite statistically significant results. In our empirical setting, the most serious threat is that US scholars may have withheld citations to Germans during the war and resumed them afterwards. For example, Iaria and Waldinger (2015) show that – during World War I – a US boycott of scientists from Central countries led to a decline in the transmission of knowledge. Although changes in ethnic preferences are difficult to observe, related data are available for the two World Wars. These data confirm that World War I created a strong change in ethnic preferences towards Germans, whereas Pearl Harbor focused ethnic distastes on Asia during World War II. For example, the share of German-language operas dropped dramatically from 50 to 7 percent at the eve of World War I, but declined only slightly in World War II (Appendix Figure A2). Alternative measures of ethnic preferences, including purchases of ethnic foods and changes in baby names, confirm these patterns (Moser 2012b).

D. Books in US Library

Historical library holdings are recorded in the *National Union Catalog (NUC), pre-1956 imprints*, a "cumulative author list representing Library of Congress printed cards and titles reported by other libraries" (Mansell 1968-1981). To collect these data, we have accessed physical copies of the NUC at the Hoover Institution Library & Archive. These records allow us to identify books that had entered at least one US library by 1956.

Among 291 BRP books with at least one citation, 283 are in the NUC, including 228 of 236 books in chemistry (97 percent) and all 55 books in mathematics (100 percent). We examine these 283 BRP books in the main specifications and use the full sample of 291 BRP books in robustness checks (e.g., in Appendix Table A9). BRP books in the NUC receive 0.263 citations per year until 1941 and 0.566 afterwards (Table 1). Among 486 Swiss books with at least one citation, 247 Swiss books are in the NUC, including 161 of 373 Swiss chemistry books (43 percent), and 86 of 113 Swiss math books (77 percent). Swiss books in the NUC receive 0.024 citations until 1941, and 0.078 afterwards (Appendix Table A2).

[23] More generally, citations may initially be biased against novel findings. For example, Wang, Veugelers and Stephan (2016) document that, among articles published in the Web of Science in 2001, articles that make more "first-time" ever combination across journals are published in journals with lower impact factors, and less likely to be cited in the short run but more likely to enter the top one percent of highly cited papers in the long run.

E. Publications in English and Other Languages

To distinguish citations by authors who were differentially affected by the BRP, we identify the publication language of all 10,141 citing publications. Among 9,053 citations to 283 BRP books between 1920 and 1970, 5,141 originate from English-language publications. With 243 English-language citations, Courant and Hilbert's *Methoden der Mathematischen Physik* (1931) is the most cited book (Appendix Table A12). To check whether English-language citations are a useful proxy for citations from US scholars, we collect data on publication cities for four highly cited books.[24] These data indicate that the large majority of English-language publications (73 percent) originate from the United States.

F. Geographic Locations of Citing Authors in the Year of the Citation

To investigate changes in the location of citing and cited authors, we collect detailed data on employment histories for all 283 authors. To identify BRP authors who were émigrés, we examine records in the *International Biographical Dictionary of Central European Émigrés* (Strauss et al. 1983) and the Mathematics Genealogy Project (MGP).[25]

We also use the MGP to capture variation in the geographic locations of 1,812 authors who cite BRP books. The MGP offers comprehensive coverage on advisors, advisees, and PhD-granting institutions for 196,303 mathematicians between 1666 and 2016.[26] We use information on PhD-granting institutions for professors and their advisees to identify the location of citing authors and PhD students. Location data are available for all 2,008 citations by 1,812 authors to BRP books in mathematics. For example, David Gilbarg cites Courant and Hilbert's *Methoden der Mathematischen Physik* in his article on "Asymptotic Behavior and Uniqueness of Plane Subsonic Flows" in the *Journal of Pure and Applied Mathematics* in 1957. We assign this citation to Bloomington, Indiana because Gilbarg was an advisor to Norman Meyers, who graduated from Indiana University in 1957.

G. US Patents that Build on Knowledge in BRP Books

To investigate the effects of the BRP on economically useful knowledge and to measure the program's effects on private firms, we examine changes in the number of

[24] Alexandroff and Topf (1935) *Topologie* (1935, BRP), van der Warden (1931, BRP) *Moderne Algebra* Stiefel (1936, Swiss) *Mannigfaltigkeiten* and Leser (1939, Swiss) *Invariantentheorie Algebraische Formen*.
[25] Five of six émigrés from Straus (1983) appear as an advisor of at least one American PhD student in the MGP after 1932. The only missing émigré, Max Herzberger, worked in the private sector, and did not advise students.
[26] http://www.genealogy.ams.org/index.php, accessed January 28 to March 25, 2016.

patented inventions that cite BRP books as relevant scientific knowledge. Specifically, we search the full text of US patent documents between 1920 and 1970 for patented inventions that cite a BRP book as relevant prior art.[27] For example, US2,701,248A for "Esters of pseudothiohydantoin-5-acetic acid and method for their preparation" (issued to Ferdinand B. Zienty, Brentwood MO on February 1, 1955) cites Beilstein's *Handbuch der Organischen Chemie*. A total of 238 US patents between 1920 and 1970 cite a BRP book, including 35 patents until 1941, and 203 afterwards.[28] We also construct geographic data on the location of inventors. For example, Ferdinand Zienty (of US2,701,248A above) is located in Brentwood, MO, in 1955. Such data are available for 219 of 238 citing patents.

H. Research Fields of BRP and Swiss Books

Citations may also vary systematically across research fields. To control for such variation, we match subject codes in the reports of the US Alien Property Custodian (1944) with subject codes in the Swiss National Library. The Custodian (1944) assigns 228 chemistry books to 38 topics (such as "catalysis"), and 55 books in mathematics to 14 topics (such as "non-Euclidean geometry"). The Swiss National Library distinguishes 128 topics within chemistry and 28 topics within mathematics. We match these topics to create 25 mutually exclusive research fields within chemistry and 8 within mathematics.

For BRP books in chemistry, compounds are the most common research field (58 books, Appendix Table A3). Prices for books on compounds decline by an average of 24.7 percent from an average original price of $29.60 ($802 in 2015). English-language citations to these books increase from 0.191 per book and year until 1941 to 0.441 afterwards. Organic chemistry and metals are the next largest fields, with 28 and 27 books, respectively. For organic chemistry, price declines by 34.7 percent from $200.30 ($5,430 in 2015), and citations increase from 0.367 to 0.508 after the BRP. For metals, price declines by 18.6 percent from $16.27 ($441 in 2015), and citations increase from 0.427 to 0.696. For BRP books in mathematics, general mathematics is the most common field, with 14 books (Appendix Table A3). In this field, price declines by 38.8 percent, from $11.96 ($324 in 2015); citations increase from 0.520 until 1941 to 1.740 afterwards. Geometry is the next largest field, with 12 books, a price decline of 29.3 percent from $7.75 ($210 in 2015), and an increase in citations from 0.054 to 0.330.

[27] We perform an automatic search of the full text of patents in the *USPTO Bulk Data Downloads: Patent OCR Text* (available at www.google.com/patents) for authors and titles, and then hand-check all potential matches.
[28] Among 283 BRP books in the NUC, 50 are cited in at least one US patent, including 46 BRP books in chemistry and 4 in mathematics; 233 patents cite one BRP book, and 5 patents cite 2 BRP books.

I. Substitutes for BRP Books

A potential shortcoming with citations is that scientists may have shifted citations from substitutes to BRP books when the price of BRP books declined. Contemporaries of the BRP, such as Ralph Mann of the American Library Association, thought that there were no suitable substitutes for BRP books, which summarized the state of German science (Richards 1981, p. 254). Nevertheless, we use Amazon's sales algorithm to identify books that customers who bought BRP books "also bought" or "frequently bought together" with the four most highly cited BRP books in mathematics.[29] We then collect the year of the first edition of all of these related books to check whether they may have been available in the United States before 1942. These data show that most of the books that are thematically related to BRP books were first published *after 1942* (Appendix Figure A3).

III. Difference-in-Differences Estimates for the BRP

To investigate the effects of the BRP, we pursue two independent identification strategies. The first strategy, which we present in this section, compares changes in citations to the *same BRP books* from English-language authors and authors publishing in other languages. It addresses the empirical challenge that books did not enter the BRP program at random, and instead were selected for the BRP.

A. Changes in Citations to BRP Books by English-language authors vs. Other Authors

Counts of new publications that cite BRP books in English and other languages are similar in levels and trend until 1941, and they diverge visibly after 1941 (Figure 1); 0.26 publications in English and 0.30 publications in other languages cite the average BRP book per year until 1941 (Table 1). After 1941, English-language publications increase to 0.566 per year, a 118 percent increase from pre-BRP levels, while other language publications only increase to 0.391, a 30 percent increase (Table 1).[30] This differential increase is particularly remarkable given that many US scientists continued to publish in German until the late 1960s (e.g. Ammon 2001, p. 465), so that part of the increase in other language publications may reflect an effect of the BRP. Notably, citations to the original German version of individual BRP books (such as *Methoden der Mathematischen Physik,* Appendix Figure A5) decline

[29] Data collected from www.amazon.com, accessed September 19-30, 2016.
[30] Including 8 BRP books *not in the NUC*, English-language citations increase by 117 percent from 0.256 to 0.557, and citations from other languages increase by 31 percent from 0.294 to 0.386.

after the introduction of their English-language translations. Moreover, the decline in other-language publications coincides with the decline of German as a lingua franca.

To estimate the aggregate effect of the BRP on the creation of new English-language publications, we begin by estimating OLS difference-in-differences regressions:

$$cites_{ilt} = \alpha\ English_l + \beta\ English_l \times post_t + book_i + \tau_t + \varepsilon_{it} \quad (1)$$

where the dependent variable $cites_{ilt}$ measures citations to book i in language l and year t. The variable $English_l$ indicates new scientific publications in English that cite BRP books and $post_t$ indicates years after 1941. The control group are citations to the same BRP book by non-English language citations. A vector of $book_i$ fixed effects controls for book-specific differences in levels of citations across books. Citation year fixed effects τ_t control for variation in scientific output over time.

The identifying assumption of this basic regression is that changes in English-language and non-English language citations for BRP books would have been similar in the absence of the BRP. If this assumption is satisfied (as data on citations per year in Figure 1 suggest), the coefficient β estimates the effect of the BRP.

OLS estimates indicate that citations to BRP books increased by an additional 0.211 per book and year after 1941 compared with citations from other languages (Table 2, column 1, significant at 1 percent). Relative to a pre-BRP average of 0.263 English-language citations for BRP books, this implies an 80 percent increase. Replacing book fixed effects with controls for the research fields and publication year of BRP books yields an estimate of 0.229 (Table 2, column 3, significant at 1 percent), which implies an 87 percent increase.

Confirming plots of the raw data (in Figure 1), year-specific estimates indicate no significant differences in citations before the BRP, and they show a large increase in citations after the war. Until 1941, estimates are not significant and range from -0.212 in 1933-34 (p-value 0.01) to 0.042 in 1941-42 (p-value 0.48). In the final years of the war, estimates decline to -0.051(1943-44, p-value 0.17). After 1945, estimates increase to 0.200 in 1947-48 (p-value 0.00) and 0.210 in 1953-54 (p-value 0.03). Time-varying estimates remain large and significant until the final period in 1969-70, with 0.412 additional citations (p-value 0.00). Compared with a pre-BRP mean of 0.263, this implies a 157 percent increase.

B. Robustness Checks

A potential challenge to the identifying assumption is that scientific output varies across research fields and over time, for example, due to variation in the fertility of research fields. If such changes favor English-language publications in BRP fields after 1941, then the

basic difference-in-differences test overstates the effect of the BRP. To address this issue, we estimate the regressions with fixed effects for the *fields* and *publication years* of BRP books.

These tests confirm the main results: English-language publications increase by an additional 0.229 per book and year (Table 2, column 2, significant at 1 percent), which implies an 85 percent increase. In alternative specifications with a linear pre-trend for English-language publications, the trend is not statistically significant (with a p-value of 0.24), but the estimated effect of the BRP is large, at 0.448 (Appendix Table A4, column 1, significant at 10 percent).

Even though OLS is our preferred model for the linear difference-in-difference specifications, we estimate robustness checks with a non-linear quasi-maximum likelihood (QML) Poisson model to address the count data nature of citations.[31] QML Poisson estimates confirm the main results, with a 0.497 increase in the growth rate of English-language publications compared with other languages (Table 2, column 7, significant at 1 percent). We also re-estimate the main specifications with the logarithm of citations as the dependent variable. Log regressions indicate an additional 65 percent increase in citations for BRP books (Table 2, column 4, significant at 1 percent).[32]

C. The Influence of Émigrés

Previous research has shown that research fields in which the United States received a German Jewish refugee chemist after 1932 experienced a 31 percent increase in patenting by US inventors compared with fields of other German chemists (Moser et al. 2014). Similarly, the arrival of émigrés may have amplified the effects of their books on science and innovation in the United States. Five authors of BRP math books moved to the United States (Appendix Table A5): Richard Courant (1888-1972), Max Herzberger (1899-1982), John von Neumann (1883-1953), George Pólya (1887-1985), and Gábor Szegő (1895-1985).

Plots of citations show that books by émigrés experienced a much larger increase in citations after 1941 compared with other BRP books. The average émigré book received 0.500 citations in 1934, and 0.750 citations in 1940 and 1941. Citations increase after 1941 to 3.250 in 1953 and stay high until 1970, with 3.500 new citing publications per émigré book (Figure 2). Excluding émigré books, however, does not change the results. Citations per book

[31] Among 19,680 year-book-language pairs of the dependent variable, 15,504 (78 percent) take a value of zero.
[32] In log regressions, we add a tiny number (0.0005) to keep observations with zero citations in the regressions.

and year to non-émigré BRP books increased from 0.350 per book in 1934, 0.325 in 1940 and 0.689 in 1941, to 2 in 1953, and remained at this level until 1965 (Figure 2).[33]

IV. Effects of Changes in the Price of Books

A major benefit of the empirical setting is that prices for the same books are observable under two different copyright regimes. Price data indicate that the average BRP book became 25 percent cheaper as a result of the BRP. These results are consistent with existing analyses of historical book price data, which have found that stronger copyrights increased the price of books (by improving publishers' ability to practice intertemporal discrimination, Li et al. 2015). We exploit the decline in price under the BRP to examine the effects of price on new scientific knowledge that builds on BRP books. To motivate the empirical analysis, we first construct a simple model of cumulative science.

A. Aggregate Effects of Price

Suppose two identical generations of researchers produce new knowledge in periods $t\text{-}1$ and t.[34] The concept of cumulative science (Scotchmer 1991) is captured by allowing second-generation scientists in period t to build on knowledge y_{t-1} created by researchers in the first generation $t\text{-}1$. Normalizing the price of new knowledge y_t to equal 1, scientists receive a sure payoff y_t if they produce cumulative knowledge; this payoff can be in the form of a monetary reward, peer recognition, or other types of rewards that scientists value.

To access existing knowledge y_{t-1}, second-generation scientists pay a price p. Here p represents the price of a book, but it could equally be a fee to access a resource center (as in Furman and Stern 2012), or an online depository of scientific articles. To reflect the indivisibility of existing knowledge, we assume that scientists pay p to use any quantity of existing knowledge. In other words, scientists must buy the entire book, or pay the full fee to access any part of the collection.

In addition to existing knowledge y_{t-1}, scientists use capital k_t, which is available at the rental rate r. Unlike existing knowledge, capital is divisible. Scientists are price takers for

[33] We also re-estimate the baseline specification for mathematics with an additional interaction term for books by émigrés. These estimates confirm that the effect of the BRP was not driven by émigré books. Controlling for émigrés leaves the estimate for *BRP * post* at 0.479 (Appendix Table A6, column 1, significant at 10 percent). Estimates of φ are large (at 1.614) but they are not statistically significant (with a p-value of 0.31).

[34] For simplicity, we assume that knowledge transmission only occurs through impersonal mechanisms, such as books, research libraries or deposits of research materials. A more general model with overlapping generations allows for knowledge transmission across individuals, e.g. from émigrés to natives.

p and r. Depending on input prices p and r, scientists either invest in follow-on science (and receive $y_t = f(y_{t-1}, k_t)$ or they do nothing and receive a payoff of zero.

Second-generation scientists choose k_t* to maximize net payoffs $y_t - p - rk_t^*$. They invest in cumulative knowledge only if p is below a threshold price p' such that

$$f(y_{t-1}, k_t^*) - p' - rk_t^* \geq 0 \text{ or } p' = f(y_{t-1}, k_t^*) - rk_t^* \quad (4)$$

This implies – under a general set of production functions - that scientists produce more new knowledge when p is low. For a Cobb-Douglas production function $y_t = y_{t-1}^{1-\alpha} k_t^{\alpha}$, the threshold price equals

$$p' = \alpha^{\alpha/1-\alpha}(1-\alpha)\, y_{t-1}\, r^{-\alpha/1-\alpha}$$

To examine whether and how changes in price influence the creation of new science that builds on BRP books, we re-estimate the baseline equation (1) with an interaction for changes in the price of BRP books:

$$cites_{ilt} = \alpha\, English_l + \beta\, English_l \times post_t + \theta\, \Delta p_i * English_l * post_t + book_i + \tau_t + \varepsilon_{it} \quad (5)$$

where Δp_i measures the difference between the original price and the republication (BRP) price for book i normalized by the original price.

OLS estimates of equation (5) indicate that a 10-percent decline in price is associated with 0.119 additional citations (Table 3, column 2, significant at 1 percent). Compared with a pre-BRP mean of 0.264 annual citations for BRP books, this implies a 45 percent increase.[35]

A potential concern for estimating the effect of a decline in price is that we cannot observe the process by which publishers set the price for BRP books. To investigate this issue, we check whether price declined more for books with more pre-BRP citations by non-English publications. This correlation is small and not statistically significant (Appendix Figure A4). A related concern is that we cannot measure cross-price elasticities across books, and that US publishers may have lowered prices more for books with close substitutes. Historical sources, however, indicate that there were no close substitutes for BRP books in the US market.[36] If there was unobservable variation in the price setting behavior of publishers, substitution effects would cause the estimate of θ to be downward biased, as long as books with close substitutes experienced a smaller increase in citations.

To investigate the timing of changes, we estimate $BRP * \Delta p_i * post$ separately for two-year intervals between 1930 and 1970:

$$cites_{ilt} = \alpha\, English_l + \beta\, English_l \times post_t + \Sigma_s\, \theta_s\, \Delta p_i * English_l * \eta_s + book_i + \tau_s + \varepsilon_{it} \quad (6)$$

[35] With a separate linear pre-trend for English-language citations, the estimate is 0.119 (significant at 1 percent, Appendix Table A4, column 2).

[36] E.g., the 1939 letter of Ralph Mann to Secretary of State Cordell Hull (cited in Richards 1981, p. 254).

where the indicator variable τ_t denotes two-year intervals 1930-31, 1932-1933,…to 1969-70, and years between 1920 and 1929 are the excluded period.

Year-specific estimates indicate no significant differences in citations before the BRP, and they show a large increase in citations after the war (Figure 3). Until 1941, estimates range from -0.025 in 1931-32 (p-value 0.20) to 0.041 in 1941-42 (p-value 0.04). In the final years of the war, estimates decline to 0.019 in 1943-44 (p-value 0.29). After 1945, estimates increase to 0.102 in 1947-48 (p-value 0.00) and 0.153 in 1953-54 (p-value 0.00). Annual estimates remain large and significant until 1969-70, with 0.180 additional citations (p-value 0.00). Compared with a pre-BRP mean of 0.263, this implies a 68 percent increase.

B. Differential Effects across Disciplines

Another prediction is that the effects of price vary across disciplines, depending on the capital-intensity of knowledge creation. Suppose $y_{c,t} = z(y_{c,t-1},k_t)$ represents chemistry, which is more dependent on physical capital (e.g., in the form of laboratory space and specialized equipment), and $y_{m,t} = g(y_{m,t-1},k_t)$ denotes mathematics. Let the elasticity of knowledge production with respect to physical capital be $e^c(y_{c,t-1},k_t) = z_k(y_{c,t-1},k_t)\, k_t / z(y_{c,t-1},k_t)$ for chemistry and $m^c(y_{c,t-1},k_t) = g_k(y_{m,t-1},k_t)\, k_t / g(y_{m,t-1},k_t)$ for mathematics, and suppose $e^m(y_{m,t-1},k_t) < e^c(y_{c,t-1},k_t)$ for every $\{y_{m,t-1}, y_{c,t-1}, k_t\}$. Then discipline-threshold prices are

$$p_c' = z(y_{c,t-1},k_c^*) - z_k(y_{c,t-1}, k_c^*)\, k_c^* = z(y_{c,t-1},k_c^*)(1 - e^c(y_{c,t-1},k_c^*))$$
$$p_m' = g(y_{m,t-1}\, k_m^*) - g_k(y_{m,t-1},k_m^*)k_m^* = g(y_{m,t-1}\, k_m^*)(1-e^m(y_{m,t-1}, k_m^*))$$

If existing knowledge is equally valuable across disciplines, so that $y_{c,t-1} = y_{m,t-1}$, then $p_m' \geq p_c'$. More generally, p' is weakly decreasing in the elasticity of knowledge with respect to physical capital

$$\frac{\mathrm{d}\,p'}{\mathrm{d}e(y_{t-1},k*)} = -\mathrm{f}(y_{t-1}, k*) \leq 0 \text{ if } \mathrm{f}(y_{t-1}, k*) > 0 \quad (7)$$

For a Cobb-Douglas production function $y_t = y_{t-1}^{\,1-\alpha} k_t^{\alpha}$, where α is the elasticity of knowledge production with respect to physical capital

$$\frac{\mathrm{d}\,p'}{\mathrm{d}\alpha} = \alpha^{\frac{\alpha}{1-\alpha}}\, y\, r^{\frac{\alpha}{\alpha-1}} \frac{1}{1-\alpha} \log(\alpha/r) \leq 0 \;\; if \;\; \alpha \leq r$$

which implies that the threshold price of existing knowledge at which scientists invest in new knowledge is (weakly) increasing in the elasticity of knowledge with respect to capital.

Plots of citations confirm that the differential increase in citations after 1941 was significantly stronger for mathematics than chemistry. English-language citations to BRP books in mathematics increased from 0.198 citations per book and year until 1941 to 0.472 in

1946 and 1.890 in 1956, while non-English language citations remained low (Figure 4). By comparison, English-language citations to BRP books in chemistry only increase from 0.244 per book and year until 1941 to 0.281 in 1946 and 0.469 in 1956, while non-English language citations decrease from 0.375 until 1941 to 0.114 in 1946, and increase to 0.399 in 1956 (Appendix Figure A6). To evaluate the statistical significance of a differential effect on mathematics, we estimate

$$cites_{ilt} = \alpha\ English_l + \beta\ English_l \times post_t + \varphi\ English_l * math_i * post_t + book_i + \tau_t + \varepsilon_{it} \quad (8)$$

where $math_i$ is an indicator for BRP books in mathematics. Estimates for the triple differences estimator *English * math * post* indicate that, compared with citations in chemistry, English–language citations to BRP in mathematics increase by an additional 0.674 compared with citations in other languages after 1941 (Table 4, column 1, significant at 5 percent). Relative to a pre-BRP mean of 0.263 citations, this implies an additional 2.6 fold increase for mathematics.[37] Estimates with fixed effects for the research fields and the publication years of BRP books indicate 0.565 additional citations (Table 4, column 2, significant at 5 percent), which implies an additional 2.2-fold increase.[38]

To further investigate differential effects of price across disciplines, we estimate

$$cites_{ilt} = \alpha\ English_l + \beta\ English_l \times post_t + \varphi\ English_l * math_i * post_t + \eta\ \Delta p_i * English_l * math_i * post_t + book_i + \tau_t + \varepsilon_{it} \quad (9)$$

OLS estimates of this specification imply that a 10-percent decline in price is associated with 0.238 additional English-language publications for mathematics compared with chemistry (*English * math * Δp * post*, Table 4, column 5, significant at 1 percent).[39] Relative to a pre-BRP mean of 0.263 citations for BRP books, this implies an additional 90 percent increase.

Time-varying estimates indicate no significant differences until 1941. Until 1941 estimates range from -0.051 citations in 1931-32 (p-value 0.03, Figure 5) to 0.066 in 1935-36 (p-value 0.07). After the war, estimates increase to 0.309 for 1951-52 (p-value 0.05, Figure 5), and 0.447 in 1953-54 (p-value 0.00). Estimates remain large and significant until 1969-70, with 0.438 (p-value 0.00), which implies a 166 percent increase.[40]

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[37] BRP math books receive 0.753 additional English-language citations compared with non-English language citations after 1941 ($BRP_i \times post_t + BRP_i \times math_i \times post_t$, significant at 10 percent, Table 4, column 1).
[38] Controlling for a linear pre-trend leaves the estimate for *English * math * post* unchanged at 0.674 (Appendix Table A4, column 3, significant at 5 percent), and increases *English * post* to 0.317 (p-value 0.18).
[39] For each 10-percent decline in price, BRP math books receive 0.303 additional English-language citations after 1941 ($BRP_i * \Delta p_i * post_t + BRP_i * math_i * \Delta p_i * post_t$, significant at 10 percent, Table 4, column 5).
[40] For chemistry, estimates of time-varying effects range from -0.019 in 1933-34 (with a p-value of 0.47) to 0.038 in 1941-42. After 1941, estimates reach 0.066 in 1947-48 (p-value of 0.02), 0.068 in 1953-54 (p-value of 0.04), and remain large and significant until 1969-1970 with an estimate of 0.104 (p-value of 0.19).

V. Comparisons of BRP and Swiss books

Our second identification approach compares changes in *citations by English-language authors* to BRP books and Swiss books. It addresses the potential issue that citations by English-language authors may have increased independently of the BRP, e.g., as a result of a differential expansion in the US economy after World War II. Like German chemists and mathematicians, Swiss scientists - such as Alexander Ostrowski (1893-1986) and Eduard L. Stiefel (1909-1978) - were leaders in their fields, and they also published primarily in German.[41] Books with Swiss-owned copyrights were, however, not available for the BRP due to Switzerland's neutrality during the war.

Swiss books receive fewer citations overall, but trends in citations are comparable until 1942 (Figure 6). In 1932, for example, the average BRP book is cited by 0.182 new English-language publications per book and year, and the average Swiss books is cited by 0.016 new scientific publications per year. Citations increase slightly until 1938 and decline to 0.285 for BRP books and 0.012 for Swiss books in 1940.[42] After the war, citations to BRP books grow to 0.746 in 1956, while citations to Swiss books increase only to 0.065. Citations to BRP books remain high around 0.700 per book year until 1970, while citations to Swiss books remain below 0.150 (Figure 6).

To systematically investigate this differential change, we estimate OLS regressions with controls for book fixed effects and for the publication years of citing publications:

$$cite_{it} = \beta\, BRP_i * post_t + book_i + \tau_t + \varepsilon_{it} \quad (10)$$

where the dependent variable $cite_{it}$ measures citations to BRP and Swiss books by new English-language publications to book i per year t between 1920 and 1970, and the indicator variable *BRP* equals 1 for books that US publishers reprinted under BRP.

OLS estimates indicate that an additional 0.392 new publications by English-language authors per year cite BRP book after 1941 compared with Swiss books (Table 5, column 1, significant at 1 percent). Relative to a pre-BRP mean of 0.263, this implies a 149 percent increase. Alternative specifications with controls for the publication year and the research

[41] Stiefel's (1935) dissertation *Richtungsfelder und Fernparallelismus in n-dimensionalen Mannigfaltigkeiten* describes n-dimensional (Stiefel) manifolds $V_k(R^n)$, or the set of all orthonormal k-frames in R^n. Stiefel was a co-inventor of the conjugate gradient method and the study of characteristic classes. He founded the Swiss Institute of Applied Mathematics, whose objective was to design and construct an electronic computer.

[42] Between 1941 and 1945, when the Allied bombing campaign destroyed research facilities in Germany, citations to BRP books declined more than citations to Swiss books. Bombings reached a peak of 130 tons per months at the beginning of 1945 (Webster and Frankland 1961, Annex). Waldinger (forthcoming) estimates that a 10 percent increase in the destruction of physical capital reduced research output by 0.05 standard deviations.

fields of BRP and Swiss books show that BRP books received an additional 0.436 citations (Table 5, column 4, significant at 1 percent), which implies a 163 percent increase.[43]

The main challenge for comparing changes in citations for BRP and Swiss books is that some of the observed increase in citations may reflect pre-existing characteristics of books that US publishers selected for the BRP. Qualitative historical evidence alone cannot pin down the direction of selection. For example, archival records for J.W. Edwards only specify that "Edwards Brothers' editor, Bernard A Uhlendorf, formerly employed by the University of Michigan Library, was responsible for choosing the titles appropriate for EB's publication program" (Bokas and Edwards 2011, p. 25). BRP books may be positively selected if publishers chose books with high expected demand, but they may be negatively selected because US publishers had not chosen to publish them under the market price for copyright licenses. To address this issue, we include book fixed effects to control for differences in the level of citations (e.g. Table 5, column 1), and robustness checks allow for BRP-specific pre-trends in citations (Table 5, columns 3).

We also we estimate Mahalanobis propensity score matching regressions (Abadie and Imbends 2002) for 214 BRP books and 39 Swiss books with similar research fields and pre-BRP stocks of citations (Appendix Table A8). In the matched sample, citations to BRP books increase from 0.283 per book and year until 1941 to 0.661 afterwards, while citations to Swiss books remain low around 0.2 (Appendix Figure A7). OLS estimates for the matched sample indicate that BRP books receive 0.386 additional citations after 1941 (Appendix Table A8, column 1, significant at 1 percent). Relative to the pre-BRP mean of 0.283 for BRP books, this implies a 136 percent increase. Similarly, a 10-percent decline in price is associated with 0.112 additional citations (Appendix Table A8, column 4, significant at 1 percent), which implies a 40 percent increase.

VI. Mechanism

Historical sources suggest that lower prices helped to diffuse BRP books across US libraries and firms (e.g., Bokas and Edwards 2011, p. 25), allowing a new group of scientists to use BRP books in their research. We construct historical data on library holdings, loans, and the locations of citing authors to investigate this channel.

A. Diffusion across Libraries

[43] An additional test restricts the sample to books in the Library of Congress. Although this sample is small, with 293 BRP and 19 Swiss books, estimates are robust (Appendix Table A10).

Data on historical library holdings, which we construct from the *National Union Catalog* (NUC, Mansell 1968-1981), make it possible to examine variation in the diffusion of books across US libraries. These data indicate that BRP books had become distributed relatively evenly across US libraries after 1941 (Figure 7), with significant holdings in university libraries outside of the US Northeast, such as Ohio State, Oregon, and Virginia. By comparison, Swiss books remained more concentrated in the holdings of two exceptionally wealthy libraries, the John Crerar Research Library at Chicago and the Yale University Library (Figure 7), while the average US library held only 4 Swiss books.

Library data also show that BRP books whose price declined more in 1942 had become more widely available across US libraries by 1956. BRP books in the top quartile of the price decline (ranging from 40 to 90 percent) had become available in 20 libraries and 11 US states on average by 1956 (Appendix Figure A8). Beilstein's *Handbuch der Organischen Chemie* (1918), with a price decline of 90 percent, had become available in 90 of 218 US libraries by 1956. By comparison, BRP book in the bottom quartile of the price decline (8 percent or less) had become available only in 14 of 218 US libraries.[44]

B. Data on the Timing of Loans for BRP Books

Despite the richness of the data, the NUC alone cannot capture variation in the availability and in the usage of BRP books over time, because libraries did not systematically record acquisition dates for science books.[45] To address this issue and to capture variation in usage over time, we therefore examine physical copies of check-out sheets that are attached to the inside back cover of a book. We have been able to collect these data for 127 BRP books, 45 percent of all BRP books in the holdings of Stanford's library in 2016.[46]

Data on library loans reveal a striking increase in the use of BRP books after 1941 (Figure 8). Until 1941, only two BRP books had been borrowed from the Stanford library at least once (*Stereochemie* by K. Freudenberg and *Die Mathematischen Hilfsmittel des Physikers* by E. Madelund). After 1941, three additional BRP books were borrowed for the

[44] Each additional 10 percent decline in price was associated with a 1.3 percent increase in the share of libraries that held a BRP book (with a p-value of 0.00). Excluding outliers (such as Beilstein), which can be found in more than 40 percent of US libraries, leaves the estimate at 0.8 (with a p-value of 0.00).

[45] For example, we received the following response from a Curator of Special Collections at Stanford's Library: "The library did not maintain any acquisition records before 1994 for this type of materials. I asked our acquisitions department if there is any way to capture this information, but it appears unlikely. This type of information simply was not considered useful for these books" (Kathleen M. Smith, Stanford, April 4, 2016).

[46] The average BRP book in Stanford's library sold for $68.16 until 1941, and became 34 percent cheaper under the BRP. Loan data exclude reference works, such as Beilstein, because they cannot be borrowed. We are less likely to observe the original cards for popular books because check-out sheets were replaced once they had filled up; this lead us to estimate usage with a delay for more popular books.

first time in 1944, two in 1945, 1948, 1949, and 1952 each, and five in 1955. Data on the overall use of books (shown as the dashed line in Figure 8) further indicate that scientists used BRP books repeatedly in the 1940s and 50s.

C. Citing Authors Near BRP Libraries

Next, we explore whether the diffusion of BRP books across US libraries triggered an increase in citations. Location data suggest that citations tracked the geographic diffusion of BRP books. Until 1941, 64 percent of citations to BRP books originate from the Northeast (Cambridge MA, Princeton, and Providence) and Chicago. After 1941, citations to BRP books expand to the West Coast (including 63 citations from Los Angeles, 47 from Stanford and 36 from Berkeley), and the Midwest (with 36 citations in Madison, WI, Figure 9).

We now examine whether locations near BRP books – defined by a 25-mile commute - experienced a larger increase in citations. Eighty-seven of 101 total locations are within a 25-mile radius of BRP books, and 21 locations are further away. We estimate:

$$cite_{kt} = \beta \text{ within 25 miles}_k \times post_t + \eta_k + \tau_t + \varepsilon_{it} \quad (11)$$

where the dependent variable $cite_{kt}$ counts citations from authors at location k and year t. The explanatory variable *within 25 miles*$_k$ equals 1 for locations within 25-mile radius of a BRP book. The vector η_k includes dummies to control for geographic variation, e.g., if some locations were always more productive because they have better resources, or if they are always more likely to cite German science books.

OLS estimates confirm that locations near BRP books experienced a larger increase in citations. Authors who are within 25 miles of BRP books produce an additional 0.184 publications that cite BRP books per year after 1941(Appendix Table A11, column 1, significant at 1 percent) compared with authors in more distant locations. Relative to a pre-BRP mean of 0.031, this implies a 5.93-fold increase.

Importantly, there is no evidence of differences in the trends of citations before 1941, even though levels of citations are lower in more distant locations (Appendix Figure A9). The estimated effects of nearness also attenuate with distance and eventually become negative. Locations within a 50-mile radius produce 0.138 additional citations (Appendix Table A11, column 2, significant at 1 percent), which implies a 4.45-fold increase. With a full set of distance dummies, coefficients for locations *within 25 miles* and *25-50 miles* are positive, large, and statistically significant (at the 1 percent level, Appendix Table A11, column 4), whereas estimates become negative or insignificant above 50 miles.

VI. Alternative Measures of New Science and Innovation

Although citations are the standard measure of knowledge flows and cumulative innovation (e.g., Eysenbach 2006; Evans and Reimer 2009; Furman and Stern 2012), they are imperfect (e.g. Paris et al. 1998; Jannot et al. 2013). To help address this issue, we examine two complementary measures for cumulative science and innovation: new PhDs in mathematics, and US patents that build on knowledge in BRP books.

A. New PhDs in Mathematics

Changes in the number of new PhDs are a useful complement to book-specific changes in citations, because they capture variation in scientific output *above the level of individual books*. To construct this measure, we collect data for 13,623 mathematicians who received their PhDs between 1920 and 1970 across 180 locations from the Mathematics Genealogy Project. A map of these data shows that locations with BRP books produced more PhDs after 1942 compared with other locations (Appendix Figure A10). We then estimate distance regressions in equation (11) for new PhDs:

$$PhD_{kt} = \beta \text{ within 25 miles}_k \times post_t + \eta_k + \tau_t + \varepsilon_{it} \quad (12)$$

where PhD_{kt} counts new math PhDs in location k and year t, and the variable *within 25 miles*$_k$ indicates locations that are within 25 miles of at least one BRP math book. OLS estimates indicate that locations within 25 miles of BRP books produce 0.798 additional PhDs per year after 1941 compared with more distant locations. Relative to a mean of 0.358 until 1941, this implies a 2.23-fold increase (Table 6, column 1, significant at 10 percent).

Importantly, there are no significant differences in trends for locations that are near or far from BRP books (Appendix Figure A11), even though distant locations produce fewer PhDs on average. Locations within 25 miles of a BRP books produce 0.4 new PhDs per year until 1941, compared with 0.2 in more distant locations. After 1941, the number of new math PhDs increases to 2.7 per year in locations near BRP books, compared with 1.7 in more distant locations.

B. Patents

Analyses of publications and PhDs have allowed us to examine the BRP's effects on science. Yet the BRP may have also helped to encourage innovation by private firms, which cannot be captured by these measures. Anecdotal evidence suggests that the BRP's impact on the private sector may have been significant. For example, records for J.W. Edwards's suggest that private firms bought even more copies of Beilstein's *Handbuch der Organischen*

Chemie than libraries under the BRP. NUC data on library holdings indicate that 158 libraries bought a copy of Beilstein, which leaves 442 copies (in total 600 sold copies, Bokas and Edwards 2011, p. 25) for private firms. More generally, patents measure more applied advances in cumulative innovation compared with citations and other measures of cumulative science, which makes them a useful complement to these measures.

Confirming the main results, patent data suggest that the BRP was associated with a substantial increase in cumulative invention. Until 1941, a total of 34 US patents cite at least one BRP book in the description of their invention.[47] After 1941, 200 patents cite at least one BRP book. Beilstein, for example, receives 0.304 patent citations per year until 1941, and 1.345 afterwards. For the average BRP book, counts of citing patents increase by 15 percent, from 0.005 per book and year until 1941 to 0.024 afterwards (Figure 10).

VII. Conclusions

In 1942, the US Book Republication Program licensed German science books to US publishers, allowing them to reprint exact copies. A key effect of the program was a 25 percent decline in the price of the average book. We use this decline in price to examine the influence of price on the creation of new, cumulative knowledge. Two independent identification strategies show that lower prices led to a great increase in citations to BRP books. This increase is stronger for mathematics (a discipline that is less dependent on physical capital) than chemistry (which requires physical capital, for example, in the form of laboratory space). Books by émigrés became even more heavily cited than the average BRP book, yet émigré books cannot explain the overall increase in citations.

How can lower book prices promote the creation of new knowledge? Historical data on library holdings indicate that the lower prices helped to diffuse German science books across US libraries. Compared with Swiss books, for example, BRP books became substantially more evenly diffused across US libraries in the Western and Southern United States. This shift enabled a new group of US scientists to access German science books and use them in their own research. Two alternative measures of scientific output and innovation – new PhDs and new patents – confirm the main results.

These findings highlight an important tradeoff for intellectual property rights policy. Previous work has shown that short and narrow copyright terms can encourage creativity by

[47] Thirty patents cite a BRP chemistry book and 4 cite a BRP math book until 1941; 190 patents cite a BRP chemistry book and 10 cite a BRP math book after 1941 (530 and 150 percent more, respectively.) The larger number of chemical patents reflects the exceptional effectiveness of patents in chemicals (e.g. Moser 2012a).

increasing the payoffs from creative work (e.g., MacGarvie and Moser 2013), and by encouraging creative individuals to invest in high-quality pieces (Giorcelli and Moser 2015). Yet copyrights also increase the costs of accessing existing work for later generations. These costs are especially high when copyright terms are long-lived, as they are today. The main result of this paper - that lower access costs can promote new science - underscores the benefits of short-lived intellectual property.

REFERENCES

Katalog. Systematisches Verzeichnis der Schweizerischen oder die Schweiz betreffenden Veröffentlichungen (vols. 1921-1939 and 1931-1940), Bern, H. Huber.

Library of Congress, 1968-1981. *The National Union Catalog, pre-1956 Imprints: A Cumulative Author List Representing Library of Congress Printed Cards and Titles Reported by Other American Libraries, Compiled and Edited with the Cooperation of the Library of Congress and the National Union Subcommittee of the Resources Committee of the Resources and Technical Services Division, American Library Association.* London, Mansell.

Abadie, Alberto, and Guido Imbens. 2011. "Simple and Bias-corrected Matching Estimators for Average Treatment Effects." *Journal of Business & Economics Statistics* 29 (1): 1-11.

Alien Property Custodian Office. 1944. "*Book Republication Program: Titles Suggested for Republication, an Alphabetical List with a Subject Index.*" United States.

Ammon, Ulrich. 2001. *The Dominance of English as a Language of Science: Effects on Other Languages and Language Communities.* Berlin: Mouton de Gruyter

Beilstein, Friedrich Konrad. 1918. *Beilstein's Handbuch der Organischen Chemie.* Berlin: J. Springer.

Bird, Kai and Martin J. Sherwin. 2005. "American Prometheus. The Triumph and Tragedy of J. Robert Oppenheimer." New York. Alfred A. Knopf.

Bokas, Carol and Jim Edwards. 2011. *Then and Now. A History Thomas Edwards Senior, His Descendants, and Related Families, 1826-2011*. Ann Arbor Editions.

DiCola, Peter. 2013. "Money from Music: Survey Evidence on Musicians' Revenue and Lessons About Copyright Incentives." *Arizona Law Review* 301.

Evans, James A., and Jacob Reimer. 2009. "Open Access and Global Participation in Science." *Science* 323 (5917): 1025.

Eysenbach, Gunther. 2006. "Citation Advantage of Open Access Articles." *Public Library of Science Biology* 4 (5): 692.

Furman, Jeffrey, and Scott Stern. 2011. "Climbing atop the Shoulders of Giants: The Impact of Institutions on Cumulative Research." *American Economic Review* 101 (5): 1933-63.

Galasso, Alberto and Mark Schankerman. 2015. "Patents and Cumulative Innovation: Causal Evidence from the Courts." *The Quarterly Journal of Economics* 130 (1): 317-369.

Giorcelli, Michela, and Petra Moser. 2015. "Copyright and Creativity: Evidence from Italian Operas." Working Paper. http://ssrn.com/abstract=2505776.

Goldstein, Paul. 2003. *Copyright's Highway: From Gutenberg to the Celestial Jukebox*. Stanford, CA: Stanford University Press, Revised Edition.

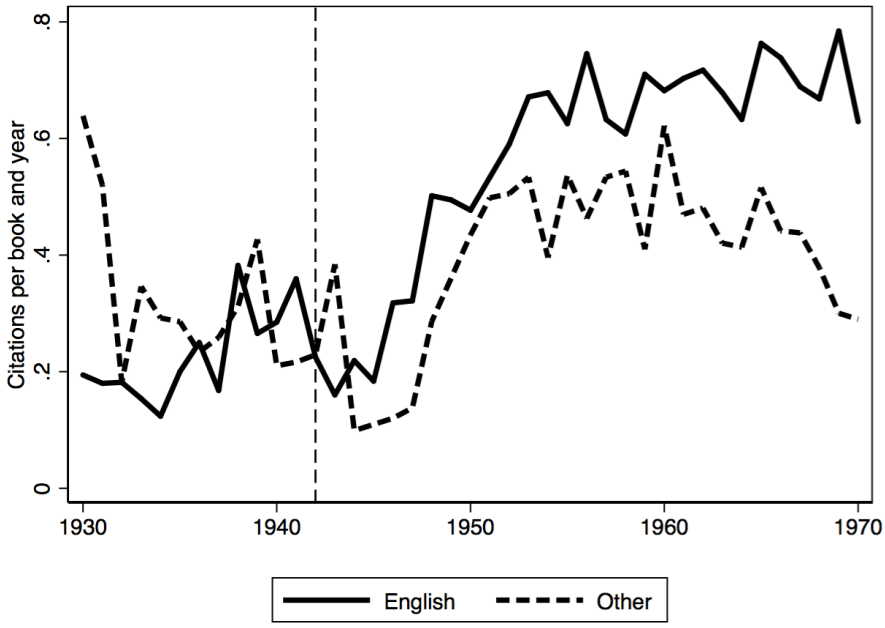
Hargittai, István. 2006. *Martians of Science: Five Physicists Who Changed the Twentieth Century*. Oxford: Oxford University Press.

Heald, Paul J. 2014. "How Copyrights Keeps Works Disappeared." *Journal of Empirical Legal Studies* 11 (4): 829-866.

Iaria, Alessandro, and Fabian Waldinger. 2015. "International Knowledge Flows: Evidence from the Collapse of International Science in the Wake of WWI." Working Paper, Warwick University.
Jannot, Anne-Sophie, Thomas Agoritsas, Angèle Gayet-Ageron, and Thomas V. Perneger. 2013. "Citation Bias Favoring Statistically Significant Studies was Present in Medical Research." *Journal of Clinical Epidemiology* 66 (3): 296-301.
Landes, William M., and Richard A. Posner. 1989. "An Economic Analysis of Copyright Law." The *Journal of Legal Studies* 18 (2): 325-363.
Li, Xing, Megan MacGarvie, and Petra Moser. 2015. "Dead Poets' Property – How Does Copyright Influence Price?" http://ssrn.com/abstract=2170447.
MacGarvie, Megan and Petra Moser. 2013. "Copyright and the Profitability of Authorship: Evidence from Payments to Writers in the Romantic Period," in Shane M. Greenstein, Avi Goldfarb, and Catherine Tucker (eds.) *The Economics of Digitization* Chicago, Illinois: University of Chicago Press.
McCabe, Mark J., and Christopher M. Snyder. 2015. "Does Online Availability Increase Citations? Theory and Evidence from a Panel of Economics and Business Journals." *Review of Economics and Statistics* 97 (1): 144-165.
Meho, Lokman I., and Kiduk Yang. 2007. "Impact of Data Sources on Citation Counts and Rankings of LIS Faculty: Web of Science Versus Scopus and Google Scholar." *Journal of the American Society for Information Science and Technology* 58 (13): 2105-2125.
Moser, Petra. 2012a. "Innovation without Patents" Innovation without Patents: Evidence from World's Fairs." *The Journal of Law & Economics* 55 (1): 43-74
Moser, Petra. 2012b. "Taste-Based Discrimination: Evidence from a Shift in Ethnic Preferences after WWI." *Explorations in Economic History* 49 (2): 167-188.
Moser, Petra and Alessandra Voena. 2012. "Compulsory Licensing: Evidence from the Trading with the Enemy Act." *American Economic Review*, 102(1): 396-427.
Moser, Petra, Alessandra Voena, and Fabian Waldinger. 2014. "German-Jewish Émigrés and US Invention." *American Economic Review* 104 (10): 3222-3255.
Müller-Langer, Frank, and Richard Watt. 2014. "The Hybrid Open Access Citation Advantage: How Many More Cites is a $3,000 Fee Buying You?" *Max Planck Institute for Innovation & Competition Research Paper*, (14) 2.
Murray, Fiona, Philippe Aghion, Mathias Dewatripont, Julian Kolev, and Scott Stern. 2016. "Of Mice and Academics: Examining the Effect of Openness on Innovation." *American Economic Journal: Economic Policy,* (8) 1, pp. 212-252.
Myron, Paul. 1945. "The Work of the Alien Property Custodian." *Law and Contemporary Problems* 11: 76-91.
Nagaraj, Abishek. 2015. "Does Copyright Affect Reuse? Evidence from the Google Books Digitization Project." Working Paper.
Oberholzer-Gee, Felix, and Koleman Strumpf. 2007. "The Effect of File Sharing on Record Sales: An Empirical Analysis." *Journal of Political Economy*, 115 (1): 1-42.
Paris, Gianmarco, G. De Leo, P. Menozzi, M. Gatto. 1998. "Region-based Citation Bias in Science." *Nature* 396 (6708): 210-210.
Reimers, Imke. 2014. "Copyright and Generic Entry in Book Publishing." Northeastern University, Working Paper.
Richards, Pamela Spence. 1981. "Gathering Enemy Scientific Information in Wartime: The OSS and the Periodical Republication Program." The Journal of Library History (1974-1987), 16 (2): 253-264.
Sampat, Bhaven, and Heidi L. Williams. 2016. "How do patents affect follow-on innovation? Evidence from the human genome." NBER Working Paper No. w21666.

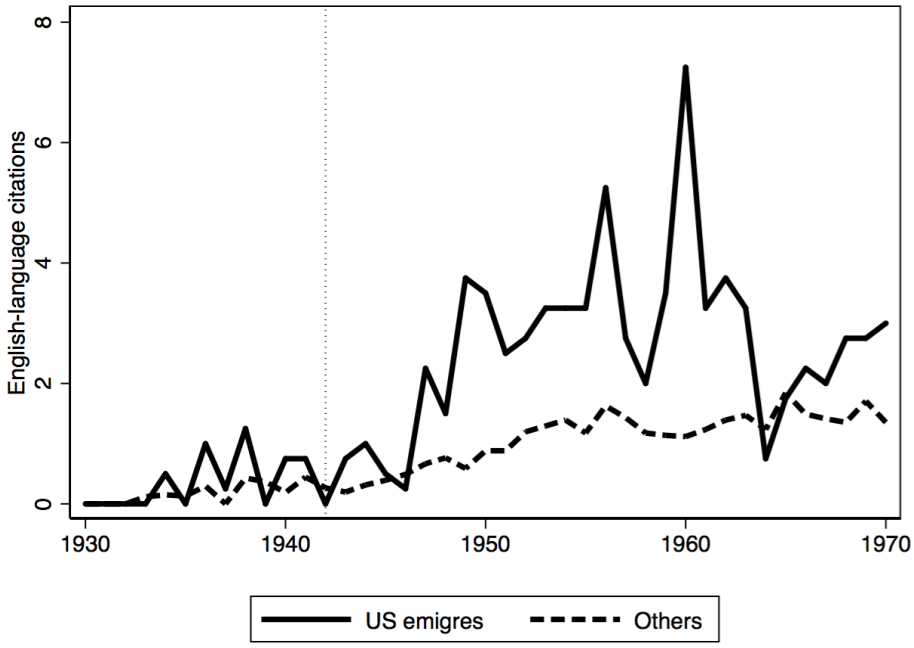
Scotchmer, Suzanne. 1991. “Standing on the Shoulders of Giants: Cumulative Research and the Patent Law.” *The Journal of Economic Perspectives* 5 (1): 29-41.
Stern, Scott. “Do Scientists Pay to Be Scientists?”*Management Science* 50 (6): 835-853.
Strauss, Herbert A., Werner Röder, Belinda Rosenblatt, and Hannah Caplan. 1983. *International Biographical Dictionary of Central European Émigrés 1933-1945. Vol II: Arts, Sciences and Literature*. New York: K.G. Saur.
Varian, Hal R. 2005. “Copying and Copyright.” *The Journal of Economic Perspectives* 19 (2): 121-138.
Waldfogel, Joel. 2012. “Copyright Protection, Technological Change, and the Quality of New Products: Evidence from Recorded Music since Napster.” *Journal of Law and Economics* 55 (4): 715-740.
Waldinger, Fabian. forthcoming. “Bombs, Brains, and Science - The Role of Human and Physical Capital for the Creation of Scientific Knowledge.” *Review of Economics and Statistics*.
Webster, Charles K. and Noble Frankland. 1961. *The Strategic Air Offensive Against Germany 1939-1945*. vol. 1-4, London: Her Majesty’s Stationary Office.
Williamson, Samuel H. 2016. "Seven Ways to Compute the Relative Value of a U.S. Dollar Amount, 1774 to present." *MeasuringWorth*.

FIGURE 1 – CITATIONS TO BRP BOOKS
FROM PUBLICATIONS IN ENGLISH VERSUS OTHER LANGUAGES



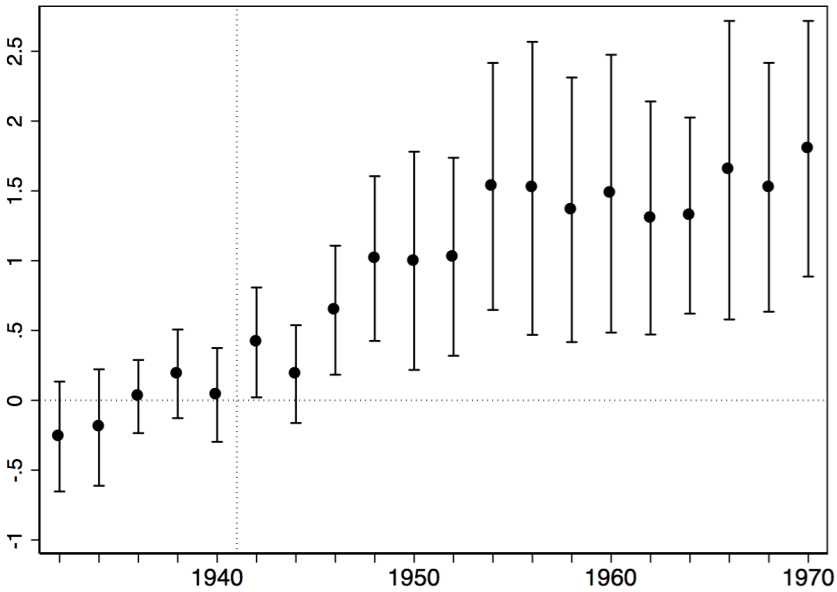
Notes: *English* are citations to BRP books by English-language authors by the publication year of the citing publication. *Other* are citations from authors publishing in other languages). Citations collected from Google Scholar (http://scholar.google.com, accessed July 1st-September 25th, 2014), and manually assigned to a publication language.

FIGURE 2 – CITATIONS TO BRP BOOKS BY ÉMIGRÉS COMPARED WITH OTHER BOOKS



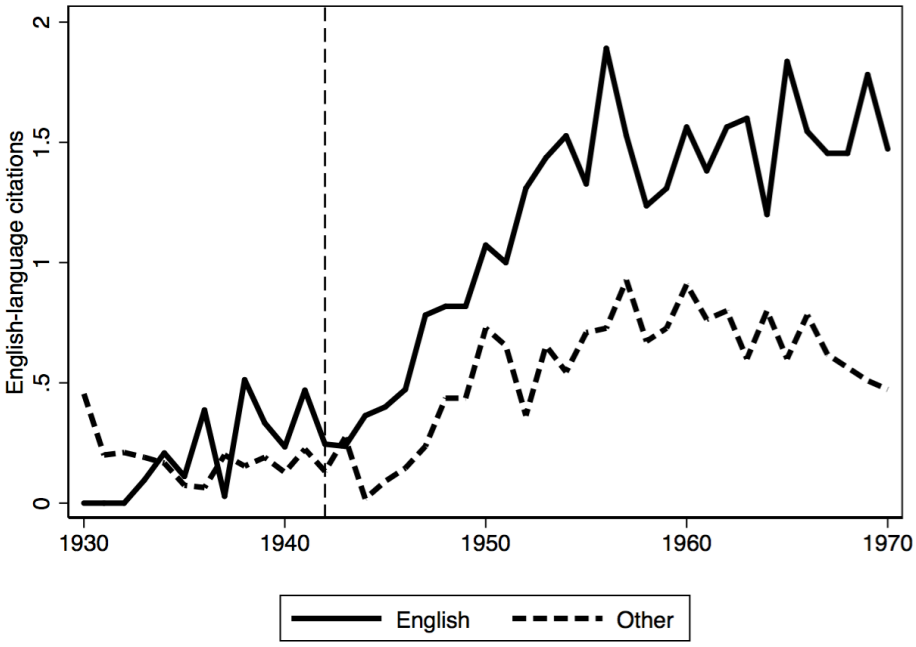
Notes: *US emigres* captures English-language citations per book and year for five BRP books by seven mathematicians who emigrated to the United States after 1932. *Others* counts English-language citations to BRP books by other authors who did not move to the United States. Data on émigrés from the *Dictionary of Central European Émigrés* (Straus et al. 1983) and Mathematics Genealogy Project.

FIGURE 3– TIME-VARYING EFFECTS OF CHANGES IN THE PRICE OF BOOKS



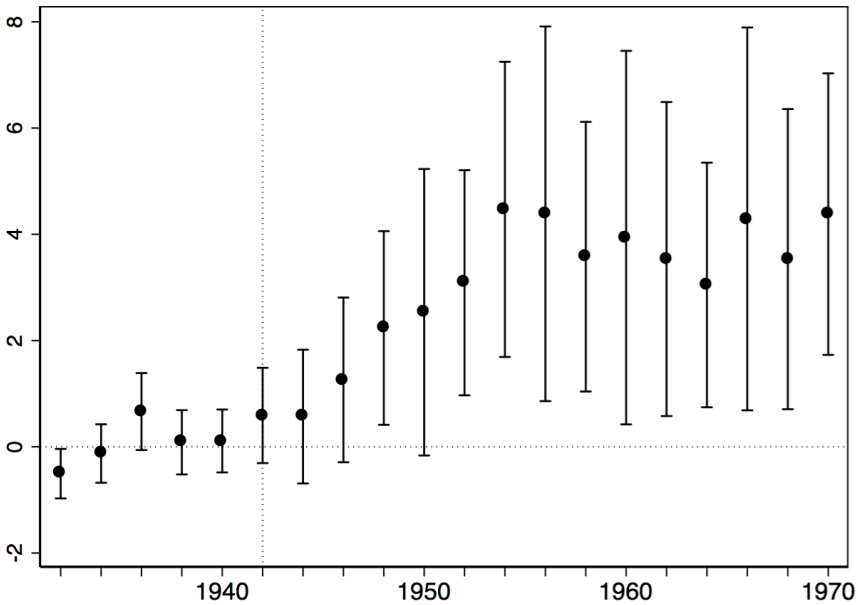
Notes: Estimates of θ_s (with a 95-percent confidence interval) in the OLS regression $cites_{ilt} = \alpha\ English_l + \beta\ English_l \times post_t + \Sigma_s\ \theta_s\ \Delta p_i * English_l * \eta_s + book_i + \tau_t + \varepsilon_{it}$ for two-year intervals 1930-131,…,1969-70, with years before 1930 as the excluded period. The dependent variable $cite_{it}$ counts citations to BRP book *i* in year *t.* The indicator *English* equals 1 for citations from English-language authors. $Book_i$ is a vector of book fixed effects; τ_t indicates 2-years intervals 1930-31, 1932-33, ….1969-70. The variable Δp measures the difference between the original price and the BRP price for book *i*, divided by the original price. Standard errors are clustered at the book level.

FIGURE 4 – CITATIONS PER BOOK AND YEAR IN MATHEMATICS



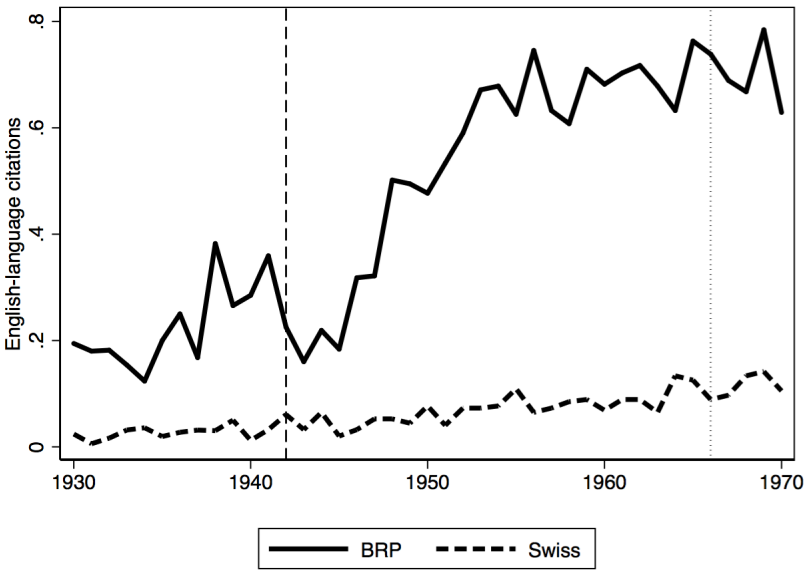
Notes: *English* are citations by English-language authors. *Other* measures citations by authors publishing in other languages. Citations to BRP books collected from Google Scholar (http://scholar.google.com, accessed July 1st-September 25th, 2014).

FIGURE 5 – TIME-VARYING EFFECTS OF PRICE IN MATHEMATICS



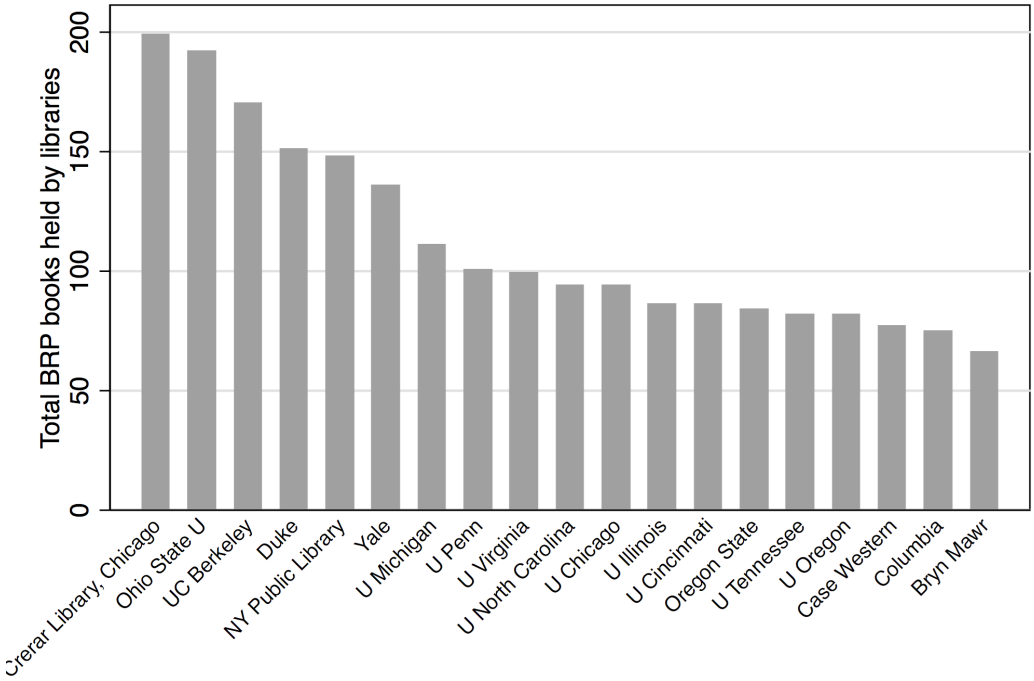
Notes: Estimates of β_s (with a 95-percent confidence interval) in the OLS regression $cites_{ilt} = \alpha\ English_l + \beta\ English_l \times post_t + \Sigma_s\ \theta_s\ \Delta p_i * English_l * \eta_s + book_i + \tau_t + \varepsilon_{it}$ for two-year intervals 1930-1931,…,1969-70, with years before 1930 as the excluded period. The dependent variable $cite_{it}$ counts citations to BRP math book i in year t. The indicator *English* equals 1 for citations by English-language authors. $Book_i$ is a vector of book fixed effects; τ_t indicates 2-years intervals 1930-31, ….1969-70. The variable Δp measures the difference between the original price and the BRP price, divided by the original price. Standard errors are clustered at the book level.

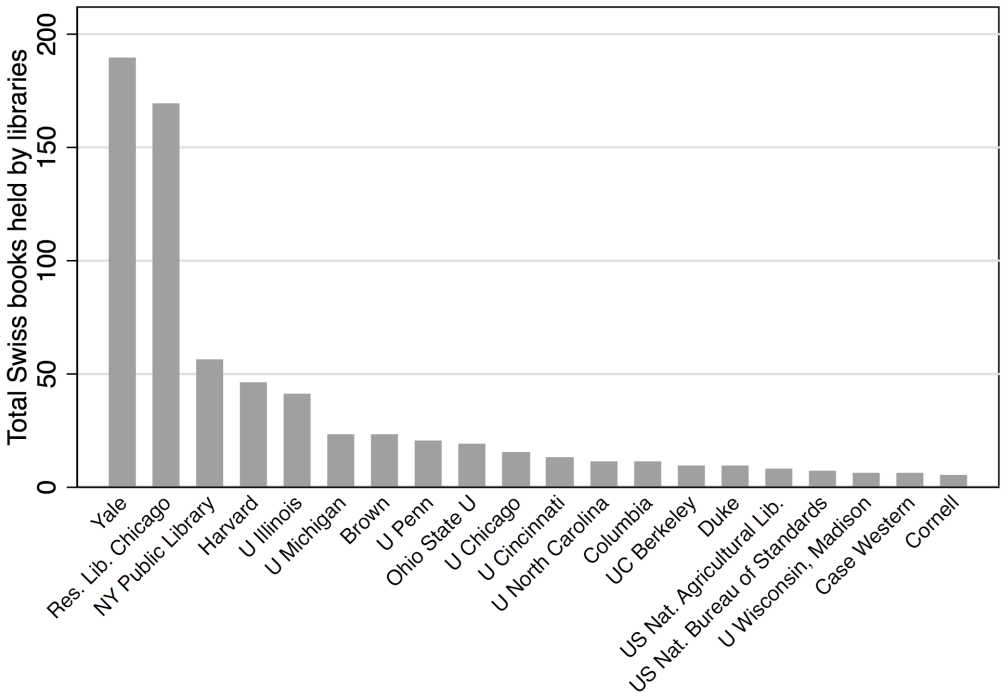
FIGURE 6 – ENGLISH-LANGUAGE CITATIONS TO BRP BOOKS AND SWISS BOOKS



Notes: Citations by new English-language publications to BRP and Swiss books in the National Union Catalog (NUC). Data include 5,141 English-language citations to 283 BRP books and 247 Swiss by new publications between 1930 and 1970 collected from Google Scholar (http://scholar.google.com, accessed July1st to September 25th, 2014).

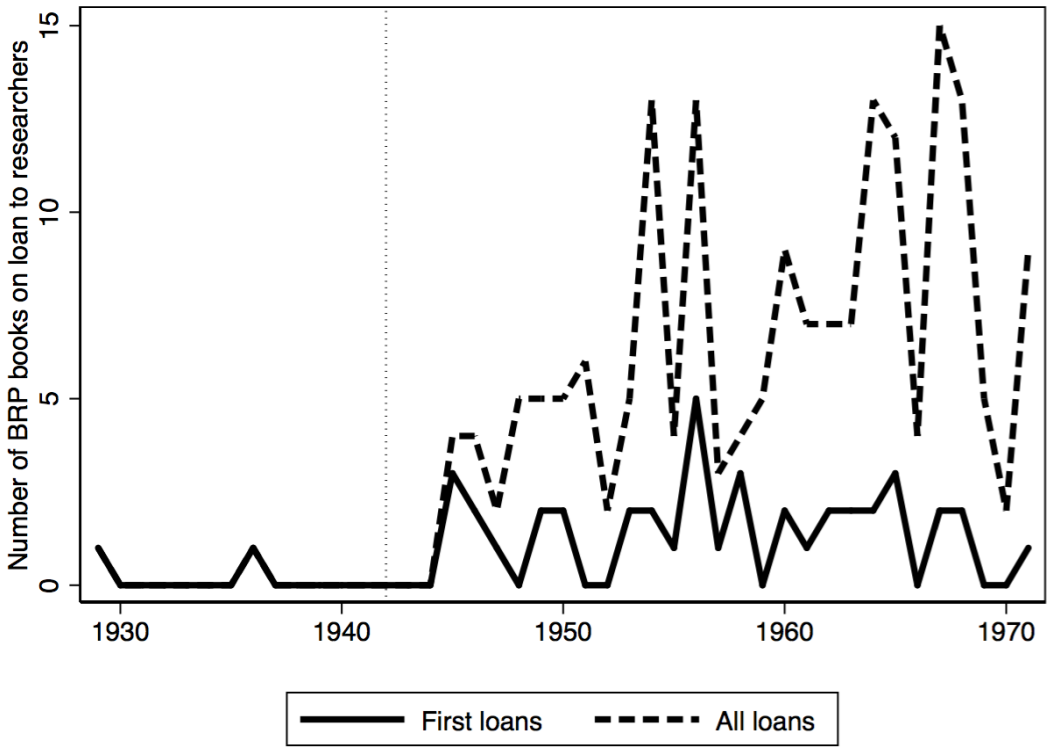
FIGURE 7 – COUNTS OF BRP BOOKS (TOP) AND SWISS BOOKS (BOTTOM) IN THE HOLDINGS OF US LIBRARIES





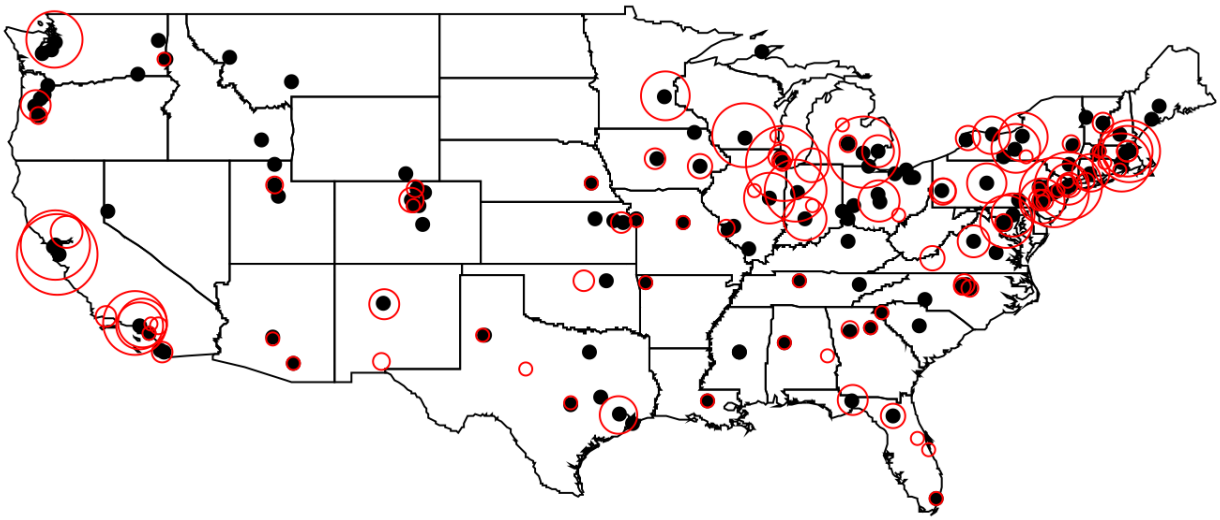
Notes: Counts of BRP books (top panel) and Swiss books (bottom panel) in the holding of a given library. For example, the Crerar Library owned 199 BRP books (top) and 15 Swiss books by 1956. Data on historical library holdings collected from the National Union Catalog (Mansell 1968-1981), accessed at the Hoover Institution Library and Archives.

FIGURE 8 – BRP BOOKS ON LOAN, 1930-1970



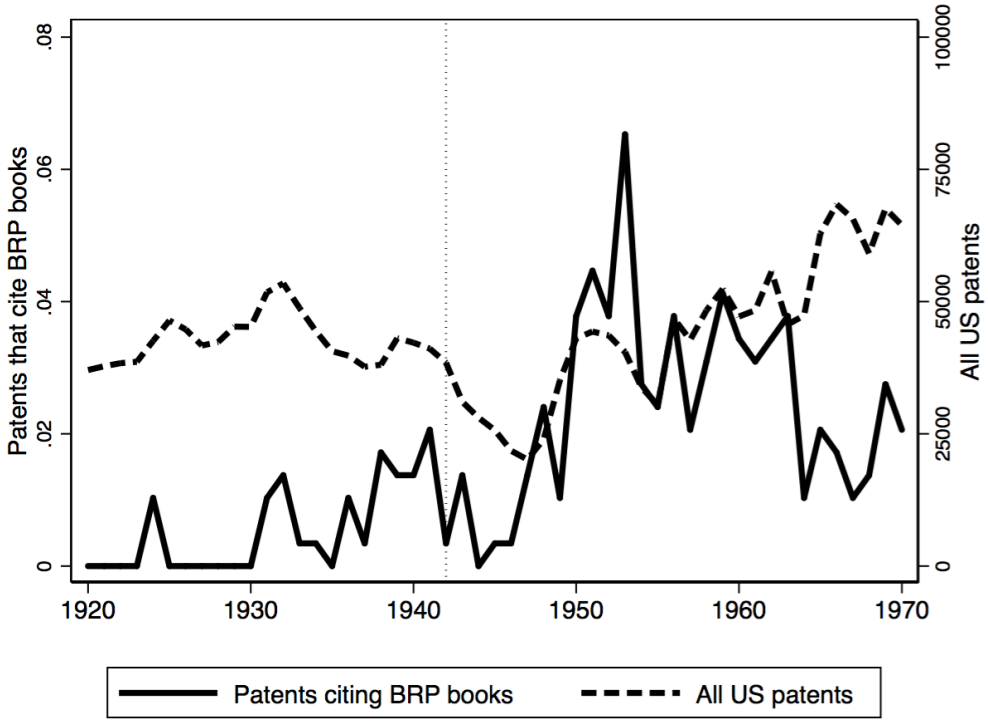
Notes: BRP books on loan to researchers from Stanford's library in year *t*. The solid line (*First loans*) represents the number of BRP books that were first lent to a researcher in year *t*. The interrupted line (*All loans*) plots the total number of BRP books on loan in year *t*.

FIGURE 9 – LOCATIONS OF BRP MATH BOOK AND CITING MATHEMATICIANS



Notes: Black circles are libraries that had acquired BRP math books by 1956. Red circles show the locations of authors who cite BRP math book after the 1942; the size of the red circle represents the number of citations. To identify the locations of citing authors we use records of PhD granting institution of advisors and advisees in the Mathematics Genealogy Project (accessed January 28th-March 10, 2016).

FIGURE 10 – PATENTS THAT CITE BRP BOOKS



Notes: Patents that cite BRP books as relevant scientific knowledge (per filing year, solid line), compared with the total number of US patent filings in the same year. Patents collected from Google Patents (http://patents.google.com, accessed January 1st-April 30th, 2016).

TABLE 1 – COMPARISON OF MEANS
NEW PUBLICATIONS THAT CITE BRP BOOKS PER BOOK AND YEAR

	1920-41	1942-1970	Difference
All (N=283)	0.281	0.479	0.197***
	(0.784)	(1.371)	(0.025)
English	0.263	0.566	0.303***
	(0.775)	(1.653)	(0.041)
Other languages	0.299	0. 391	0. 092***
	(0.793)	(1.006)	(0.026)
Difference	0.036	0.174***	0.211***
	(0.027)	(0.021)	(0. 049)
Chemistry (N=228)	0.306	0.384	0.078***
	(0.838)	(1.088)	(0.023)
English	0.274	0.414	0.140***
	(0.814)	(1.251)	(0.037)
Other languages	0.337	0.353	0.016
	(0.860)	(0.895)	(0.027)
Difference	0.063	0.060***	0.124***
	(0.033)	(0.019)	(0.046)
Mathematics (N=55)	0.204	0.872	0.667***
	(0.574)	(2.138)	(0.077)
English	0.230	1.195	0.965***
	(0.633)	(2.661)	(0.135)
Other languages	0.179	0.549	0.369***
	(0.509)	(1.363)	(0.070)
Difference	0.050	0.647***	0.596***
	(0.041)	(0.075)	(0.152)

Notes: Means and standard deviations (in parentheses) of the number of new scientific publications (including articles and books) that cite a BRP book *i* per year *t* between 1920 and 1970. *English* are citations by English-language authors; *other languages* are citations by authors in other languages that cite the same books. To construct data on citations from different languages, we first collected citations from Google Scholar (available at http://scholar.google.com, accessed July 1st - September 25th, 2014), and then manually assigned all citing publications to their publication language.

TABLE 2 – OLS AND QML POISSON REGRESSIONS

	OLS (1-6)						Poisson (7)
Dependent variable	Citations (1-3)			Ln(Citations) (4-6)			Citations (7)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
English	-0.036	-0.034	-0.034	-0.353**	-0.340*	-0.340*	
	(0.042)	(0.039)	(0.042)	(0.173)	(0.189)	(0.174)	
English x post	0.211***	0.229***	0.229***	0.500***	0.542***	0.542***	0.497***
	(0.066)	(0.061)	(0.067)	(0.179)	(0.179)	(0.181)	(0.157)
Citation year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Book FE	Yes	Yes	No	Yes	Yes	No	Yes
Field * Citation year FE	No	Yes	No	No	Yes	No	No
Publication year FE	No	No	Yes	No	No	Yes	No
Field FE	No	No	Yes	No	No	Yes	No
R-squared	0.357	0.401	0.117	0.316	0.367	0.100	-
N	19,680	19,162	19,162	19,680	19,162	19,162	18,610
Pre-1942 mean	0.263	0. 268	0.268	0.263	0. 268	0.268	0.268

Standard errors in parentheses clustered at the book level. *** p<0.01, ** p<0.05, * p<0.1

Notes: Columns (1-3) estimate OLS; the dependent variable measures citations to book *i* per year *t* between 1920 and 1970. Column (4-6) estimate OLS for the natural logarithm of citations. 15,504 observations (82 percent of all citation year-book pairs) have zero citations; to keep these observations in regressions with logs, we add a tiny number (0.0005). Column (7) estimates quasi-maximum likelihood (QML) Poisson regressions to address the count data characteristics of citations. The indicator *English* equals 1 for citations by *English-language* authors; the control group are citations to the same book from authors in other languages. The variable *post* equals one for years after 1941.

TABLE 3 – OLS AND QML POISSON REGRESSIONS

Dependent variable	OLS (1-6)						Poisson (7)
	Citations (1-3)			ln(Citations) (4-6)			Citations (7)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
English	-0.036	-0.034	-0.034	-0.702***	-0.341*	-0.341*	
	(0.042)	(0.039)	(0.042)	(0.141)	(0.190)	(0.175)	
English x post	-0.077	-0.058	-0.070	0.349*	-0.004	-0.038	0.010
	(0.091)	(0.120)	(0.091)	(0.208)	(0.321)	(0.242)	(0.208)
English x Δp x post	1.192***	1.188***	1.235***	2.413***	2.318***	2.454***	1.470***
	(0.344)	(0.431)	(0.342)	(0.647)	(0.787)	(0.635)	(0.409)
Δp			0.241			1.452**	
			(0.176)			(0.646)	
Citation Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Book FE	Yes	Yes	No	No	Yes	No	Yes
Field FE * Citation year FE	No	Yes	No	No	Yes	No	No
Publication year FE	No	No	Yes	Yes	No	Yes	No
Field FE	No	No	Yes	Yes	No	Yes	No
R-squared	0.366	0.411	0.138	0.305	0.373	0.119	-
N	18,986	18,524	18,524	18,986	18,524	18,524	17,972
Pre-1942 Mean	0.264	0.269	0.269	0.264	0.269	0.269	0.269

Standard errors in parentheses clustered at the book level. *** p<0.01, ** p<0.05, * p<0.1

Notes: Columns (1-3) estimate OLS; the dependent variable measures citations to book *i* per year *t* between 1920 and 1970. Column (4-6) estimate OLS for the natural logarithm of citations. 15,504 observations (82 percent of all citation year-book pairs) have zero citations; to keep these observations in regressions with logs, we add a tiny number (0.0005). Column (7) estimates quasi-maximum likelihood (QML) Poisson regressions to address the count data characteristics of citations. The indicator *English* equals 1 for citations by *English-language* authors; the control group are citations to the same book from authors in other languages. The variable *post* indicates years after 1941. The variable *post* indicates years after 1941. The variable *Δp* measures the difference between the original price and the BRP price for book *i*, divided by the original price.

TABLE 4 – DIFFERENTIAL EFFECTS BY DISCIPLINE
OLS, DEPENDENT VARIABLE IS CITATIONS TO BRP BOOKS PER BOOK AND YEAR

	(1)	(2)	(3)	(4)	(5)	(6)
English	-0.036	-0.034	-0.034	-0.036	-0.034	-0.034
	(0.042)	(0.039)	(0.042)	(0.042)	(0.039)	(0.042)
English x post	0.079	0.115*	0.103**	-0.074	-0.058	-0.072
	(0.053)	(0.063)	(0.052)	(0.091)	(0.120)	(0.091)
English x Math x post	0.674**	0.565**	0.629**			
	(0.279)	(0.218)	(0.266)			
English x Δp x post				0.646**	0.706**	0.650**
				(0.288)	(0.266)	(0.294)
English x Math x Δp x post				2.383***	2.110**	2.588***
				(0.907)	(0.887)	(0.930)
Δp						0.286
						(0.178)
Citation Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Book FE	Yes	Yes	No	Yes	Yes	No
Field * Citation year FE	No	Yes	No	No	Yes	No
Publication year FE	No	No	Yes	No	No	Yes
Field FE	No	No	Yes	No	No	Yes
R-squared	0.367	0.407	0.126	0.382	0.422	0.160
N	19,680	19,162	19,162	18,986	18,524	18,524
Pre-1942 Mean	0.263	0.268	0.268	0.268	0.269	0.269

Standard errors in parentheses clustered at the book level. *** p<0.01, ** p<0.05, * p<0.1

Notes: The dependent variable measures citations to book *i* per year *t* between 1920 and 1970. The indicator *English* equals 1 for citations by *English-language* authors; the control group are citations to the same book from authors in other languages. The variable *post* indicates years after 1941, and *Math* indicates 55 books in mathematics. The variable *Δp* measures the difference between the original price and the BRP price for book *i*, divided by the original price.

TABLE 5 – OLS WITH SWISS BOOKS AS A CONTROL, DEPENDENT VARIABLE IS CITATIONS PER BOOK AND YEAR

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
BRP			-0.635***	0.222**			0.814***	0.159*
			(0.145)	(0.088)			(0.262)	(0.086)
BRP x post	0.392***	0.392***	0.433***	0.436***	0.099	0.097	0.170*	0.127
	(0.086)	(0.086)	(0.146)	(0.096)	(0.078)	(0.077)	(0.100)	(0.087)
BRP x Δp x post					1.011***	1.006***	0.961**	1.066***
					(0.346)	(0.344)	(0.433)	(0.313)
Δp								0.282
								(0.230)
Citation Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Book FE	Yes	Yes	Yes	No	Yes	Yes	Yes	No
Linear pre-trend	No	Yes	No	No	No	Yes	No	No
Field *Citation year FE	No	No	Yes	No	No	No	Yes	No
Publication year FE	No	No	No	Yes	No	No	No	Yes
Field FE	No	No	No	Yes	No	No	No	Yes
R-squared	0.550	0.544	0.584	0.146	0.555	0.548	0.587	0.167
N	20,191	20,191	19,702	19,702	19,383	19,844	19,383	19,383
Pre-1942 Mean	0.263	0.268	0.263	0.268	0.269	0.269	0.264	0.269

Standard errors in parentheses clustered at the book level. *** p<0.01, ** p<0.05, * p<0.1

Notes: The dependent variable measures citations to book *i* per year *t* between 1920 and 1970. The indicator *BRP* equals 1 for 283 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group covers 247 Swiss books that were not available for licensing due to Switzerland's neutrality during the war. The variable *post* equals for years after 1941. The variable *Δp* measures the difference between the original price and the BRP price for book *i*, divided by the original price. In columns 2 and 6 the dependent variable is de-trended by estimating separate linear pre-trends for BRP and Swiss books for pre-BRP years and controlling for trends in the post-period.

TABLE 6 – OLS, DEPENDENT VARIABLE IS NUMBER OF NEW PHDS IN MATH

	(1)	(2)	(3)	(4)
Within 25 miles * post	0.798*			0.542
	(0.481)			(0.430)
Within 50 miles * post		0.792*		
		(0.464)		
Within 75 miles * post			0.808*	
			(0.467)	
25-50 miles * post				0.890
				(0.613)
50-75 miles * post				0.049
				(0.599)
75-100 miles * post				-0.778
				(0.553)
Year FE	Yes	Yes	Yes	Yes
Location FE	Yes	Yes	Yes	Yes
R-squared	0.504	0.504	0.504	0.507
N	9,180	9,180	9,180	9,180
Pre-1942 Mean	0.358	0.358	0.358	0.358

Standard errors in parentheses clustered at the location level. *** p<0.01, ** p<0.05, * p<0.1

Notes: The dependent variable measures the number of new PhDs in mathematics at location *k* in year *t.* The indicator within *x miles* equals 1 for locations that are within *x* miles of a library with at least one BRP math book. The indicator *x-y miles* equals 1 for locations that are further between *x* and *y* miles away from a library with BRP books. The variable *post* equals 1 for years after 1941.