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

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Copyrights, which establish intellectual property in music, science, and other creative goods, are intended to encourage creativity. Yet, copyrights also raise the cost of accessing existing work - potentially *discouraging* future innovation. This paper uses an exogenous shift towards weak copyrights (and low access costs) during WWII to examine the potentially adverse effects of copyrights on science. Using two alternative identification strategies, we show that weaker copyrights encouraged the creation of follow-on science, measured by citations. This change is driven by a reduction in access costs, allowing scientists at less affluent institutions to use existing knowledge in new follow-on research.

KEYWORDS: INTELLECTUAL PROPERTY, COPYRIGHT, SCIENCE, AND BOOKS.

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Copyrights establish intellectual property in cultural goods such as music, literature, and science. Existing empirical analyses have found that copyrights can encourage creativity by increasing payments to authors.[1] Yet copyrights also impose important welfare costs, by restricting access to existing content (Heald 2014, Reimers 2019) and by generating deadweight loss similar to monopolies for traditional goods.[2] Moreover, copyrights raise the costs that future innovators face when they build on existing work. Through this mechanism, copyrights may *discourage* future innovation. This paper investigates these potentially adverse effects of copyrights for science, a field in which the creation of new, cumulative knowledge depends critically on access to existing work (Scotchmer 1991).

Empirical analyses of copyrights face two major challenges. First, the extreme length of copyrights today – at roughly 100 years - prevents researchers from observing all but the most durable goods *off copyrights*. Second, most modern changes in copyrights occur in response to lobbying, reflected in names such as the 1998 US "Mickey Mouse Protection Act." Such lobbying makes it difficult to identify the causal effects of copyrights today.

This paper exploits an exogenous change towards weaker copyrights, as a result of World War II, to examine the effects of copyrights on science. In 1942, the Book Republication Program (BRP) allowed US publishers to reprint exact copies of enemy-owned science books. One of the immediate effects of the program was a dramatic decline in the price of German-owned science books, 25 percent for the average BRP book. Using citations to BRP books as a measure for new cumulative knowledge building on these books, we examine the effects of this change on American science.

To identify the causal effects of the BRP, we employ two complementary identification strategies. First, we compare changes in citations to the same BRP book from English-language authors with changes in citations from other, non-English speaking authors. Since the BRP was a change in US policy, English-language authors were more likely to benefit from the BRP than other authors. A key benefit of this comparison is that it addresses the issue of selection into the BRP, by examining citations to the *same* book.
Second, we compare English-language citations to BRP books with English-language citations to a control group of books with Swiss-owned copyrights. Like Germany,

[1] Li et al. (2018) show that extensions in the length of copyrights increase the price of content by improving publishers' ability to practice intertemporal price discrimination. Publishers pass some of the resulting profits on to authors (MacGarvie and Moser 2013). In Napoleonic era Italy, the adoption of copyrights led to an increase in the quantity and quality of creative work (measured by operas, Giorcelli and Moser 2019).
[2] Consistent with such deadweight loss, Heald (2014) and Reimers (2019) show that books which are slightly less than 95 years old, and therefore still on copyright, are less likely to be available for sale today than books that are slightly older than 95 years.

Switzerland was a leader in mathematics and chemistry at the time. Importantly, however, due to Switzerland's neutrality during the war, Swiss-owned copyrights were not available to the BRP. This strategy addresses the issue that English-language citations may have increased mechanically if US authors published more after World War II. To mitigate the issue of selection into the BRP in this second identification strategy, we use propensity score matching to create a comparable sample of BRP and Swiss books. In addition, all regressions include book fixed effects to control for differences in levels of citations across books.

Results from both identification strategies show that a shift towards weaker copyrights encouraged the creation of new follow-on science: BRP books are cited in an additional 80 percent new articles and books by English language authors compared with authors writing in other languages. BRP books are also cited by 136 percent more new articles and books relative to Swiss books. Triple-differences regressions combine the two identification strategies by comparing the differential change in citations to BRP books from English-language and other-language authors with the same differential change for Swiss books. These estimates, which combine the strengths of the two identification strategies and, as such, are our most conservative and preferred estimates, imply a 67 percent increase in English-language citations to BRP books.

Using unique data on changes in price for the same book on and off copyrights, we estimate the effects of reductions in access costs on the creation of new follow-on science. These estimates indicate that a 10 percent decline in price led to an additional 45 percent increase in citations by English-language authors, compared with citations to the same book by other authors. Regressions that compare English-language citations to BRP and Swiss books yield comparable estimates: Each 10 percent decline in price led to an additional 39 percent increase in citations to BRP books compared with English-language citations to books with Swiss-owned copyrights. Triple-difference estimates, which compare the differential change in citations to BRP books from English-language and other authors with the same differential change for Swiss books, indicate that the same decline in price led to a 43 percent increase in citations.

Robustness checks confirm the main results. Importantly, all of the main findings are robust to controlling for interactions between research fields and citation year fixed effects, to account for variation in research output across fields and over time. Similarly, results are robust to including interactions between the publication years of BRP books and the publication years of the citing publications; these interactions control for variation in citations

across the life cycle of a book. All results are robust to including interactions between book fixed effects and publication year fixed effects and to controls for linear pre-trends.

Additional tests examine the influence of émigré scientists who fled from Nazi Germany (Moser, Voena, and Waldinger 2014). Importantly, all of our results are robust to excluding books and citations by the émigrés, as well as by their students and the students of students. Results are also robust to excluding citations by the colleagues of émigrés. These analyses suggest that the observed increase in citation cannot be explained by a shift in immigration, and instead appears to be due to the BRP.

We also test for heterogeneous effects across disciplines. Predictions from a simple model imply that the effects of lower access costs will be larger for disciplines that are less intensive in physical capital, such as mathematics. For a mathematician, who can create new knowledge with little more than a pen and paper, access to a new knowledge can create an enormous boost in creativity. Chemists, however, are more likely to require laboratory space and expensive equipment to explore and execute new ideas. This difference in the need for physical capital implies that the benefits of accessing new knowledge may be greater for math and other disciplines that are less intensive in physical capital. Our data confirm this prediction by showing differential benefits for mathematics.

To further investigate the mechanism by which lower access costs encouraged the creation of follow-on science, we perform an in-depth analysis of US library holdings in the National Union Catalog (Library of Congress, 1968-1981). These data reveal a striking difference in the diffusion of BRP and Swiss books: By 1956, BRP books had become available across both rich and poor libraries, whereas Swiss books remained concentrated in the holdings of two wealthy research libraries, Yale and Chicago. A geographic analysis further indicates that books which experienced a larger decline in price had become more diffused beyond the American Northeast. These patterns suggest that the BRP may have increased citations by improving access to BRP books.

Next, we examine *when* and *where* scientists started to use BRP books at new locations. First, we collect information on loans of BRP books from lending cards that are attached to the back of library books. These data show that scientists began to use BRP books around 1946, four years after the BRP. First loans of BRP books peak around 1955, matching the timing of the observed increase in citations. A geographic analysis shows that citations increased most around libraries that received BRP books. After 1941, scientists within 25 miles of a BRP book began to cite BRP books more than scientists who were further away.

Estimates attenuate with increasing distance from BRP books. Importantly, pre-trends in citations are comparable for locations with and without a BRP book.

While most of our analyses examine scientific citations, we also present results from two alternative measures for changes in US science: new PhDs and patents that use knowledge in BRP books. Data on newly minted PhDs in math confirm the expansion in the geographic scope of citations. Universities located within 25 miles of BRP books produce 2.2 times more PhDs per year after the BRP compared with universities located further away. An analysis of US patents indicates a 15 percent increase in patents that use BRP books. Notably, there are no significant differences in pre-trends for PhD theses or US patents across locations with and without BRP books.

Our findings highlight the important tradeoff between the positive effects of copyrights on creativity and the potential welfare loss that copyrights impose by restricting access to existing work. Exploiting exogenous variation in the adoption of copyright laws in Italy, Giorcelli and Moser (2019) find that basic levels of copyrights raised both the quantity and quality of new operas. Copyrights, however, also appear to negatively influence the availability of books that are for sale today (Reimers 2019) as well as access to images that appear on Wikipedia (Nagaraj 2018). In the context of early 20th-century science, Iaria, Schwarz, and Waldinger (2018) find that a boycott of enemy science during World War I discouraged the creation of new science. Furman and Stern (2012) show that the creation of research centers, which facilitate access to biological materials, has encouraged follow-on science. The present analysis connects these strands of research by examining the effects of copyrights on knowledge flows and follow-on science.[3]

More broadly, our findings contribute to the literature on the effects of intellectual property rights on the creation of "cumulative" science and innovation. Existing research on patents has found that policies which weaken patents can encourage cumulative invention (e.g., Moser and Voena 2012, Galasso and Schankerman 2015, Sampat and Williams 2019). These results, however, do not generalize to copyrights, which create a fundamentally different type of intellectual property. Compared with patents, copyrights are much narrower, which avoids pitfalls that result from overly broad patents. But copyrights have also become extremely long-lived. Our research indicates that such extensions create enormous social costs in terms of lost creativity and innovation."

[3] Our analyses also complement recent work of textbooks and encyclopedias, which have shown that books are a powerful tool to shape attitudes and beliefs (Cantoni et al. 2017), and that access to existing knowledge may boost economic growth by promoting innovation (Squicciarini and Voigtländer 2015).

In recent years, digitization has led to a dramatic decline in the cost of accessing scientific knowledge. Funding agencies increasingly require grant recipients to make new papers "open access," charging a price of zero.[4] A strong interdisciplinary literature on open access has found that open-access articles are cited more by new research, suggesting that open access facilitates follow-on science.[5] McCabe and Snyder (2014, 2015), however, show that even basic controls for article quality reduce the correlation between open access and citations. Our analysis extends this literature in two ways. First, we exploit exogenous variation in copyrights to examine the effects of changes in access costs on follow-on science. Second, we examine effects of lower prices (rather than a price of zero). Compared with policies that enforce open access, lower prices (or subsidies) offer a more flexible policy instrument to encourage follow-on science. Such policies are particularly important for promoting the creation of new knowledge among researchers at institutions that are cash-constrained.

The costs of accessing existing research were extremely high during the BRP. Yet, even today, access costs can be substantial, effectively preventing researchers from reading copyrighted work. *JSTOR* offers online access to copyrighted articles to researchers at roughly 1,500 institutions in 69 countries but excludes thousands of US and foreign scientists.[6] When asked "how much would it cost to make this available to the whole world, how much would we need to pay you?" *JSTOR's* representatives allegedly responded "$250 million," an enormous sum even compared with prices during the BRP.[7] To improve access, *JSTOR* offers differential license fees, which range from $20,000 per year for the smallest institutions to $150,000 per year for the largest ones, and it charges no archival journal fee in African nations. The academic publisher *Elsevier* similarly offers reduced access fees to researchers in developing countries.[8] Our research indicates that such schemes of price

[4] See, for example Bill & Melinda Gates Foundation Open Access Policy (http://www.gatesfoundation.org/how-we-work/general-information/open-access-policy, accessed December 3, 2015).

[5] For example, see the influential analyses of Lawrence (2001), Eysenbach (2006), and Evans and Reimer (2009). Davis et al. (2008) address the issue of selection by randomly assigning articles to open access across 11 journals of the American Physiological Society and find that scientists are more likely to download (but not cite open access articles within 12 months. This window may, however, be too short to capture the full effects on the creation of new knowledge. Our research addresses this issue by examining the long-run effects of changes in access costs. A recent working paper by Bryan and Ozcan (2018) finds that open access mandates from the National Institute of Health (NIH) have increased citations to biomedical research in US patents.

[6] https://www.jstor.org/librarians/fees/, accessed August 2, 2019.

[7] Lawrence Lessig on "Aaron's Laws—Law and Justice in a Digital Age," available at https://www.youtube.com/watch?v=9HAw1i4gOU4#t=44m39, accessed August 1, 2019.

[8] https://www.elsevier.com/about/open-science/science-and-society/access-for-developing-countries, accessed August 2, 2019.

discrimination can encourage follow-on science, especially when regular fees may be prohibitive.

The remainder of the paper is structured as follows. Section I summarizes relevant institutional details about the BRP. Section II describes the data on citations. Section III presents estimates of the aggregate effects of the BRP, and Section IV investigates the effects of changes in price. Section V presents a geographic analysis of library holdings and changes in the location of citing authors. Section VI examines two alternative proxies for advances in science, and Section VII concludes.

## I. Institutional Background

Until the BRP, German-owned copyrights were protected for the same length of time as American books - 56 years under the 1909 Copyright Act.[9] At a time when German scientists were at the forefront of research in math, chemistry, and physics, US researchers depended heavily on access to German books. In 1940, the President of the American Library Association Ralph Munn wrote to Secretary of State 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).

In that year, the United States had spent a total of $1.5 million ($54.2 million in year 2016 dollars) on foreign books and journals, mostly by German scientists (Richards 1981, p. 253).

Throughout the mid 1940s, US libraries were able to source German books 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). When the Department of State prohibited money transfers to Germany, the Federal Government's Interdepartmental Committee for the Acquisition of Foreign Publications and the library-sponsored Joint Committee began to transfer German publications onto microfilm to distribute across the United States (Richards 1981, p. 255).

[9] 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. See Goldstein (2003) for a history of copyrights. Equal treatment had been established by international copyright treaties (April 15, 1892, United States Copyright Office, Circular 38A). 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).

On July 6, 1942, President Roosevelt's Executive Order No. 9193 authorized the US Alien Property Custodian to "direct, manage, supervise, control or vest […] Patents, patent applications, copyrights, copyright applications, trademarks, or trademark applications or rights" (Myron 1945, p. 76). Now a prominent group of librarians and scientists urged the Custodian to seize German-owned copyrights to reduce payments to Nazi Germany (Richards 1981, p. 255). Between 1942 and 1944, the Custodian seized all enemy-owned copyrights and patents.[10]

Starting in 1942, 36 US publishers bid on temporary licenses to republish exact copies of enemy-owned books (Myron 1945, p. 85). Two publishers, Dover and J.W. Edwards, won the largest number of bids (Bokas and Edwards 2011, p. 22). J.W. Edwards had already bought German machines that allowed quick republication and licensed 650 titles from the Alien Property Custodian (Bokas and Edwards 2011, p. 23).[11] Licenses were limited to 6 months and non-extendable (Myron 1945, p. 85). As a result, publishers faced a threat of competitive entry, which effectively broke their monopoly on a book.[12]

In the 1940s most scientists still read German, so that US publishers simply copied the original text (Ammon 2001).[13] For example, JW Edwards re-published an exact copy of Beilstein's (1918) *Handbuch der Organischen Chemie*, "a critical tool for every organic chemist working in a lab until the early 1970s." By the 1960s, many BRP books were translated to English. The first English version of Beilstein appeared in 1960 (Luckenback, 1981). As soon as English versions became available, US researchers began to use and cite them instead of the original BRP book. Limiting the analysis to citations to the German-language original, therefore, estimates a lower bound of the true effects of the BRP.

## II. Data

Our main data include BRP books in chemistry and mathematics, a control group of Swiss books in the same fields, and all new articles and books that cite BRP and Swiss books between 1920 and 1970. Two alternative measures for scientific output capture new PhD theses in mathematics and US patents that use knowledge in BRP books.

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[10] *Forty-Sixth Annual Record of the Register of Copyrights* 1944, p. 8.

[11] "…[C]onsiderable royalties amounting to many thousands of dollars were accumulated and remitted to the U.S. Government for the benefit of the original copyright owner" (Bokas and Edwards 2011, p. 25).

[12] Menu costs from printing catalogues were substantial, so that publishers could not adjust prices dynamically and instead charged a single price for each edition.

[13] J.W. Edwards alone published 700 books and 140 journals, "most of which have been published under license by the Alien Property Custodian Office" (Bokas and Edwards 2011, p. 23). Editions ranged from 200 to 500 copies (Bokas and Edwards 2011, p. 25).

*A. Information on Books in the BRP and Their Changes in Price*

We collect the full list of all 535 BRP books from a 1944 publication of the Alien Property Custodian Office: *Book Republication Program: Titles Suggested for Republication, an Alphabetical List with a Subject Index.* Excluding physics (a field in which much research was kept secret due to its strategic importance) we focus our analysis on a total of 334 BRP books, including 274 books in chemistry and 60 books in mathematics."

For all 334 BRP books in chemistry and mathematics, the Custodian (1944, pp. 1-102) lists the title, author, research field, publication year, and publication city.[14] 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 years old in 1944. Without the BRP, German publishers would have had exclusive rights to the average book for another 51 years, until 1995.[15]

The Custodian lists the BRP price charged by US publishers for all 334 books. For 319 BRP books (96 percent), the Custodian also lists the original price immediately *before* the BRP.[16] Under the pre-BRP copyright regime, German publishers sold 319 books for an average of $41.40 (equivalent to $1,300 in 2016, Appendix Figure A1).

Under the BRP, book prices declined by an average of 24.97 percent ($\Delta p_i = 1 - BRP\ price/\ original\ price$, Appendix Table A1).[17] The book with the largest price decline, Saccardo's *Sylloge fungorum,* sold for an original price of $2,000 ($63,000 in 2016) and for $200 ($5,420) under the BRP. Beilstein's (1918) *Handbuch der Organischen Chemie* also sold for an original price of $2,000. Under the BRP, Edwards Brothers offered Beilstein "for $400 a set, and the company sold more than 600 sets to laboratories, researchers, and academicians" (Bokas and Edwards, 2011 p. 25).[18] Price declines were similar across disciplines, with 24.3 percent in chemistry and 27.4 percent in mathematics.

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[14] Most (323 of 334 BRP books) were published in German; 5 were English translations. Prices declined less for these 5 books (by 16.9 percent), and citations increased more (from 0.388 to 0.838 per year).
[15] 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.
[16] Thirteen of the remaining 15 books were published after 1941.
[17] Prices declined for 242 of 271 BRP books with information on the original price. Another 20 books experienced no change in price, and 9 chemistry books became more expensive under the BRP, increasing by 17.47 percent from an average of $36.46.
[18] Equivalent to $63,000 in 2016, using unskilled wage labor value conversions, Williamson 2016.

*B. Books with Swiss-Owned Copyrights*

The second identification strategy uses English-language citations to books with Swiss-owned copyrights to control for unobservable factors that may have increased English-language citations to German-language books after 1941. To construct this control group, we collect all Swiss books in section 51 "Mathematik" and section 54 "Chemie" from the catalogs of the Swiss National Library (founded in 1895). The Library holds 1,683 books in chemistry that were published between 1921 and 1941, and 447 books in mathematics.

*C. Citations: New Articles and Books that Cite BRP and Swiss Books, 1920-1970*

Our main outcome variable is citations, which are the standard proxy for cumulative innovation in science (Meho and Yang 2007). Roach and Cohen (2012), for example, show that citations to scientific articles correspond closely to scientific knowledge that firms use in their own R&D. Meho and Yang (2007) show that Google Scholar is the most complete source of citations to foreign language books, even though it is also the most computationally intensive.[19] Google Scholar searches "articles, theses, books, abstracts and court opinions from academic publishers, professional societies, online repositories, universities, and other web sites."[20]

We begin by searching Google Scholar for the title (such as *Die Chemie des Pyrrols*) and author (such as "Fischer") of each BRP book.[21] This search yields a total of 11,249 citations. To create a sample of books that are relevant for science, we focus on BRP and Swiss books that are cited at least once between 1920 and 1970. Among 334 BRP books in chemistry and mathematics, 291 (87 percent) are cited at least once. Among all 2,130 books that are listed in the catalog of the National Swiss Library (including many dissertations that are never cited), only 486 books (23 percent) are cited at least once. We focus our main analysis on these 291 BRP and 486 Swiss books to create a comparable sample of Swiss and BRP books. Since Google's effectiveness may vary across cohorts of publication years, all regressions include controls for the publication year of citing articles.

[19] 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 Scholar. Google Scholar has better coverage, but also requires substantially greater efforts of data collection (with a total of 3,000 hours compared with 1000 for Web of Science and 200 for Scopus).

[20] 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.

[21] 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.

To measure the effect of the BRP conservatively, we only include citations to the original German version of BRP books. Excluding translations estimates a lower bound of the effects of the BRP. Successful BRP books were more likely to be translated, and citations to the original book slowed as soon translation became available. For example, 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, the English version of *Methods* had received more than 16,000 citations.

A potential drawback of citations is that they may be biased by unobservable changes in tastes.[22] 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. The most severe threat in our empirical setting is that US scholars may have withheld citations to German authors during the war and resumed citing German authors afterwards. For World War I, Iaria et al (2018) show that US boycott of scientists from Central countries led to a decline in the transmission of knowledge, measured by new articles and Nobel-nominated work of scientists who had previously cited foreign or domestic research. To examine the severity of bias during World War II, we analyze data on preferences for ethnically-themed goods, such as German foods and operas, as well as baby names with strong ethnic connotations. These measures document a strong and persistent change in ethnic preferences during World War I, but not during World War II. For example, the share of German-language operas dropped from 50 to 7 percent at the beginning of World War I but declined only slightly in World War II (Appendix Figure A2, also Moser 2012b).

*D. US Library Holdings of BRP and Swiss Books*

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" (Library of Congress, 1968-1981). To collect these data, we have accessed physical copies of the NUC at the Hoover Institution Library & Archive (Stanford, CA). 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 and all 55 books in mathematics. Among 486 Swiss books with at

[22] Citations may initially be biased against novel findings. For research published in the Web of Science, Wang et al (2017) show that articles which make more first-time ever combination across journals are 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.

least one citation, 247 Swiss books are in the NUC, including 161 of 373 Swiss chemistry books and 86 of 113 Swiss math books. We examine the restricted data set of NUC books in the main specifications and use the full sample of 11,249 citations to 291 BRP and 486 Swiss books in robustness checks (e.g., Appendix Table A18).

*E. Citations by English-Language vs. Other Authors*

To distinguish citations by authors who were differentially affected by the BRP, we identify the publication language of all citing publications. Among 9,053 citations to 283 BRP books between 1920 and 1970, 5,067 originate from English-language publications. Among 1,788 citations to 247 Swiss books, 1,014 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 A2).

To check whether English-language citations are a useful proxy for citations from US scholars, we collect data on the location of the publication for books and articles that cite four highly-cited books in our sample, including two BRP books (Alexandroff and Topf, 1935, *Topologie* and Van der Waerden, 1931, *Moderne Algebra*) and two Swiss books (Stiefel 1936, *Mannigfaltigkeiten* and Leser 1939, *Invariantentheorie Algebraische Formen*). These data indicate that the large majority of English-language publications (73 percent) originate from the United States.

*F. Research Fields*

To control for variation in citations across research fields, we match the classification of research topics in the reports of the US Alien Property Custodian (1944) with the classification of topics in the Swiss National Library. The Custodian (1944) assigns 228 chemistry books to 38 topics, such as "catalysis," and 55 mathematics books 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 two systems 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, followed by organic chemistry and metals (Appendix Table A4). In mathematics, general mathematics and geometry are the most common research fields. In both fields prices decline after 1941, and citations to BRP books increase (Appendix Table A4).

## III. Effects of the BRP

To investigate the effects of the BRP, we pursue two complementary identification strategies. The first strategy addresses selection by comparing changes in citations from English-language authors with changes in citations from other-language authors to the *same book*. Since the BRP was a change in US copyrights, US authors were most directly affected by the program, and we use English-language authors as a proxy for US authors (in a sample of English-language authors, which we discuss in the data section, 73 percent of English-language authors were based in the United States).

### *A. Comparing Citations to the Same BRP Book by English-Language and Other Authors*

Before the BRP, counts of new publications that cite BRP books in English and other languages are similar in levels and trends (Figure 1); 0.26 publications in English and 0.30 publications in other languages cite the average BRP book per year until 1941 (Appendix Table A5). After 1941, English-language publications increase to 0.566 per year, a 118 percent increase from pre-BRP levels. At the same time, citations to the same books by authors writing in other languages only increase to 0.391, a 30 percent increase (Appendix Table A5).[23] 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), causing their citations to be counted in the control. Notably, citations to the German-language BRP books (such as *Methoden der Mathematischen Physik,* Appendix Figure A3) decline after the introduction of English translations, suggesting that translations were the closest substitute to BRP books.

To estimate the effects of the BRP, we first estimate OLS regressions:

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

where the dependent variable $cites_{ilt}$ measures citations to book $i$ in language $l$ (English vs. other languages) 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 authors writing in *other* languages. A vector of $book_i$ fixed effects controls for book-specific differences in levels of citations across books. Citation year fixed effects $\tau_t$ control for variation in scientific output over time, e.g., as a result of variation

[23] 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.

in funding for research.[24] The identifying assumption for this test is that changes in English-language and other citations to BRP books would have been similar in the absence of the BRP. If this assumption is satisfied, the coefficient $\beta$ estimates the causal effect of the BRP. Comparisons of English-language and other citations support the identifying assumption: Trends in English-language and other citations were nearly identical until 1942 (Figure 1).

FIGURE 1 – CITATIONS TO BRP BOOKS
FROM NEW WORK 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 are collected from Google Scholar (http://scholar.google.com, accessed July 1-September 25, 2014), and manually assigned to a publication language.

OLS estimates indicate that citations to BRP books increased by an additional 0.211 citations per book and year after 1941 compared with citations from other languages (Table 1, 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 in citations in response

[24] Azoulay et al (2016) show that funding from the U.S. National Institutes of Health for basic biomedical research encourages patenting by private sector firms.

to the BRP.[25] Estimates of a specification with the inverse hyperbolic sine of citations as the dependent variable yield very similar results (Appendix Table A6, column 1).[26]

TABLE 1 – OLS, EFFECT OF BRP ON CITATIONS – ENGLISH VS. OTHER LANGUAGE

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| English | -0.036 | -0.034 | -0.034 | -0.034 | -0.036 |
| | (0.042) | (0.039) | (0.039) | (0.042) | (0.042) |
| English x post | 0.211*** | 0.229*** | 0.228*** | 0.229*** | 0.211*** |
| | (0.066) | (0.061) | (0.060) | (0.067) | (0.065) |
| Citation year FE | Yes | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | Yes | No | No |
| Field * cit. year FE | No | Yes | No | No | No |
| Publ. year * cit. year FE | No | No | Yes | No | No |
| Publication year FE | No | No | No | Yes | No |
| Field FE | No | No | No | Yes | No |
| Book * Publ. year FE | No | No | No | No | Yes |
| R-squared | 0.357 | 0.401 | 0.384 | 0.117 | 0.642 |
| N | 19,680 | 19,162 | 19,162 | 19,162 | 19,680 |
| Pre-1942 mean | 0.263 | 0.268 | 0.268 | 0.268 | 0.263 |

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* equals one for years after 1941.

*B. Flexible Controls for Variation Across Research Fields and Over Time*

A potential challenge to the identifying assumption is that scientific output varies across research fields and over time. For example, research output may vary due to variation in funding (e.g., Azoulay et al. 2016, Tabakovic and Wollmann 2016) or as a result of scientific breakthroughs, independent of the BRP. 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 re-estimate the baseline regressions with an interaction between *research fields* and *citation year* of BRP books. These tests, which account for the possibility that research output may vary across fields over time, confirm the main results: English-language citations increase by an additional 0.229 per book and year (Table 1, column 2, significant at 1 percent), which implies an 85 percent increase. Moreover, all tables

[25] Restricting the sample to 1960 yields an estimate of 0.151 additional citations (significant at 5 percent), while restricting it to 1950 shows 0.119 additional citations (significant at 5 percent).
[26] The inverse hyperbolic sine of citations $c_{it}$ is defined as $ln(c_{it} + (c_{it}^2+1)^{0.5})$.

in the remainder of this paper include a robustness test with the *Field x Citation* year fixed effects, analogous to column 2 in Table 1.

Additional tests control for variation in citations across the life cycle of a book, through interactions between the publication years of BRP books and the year of citation. These regressions yield an estimate of 0.228 (Table 1, column 3, significant at 1 percent). Lastly, in column 4 of Table 1 we control for interactions between book fixed effects and publication year fixed effects. This test yields an estimate of 0.211 (Table 1, column 4, significant at 1 percent). In specifications with a linear pre-trend for English-language publications the estimated effect of the BRP is large, at 0.211 (Appendix Table A7, column 1, significant at 1 percent).

Consistent with the visual evidence in Figure 1, time-varying effects indicate no significant differences in citations before the BRP (Figure 2). Estimates increase and become significant in 1946, with an estimate of 0.140 in 1945-46 (p-value 0.00) and 0.232 in 1953-54 (p-value 0.02). They remain large and statistically significant until 1969-70, with 0.440 additional citations (p-value 0.00). Compared with a pre-BRP mean of 0.263, this implies a 157 percent increase in English-language citations to BRP books.

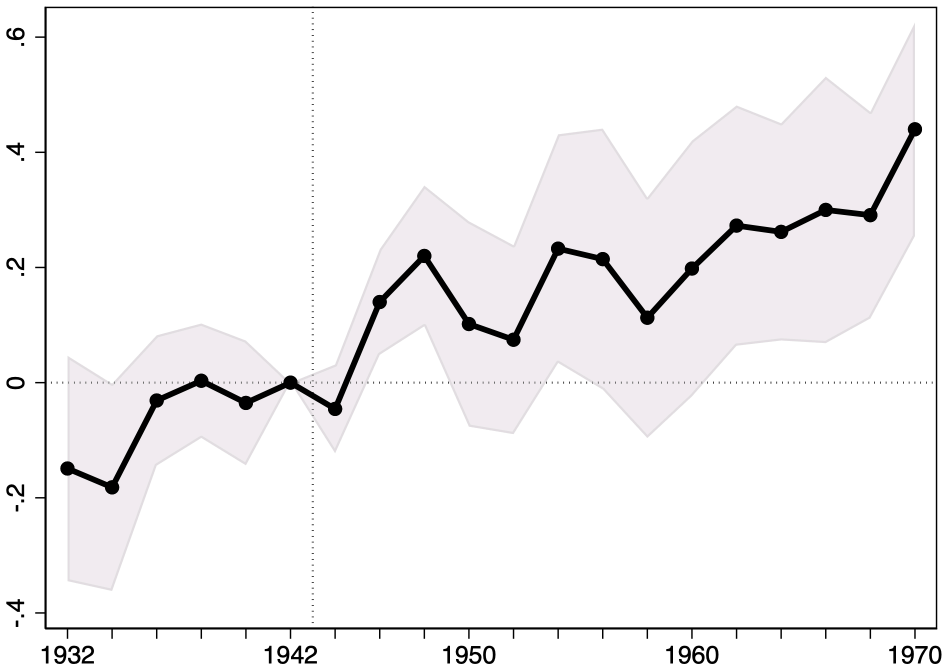
*C. Comparing BRP and Swiss Books: Matching Estimates*

Our second identification strategy compares changes after 1941 in English-language citations to BRP books with changes in English-language citations to Swiss books. This approach addresses the potential issue that English-language citations may have increased mechanically after World War II if the research output of US scholars increased after World War II, relative to other authors. Tabakovic and Wollmann (2019), for example, find that both the number and the quality of scientific publications increased in response to exogenous increases in research funding as a result of football wins. In the post-war United States, geopolitically motivated investments in science may have led to an increase in English-language publications, mechanically increasing English-language citations.

To address this issue, we compare changes in citations by English-language authors to BRP books with changes in citations by English-language authors to Swiss books. 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 published

primarily in German.[27] Unlike German-owned books, however, books with Swiss-owned copyrights were not eligible for the BRP due to Switzerland's neutrality during the war.

FIGURE 2 – TIME-VARYING EFFECTS, ENGLISH VS. NON-ENGLISH CITATIONS TO BRP BOOKS




*Notes*: Estimates of $\beta_s$ (with a 95-percent confidence interval) in the OLS regression $cites_{ilt} = \Sigma_s \beta_s English_l * \tau_s + book_i + \mu_{ft} + \tau_t + \varepsilon_{ilt}$ for two-year intervals 1931-1932,…,1969-70, with years 1941-42 as the excluded period. The dependent variable $cites_{ilt}$ counts citations to 283 BRP books $i$ in language $l$ (English vs. non-English) in year $t$. The indicator *English* equals 1 for citations from English-language authors. $Book_i$ is a vector of book fixed effects; $\mu_{ft}$ are field-by-citation year fixed effects, and $\tau_t$ are year fixed effects. Standard errors are clustered at the book level.

*D. Selection into the BRP*

A major advantage of our identification strategy is that we can address selection by examining changes in citations to *the same book*. In addition, all regressions include book fixed effects to control for differences in levels of citations across books. Yet, selection into the BRP becomes an issue when we compare citations to BRP and Swiss books.

Historical records indicate that BRP books were selected for idiosyncratic reasons, based on the holdings of the library at the University of Michigan. Primary sources from the archives of J.W. Edwards explain that "Edwards Brothers' editor Bernard A. Uhlendorf (formerly employed by the University of Michigan Library) was responsible for choosing the

[27] Stiefel's dissertation *Richtungsfelder und Fernparallelismus in n-dimensionalen Mannigfaltigkeiten* (1935) 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.

titles appropriate for EB's publication program" (Bokas and Edwards 2011, p. 25). This suggests that Uhlendorf may have chosen books based on his experiences with popular books in the holdings of the University of Michigan's library. If he and other editors were able to predict future increases in the demand for books after 1941, our baseline estimates overstate the effects of the BRP on a randomly selected book.

*E. Mahalanobis Propensity Score Matching*

To mitigate selection and to control for potential differences in time trends of citations between BRP and Swiss books, we use Mahalanobis propensity score matching (with replacement, Abadie and Imbens 2011) to create a comparable sample of Swiss books. Specifically, we match each BRP book with a Swiss book in the same research field and with a comparable pre-BRP stock of non-English language citations (see Appendix Table A9 for a comparison of means).[28] Alternative estimates implement a synthetic-controls procedure (Abadie et al. 2010, Appendix Figure A13 and Table A19).[29]

Although Swiss books in this matched sample receive on average fewer citations than BRP books they exhibit comparable trends in citations before the BRP (Figure 3).[30] After the BRP, citations to BRP books grow to 0.360 in 1946 and 0.888 in 1956, while citations to Swiss books increase much less. Citations to BRP books remain high around 0.800 per book and year until 1970, while citations to Swiss books remain below 0.400.

OLS regressions with for the matched sample estimate

$$cites_{it} = \beta\, BRP_i * post_t + book_i + \tau_t + \varepsilon_{it} \quad (2)$$

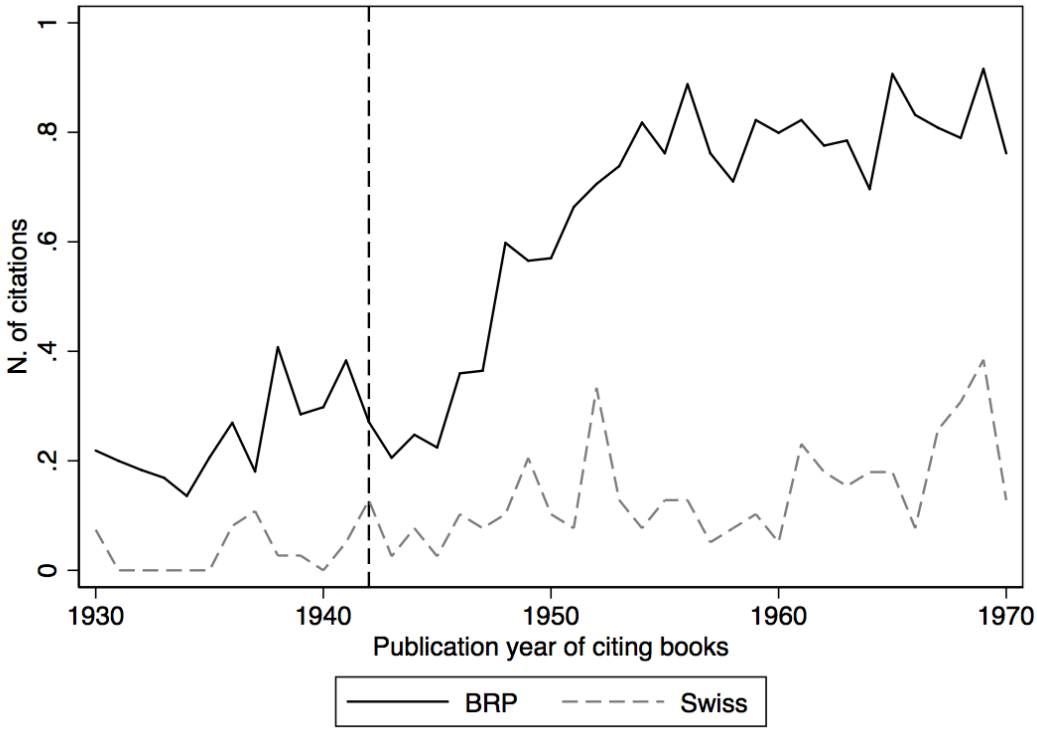
where the dependent variable $cites_{it}$ measures citations to BRP and Swiss books by new English-language publications to book $i$ per year $t$ between 1920 and 1970, and the indicator variable *BRP* equals 1 for BRP books.

OLS estimates show that BRP books receive 0.386 additional citations by English-language authors per year after the BRP compared with Swiss books (Table 2, column 1,

[28] Pre-BRP citations to BRP books are a good predictor for marketing efforts, as we show below. Matching procedures with different attributes yield nearly identical estimates, available upon request.
[29] Specifically, we construct a "synthetic control" for each BRP book by estimating the weighted sum of Swiss books in the same field (math or chemistry). The synthetic weights are calculated as in Abadie et al. (2010) using English citations as the dependent variable and non-English citations as the independent variable.
[30] In the final years of the war, the Allied bombing campaign destroyed research facilities in Germany. We observe bombing as a decline in citations to BRP books compared with Swiss books. Bombings reached a peak of 130 tons per month at the beginning of 1945 (Webster and Frankland 1961, Annex, Waldinger 2016).

significant at 1 percent). Relative to a pre-BRP mean of 0.283, this implies an additional 136 percent increase in citations.[31]

FIGURE 3 – CITATIONS TO A MATCHED SAMPLE OF BRP AND SWISS BOOKS




*Notes*: Citations for a matched sample of 214 BRP books and 39 Swiss books. Books are matched with a Mahalanobis propensity score procedure using research *fields* and the stock of *pre-1942 Non-English citations* as matching variables.

These estimates are robust to controlling flexibly for idiosyncratic variation in citations across research fields, with interactions for *research fields * citation year* fixed effects (Table 2, column 2, significant at 1 percent), and for a book's age, with an interaction for *publication year * citation year* fixed effects (Table 2, column 3, significant at 10 percent), which implies a 86 percent increase. Estimates are also robust to using the inverse hyperbolic sine of citations as the dependent variable (Appendix Table A6, column 4).[32]

Time-varying estimates for the matched sample reveal no significant differences in citations until 1941 but show a substantial increase in citations to BRP books after the BRP. Until 1941, estimates are not significant and range from -0.212 in 1931-32 (p-value 0.17,

[31] Restricting the sample to 1960 yields an estimate of 0.322 additional citations (significant at 1 percent), while restricting it to 1950 shows 0.108 additional citations (significant at 10 percent).
[32] Estimates for all 293 BRP books and 247 Swiss books show 0.392 additional new articles or books cite BRP books after 1941 (Appendix Table A10). An additional test restricts the sample to books in the Library of Congress; estimates are robust to this restriction (Appendix Table A11).

Figure 4) to -0.022 in 1939-40 (p-value 0.76). After 1941, estimates increase to 0.154 in 1947-48 (p-value 0.02) and 0.438 in 1953-54 (p-value 0.00). Estimates remain large and significant until 1969-70, with 0.345 additional citations (p-value 0.05). Compared with a pre-BRP mean of 0.283, this implies a 122 percent increase (Figure 4).

TABLE 2 – OLS, EFFECT OF BRP ON ENGLISH-LANGUAGE CITATIONS. BRP VS. SWISS BOOKS (MATCHED SAMPLE)

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| BRP | | | | 0.116 |
| | | | | (0.143) |
| BRP x post | 0.386*** | 0.376** | 0.188* | 0.438*** |
| | (0.101) | (0.156) | (0.102) | (0.117) |
| Citation year FE | Yes | No | Yes | Yes |
| Book FE | Yes | Yes | Yes | No |
| Field * cit year FE | No | Yes | No | No |
| Publ. year * cit. year FE | No | No | Yes | No |
| Publication year FE | No | No | No | Yes |
| Field FE | No | No | No | Yes |
| R-squared | 0.558 | 0.622 | 0.58 | 0.182 |
| N | 9,365 | 9,365 | 9,111 | 9,365 |
| Pre-1942 mean | 0.283 | 0.283 | 0.218 | 0.283 |

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

*Notes*: The dependent variable counts English-language citations to book *i* per year *t* between 1920 and 1970. The indicator *BRP* equals 1 for 214 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group includes 39 Swiss books that were not available for licensing due to Switzerland's neutrality. The variable *post* equals for years after 1941. BRP and Swiss books are matched using the Mahalanobis propensity score algorithm with fields and pre-1942 average non-English language citations per year as matching variables.

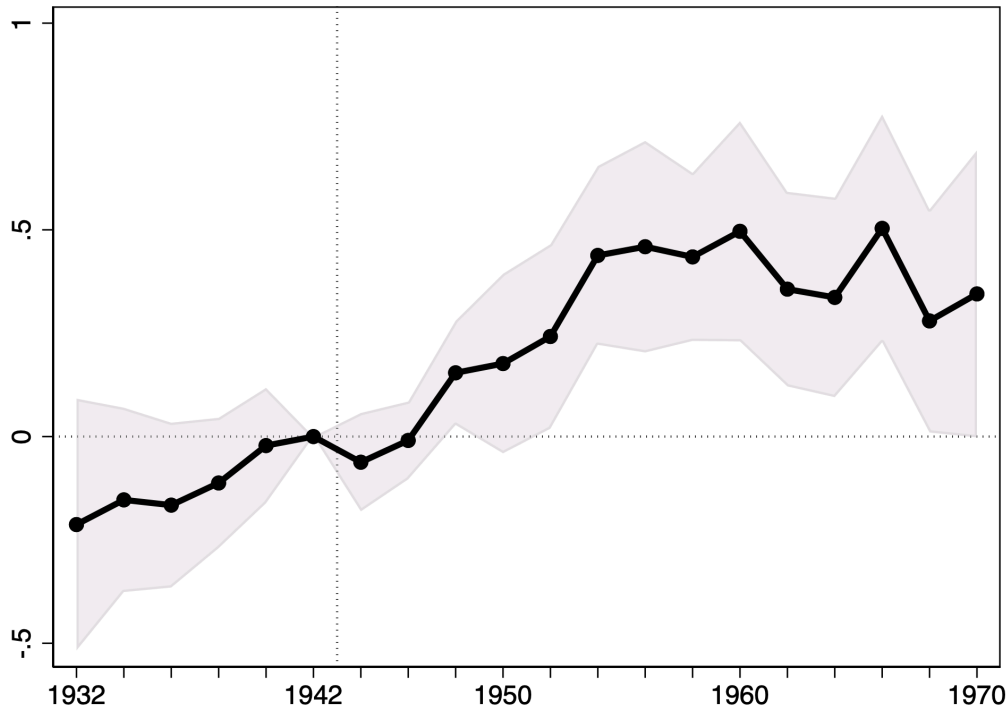
In sum, matching estimates for a comparable set of BRP and Swiss books (in the same fields and with similar pre-BRP citations) confirm that citations to BRP books increased significantly after the BRP. Notably, these estimates are most informative for books that publishers considered important enough to republish, rather than for a randomly selected book.

*F. Combining the Two Identification Strategies*

Our preferred specifications join the two identification strategies in a triple-differences regression that compares the differential change in citations to BRP books from English-language and other-language authors with the same differential change for Swiss books. This approach combines the strengths of the two complementary difference-in-differences tests: The comparison of changes in English vs. other-language citations to BRP

books mitigates selection by examining citations to the same book. The comparison of changes in English-language citations to BRP and to Swiss books addresses the issue that English-language citations may have increased mechanically if US researchers published more than other authors after World War II.

FIGURE 4 – TIME-VARYING EFFECTS, BRP VS. SWISS, MATCHED SAMPLE




*Notes*: Estimates of $\beta_s$ with a 95-percent confidence interval in the OLS regression $cites_{it} = \Sigma_s \beta_s BRP_i * \tau_s + book_i + \tau_t + \varepsilon_{it}$ for two-year intervals 1931-1932,…1969-70, with years 1941-42 as the excluded period. The dependent variable $cites_{it}$ counts English-language citations to 214 BRP and 39 Swiss book *i* in year *t.* The indicator *BRP* equals 1 for 214 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group covers 39 Swiss books that were not available for licensing due to Switzerland's neutrality during the war. $Book_i$ is a vector of book fixed effects, and $\tau_t$ are year fixed effects. Standard errors are clustered at the book level.

OLS triple-difference regressions estimate

$$cites_{ilt} = \beta_1 English_l + \beta_2 English_l * BRP_i + \beta_3 English_l * post_t + \beta_4 BRP_i * post_t + \beta_5 English_l * BRP_i * post_t + book_i + \tau_t + \varepsilon_{ilt} \quad (3)$$

where the triple-differences coefficient $\beta_5$ captures the differential increase in citations to BRP books compared with similar Swiss books from English-language authors compared with other-language authors.[33] The identifying assumption is that the difference between

[33] As above, books are matched using propensity score matching with two matching variables: research fields and pre-BRP non-English citations.

citations by English-language authors and citations by other authors would have been similar for BRP books and the comparable set of Swiss books in the absence of the BRP. The interaction term $English_l$ x $post_t$ controls for the differential increase in citations by English-language authors relative to other-language authors after 1941 (e.g., as a result of a relative increase in the size of US science after World War II).

TABLE 3 – OLS, EFFECT OF BRP ON ENGLISH-LANGUAGE VS. OTHER CITATIONS. BRP VS. SWISS BOOKS (MATCHED SAMPLE)

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| English | -0.035** | -0.035** | -0.035** | -0.035** | 0.534 |
| | (0.014) | (0.015) | (0.014) | (0.014) | (0.403) |
| BRP | | | 0.167 | | |
| | | | (0.112) | | |
| BRP x post | 0.118* | 0.127 | 0.156** | | 0.100 |
| | (0.061) | (0.077) | (0.070) | | (0.068) |
| English x BRP | 0.002 | 0.002 | 0.002 | 0.002 | -0.034 |
| | (0.048) | (0.046) | (0.047) | (0.047) | (0.060) |
| English x post | 0.115** | 0.115** | 0.115** | 0.115** | |
| | (0.045) | (0.048) | (0.045) | (0.045) | |
| English x BRP x post | 0.202** | 0.202** | 0.202** | 0.202** | 0.238** |
| | (0.088) | (0.086) | (0.087) | (0.087) | (0.097) |
| Citation year FE | Yes | No | No | Yes | Yes |
| Book FE | Yes | Yes | No | Yes | Yes |
| Cit. year * book FE | No | No | No | Yes | No |
| Field * year FE | No | Yes | No | No | No |
| Publ. year & field FE | No | No | Yes | No | No |
| English * cit. year | No | No | No | No | Yes |
| R-squared | 0.372 | 0.414 | 0.132 | 0.654 | 0.375 |
| N | 18,730 | 18,730 | 18,730 | 18,730 | 18,730 |
| Pre-1942 Mean | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 |

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

*Notes*: BRP and Swiss books are matched using the Mahalanobis propensity score algorithm with fields and pre-1942 average non-English language citations per year as matching variables. The dependent variable measures citations to book *i* per year *t* and language *c* (English vs. other) between 1920 and 1970. The indicator *English* equals 1 for citations by *English-language* authors. The indicator *BRP* equals 1 for 214 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group covers 39 Swiss books that were not available for licensing due to Switzerland's neutrality during the war. The variable *post* equals for years after 1941.

Triple differences coefficients confirm that the BRP led to a significant increase in new science building on knowledge in BRP books. Estimates of $\beta_5$ indicate that BRP books receive an additional 0.202 English-language citations per year after the BRP compared with Swiss books and compared with citations by non-English language authors (Table 3, column

1, significant at 5 percent). Relative to an average of 0.300 English-language citations per year to BRP books before the BRP, this implies a 67 percent increase. Importantly, this 67-percent increase in citations is net of the overall increase in English-citations relative to other-language citations. An estimate of 0.115 for the coefficient $\beta_5$ on *English* x *post* confirms that English-language citations increased overall relative to other language citations (Table 3, column 1, significant at 5 percent).

All triple-differences estimates are robust to controlling for differential changes in citations across research fields and over time (with interactions between research fields and citation year fixed effects, Table 3, column 2, significant at 5 percent) and for age effects (with interactions between book and citation year fixed effects, Table 3, column 4, significant at 5 percent).

*G. Controlling for the Influence of Émigrés*

Moser, Voena, and Waldinger (2014) show that US invention increased in the research fields of German émigrés to the United States after Jews were expelled from German universities in 1933 (Moser et al. 2014). These émigrés may have also increased scientific output (and thereby citations) in the fields of BRP books, especially if the émigrés expertise complemented the knowledge in BRP books. In the main specification we control for these and other unobservable factors that may have increased citations to BRP books over time through interactions between research fields and year fixed effects. In this section we present additional test that explicitly control for the influence of émigrés.

Importantly, BRP books by émigré authors account for a very small share of citations. Four BRP books were written by a total of five émigrés: Richard Courant, Max Herzberger, John von Neumann, George Pólya, and Gabór Szego (Appendix Table A12). Their books account for less than 10 percent of books in mathematics and less than 15 percent of citations to BRP math books. Excluding these authors and their citations leaves our estimates substantially unchanged (e.g., Table 4, column 3, with an estimate of 0.508 for *English* x *post*, significant at 5 percent).[34]

We also test whether the observed increase in citations to BRP books may have been driven by the *colleagues* or students of émigré authors of BRP books. Citations by colleagues of émigré authors only account for 0.1 percent of our citations data; excluding them does not

[34] To identify BRP books whose authors were German émigrés we first searched for all authors in the *International Biographical Dictionary of Central European Émigrés* (Strauss et al. 1983) and in the records of the Mathematics Genealogy Project.

affect the estimates (estimate of *English* x *post* equal to 0.606, Table 4, column 3, significant at 5 percent).[35] Results are also robust to excluding the students of émigré authors of BRP books, as well as their students. To perform this test, we identify the students of émigrés and the students of their students from the records of the Mathematics Genealogy Project. Less than 0.1 percent of all citations to math books are by academic descendants of émigré authors of BRP books; all results are robust to excluding their citations (Table 4, column 5).

TABLE 4 – DIFFERENTIAL EFFECTS FOR BOOKS BY ÉMIGRÉS.
CITATIONS TO BRP BOOKS BY ENGLISH VS. OTHER LANGUAGE AUTHORS

| | (1) Baseline estimate for mathematics | (2) Excl. cit. & BRP books by émigrés | (3) Excl. cit. from institutions with émigré BRP authors | (4) Excl. cit. from students of émigré BRP authors | (5) Excl. cit. from institutions with any émigrés |
|---|---|---|---|---|---|
| English | 0.051 | 0.012 | 0.053 | 0.053 | 0.053 |
| | (0.065) | (0.069) | (0.069) | (0.069) | (0.069) |
| English x post | 0.596** | 0.508** | 0.606** | 0.606** | 0.606** |
| | (0.253) | (0.242) | (0.257) | (0.257) | (0.257) |
| Citation year FE | Yes | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | Yes | Yes | Yes |
| R-squared | 0.389 | 0.405 | 0.388 | 0.388 | 0.388 |
| N | 3,978 | 3,648 | 3,884 | 3,884 | 3,884 |
| Pre-1942 Mean | 0.210 | 0.210 | 0.241 | 0.241 | 0.241 |

Standard errors in parentheses are 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 books from authors in other languages. The variable *post* indicates years after 1941. The variable *US émigré* equals 1 for books by émigrés to the United States. Column 2 excludes citations and books by US émigrés. Column 3 excludes citations from colleges and universities that employed one or more émigré authors of a BRP book. Column 4 excludes citations by students of émigrés and their students. Column 5 excludes citations from colleges and universities that employed one or more émigré (including those who were not authors of a BRP book).

Finally, we exclude citations from any universities that employed an émigré scholar, even if that émigré was not an author of a BRP book. This test allows us to control for cultural influences or differences in education that may led German-born authors (and possibly the people who worked with them) to cite BRP books.[36] The coworkers of German-

[35] Specifically, we exclude scholars at New York University (which employed Richard Courant), Stanford (George Pólya and Gábor Szegő), and Washington University in St. Louis (Gábor Szegő).
[36] To perform this test, we use information on the names of all the American scientists who were born and educated in Germany from Moser and San (2019). Among 1,029 American mathematicians in 1956, 27 were born and educated in Germany; among 6,664 chemists, 129 were born and educated in Germany.

born émigrés account for 0.3 percent of citations; excluding them does not substantially change our estimates (Table 4, column 6). Moreover, a geographic analysis of citations (shown below in Section V.C) is robust to controlling for geographic proximity to émigrés.

Taken together, these tests show that the observed increase in citations to BRP books cannot be driven by the influence of émigrés.[37]

## IV. Mechanism: Decline in Price for BRP Books

In this section, we examine the mechanisms by which copyrights influence the creation of new science. Predictions from a purposefully simple model of cumulative knowledge, outlined in Appendix B, guide our empirical analysis. In the model, two identical generations of researchers produce new knowledge in two consecutive periods. The concept of cumulative science (Scotchmer 1991) is captured by allowing second-generation scientists to build on knowledge created by researchers in the first generation. A general production function represents the scientist's decision to invest in the creation of new knowledge. This decision depends on the cost of two inputs, physical capital and access to existing knowledge. Physical capital can be bought incrementally, while knowledge must be bought as a whole. This feature represents the choice of buying a book, or paying access fees for *Jstor* or another data base of existing research.

With these conservative assumptions, our model yields two main predications, which we test below: 1) scientists produce more new knowledge when the price of existing knowledge is low and 2) the effects of access costs are larger for disciplines that are less dependent on physical capital.

### *A. Comparing Citations by English-language with Other Authors*

A key benefit of the empirical setting is that prices are observable under different copyright regimes for the same book and in the same year, when knowledge in the book is still relevant and new. For BRP books, prices declined by an average of 25 percent when competing publishers were allowed to enter. We exploit this change in price to empirically examine the effects of reductions in access costs on follow-on science.

[37] Yet, the interaction between lower book prices and human capital is important and interesting in its own right. Book-level analyses show that books by émigrés experienced an additional increase in citations compared with other BRP books (Appendix Figure A5A) and with other non-BRP books by émigrés (Appendix Figure A5B). These results suggest important complementarities between copyrights and human capital.

To test empirically how changes in price influence the creation of new science, we re-estimate the baseline equation (1) with an interaction term for changes in price:

$$cites_{ilt} = \alpha\ English_l + \beta\ English_l \times post_t + \theta\ \Delta p_i * English_l * post_t + book_i + \tau_t + \varepsilon_{ilt} \quad (4)$$

where $\Delta p_i$ measures the difference between the original price and the republication (BRP) price for BRP book *i* normalized by the original price.

TABLE 5 – OLS, EFFECTS OF PRICE DECLINE ON CITATIONS – ENGLISH VS. OTHER LANGUAGE

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| English | -0.036 | -0.034 | -0.034 | -0.034 |
| | (0.042) | (0.039) | (0.039) | (0.042) |
| English x post | -0.077 | -0.058 | -0.054 | -0.070 |
| | (0.091) | (0.120) | (0.116) | (0.091) |
| English x Δp x post | 1.192*** | 1.188*** | 1.170*** | 1.235*** |
| | (0.344) | (0.431) | (0.447) | (0.342) |
| Δp | | | | 0.241 |
| | | | | (0.176) |
| Citation year FE | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | Yes | No |
| Field * citation year FE | No | Yes | No | No |
| Publ. year * citation year FE | No | No | Yes | No |
| Publication year FE | No | No | No | Yes |
| Field FE | No | No | No | Yes |
| R-squared | 0.366 | 0.411 | 0.393 | 0.138 |
| N | 18,986 | 18,524 | 18,524 | 18,524 |
| Pre-1942 Mean | 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

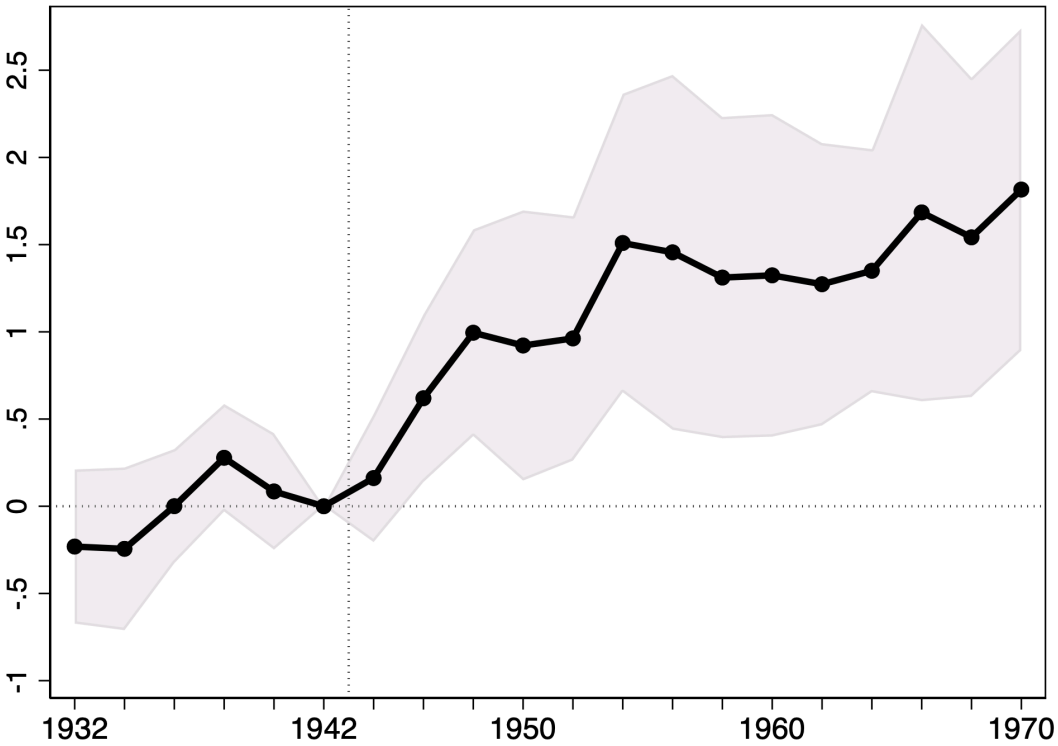
*Notes*: The dependent variable measures citations to book *i* per year *t* between 1920 and 1970. The indicator *English* equals 1 for citations by *English-language* authors; the control group are citations to the same book from authors in other languages. The variable *post* indicates years after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

OLS estimates show that a 10 percent decline in price is associated with 0.119 additional citations (Table 5, column 1, significant at 1 percent). Compared with a pre-BRP mean of 0.264 annual citations for BRP books, this implies a 45 percent increase.[38] Estimates are robust to using the inverse hyperbolic sine of citations as the dependent variable (Appendix Table A13, column 1).

[38] Estimates are robust to controlling for interactions between research fields and citation year fixed effects (Table 5, column 2, significant at 1 percent) and for the age of each book (through interactions between publication year and citation year fixed effects, Table 5, column 3, significant at 1 percent). Estimates are also robust to controlling for a separate linear pre-trend for English-language citations, with an estimate of 0.119, significant at 1 percent (Appendix Table A7, column 2).

These results are confirmed in specifications that use the original BRP price as an instrument for the decline in price (Appendix Table A14). Reduced-form estimates use the natural logarithm of the original price as an explanatory variable instead of the decline in price. These estimates indicate that books whose original price was 10 percent higher before the BRP received 0.012 additional citations per year after the BRP. Relative to an average of 0.264 citations per year before the BRP, this implies an additional 5 percent increase in citations (Appendix Table A14, column 1, significant at 5 percent).

FIGURE 5– TIME-VARYING EFFECTS OF CHANGES IN PRICE
ENGLISH VS. OTHER LANGUAGE CITATIONS TO BRP BOOKS




*Notes*: Estimates of $\theta_s$ with a 95-percent confidence interval in the OLS regression $cites_{ilt} = \alpha\ English_l + \beta\ English_l * post_t + \Sigma_s\ \theta_s\ \Delta p_i * English_l * \tau_s + book_i + \mu_{ft} + \tau_t + \varepsilon_{ilt}$ for two-year intervals 1931-32,…1969-70, with years 1941-42 as the excluded period. The dependent variable $cites_{ilt}$ counts citations to BRP book $i$ in language $l$ and year $t$. The indicator *English* equals 1 for citations from English-language authors. $Book_i$ is a vector of book fixed effects; $\mu_{ft}$ are field-by-year fixed effects, and $\tau_t$ indicates year fixed effects. The variable $\Delta p$ 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.

IV estimates use the original price as an instrument for the change in price $\Delta p$. A Kleibergen-Paap F-statistic of 75.3 for the first stage indicates that the instrument is strong (Appendix Table A14, column 3). An estimate of 1.357 for *English* x *ln(orig p)* x *post* indicates that a 10-percent decline in price leads to 0.136 additional English-language

citations per year to BRP books compared with other-language citations. Relative to a pre-BRP average of 0.264 citations, this implies a 52 percent increase (Appendix Table A14, column 4, significant at 5 percent).

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

$$cites_{ilt} = \alpha\ English_l + \beta\ English_l \times post_t + \Sigma_s\ \theta_s\ \Delta p_i * English_l * \tau_s + book_i + \tau_t + \varepsilon_{ilt} \quad (5)$$

where the indicator variable $\tau_t$ denotes two-year intervals 1931-32, 1933-1934,…1969-70, and years 1941-42 are the excluded period. Time-varying estimates indicate no significant differences in citations before the BRP and show a large increase in citations afterwards (Figure 5). Until 1941, estimates range from -0.024 in 1933-34 (p-value 0.30) to 0.028 in 1937-38 (p-value 0.08). After 1945, estimates increase to 0.100 in 1947-48 (p-value 0.00) and 0.151 in 1953-54 (p-value 0.00). Estimates remain large and significant until 1969-70, with 0.182 additional citations (p-value 0.00). Compared with a pre-BRP mean of 0.263, this implies a 69 percent increase in citations.

*B. Comparing Citations to BRP and Swiss Books*

As above, our second, complementary identification strategy compares changes after 1941 in English-language citations to BRP books with changes in English-language citations to Swiss books. This strategy addresses the potential issue that English-language citations may have increased mechanically after World War II, if English-language authors published more than other authors after the war. BRP books are matched with Swiss books in the same research fields and similar levels of pre-BRP citations (using propensity score matching, as described in section III.C above).

OLS estimates imply that a 10-percent decline in price yields 0.112 additional English-language citations per year (Table 6, column 1, significant at 1 percent). Compared with an average of 0.284 citations until 1941, this implies 39 percent increase.[39] Estimates are also robust to using the inverse hyperbolic sine of citations as the dependent variable (Appendix Table A13, column 4). Year-specific estimates reveal no differences in citations

[39] Results on the full sample of BRP and Swiss books indicate that a 10 percent decline in price is associated with 0.101 additional citations per year, or 38 percent (Appendix Table A10, column 1, significant at 1 percent).

TABLE 6 – OLS, EFFECT OF PRICE DECLINE ON ENGLISH-LANGUAGE CITATIONS
BRP VS. SWISS BOOKS (MATCHED SAMPLE)

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| BRP | | | | 0.022 |
| | | | | (0.141) |
| BRP x post | 0.056 | 0.086 | -0.126 | 0.085 |
| | (0.089) | (0.143) | (0.164) | (0.101) |
| BRP x Δp x post | 1.116*** | 1.060* | 1.035 | 1.201*** |
| | (0.376) | (0.527) | (0.621) | (0.361) |
| Δp | | | | 0.307 |
| | | | | (0.302) |
| Citation year FE | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | Yes | No |
| Field * citation year FE | No | Yes | No | No |
| Publ. year * citation year FE | No | No | Yes | No |
| Publication year FE | No | No | No | Yes |
| Field FE | No | No | No | Yes |
| R-squared | 0.562 | 0.624 | 0.583 | 0.205 |
| N | 9,302 | 9,302 | 9,048 | 9,302 |
| Pre-1942 Mean | 0.284 | 0.284 | 0.242 | 0.284 |

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

*Notes*: BRP and Swiss books are matched using the Mahalanobis propensity score algorithm with fields and pre-1942 average non-English language citations per year as matching variables. The dependent variable counts citations to book *i* per year *t* between 1920 and 1970. The indicator *BRP* equals 1 for 214 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group covers 39 Swiss books that were not available for licensing due to Switzerland's neutrality. 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.

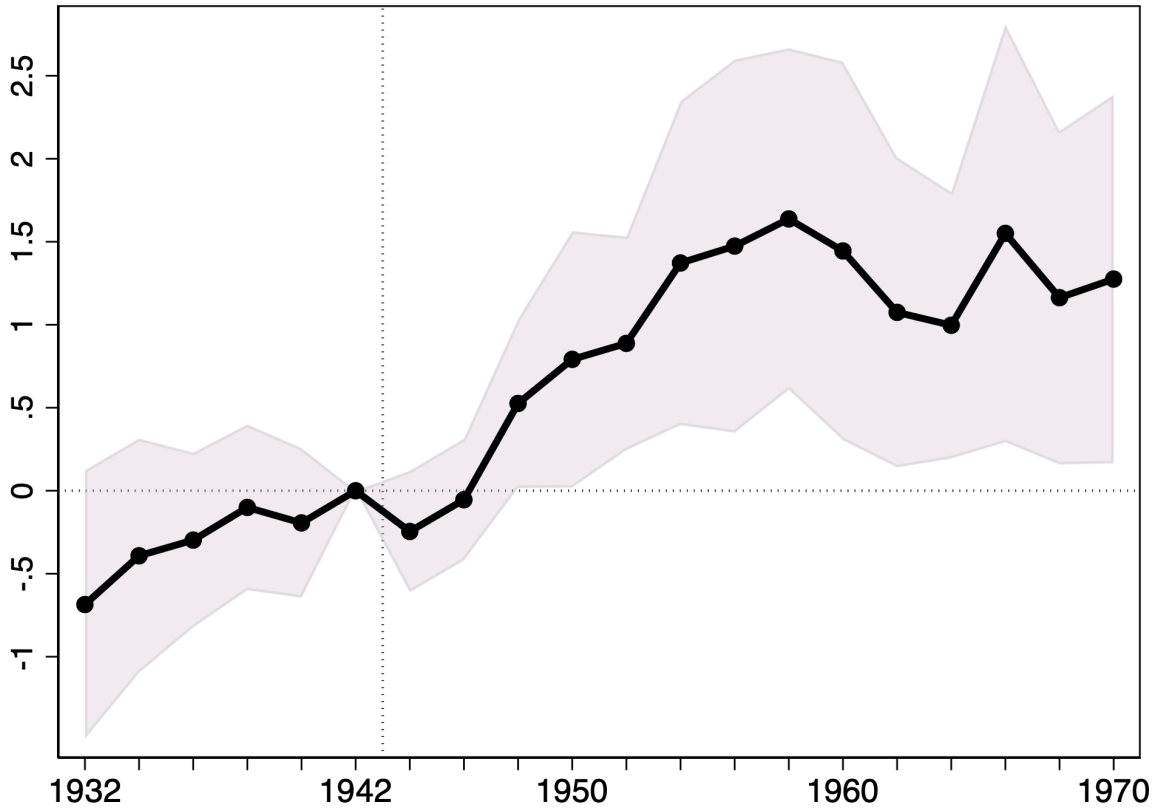
by English-language and other authors before the BRP, but they show a large increase in English-language citations afterwards (Figure 6).

Triple differences estimates, which combine the two identification strategies, indicate that a 10 percent decline in price is associated with 0.128 additional English-language citations relative to other-language citations for BRP books relative to Swiss books (Table 7, column 1, significant at 1 percent), with no evidence for differential pre-trends in citations (Appendix Figure A4).

*C. Complementarities with Physical Capital*

Our motivating model predicts that the benefits of lower access costs vary across disciplines: The effects of lower prices on the creation of new knowledge should be

FIGURE 6 – TIME-VARYING EFFECTS OF CHANGES IN PRICE CITATIONS TO BRP VS. SWISS BOOKS - MATCHED SAMPLE




*Notes*: Estimates of $\theta_s$ with a 95-percent confidence interval in the OLS regression $cites_{it} = \beta\ BRP_i * post_t + \Sigma_s\ \theta_s\ \Delta p_i * BRP_i * \tau_s + book_i + \tau_t + \varepsilon_{it}$ for two-year intervals 1931-1932,…,1969-70, with years 1941-42 as the excluded period. The dependent variable $cites_{it}$ counts citations to a matched sample of 214 BRP and 39 Swiss book *i* in year *t.* The indicator *BRP* equals 1 for 214 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group covers 39 Swiss books that were not available for licensing due to Switzerland's neutrality during the war. $Book_i$ is a vector of book fixed effects, and $\tau_t$ indicates year fixed effects. The variable $\Delta p$ measures the difference between the original price and the BRP price, divided by the original price. Standard errors are clustered at the book level.

larger for disciplines in which knowledge production is less dependent on physical capital. In the context of the current analysis, chemical research was heavily dependent on physical capital in the form of laboratory space. By comparison, research in mathematics was less intensive in physical capital and depended primarily on access to existing work.

Plots of citations by field confirm the prediction of differential effects across disciplines, with a stronger increase in citation for mathematics (Appendix Figure A6, top panel.

TABLE 7 – OLS FOR A MATCHED SAMPLE OF COMPARABLE BRP AND SWISS BOOKS
EFFECTS OF PRICE DECLINE ON ENGLISH-LANGUAGE VS. OTHER CITATIONS

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| English | -0.035** | -0.035** | -0.035** | -0.035** | -0.035** |
| | (0.014) | (0.015) | (0.014) | (0.014) | (0.014) |
| BRP | | | 0.111 | | |
| | | | (0.103) | | |
| English x BRP | 0.002 | 0.002 | 0.002 | 0.002 | 0.002 |
| | (0.048) | (0.046) | (0.048) | (0.048) | (0.048) |
| BRP x post | 0.071 | 0.103 | 0.089 | | 0.071 |
| | (0.047) | (0.075) | (0.057) | | (0.047) |
| English x post | 0.115** | 0.115** | 0.115** | 0.115** | 0.115** |
| | (0.045) | (0.048) | (0.045) | (0.045) | (0.045) |
| English x BRP x post | -0.140 | -0.140 | -0.140 | -0.140 | -0.140 |
| | (0.109) | (0.107) | (0.108) | (0.108) | (0.109) |
| BRP x Δp x post | 0.101 | 0.077 | 0.170 | | 0.101 |
| | (0.193) | (0.235) | (0.189) | | (0.193) |
| English x BRP x Δp x post | 1.276*** | 1.276** | 1.276*** | 1.276*** | 1.276*** |
| | (0.402) | (0.468) | (0.400) | (0.399) | (0.402) |
| Δp | | | 0.181 | | |
| | | | (0.246) | | |
| Citation year FE | Yes | No | No | Yes | Yes |
| Book FE | Yes | Yes | No | Yes | Yes |
| Cit. year * book FE | No | No | No | Yes | No |
| Subject * year FE | No | Yes | No | No | No |
| Publ. year & subject FE | No | No | Yes | No | No |
| English * cit. year | No | No | No | No | Yes |
| R-squared | 0.383 | 0.424 | 0.155 | 0.662 | 0.383 |
| N | 18,604 | 18,604 | 18,604 | 18,604 | 18,604 |
| Pre-1942 Mean | 0.300 | 0.300 | 0.300 | 0.300 | 0.300 |

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

*Notes*: BRP and Swiss books are matched using the Mahalanobis propensity score algorithm with fields and pre-1942 average non-English language citations per year as matching variables. The dependent variable measures citations to book *i* per year *t* and language *c* (English vs. other) between 1920 and 1970. The indicator *BRP* equals 1 for 214 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group covers 39 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.

To systematically examine these effects across disciplines, we estimate

$$cites_{ilt} = \alpha\ English_l + \beta\ English_l \times post_t + \varphi\ English_l * math_i * post_t + book_i + \tau_t + \varepsilon_{ilt} \quad (6)$$

where $math_i$ is an indicator for BRP books in mathematics.

TABLE 8 – OLS, DIFFERENTIAL EFFECTS OF PRICE ON CITATIONS, BY DISCIPLINE

| | (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

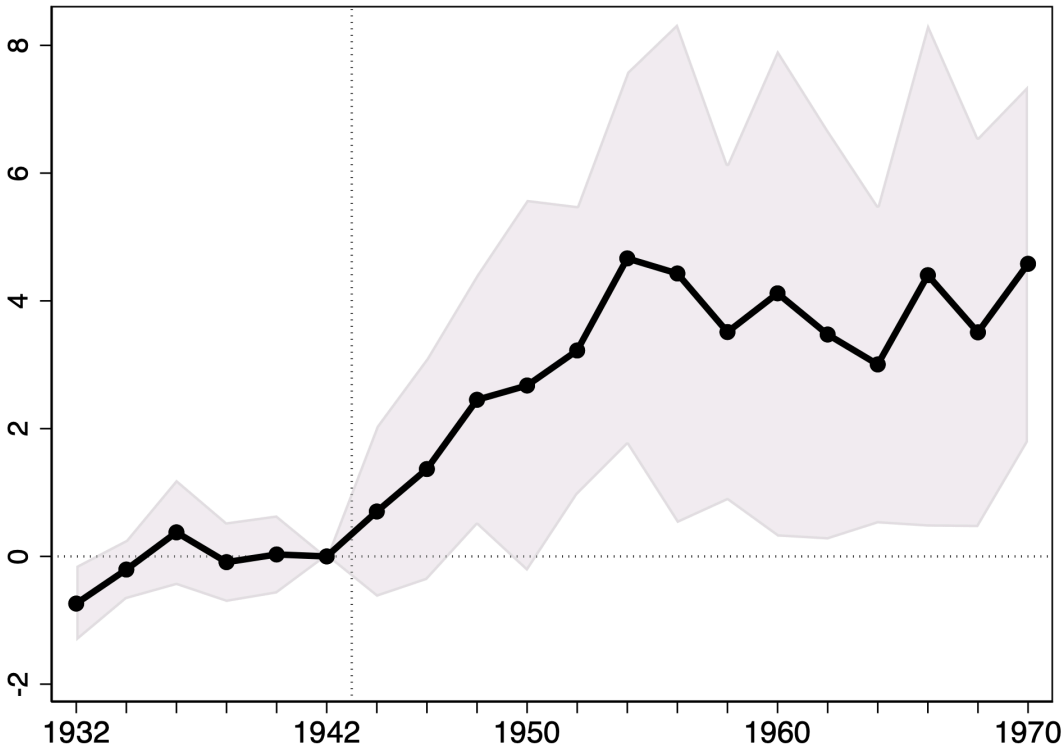
*Notes*: The dependent variable measures citations to book *i* per year *t* between 1920 and 1970. The indicator *English* equals 1 for citations by *English-language* authors; the control group are citations to the same book from authors in other languages. The variable *post* indicates years after 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.

Estimates for *English * math * post* indicate that English–language citations to BRP books in mathematics increase by an additional 0.674 compared with chemistry and citations in other languages after 1941 (Table 8, column 1, significant at 5 percent). Relative to a pre-BRP mean of 0.263 citations, this implies an additional 2.6-fold increase.[40] Intensity regressions imply that a 10 percent decline in price is associated with 0.238 additional English-language publications for mathematics (*English* x *math* x Δ*p* x *post*, Table 8, column 4, significant at 1 percent).[41] Relative to a pre-BRP mean of 0.263 for BRP books, this implies a 90 percent increase.

[40] Estimates with flexible controls for idiosyncratic variation in research output over time and across fields yield 0.565 additional citations, which implies an additional 2.2-fold increase for mathematics (Table 8, column 2, significant at 5 percent, with interaction terms *fields * citation years*). Controlling for a linear pre-trend leaves the estimate for *English * math * post* unchanged at 0.674 (Appendix Table A7, column 3, significant at 5 percent), and increases *English * post* to 0.317 (p-value 0.18).

[41] For each 10 percent decline in price, BRP math books receive 0.303 additional English-language citations after 1941 ($English_I * \Delta p_i * post_t + English_I * math_i * \Delta p_i * post_t$, significant at 10 percent, Table 7, column 4).

FIGURE 7 – TIME-VARYING EFFECTS OF PRICE IN MATHEMATICS




*Notes*: Estimates of $\theta_s$ (with a 95-percent confidence interval) in the OLS regression $cites_{ilt} = \alpha\ English_l + \beta\ English_l * post_t + \Sigma_s\ \theta_s\ \Delta p_i * English_l * \tau_s + book_i + \mu_{ft} + \tau_t + \varepsilon_{it}$ for two-year intervals 1931-1932,…1969-70, with years 1941-42 as the excluded period. The dependent variable $cites_{it}$ 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; $\mu_{ft}$ are field-by-year fixed effects, and $\tau_t$ indicates year fixed effects. The variable $\Delta p$ measures the difference between the original price and the BRP price, divided by the original price. Standard errors are clustered at the book level.

Time-varying estimates of a decline in price indicate no significant differences in English-language citations to BRP math books compared with other citations before 1942. Until 1941 estimates of a 10-percent decline in price range from -0.074 citations in 1931-32 (p-value 0.02, Figure 7) to 0.038 in 1935-36 (p-value 0.91). After the war, estimates increase to 0.245 for 1947-48 (p-value 0.02, Figure 7), and 0.467 in 1953-54 (p-value 0.00). Estimates remain large and significant until 1969-70, with 0.458 (p-value 0.00), implying a 166 percent increase.[42]

*D. Controlling for Substitution or "Business-Stealing" Effects*

Did citations to BRP books increase at the expense of other books? Historical records indicate that there were no good substitutes for BRP books, because these books were at the

[42] 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).

frontier of science (Richards 1981, p. 254). Yet, citations to BRP textbooks may have replaced citations to original research literature in a socially inefficient substitution or "business stealing effect," if lower prices for BRP texts motivated scientists to cite BRP texts instead of original research.[43]

To investigate this issue, we separately estimate changes in citations to BRP textbooks and original research. Specifically, we create an indicator for texts by manually searching all book titles for German words that indicate textbooks, handbooks, or manuals,[44] and re-estimate the baseline specifications with an additional interaction with texts:

$$cites_{ilt} = \alpha_0\, English_l + \alpha\, English_l \times post_t + \gamma_0\, English_l \times text_i + \gamma_l\, text_i \times post_t + \gamma\, English_l \times text_i \times post_t + book_i + \tau_t + \varepsilon_{ilt} \quad (7)$$

In this regression, the coefficient $\gamma$ estimates the increase in English-language citations to BRP texts compared with other BRP books and with the increase in citations in other languages. This estimate is negative and not statistically significant (with a p-value of 0.25, Table 8, column 1).

These tests show that the effects of the BRP on textbooks were negligible. Instead, the observed increase in citations appears to have been driven almost entirely by additional citations to original research. Controlling for textbooks, English-language citations to original research increase by 0.253 citations per year after the BRP (96 percent) relative to other-language citations (English x post, column 1, significant at 1 percent). Equivalent estimates for the two alternative identification strategies confirm these results (Table 8, columns 3-6).

In a complementary set of tests, we use Amazon's sales algorithm to identify potential substitutes for BRP books and check whether these books were published before or after the BRP books. Specifically, we identify books that customers who bought BRP books "also bought" or "frequently bought together."[45] We apply this algorithm to identify related books for the four most highly cited BRP books in mathematics, and 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.

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[43] Mankiw and Whinston (1986, p. 49) define the "business stealing effect: "The business-stealing effect exists when the equilibrium strategic response of existing firms to new entry results in their having a lower volume of sales - that is, when a new entrant 'steals business' from incumbent firms. Put differently, a business-stealing effect is present if the equilibrium output per firm declines as the number of firms grows."

[44] In alphabetical order, these words are : *Allgemeine* (General), *Einführung* (Introduction), *Grundlagen* (Foundations), *Grundzüge* (Principles), *Handbuch* (Handbook), *Hilfsbuch* (Manual), *Laboratoriumsbuch* (Laboratory Manual), *Methoden* (Methods), *Praktiker* (Practitioners), *Praktikum* (Handbook for Practical Training), and *Vorlesungen* (Lectures). In the matched sample, 64 of 214 BRP books (30 percent) are textbooks.

[45] Data collected from www.amazon.com, accessed September 19-30, 2016.

These data confirm that nearly all books that are thematically related to BRP books were first published after 1941 (Appendix Figure A7). We also examine data on citations to these books in newly issued US patents per year (described in more detail below). This test confirms that there were no good substitutes for BRP books before the BRP. Moreover, none of the potential substitutes for BRP books were cited in a US patents until 1957.

TABLE 8 – OLS, DIFFERENTIAL EFFECTS OF BRP FOR TEXTBOOKS

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| English | -0.040 | -0.036 | | | -0.035** | -0.035** |
| | (0.061) | (0.065) | | | (0.015) | (0.015) |
| English x post | 0.253*** | 0.278*** | | | 0.121** | 0.121** |
| | (0.084) | (0.089) | | | (0.047) | (0.049) |
| BRP x post | | | 0.456*** | 0.536*** | 0.110 | 0.181* |
| | | | (0.121) | (0.144) | (0.084) | (0.100) |
| English x BRP x post | | | | | 0.263** | 0.263** |
| | | | | | (0.106) | (0.110) |
| English x BRP | | | | | 0.003 | 0.003 |
| | | | | | (0.070) | (0.072) |
| Text x English | 0.011 | 0.007 | | | 0.002 | 0.002 |
| | (0.070) | (0.074) | | | (0.027) | (0.028) |
| Text x post | 0.031 | -0.118 | -0.078** | 0.587*** | 0.045 | 0.517*** |
| | (0.093) | (0.119) | (0.036) | (0.195) | (0.028) | (0.191) |
| Text x English x post | -0.150 | -0.175 | | | -0.122** | -0.122** |
| | (0.130) | (0.137) | | | (0.052) | (0.054) |
| Text x BRP x post | | | -0.123 | -0.951*** | 0.005 | -0.578** |
| | | | (0.193) | (0.250) | (0.099) | (0.243) |
| Text x English x BRP | | | | | -0.004 | -0.004 |
| | | | | | (0.082) | (0.084) |
| Text x English x BRP x post | | | | | -0.103 | -0.103 |
| | | | | | (0.162) | (0.167) |
| Citation year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Subject * cit year FE | No | Yes | No | Yes | No | Yes |
| R-squared | 0.358 | 0.402 | 0.559 | 0.622 | 0.374 | 0.416 |
| N | 19,680 | 19,162 | 9,365 | 9,213 | 18,730 | 18,730 |
| Pre-1942 Mean | 0.263 | 0.268 | 0.283 | 0.282 | 0.300 | 0.300 |

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

*Notes*: BRP and Swiss books are matched using the Mahalanobis propensity score algorithm with fields and pre-1942 average non-English language citations per year as matching variables. The dependent variable measures citations to book *i* per year *t* and language *c* (English vs. other) between 1920 and 1970. The indicator *English* equals 1 for citations by *English-language* authors. The indicator *BRP* equals 1 for 214 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group covers 39 Swiss books that were not available for licensing due to Switzerland's neutrality during the war. The variable *text* indicates textbooks; *post* indicates years after 1941.

These results are consistent with the time patterns of citations, which indicate that English language translations for (German-language) BRP books were the closest substitute for a BRP book. Translations began to appear in the 1960s, when English replaced German as the *lingua franca* of science. After the publication of a translation, citations to the original BRP book declined. For example, citations to Courant and Hilbert's *Methoden der Mathematischen Physik* slowed dramatically when translations hit the market (Appendix Figure A3).

A related 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 prices declined more for books with more pre-BRP citations by non-English publications. This analysis shows that the correlation is small and not statistically significant (Appendix Figure A8). 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. If there were unobservable variation in the price setting behavior of publishers, substitution effects would cause the estimate of $\theta$ to be downward biased, as long as books with close substitutes experienced a smaller increase in citations.

*E. Marketing: Books with and without Mentions in the Library Journal*

Importantly, some of the observed increase in citations may have been due to increased marketing efforts by publishers of BRP books. To investigate the effects of marketing by publishers, we examine historical records of the *Library Journal*, the premier trade journal in which publishers advertise new titles to librarians. First, we searched the full text of all monthly editions for 1943, 1944, 1945, and 1946 for mentions of BRP authors.[46] We use this information to create a variable for *Ads*, which counts mentions of BRP authors in the *Library Journal* between 1943 and 1946.[47] Among 283 BRP books, authors of 108 BRP books (38 percent) are mentioned in the *Library Journal*; in the matched sample, 50 percent are mentioned.

[46] A search for the original book titles yields only four books, H. Dorrig's *Vektoren*, A. Fraenken's *Einleitung in the Mengenlehre*, K Lehman and F. Flury's *Toxicology and Hygiene of Industrial Solvents* and F. Skaupy's *Principles of Powder Metallurgy.* This suggests that searching for the original (German) titles may miss some of the marketing efforts by publishers of BRP books. Searching for authors instead of books avoids this problem. Moreover, searching for authors capture positive spillovers form other books by the same author.

[47] The median number of *Ads* is zero and the mean is 22.6. The most advertised author is M. Hansen who wrote *Der Aufbau der Zweistofflegierungen*, mentioned 84 times in 1943, 27 in 1944, 48 times in 1945, and 220 times in 1946.

Summary statistics indicate that advertising cannot explain the increase in citations. Citations to advertised BRP books increase by 221 percent, from 0.374 until 1941 to 0.827 afterwards. By comparison, citations to other BRP books increase by 227 percent, nearly the same increase (from 0.178 citations until 1941 to 0.404 citations afterwards).[48]

TABLE 9 – MARKETING EFFECTS: BRP BOOKS WITH ADS IN THE LIBRARY JOURNAL
OLS, DEPENDENT VARIABLE IS CITATION COUNTS

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| English | -0.058 | -0.056 | | | -0.035** | -0.035** |
| | (0.045) | (0.048) | | | (0.014) | (0.015) |
| English x post | 0.184*** | 0.204*** | | | 0.115** | 0.115** |
| | (0.070) | (0.074) | | | (0.045) | (0.047) |
| BRP x post | | | 0.400*** | 0.373*** | 0.148** | 0.148* |
| | | | (0.112) | (0.133) | (0.067) | (0.081) |
| English x BRP x post | | | | | 0.177* | 0.177* |
| | | | | | (0.092) | (0.095) |
| English x BRP | | | | | -0.022 | -0.022 |
| | | | | | (0.052) | (0.054) |
| Ads x English | 0.001 | 0.001 | | | 0.001 | 0.001 |
| | (0.000) | (0.000) | | | (0.000) | (0.000) |
| Ads x post | -0.001** | -0.001 | -0.000 | 0.000 | -0.001* | -0.001 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| Ads x English x post | 0.001 | 0.001 | | | 0.001 | 0.001 |
| | (0.001) | (0.001) | | | (0.001) | (0.001) |
| Citation year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Subject * cit. year FE | No | Yes | No | Yes | No | Yes |
| R-squared | 0.363 | 0.406 | 0.559 | 0.621 | 0.377 | 0.418 |
| N | 19,680 | 19,162 | 9,365 | 9,213 | 18,730 | 18,730 |
| Pre-1942 Mean | 0.263 | 0.268 | 0.283 | 0.282 | 0.300 | 0.300 |

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

*Notes*: BRP and Swiss books are matched using the Mahalanobis propensity score algorithm with fields and pre-1942 average non-English language citations per year as matching variables. The dependent variable measures citations to book *i* per year *t* and language *c* (English vs. other) between 1920 and 1970. The indicator *English* equals 1 for citations by *English-language* authors. The indicator *BRP* equals 1 for 214 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group includes 39 Swiss books that were not available for licensing due to Switzerland's neutrality during the war. The variable *ads* counts mentions of BRP authors in the *Library Journal* between 1943 and 1946.

To investigate marketing efforts more systematically, we estimate:

$$cites_{ilt} = \alpha_0\, English_l + \alpha\, English_l \times post_t + \beta\, BRP_i \times post_t + \delta\, English_l \times BRP_i \times post_t$$
$$+ \gamma_0\, English_l \times Ads_i + \gamma_1\, Ads_i\, x\, post_t + \gamma_2\, English_l \times Ads_i \times post_t + book_i + \tau_t + \varepsilon_{ilt} \quad (8)$$

[48] Table A15 summarizes other characteristics of BRP books advertised in the *Library Journal* and other books. Advertised books are more likely to be in the field of mathematics and slightly older.

where the coefficient $\gamma_2$ on $English_l \times Ads_i \times post_t$ estimates the differential increase in English-language citations for BRP books that is due to publishers' marketing efforts.

Controlling for marketing efforts leaves the estimated effects of the BRP substantially unchanged, and the estimated effect of marketing is small. Effects of the BRP remain large at 0.184 additional citations per year (*English* x *post;* Table 9, column 1, significant at 1 percent), which implies a 70-percent increase in citations. At 0.001, the estimate for $\gamma_2$ on *Ads* x *English* x *post* is a precisely estimated zero.[49] Analogous estimates for the two alternative identification strategies confirm these results (Table 9, columns 3-6). This analysis suggests that the observed increase in citations cannot be explained by marketing and is instead due to the decline in price.

## V. Mechanism: BRP Books Become More Evenly Diffused Across US Institutions

How did lower book prices increase citations? Our working hypothesis is that reductions in access costs enabled less affluent institutions to buy BRP books, enabling a new set of researchers to use BRP books in their work. Consistent with this mechanism, anecdotal evidence indicates that scientists considered access to a good library to be extremely important. 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.[50] Sales records for JW Edwards also show that libraries bought many BRP books (Bokas and Edwards 2011, p. 25). We now examine this mechanism systematically, using data on library holdings, scientists' loans of library books, and changes in the locations of citing authors.

### *A. Variation in Library Holdings*

Data on library holdings show that BRP books became diffused across a geographically and economically diverse set of libraries after the BRP (Figure 8).[51] By 1956, university libraries, such as Ohio State, Oregon, and the University of Virginia held a substantial number of BRP books. By comparison, Swiss books remained concentrated in the holdings of two wealthy research libraries, the John Crerar Research Library at Chicago and Yale.

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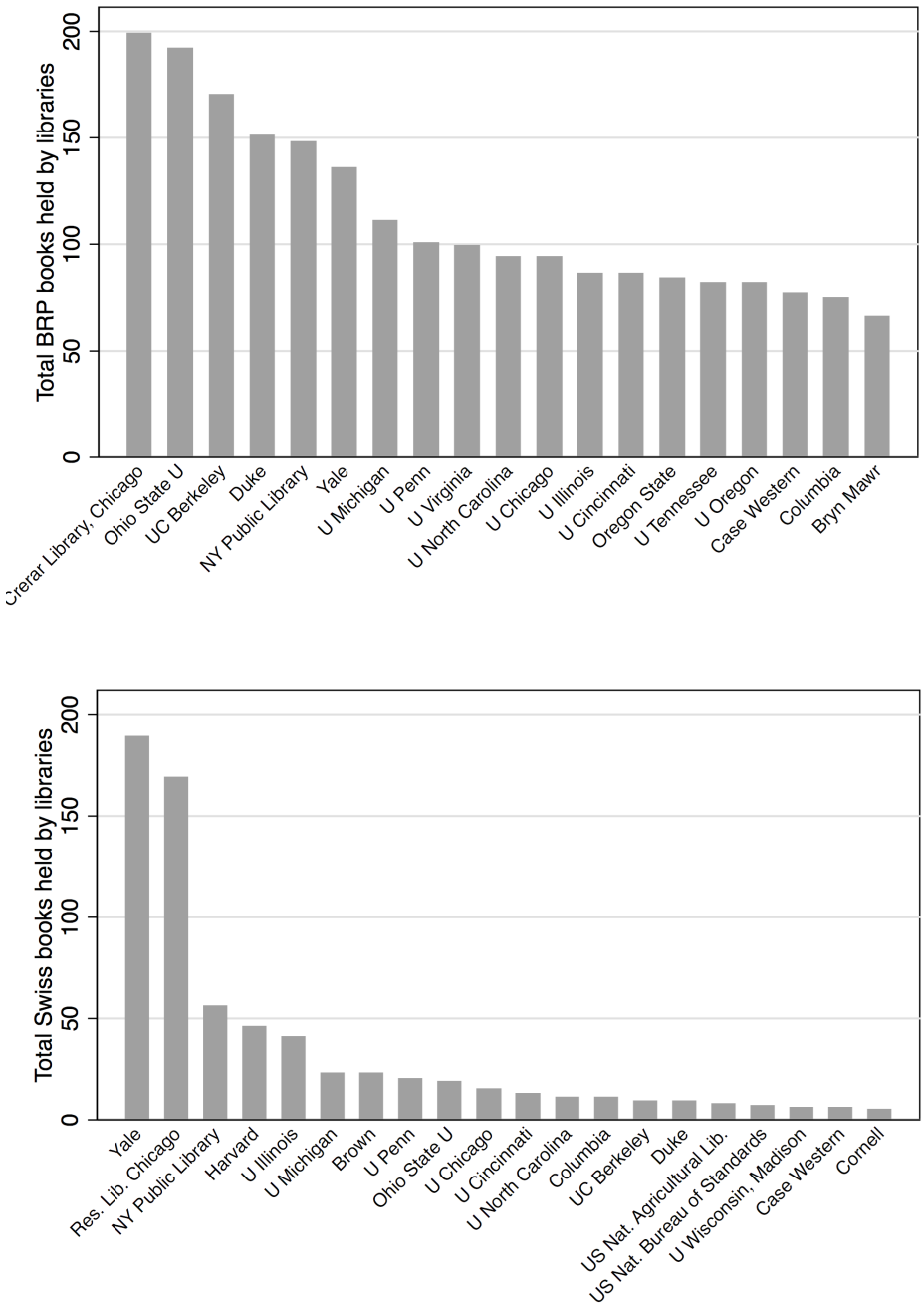
[49] With a standard error of 0.002, the 95-percent confidence interval is [0.001;0.003], which allows us to rule out effects of an additional ad larger than 0.003 citations per year (or 1 percent compared with the mean).
[50] John Manley, cited in Bird and Shirwin (2005, p. 207). Also see Hargittai (2006, pp. 89-131).
[51] To construct these data, we accessed the records of the *National Union Catalog* (NUC, Mansell 1968-1981) in the archives of the Hoover Institution at Stanford. Printed between 1968 and 1981, the NUC records the libraries that held a copy of each book by 1956. It made interlibrary loans practical, by enabling researchers to find out which libraries held a book and allowing them to request it.

FIGURE 8 – BRP BOOKS (TOP) AND SWISS (BOTTOM) BOOKS IN 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.

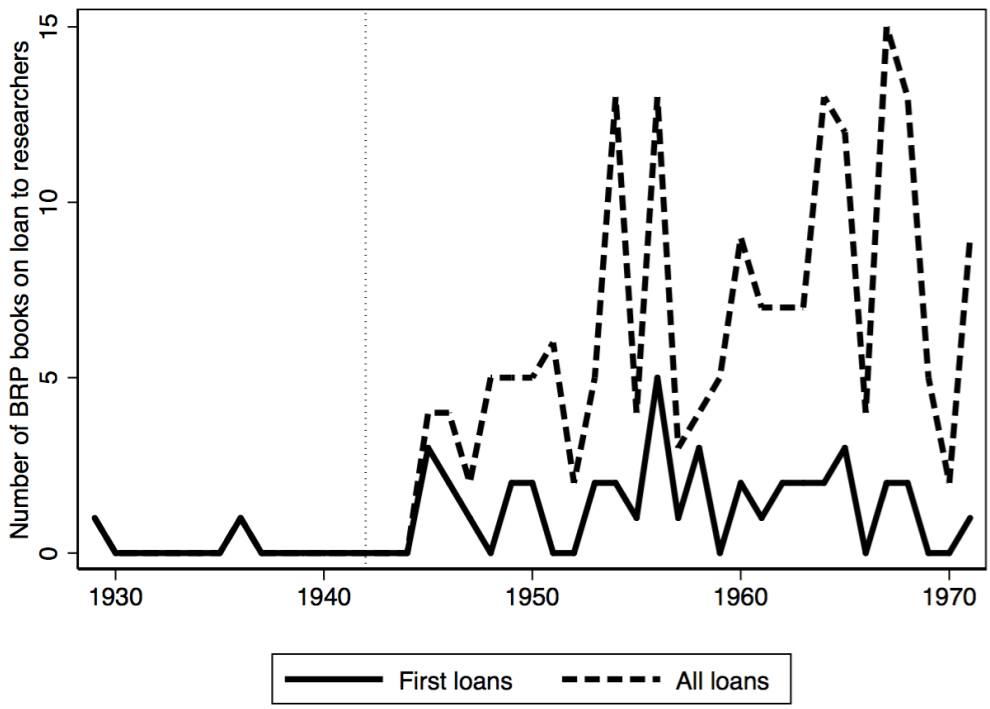
*B. Loans of BRP Books*

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 entered the holdings of 20 libraries and

11 US states by 1956 (Appendix Figure A9). For example, Beilstein's *Handbuch der Organischen Chemie* (1918), with a price decline of 90 percent, was available in 90 of 218 US libraries. By comparison, BRP book in the bottom quartile of the price decline (8 percent or less) were only accessible in 14 of 218 US libraries.[52]

Despite the richness of the data, the NUC alone cannot capture changes in the *usage* of BRP books over time.[53] To address this issue, we examine physical copies of check-out sheets that are attached to the inside back cover of each book (Appendix Figure A10). We were able to collect these data for 127 books, 45 percent of all BRP books in the Stanford University library in 2016.[54]

FIGURE 9 – 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*.

[52] 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, Appendix Figure A11). 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).
[53] Libraries did not systematically record acquisition dates for science books. 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).
[54] 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.

These data reveal a striking overlap between changes in the use and changes in citations (Figure 9). 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 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 9) further indicate that scientists used BRP books repeatedly in the 1940s and 50s.

*C. Citing Authors Near BRP Books*

Next, we examine the geographic overlap between the locations of BRP books and the locations of citations. Ideally, we would like to know where each citing author worked when they cited a BRP book. Using information on the location of PhD-granting institutions in the *Mathematics Genealogy Project* (MGP) we are able to capture the locations of 1,812 authors who cite BRP books.[55] Specifically, we use PhD-granting institutions for professors and their advisees to identify the location of citing authors. 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. Location data are available for all 1,995 citations by 1,812 authors to BRP books in mathematics.

Plots of location data already show that citations tracked the geographic diffusion of BRP books (Figure 10). Before 1942, 64 percent of citations to BRP books originate from the US Northeast (around Cambridge, MA; Princeton, NJ; and Providence, RI) and from Chicago. Afterwards, citations expand to the western and southern United States.

To test whether authors near BRP books became more likely to use BRP books after 1941, we estimate:

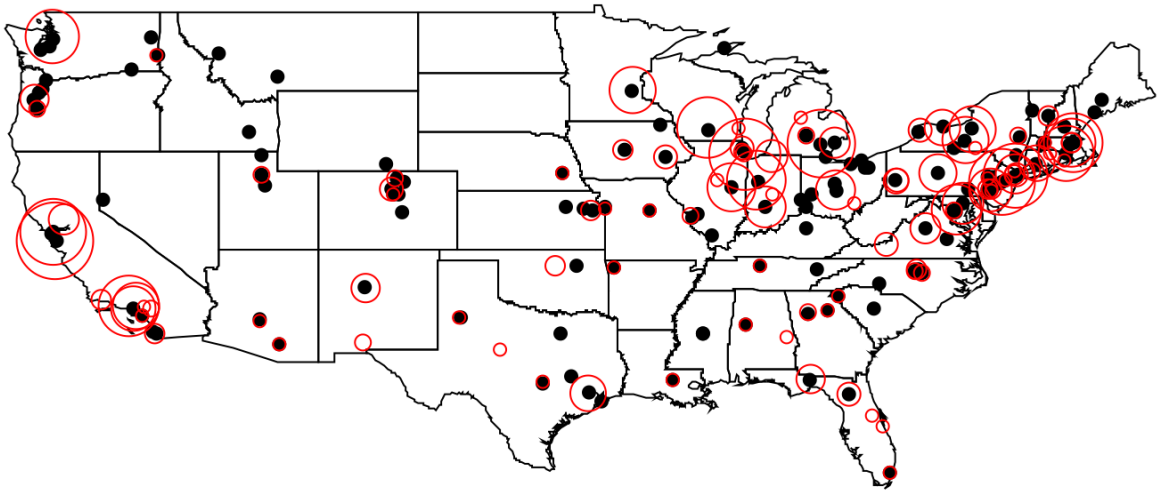
$$cites_{kt} = \beta \; within\ 25\ miles_k \times post_t + \eta_k + \tau_t + \varepsilon_{kt} \quad (9)$$

where the dependent variable $cite_{kt}$ counts citations from authors at location $k$ and year $t$. The explanatory variable $within\ 25\ miles_k$ indicates locations within a 25-mile radius of a BRP book; 87 of 101 locations are within a 25-miles of BRP books. To control for location-

[55] The MGP offers includes advisors, advisees, and PhD-granting institutions for 196,303 mathematicians between 1666 and 2016. http://www.genealogy.ams.org/index.php, accessed January 28 to March 25, 2016.

specific differences in citations (e.g., due to variation in research funding), the vector $\eta_k$ includes location fixed effects.

FIGURE 10 – 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 books after 1941; 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 28-March 10, 2016).

OLS estimates confirm that locations near BRP books experienced a larger increase in citations. Authors within 25 miles of BRP books produce an additional 0.184 publications that cite BRP books per year after 1941 (Appendix Table A16, 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 5.9-fold increase.

Importantly, there is no evidence of differences in the trends of citations before 1942, even though levels of citations are lower in more distant locations (Appendix Figure A11). 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 A16, column 2, significant at 1 percent), which implies a 4.5-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 A16, column 4), whereas estimates become negative or insignificant above 50 miles.

All estimates are robust to including additional controls for proximity to an émigré from Germany, who may have encouraged citations to BRP (and other German) books because they had read these books back home. OLS estimates for proximity to a BRP book remain large with controls for proximity to an émigré institution: Locations within a 50-mile

radius from a BRP library generate 0.117 additional citations to BRP books per year after 1941 (Appendix Table A17, column 2, significant at 5 percent). By comparison, locations within a 50-mile radius from a university with émigrés receive only 0.093 additional citations, and this estimate is indistinguishable from zero (Appendix Table A17, column 2, p-value equal to 0.17).

## VI. Complementary Measures for Knowledge Creation: PhDs and Patents

To complement our analyses of citations, this section examines two complementary measures for advances in science and innovation: new PhDs in math and new US patents that cite BRP books.

Table 9 – OLS, Effects of Distance from Libraries w/ BRP Books on New Math PhDs

| | (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 away, between *x* and *y* miles away from a library with BRP books. The variable *post* equals 1 for years after 1941.

### *A. New PhDs in Mathematics*

Changes in the number of new PhDs are a particularly useful complement to citations, because they capture variation in scientific output *above the level of BRP books*: If all of the observed increase in citations were a result of a substitution effect (away from earlier sources

of knowledge), there should be no differential increase in new PhD theses for locations that have access to BRP books. To examine changes in PhD theses across locations that were differentially affected by the BRP, we examine data on 13,623 mathematicians who received their PhDs between 1920 and 1970 across 180 locations from the Mathematics Genealogy Project.

We then re-estimate the distance regressions in equation (9) for PhDs:

$$PhD_{kt} = \beta \text{ within 25 miles}_k \times post_t + \eta_k + \tau_t + \varepsilon_{it} \quad (10)$$

where $PhD_{kt}$ counts the number of PhDs theses in mathematics 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 book in mathematics.

FIGURE 11– NEW PHDS PER YEAR, BY DISTANCE OF LOCATION FROM BRP LIBRARY


*Notes*: Citations by scientific publications per book and citation year for 55 BRP math books, by distance of the PhD-granting institution from a library holding at least one BRP book. We have collected data on the geographic locations of authors from records of PhD-granting institution of advisors and advisees in the Mathematics Genealogy Project (http://www.genealogy.ams.org, accessed January 28-March 10, 2016). Data on libraries holdings were constructed from the records of the National Union Catalog (Mansell 1968-1981) at the Hoover Institution Library and Archives.

OLS estimates indicate that locations within 25 miles of BRP books produce 0.798 additional PhDs per year after the BRP. Relative to a mean of 0.358 before 1942, this implies a 2.2-fold increase (Table 9, column 1, significant at 10 percent). Maps of new PhDs confirm

that new PhD grants became more concentrated around locations with BRP books after the BRP (Appendix Figure A12).

We present these tests as a robustness check with an alternative measure of knowledge creation, with the caveat that the identification strategy is not as strong as it is for the main analysis. The most severe concern is that universities which acquired BRP books may differ systematically from other universities.[56] For example, they may have a greater demand for BRP books because they are more research-active, and as a result they produce more PhDs. Importantly, however, there are no significant differences in pre-trends across nearby and distant locations near (Figure 11), even though distant locations produce slightly fewer PhDs on average.

*B. New US Patents*

A final test examines the effects on private sector invention. Records from J.W Edwards show that many books were sold to private sector firms. For example, Edwards sold 600 copies of Beilstein's *Handbuch der Organischen Chemie* (Bokas and Edwards 2011, p. 25), but only 158 libraries held a copy in the NUC, leaving 442 copies for private sales. We can trace the potential effects of these books on firm inventions through their patents.

To measure inventions that used knowledge in BRP books, we search the full text of all US patent documents between 1920 and 1970 for citations to BRP books as relevant scientific knowledge.[57] For example, US Patent 3,210,370 for a "PROCESS FOR PREPARING 2,2'-METHYLENE- BISARENEIMIDAZOLES" (filed on June 22, 1964, issued to Joseph J. Ursprung, Portage, MI, and assigned to The Upjohn Company, in Kalamazoo, Michigan) uses Beilstein's *Handbuch der Organischen Chemie* to illustrate the products of its invention:

> "ETHYL 2- (5,G-DEIMEEFIHYL-ZBE'NZHHDAZOLYL) ACETATE A mixture of 6.8 g. (0.05 mole) of 4,5-dimethyl-1,2- phenylenediamine (Beilsteins Handbuch der Organischen Chemie, 13, 179 4th edition, 1930)" and

> "5,5,6-TRIMETHYL-2,2-METHYLENEBIS- BENZIMIDAZOLE A mixture of 4.64 g. (0.02 mole) of ethyl 2-(5,6-dimethyl-Z-benzimidazolylacetate (prepared as described above), 2.44 g. of 4-methyl-1,2-phenylenediamine (Beilsteins Handbuch der Organischen Chemie, 13, 148, 4th edition, 1930), and 50 ml. of 1,2,4-trichlorobenzene was stirred and heated to 180 C."

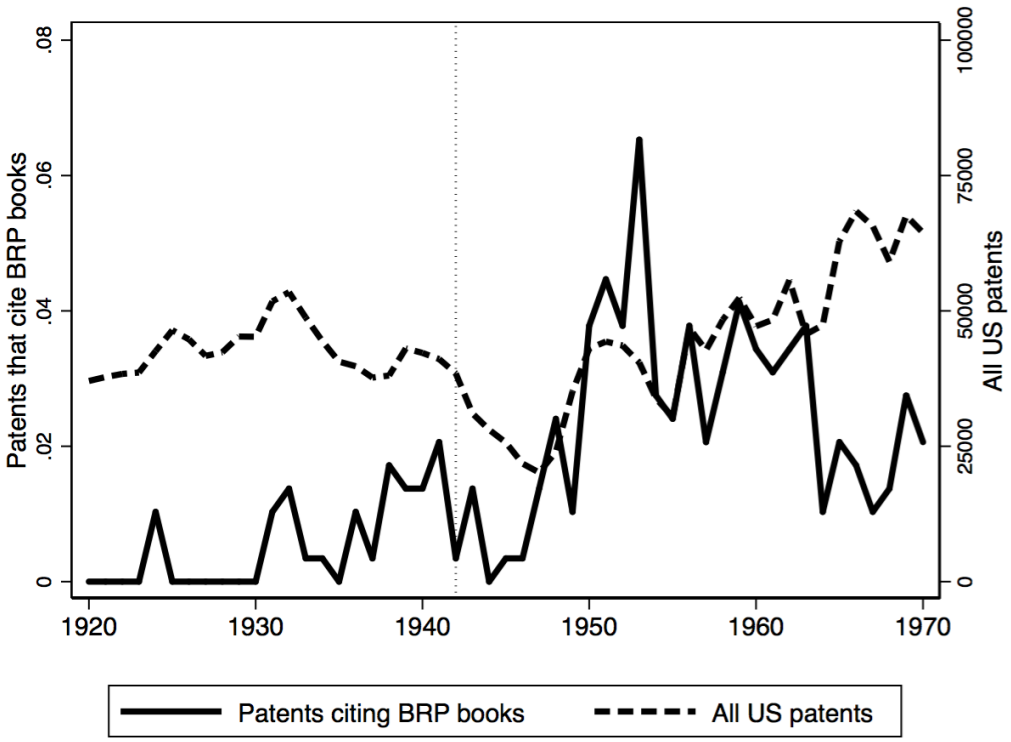
[56] Universities that bought BRP books may have been able to attract better faculty, who then produced more students. Waldinger (2010) shows that the quality of PhD advisors mattered greatly for the career outcome of PhD students in mathematics. Peer effects among faculty were much more limited (Waldinger 2012).

[57] 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.

Notably, citations include page numbers and precise references to the context in which each book was used, indicating that these were real uses, rather than courtesy citations. Between 1920 and 1970, 238 US patents include at least one citation to a BRP book.

Confirming the main results, analyses of patent data suggest a large increase in cumulative invention in response to the BRP. Before 1942, a total of 34 US patents cite at least one BRP book in the description of their invention.[58] Afterwards, 200 patents cite BRP books. Beilstein, for example, is cited as relevant scientific knowledge in 0.304 patents per year before 1942 and 1.345 afterwards. For the average BRP book, patent references increase by 15 percent, from 0.005 per book and year to 0.024 (Figure 12).

FIGURE 12 – 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 1-April 30, 2016).

## VII. CONCLUSIONS

This paper has examined the effects of a rare, exogenous change in copyright policy on the creation of new follow-on science. In 1942, the US government broke the copyright

[58] Thirty patents cite a BRP chemistry book and 4 cite a BRP math book before 1942; 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).

monopoly for German-owned science book under the US Book Republication Program (BRP). Results from two alternative identification strategies indicate that the number of new articles and books that built on BRP books increased by a minimum of 67 percent.

The main mechanism for this effect was a reduction in the price of knowledge. Books with German-owned copyrights that were subject to the BRP experienced an average price decline of 28-percent. Intensity estimates imply that each 10-percent decline in price triggered a 40 percent increase in new research that cites these books. Lower book prices helped to diffuse BRP books to a more economically diverse set of American universities, allowing a new group of researchers to use these books in their research. These researchers began to use the knowledge in BRP books in their research, causing an increase in citations. Importantly, our results are not limited to citations, but they are confirmed by two alternative measures of cumulative science – new PhDs theses and new US patents that cite BRP books.

As a first-order result, our findings inform the current debates on open access and overpricing by publishers. Digitization has led to dramatic reductions in the cost of accessing existing knowledge, much below the prevailing costs in the 20th century. Yet, even today, many platforms charge fees that are prohibitive for countless scholars at institutions in the United States and abroad. Debates on access costs have focused on the choice between open access (making new content available for free) and the extreme alternative of charging the full market price with nearly 100 years of copyright protection. Our findings point to an important middle ground through policies that *reduce* the price of knowledge.

More generally, this paper illustrates an important tradeoff for the design of copyrights and intellectual property. Existing empirical analyses of literature and music have found that basic levels of copyright protection encourage creativity by increasing payments to authors (e.g., Di Cola 2013, MacGarvie and Moser 2013, Giorcelli and Moser 2016). As a counterpoint to these findings, we show that copyrights create substantial social costs by increasing the price of existing content and restricting access for future generations. Left unchecked, these costs give rise to great dynamic losses in creativity and innovation.

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# APPENDIX –
# FOR ONLINE PUBLICATION

## APPENDIX A – ADDITIONAL TABLES AND FIGURES

TABLE A1 – SUMMARY STATISTICS, BRP BOOKS

| | N | Mean | St. Dev. | Median | Min | 25 pctile | 75 pctile | Max |
|---|---|---|---|---|---|---|---|---|
| All BRP books | | | | | | | | |
| Original *p* | 271 | 42.79 | 179.57 | 11.15 | 2.00 | 6.60 | 19.15 | 2000.00 |
| BRP *p* | 283 | 19.41 | 41.77 | 7.50 | 2.00 | 3.20 | 12.50 | 400.00 |
| Δp | 271 | 24.97 | 21.33 | 21.87 | -38.89 | 7.89 | 40.00 | 90.00 |
| Chemistry | | | | | | | | |
| Original p | 216 | 51.18 | 200.34 | 11.70 | 2.00 | 4.50 | 22.95 | 2000.00 |
| BRP p | 228 | 22.43 | 46.00 | 8.50 | 2.00 | 5.00 | 15.78 | 400.00 |
| Δp | 216 | 24.34 | 21.39 | 21.76 | -38.89 | 7.52 | 39.55 | 90.00 |
| Mathematics | | | | | | | | |
| Original p | 55 | 9.84 | 5.77 | 8.00 | 3.40 | 6.00 | 11.75 | 32.65 |
| BRP p | 55 | 6.88 | 4.32 | 5.75 | 2.50 | 3.75 | 8.75 | 25.60 |
| Δp | 55 | 27.44 | 21.11 | 23.47 | 0.00 | 9.72 | 66.09 | 74.14 |

*Notes*: Means, standard deviations, and median prices for 283 books with German-owned US copyrights that were licensed to US publishers under the 1942 BRP. The variable *Δp* measures the percentage decline in price, calculated as the difference between the original price and the BRP price, divided by the original price. Price data collected from records of the Alien Property Custodian (1942).

TABLE A2 – MOST CITED BRP BOOKS

| Author | Title | Publication Year | Citations 1920-1941 | Citations 1942-1970 | Field |
|---|---|---|---|---|---|
| Courant, R. & D. Hilbert | *Methoden der Mathematischen Physik* | 1931 | 8 | 235 | Mathematics |
| Becker, R. | *Ferromagnetismus* | 1939 | 10 | 232 | Chemistry |
| Alexandroff, P. & H. Topf, H. | *Topologie* | 1935 | 6 | 235 | Mathematics |
| Nevanlinna, R. | *Eindeutige Analytische Funktionen* | 1936 | 6 | 230 | Mathematics |
| Waerden, B. | *Moderne Algebra* | 1931 | 11 | 195 | Mathematics |
| Saccardo, P. | *Sylloge Fungorum Omnium Hucusque Cognitorum... curante Alex* | 1881 | 59 | 141 | Chemistry |
| Hansen, M. | *Der Aufbau der Zweistofflegierungen* | 1936 | 25 | 172 | Chemistry |
| Doetsch, G. | *Theorie und Anwendung der Laplace-Transformation* | 1937 | 7 | 169 | Mathematics |
| Clar, E. | *Aromatische Kohlenwasserstoffe: Polycyclische Systeme* | 1942 | 0 | 166 | Chemistry |
| Speiser, A. | *Die Theorie der Gruppen von Endlicher Ordnung* | 1937 | 2 | 112 | Mathematics |

*Notes*: Citations refer to citations to BRP books by English-language citations.

TABLE A3 – MOST CITED SWISS BOOKS

| Author | Title | Publication Year | Citations 1920-1941 | Citations 1942-1970 | Field |
|---|---|---|---|---|---|
| Leser, Conrad | *Invariantentheorie Algebraische Formen* | 1939 | 0 | 41 | Mathematics |
| Huber, Wilhelm | *Zur Kenntnis der Sulfuration Aromatischen Amine nach dem sogennanten "Backprozess"* | 1932 | 0 | 34 | Chemistry |
| Motzkin, Theodor | *Zur Theorie der Linearen Ungleichungen* | 1936 | 0 | 34 | Mathematics |
| Warschawski, Stefan | *Das Randverhalten der Ableitung der Abbildungsfunktion bei Konformer Abbildung* | 1932 | 0 | 34 | Chemistry |
| Stiefel, Edward | *Richtungsfelder und Fernparallelism in n-Dimensionalen Mannigfaltigkeiten* | 1936 | 2 | 31 | Chemistry |
| Hofmann, Albert | *Über den Enzymatischen Abbau des Chitins und Chitosans* | 1929 | 3 | 17 | Mathematics |
| Jungen, Reinwald | *Sur les series de Taylor n'ayant que des singularités algébrico-logarithmiques sur leur cercle de convergence* | 1932 | 6 | 13 | Chemistry |
| Muller, Hans. | *Zur Theorie der elektrischen Ladung und der Koagulation der Kolloide* | 1928 | 0 | 19 | Mathematics |
| Halpern, Ada | *Etude de certains potentiels logarithmiques* | 1937 | 2 | 17 | Chemistry |
| Gutzeit, Grégoire | *Sur une méthode d'analyse qualitative rapide des cations et anions les plus usuels* | 1930 | 3 | 13 | Mathematics |

*Notes*: Citations refer to citations to Swiss books by English-language citations.

TABLE A4 – CHANGES IN PRICE AND IN CITATION FOR THE TOP FIVE RESEARCH FIELDS, BRP AND SWISS BOOKS IN MATHEMATICS (TOP) AND CHEMISTRY (BOTTOM)

| | BRP Books | | | | | Swiss Books | | |
|---|---|---|---|---|---|---|---|---|
| | Price | | Citations | | N | Citations | | N |
| | Original | Δp | Pre-1941 | Post-1941 | | 1920-41 | 1941-70 | |
| Mathematics | | | | | | | | |
| General Mathematics | 11.96 | 38.80 | 0.520 | 1.740 | 14 | 0.025 | 0.112 | 4 |
| Geometry | 7.75 | 29.27 | 0.054 | 0.330 | 12 | 0.028 | 0.112 | 17 |
| Algebra | 8.74 | 15.79 | 0.143 | 0.990 | 7 | 0.017 | 0.119 | 13 |
| Set Theory | 9.99 | 31.59 | 0.447 | 2.695 | 6 | 0.047 | 0.072 | 13 |
| Analysis | 9.52 | 18.14 | 0.337 | 1.952 | 5 | 0.009 | 0.162 | 16 |
| Chemistry | | | | | | | | |
| Compounds | 29.60 | 24.68 | 0.191 | 0.441 | 58 | 0.016 | 0.059 | 74 |
| Organic Chemistry | 200.30 | 34.65 | 0.367 | 0.508 | 28 | 0.000 | 0.057 | 6 |
| Metals | 16.27 | 18.57 | 0.427 | 0.696 | 27 | 0.057 | 0.060 | 4 |
| Electrochemistry | 15.97 | 18.93 | 0.152 | 0.520 | 14 | 0.023 | 0.045 | 10 |
| Analytical Chemistry | 14.77 | 32.79 | 0.242 | 0.299 | 12 | 0.063 | 0.138 | 5 |
| Physical Chemistry | 22.01 | 26.09 | 0.249 | 0.276 | 10 | 0.000 | 0.000 | 1 |

*Notes*: Research fields for 283 BRP and 247 Swiss books in the US National Union Catalog. Research fields are constructed based on topic codes in Alien Property Custodian (1942) and the *Katalog* (vols. 1921-1939 and 1931-1940) of the Swiss National Library.

TABLE A5 – 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 A6 – OLS, EFFECTS OF BRP ON CITATIONS BY ENGLISH VS. OTHER LANGUAGE AUTHORS AND TO BRP VS SWISS BOOKS
DEPENDENT VARIABLE IS THE INVERSE HYPERBOLIC SINE OF CITATIONS PER BOOK AND YEAR

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| English | -0.032 | -0.030 | -0.030 | | | |
| | (0.022) | (0.022) | (0.022) | | | |
| English x post | 0.073*** | 0.080*** | 0.080*** | | | |
| | (0.024) | (0.023) | (0.024) | | | |
| BRP | | | | | -0.246*** | 0.080 |
| | | | | | (0.051) | (0.056) |
| BRP x post | | | | 0.141*** | 0.126** | 0.150*** |
| | | | | (0.037) | (0.054) | (0.043) |
| Citation year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | No | Yes | Yes | No |
| Subject * Year FE | No | Yes | No | No | Yes | No |
| Publ. year & subj. FE | No | No | Yes | No | No | Yes |
| R-squared | 0.374 | 0.423 | 0.124 | 0.541 | 0.607 | 0.200 |
| N | 19,680 | 19,162 | 19,162 | 9,365 | 9,365 | 9,365 |
| Pre-1942 Mean | 0.263 | 0.268 | 0.268 | 0.283 | 0.283 | 0.283 |

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

*Notes*: The dependent variable is defined as $ln(c_{it} +( c_{it}^{2}+1)^{0.5})$, where $c_{it}$ *is* citations to book *i* per year *t* between 1920 and 1970. In columns 1-3, the indicator *English* equals 1 for citations by *English-language* authors; the control group are citations to the same books from authors in other languages. In columns 4-6, the dependent variable is the log of English-language citations, the indicator *BRP* equals 1 for 283 books that were licensed to US publishers under the 1942 Book Republication Program (BRP), and 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 one for years after 1941.

TABLE A7 – OLS, EFFECTS OF BRP AND PRICE DECLINE ON ENGLISH-LANGUAGE CITATIONS. CONTROLLING FOR LINEAR PRE-TRENDS

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| English | -0.036 | -0.036 | -0.036 | -0.036 |
| | (0.042) | (0.042) | (0.042) | (0.042) |
| English x post | 0.211*** | -0.077 | 0.079 | -0.074 |
| | (0.066) | (0.091) | (0.053) | (0.091) |
| English x Δp x post | | 1.192*** | | 0.646** |
| | | (0.344) | | (0.288) |
| English x Math x post | | | 0.674** | |
| | | | (0.279) | |
| English x Math x Δp x post | | | | 2.383*** |
| | | | | (0.907) |
| Citation year FE | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | Yes | Yes |
| R-squared | 0.357 | 0.366 | 0.368 | 0.382 |
| N | 19,680 | 18,986 | 19,680 | 18,986 |
| Pre-1942 Mean | 0.263 | 0.264 | 0.263 | 0.264 |

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 depended variable is de-trended by estimating separate linear pre-trends for English-language citations and for citations by authors publishing in other languages, and then removing these different trends in the post-period. The indicator *English* equals 1 for citations by *English-language* authors; the control group are citations to the same books from authors in other languages. The variable *post* equals one for years after 1941. The variable *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 A8 – COMPARISON OF MEANS:
NEW PUBLICATIONS THAT CITE BRP VS. SWISS BOOKS

| | 1920-41 | 1942-1970 | Difference |
|---|---|---|---|
| All Books (N=530) | 0.105 | 0.338 | 0.232*** |
| | (0.487) | (0.255) | (0.018) |
| BRP (N=283) | 0.263 | 0.566 | 0.303*** |
| | (0.775) | (1.653) | (0.041) |
| Swiss (N=247) | 0.024 | 0.078 | 0. 054*** |
| | (0.171) | (0.353) | (0.007) |
| Difference | 0.239*** | 0.488*** | 0.249*** |
| | (0.014) | (0.020) | (0. 038) |
| Chemistry (N=389) | 0.111 | 0.271 | 0.160*** |
| | (0.514) | (0.993) | (0.017) |
| BRP (N=228) | 0.274 | 0.413 | 0.140*** |
| | (0.814) | (1.251) | (0.037) |
| Swiss (N=161) | 0.025 | 0.069 | 0.044*** |
| | (0.176) | (0.311) | (0.007) |
| Difference | 0.249*** | 0.345*** | 0.096*** |
| | (0.013) | (0.019) | (0.035) |
| Mathematics (N=141) | 0.089 | 0.523 | 0.434*** |
| | (0.395) | (1.776) | (0.051) |
| BRP (N=55) | 0.230 | 1.195 | 0.965*** |
| | (0.633) | (2.661) | (0.135) |
| Swiss (N=86) | 0.021 | 0.094 | 0.073*** |
| | (0.152) | (0.420) | (0.015) |
| Difference | 0.209*** | 1.101*** | 0.892*** |
| | (0.023) | (0.054) | (0.104) |

*Notes*: Means and standard deviations (in parentheses) for English-language citations to BRP and Swiss books *i* per year *t* between 1920 and 1970. *BRP* books include 283 books with German-owned copyrights in the National Union Catalog (NUC) that were licensed to US publishers under the 1942 Book Republication Program (BRP). Swiss books cover 247 books with Swiss-owned copyrights that were not available for copyright licensing due to Switzerland's neutrality during the war. To construct data on citations from different languages, we first collect 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 A9 – COMPARISON OF MEANS:
CITATIONS TO BRP VS. SWISS BOOKS, MATCHED SAMPLE

| | | 1920-41 | 1942-1970 | Difference |
|---|---|---|---|---|
| All Books (N = 255) | | 0.218 | 0.581 | 0.362*** |
| | | (0.710) | (1.667) | (0.038) |
| | BRP (N = 214) | 0.283 | 0.661 | 0.378*** |
| | | (0.804) | (1.787) | (0.047) |
| | Swiss (N = 39) | 0.027 | 0.141 | 0.113*** |
| | | (0.196) | (0.531) | (0.024) |
| | Difference | 0.256*** | 0.520*** | 0.264*** |
| | | (0.036) | (0.054) | (0.091) |
| Chemistry (N = 193) | | 0.229 | 0.405 | 0.175*** |
| | | (0.751) | (1.207) | (0.033) |
| | BRP (N = 165) | 0.302 | 0.462 | 0.160*** |
| | | (1.420) | (1.767) | (0.041) |
| | Swiss (N = 29) | 0.023 | 0.068 | 0.045*** |
| | | (0.352) | (0.460) | (0.016) |
| | Difference | 0.280*** | 0.394*** | 0.114* |
| | | (0.043) | (0.045) | (0.078) |
| Mathematics (N = 60) | | 0.186 | 1.147 | 0.961*** |
| | | (0.572) | (2.572) | (0.114) |
| | BRP (N = 49) | 0.230 | 1.331 | 1.102*** |
| | | (0.633) | (2.785) | (0.141) |
| | Swiss (N = 11) | 0.042 | 0.326 | 0.284 |
| | | (0.240) | (0.854) | (0.079) |
| | Difference | 0.188*** | 1.005 *** | 0.818*** |
| | | (0.059) | (0.158) | (0.274) |

*Notes*: Means and standard deviations (in parentheses) of the number of new scientific publications that cite book *i* per year *t* between 1920 and 1970. *BRP* books include 214 books with German-owned copyrights in the National Union Catalog (NUC) that were licensed to US publishers under the 1942 Book Republication Program (BRP). Swiss books cover 39 books with Swiss-owned copyrights that were not available for copyright licensing due to Switzerland's neutrality during the war. To construct data on citations from different languages, we first collect 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 A10– OLS, EFFECT OF CHANGE IN PRICE ON ENGLISH-LANGUAGE CITATIONS BRP VS. SWISS BOOKS (FULL SAMPLE)

| | (1) | (2) | (3) |
|---|---|---|---|
| BRP | | | 0.159* |
| | | | (0.086) |
| BRP x post | 0.097 | 0.170* | 0.127 |
| | (0.077) | (0.100) | (0.087) |
| BRP x Δp x post | 1.006*** | 0.961** | 1.066*** |
| | (0.344) | (0.433) | (0.313) |
| Δp | | | 0.282 |
| | | | 0.159* |
| Citation year FE | Yes | Yes | Yes |
| Book FE | Yes | Yes | No |
| Field FE * citation year FE | No | Yes | No |
| Publication year FE | No | No | Yes |
| Field FE | No | No | Yes |
| R-squared | 0.554 | 0.587 | 0.167 |
| N | 19,844 | 19,383 | 19,383 |
| Pre-1942 Mean | 0.264 | 0.269 | 0.269 |

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

*Notes*: The 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.

TABLE A11 – OLS, EFFECT OF PRICE DECLINE ON ENGLISH-LANGUAGE CITATION BRP VS. SWISS. BOOKS IN THE LIBRARY OF CONGRESS.

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| BRP | | | 0.742*** | | | 0.613** |
| | | | (0.259) | | | (0.264) |
| BRP x post | 0.361*** | 0.361*** | 0.439*** | 0.070 | 0.070 | 0.148 |
| | (0.089) | (0.089) | (0.151) | (0.083) | (0.083) | (0.155) |
| BRP x Δp x post | | | | 0.992*** | 0.992*** | 1.000*** |
| | | | | (0.342) | (0.342) | (0.316) |
| Δp | | | | | | 0.378 |
| | | | | | | (0.287) |
| Citation year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | No | Yes | Yes | No |
| Publication year FE | No | No | Yes | No | No | Yes |
| Field FE | No | No | Yes | No | No | Yes |
| Linear pre-trend | No | Yes | No | No | Yes | No |
| R-squared | 0.551 | 0.545 | 0.156 | 0.554 | 0.548 | 0.178 |
| N | 10,567 | 10,567 | 10,308 | 10,220 | 10,220 | 9,989 |
| Pre-1942 Mean | 0.263 | 0.263 | 0.268 | 0.264 | 0.264 | 0.269 |

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

*Notes*: OLS regressions for BRP and Swiss books that are listed among the entries of the US Library of Congress. The dependent variable measures citations to book *i* per year *t* between 1920 and 1970. The indicator *BRP* equals 1 for 283 BRP books that are listed in the Library of Congress and that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group covers 19 Swiss books in the Library of Congress 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 5 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 A12 – BOOKS BY ÉMIGRÉS TO THE UNITED STATES

| Title | Author | Publication year | English- language Citations | | Price | |
|---|---|---|---|---|---|---|
| | | | 1920-41 | 1942-70 | Original | $\Delta p$ |
| *Methoden der mathematischen Physik* | R. Courant and D. Hilbert | 1931 | 8 | 235 | 28.24 | 0.504 |
| Strahlenoptik | M. Herzberger | 1931 | 0 | 2 | 7.75 | 0.161 |
| *Mathematische Grundlagen der Quantenmechanik* | J. v. Neumann | 1932 | 6 | 28 | 7.85 | 0.554 |
| *Aufgaben und Lehrsätze aus der Analysis* | G. Pólya and G. Szegő | 1925 | 4 | 34 | 14.40 | 0.583 |

*Notes*: Emigrés are identified using entries in the *International Biographical Dictionary of Central European Émigrés 1933-1945* (Strauss et al. 1983), as well as based on affiliations with US universities, which we collect from the *Mathematics Genealogy Project* (available at http://genealogy.math.ndsu.nodak.edu, accessed February 1-18, 2015).

TABLE A13 – OLS, EFFECTS OF PRICE ON CITATIONS BY ENGLISH VS. OTHER LANGUAGE AUTHORS AND TO BRP VS SWISS BOOKS
DEPENDENT VARIABLE IS THE INVERSE HYPERBOLIC SINE OF CITATIONS

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| English | -0.036 | -0.036 | -0.034 | | | |
| | (0.042) | (0.043) | (0.042) | | | |
| English x post | -0.077 | -0.067 | -0.070 | | | |
| | (0.091) | (0.089) | (0.091) | | | |
| English x Δp x post | 1.192*** | 1.153*** | 1.235*** | | | |
| | (0.344) | (0.351) | (0.342) | | | |
| Δp | | | 0.241 | | | 0.247** |
| | | | (0.176) | | | (0.114) |
| BRP | | | | | | 0.005 |
| | | | | | | (0.055) |
| BRP x post | | | | 0.057 | -0.003 | 0.059 |
| | | | | (0.039) | (0.056) | (0.042) |
| BRP x Δp x post | | | | 0.284** | 0.270* | 0.309*** |
| | | | | (0.109) | (0.146) | (0.109) |
| 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 |
| Pub. year & subject FE | No | No | Yes | No | No | Yes |
| R-squared | 0.314 | 0.366 | 0.114 | 0.429 | 0.501 | 0.176 |
| N | 18,986 | 18,524 | 18,524 | 9,302 | 9,302 | 9,302 |
| Pre-1942 Mean | 0.264 | 0.269 | 0.269 | 0.284 | 0.284 | 0.284 |

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

*Notes*: The dependent variable is defined as $ln(c_{it} +( c_{it}^{2}+1)^{0.5})$, where $c_{it}$ *is* citations to book *i* per year *t* between 1920 and 1970. We add a small number (0.0000001) to the number of citations to account for the fact that several observations in our data have zero citations. In columns 1-3, the indicator *English* equals 1 for citations by *English-language* authors; the control group are citations to the same books from authors in other languages. In columns 4-6, the dependent variable is the log of English-language citations, the indicator *BRP* equals 1 for 283 books that were licensed to US publishers under the 1942 Book Republication Program (BRP), and 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 one 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.

TABLE A14 – OLS AND IV,
EFFECTS OF PRICE ON CITATIONS BY ENGLISH VS. OTHER LANGUAGE AUTHORS

| | OLS (1-2) | | IV (3-5) | | |
|---|---|---|---|---|---|
| | | | First Stage (3) | Second Stage (4-5) | |
| | (1) | (2) | (3) | (4) | (5) |
| English | -0.037 | -0.034 | | -0.036 | -0.034 |
| | (0.042) | (0.044) | | (0.042) | (0.044) |
| English x post | -0.090 | -0.116 | 0.021 | -0.118 | -0.136 |
| | (0.161) | (0.162) | (0.027) | (0.163) | (0.162) |
| English x ln(orig p) x post | 0.120** | 0.137*** | 0.088*** | | |
| | (0.051) | (0.052) | (0.010) | | |
| English x Δp x post | | | | 1.357** | 1.497*** |
| | | | | (0.534) | (0.539) |
| N | 19,333 | 18,843 | 18,986 | 18,986 | 18,524 |
| R-squared | 0.360 | 0.405 | 0.638 | 0.020 | 0.022 |
| Citation year FE | Yes | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | Yes | Yes | Yes |
| Subject * year FE | No | Yes | No | No | Yes |
| Pre-1942 mean | 0.265 | 0.269 | -- | 0.264 | 0.269 |
| KP F-stat | -- | -- | -- | 75.28 | 84.63 |

Standard errors in parentheses are 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. The variable *ln(orig p)* denotes the natural logarithm of the original price of BRP books. The variable *Δp* measures the difference between the original price and the BRP price for book *i*, divided by the original price. In columns 4 and 5, *Δp* is instrumented by *ln(orig p)*; *KP F-stat* refers to the Kleibergen-Paap F-statistic test for weak instruments, and the first stage is shown in column 3.

TABLE A15 – BOOKS ADVERTISED IN THE *LIBRARY JOURNAL*: SUMMARY STATISTICS

| | Advertised BRP books | Other BRP books | Difference |
|---|---|---|---|
| *English-language citations* | | | |
| pre-1942 | 0.339 | 0.153 | 0.186*** |
| | (0.698) | (0.343) | (0.069) |
| post-1942 | 0.826 | 0.403 | 0.422*** |
| | (1.570) | (1.054) | (0.156) |
| *Other-language citations* | | | |
| pre-1942 | 0.275 | 0.277 | -0.002 |
| | (0.514) | (0.534) | (0.070) |
| post-1942 | 0.387 | 0.394 | -0.007 |
| | (0.482) | (0.742) | (0.080) |
| Mathematics | 0.250 | 0.160 | 0.090* |
| | (0.435) | (0.368) | (0.048) |
| Chemistry | 0.750 | 0.840 | -0.090* |
| | (0.435) | (0.368) | (0.048) |
| Publication year | 1935 | 1937 | -2** |
| | (8) | (5) | (0.781) |
| N books | 108 | 175 | 283 |

*Note*: Means and standard deviations (in parentheses, columns 1 and 2) of select book characteristics, for books advertised in the *Library Journal* at least once and for all other books, and difference in means (column 3).

TABLE A16 – OLS,
EFFECT OF BRP ON ENGLISH-LANGUAGE CITATIONS,
BY DISTANCE FROM LIBRARY WITH BRP BOOKS

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| 25 miles * post | 0.184*** | | | 0.145*** |
| | (0.047) | | | (0.046) |
| 50 miles * post | | 0.138*** | | |
| | | (0.050) | | |
| 75 miles * post | | | 0.170*** | |
| | | | (0.040) | |
| 25-50 miles * post | | | | 0.205*** |
| | | | | (0.073) |
| 50-75 miles * post | | | | -0.126** |
| | | | | (0.060) |
| 75-100 miles * post | | | | -0.039 |
| | | | | (0.057) |
| Year FE | Yes | Yes | Yes | Yes |
| Location FE | Yes | Yes | Yes | Yes |
| R-squared | 0.272 | 0.269 | 0.269 | 0.279 |
| N | 4,752 | 4,752 | 4,752 | 4,752 |
| Pre-1942 Mean | 0.031 | 0.031 | 0.031 | 0.031 |

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

*Notes*: The dependent variable counts new citations by English-language publications to BRP books in mathematics from location *k* in year *t.* The indicator *x miles* equals 1 for locations that are within *x* miles from a library that acquired at least one BRP book by 1956. The indicator *x-y miles* equals 1 for locations that are between *x* and *y* miles away from a library with BRP books. The variable *post* equals 1 for years after 1941.

TABLE A17 – OLS,
EFFECT OF BRP ON ENGLISH-LANGUAGE CITATIONS,
BY DISTANCE FROM LIBRARY WITH BRP BOOKS AND/OR ÉMIGRÉ INSTITUTION

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Émigré at 25 miles * post | 0.087 | | | 0.073 |
| | (0.067) | | | (0.087) |
| Library at 25 miles * post | 0.177*** | | | 0.152*** |
| | (0.045) | | | (0.053) |
| Émigré at 50 miles * post | | 0.093 | | |
| | | (0.067) | | |
| Library at 50 miles * post | | 0.117** | | |
| | | (0.048) | | |
| Émigré at 75 miles * post | | | 0.090 | |
| | | | (0.063) | |
| Library at 75 miles * post | | | 0.133*** | |
| | | | (0.044) | |
| Émigré at 25-50 miles * post | | | | -0.001 |
| | | | | (0.094) |
| Library at 25-50 miles * post | | | | 0.196** |
| | | | | (0.083) |
| Émigré at 50-75 miles * post | | | | 0.063 |
| | | | | (0.075) |
| Library at 50-75 miles * post | | | | -0.130* |
| | | | | (0.066) |
| Émigré at 75-100 miles * post | | | | -0.109 |
| | | | | (0.090) |
| Library at 75-100 miles * post | | | | 0.002 |
| | | | | (0.068) |
| Year FE | Yes | Yes | Yes | Yes |
| Location FE | Yes | Yes | Yes | Yes |
| R-squared | 0.271 | 0.269 | 0.268 | 0.279 |
| N | 4,752 | 4,752 | 4,752 | 4,752 |
| Pre-1942 Mean | .031 | .031 | .031 | .031 |

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

*Notes*: The dependent variable counts new citations by English-language publications to BRP books in mathematics from location *k* in year *t.* The indicator *Émigré x miles* equals 1 for locations that are within *x* miles from an institution with an émigré that acquired at least one BRP book by 1956. The indicator *Library x-y miles* equals 1 for locations that are between *x* and *y* miles away from a library with BRP books. The variable *post* equals 1 for years after 1941.

TABLE A18 – OLS, EFFECT OF BRP ON ENGLISH-LANGUAGE CITATIONS. INCLUDING BOOKS THAT ARE NOT IN THE NUC

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| BRP | | | 0.220*** | | | 0.141** |
| | | | (0.057) | | | (0.059) |
| BRP x post | 0.393*** | 0.393*** | 0.420*** | 0.107 | 0.107 | 0.116 |
| | (0.083) | (0.083) | (0.085) | (0.076) | (0.076) | (0.078) |
| BRP x Δp x post | | | | 0.971*** | 0.971*** | 1.068*** |
| | | | | (0.338) | (0.338) | (0.305) |
| R-squared | 0.549 | 0.544 | 0.142 | 0.552 | 0.547 | 0.164 |
| Citation year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Book FE | Yes | Yes | No | Yes | Yes | No |
| Linear pre-trend | No | Yes | No | No | Yes | No |
| Publication year FE | No | No | Yes | No | No | Yes |
| Subject FE | No | No | Yes | No | No | Yes |
| R-squared | 0.549 | 0.544 | 0.142 | 0.552 | 0.547 | 0.164 |
| N | 29,879 | 29,879 | 29,241 | 29,504 | 29,504 | 28,894 |
| Pre-1942 Mean | 0.263 | 0.263 | 0.268 | 0.264 | 0.264 | 0.269 |

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

*Notes*: OLS regressions for the full sample of BRP and Swiss books, including books that are not listed in the National Union Catalog (which captures the holdings of US libraries.) The dependent variable measures citations to book *i* per year *t* between 1920 and 1970. The indicator *BRP* equals 1 for 291 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group covers 486 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.

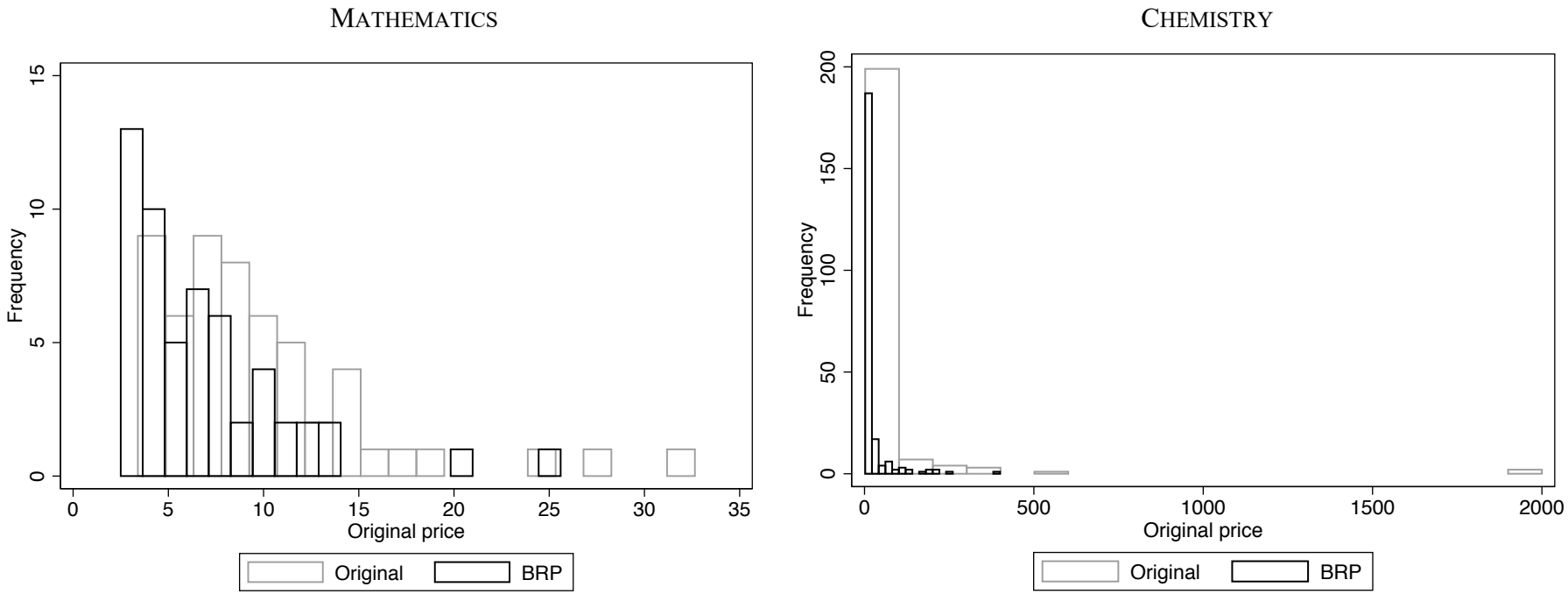
TABLE A19 – OLS, EFFECTS OF BRP ON ENGLISH-LANGUAGE CITATIONS
BRP VS. SYNTHETIC CONTROLS

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| BRP | 0.287*** | 0.287*** | 0.107 | 0.111** | 0.265*** | 0.265*** | 0.313*** | 0.312*** |
| | (0.052) | (0.052) | (0.082) | (0.049) | (0.043) | (0.043) | (0.050) | (0.050) |
| BRP x post | 0.229*** | 0.229*** | 0.027 | 0.025 | 0.095** | 0.095** | -0.067 | -0.034 |
| | (0.071) | (0.071) | (0.082) | (0.074) | (0.048) | (0.048) | (0.074) | (0.068) |
| English | | | | | -0.014*** | | 0.053 | 0.053 |
| | | | | | (0.000) | | (0.048) | (0.048) |
| English x BRP | | | | | -0.024 | | -0.116** | -0.116** |
| | | | | | (0.041) | | (0.053) | (0.053) |
| English x post | | | | | 0.049*** | | -0.033 | -0.033 |
| | | | | | (0.000) | | (0.058) | (0.058) |
| English x BRP x post | | | | | 0.163** | | | |
| | | | | | (0.065) | | | |
| Δp | | | 0.621* | 0.607*** | | | | |
| | | | (0.330) | (0.222) | | | | |
| BRP * Δp * post | | | 0.990*** | 0.994*** | | | 0.451*** | 0.319** |
| | | | (0.347) | (0.314) | | | (0.164) | (0.151) |
| English x BRP x Δp x post | | | | | | | 1.145*** | 1.145*** |
| | | | | | | | (0.325) | (0.325) |
| Citation year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Book FE | No | Yes | No | Yes | No | Yes | No | Yes |
| R-squared | 0.037 | 0.424 | 0.080 | 0.438 | 0.040 | 0.285 | 0.071 | 0.300 |
| N | 13,298 | 13,298 | 12,951 | 12,951 | 26,596 | 26,596 | 25,902 | 25,902 |
| Pre-1942 Mean | .263 | .263 | .263 | .264 | .282 | .282 | .282 | .282 |

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

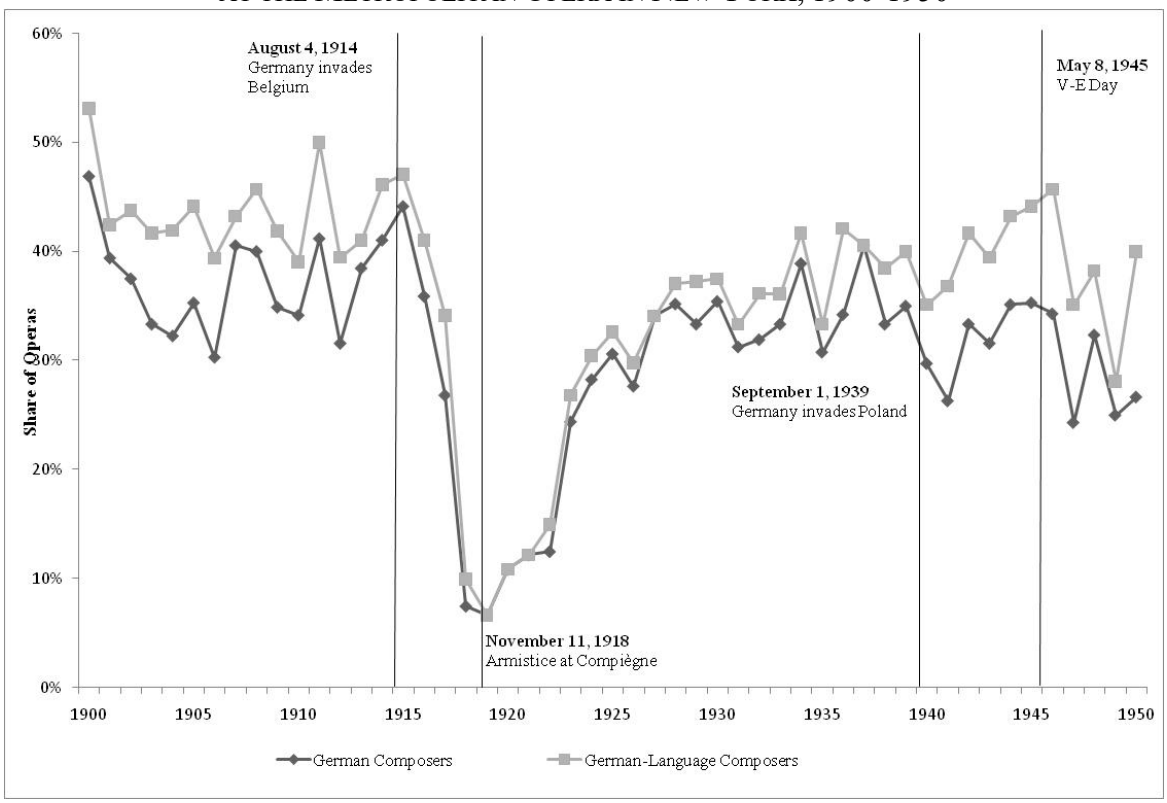
*Notes*: OLS regressions for BRP and a sample of synthetic controls based on Swiss books. The dependent variable measures citations to book *i* per year *t* between 1920 and 1970. The variable *English* denotes English-language citations. The indicator *BRP* equals 1 for 283 BRP books that are listed in the Library of Congress and that were licensed to US publishers under the 1942 Book Republication Program (BRP). The synthetic control for each BRP book is obtained using non-English citations as the covariate and searching among Swiss books in the same field (math and chemistry). 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.

FIGURE A1 – ORIGINAL AND BRP PRICES FOR BRP BOOKS



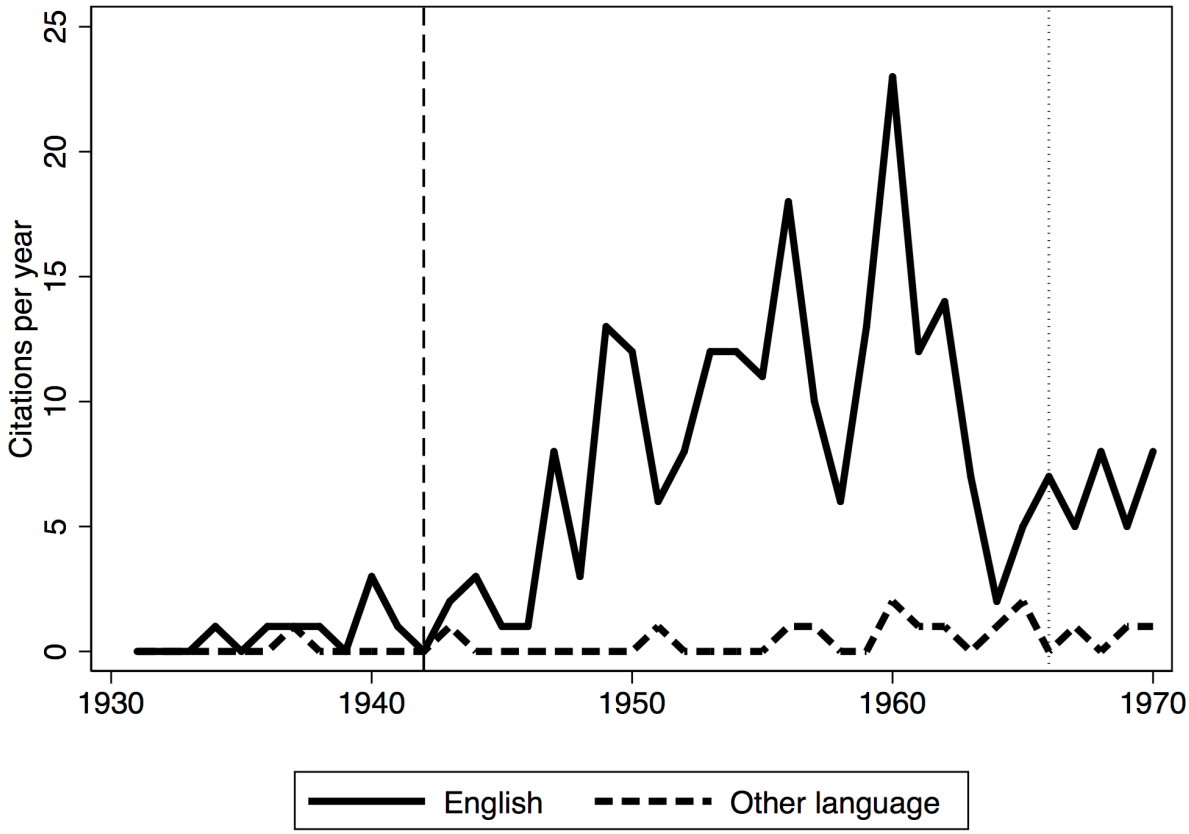

*Notes:* Original (pre-BRP) and BRP prices for 55 books in mathematics (left) and 228 books in chemistry (right). Two chemistry books sold for an original price of $2,000 each: Beilstein's *Handbuch der Organischen Chemie* (with a BRP price of $400) and Saccardo's *Silloge Fungorum* (with a BRP price of $200). The most expensive math books are Courant's *Grundlagen der Mathematik* (with an original price of $32.6 and a BRP price of $25.6) and Courant and Hilbert's *Methoden der Mathematischen Physik* (with an original price of $28.2 and a BRP price of $14).

FIGURE A2 – SHARE OF GERMAN-LANGUAGE OPERAS
AT THE METROPOLITAN OPERA IN NEW YORK, 1900-1950



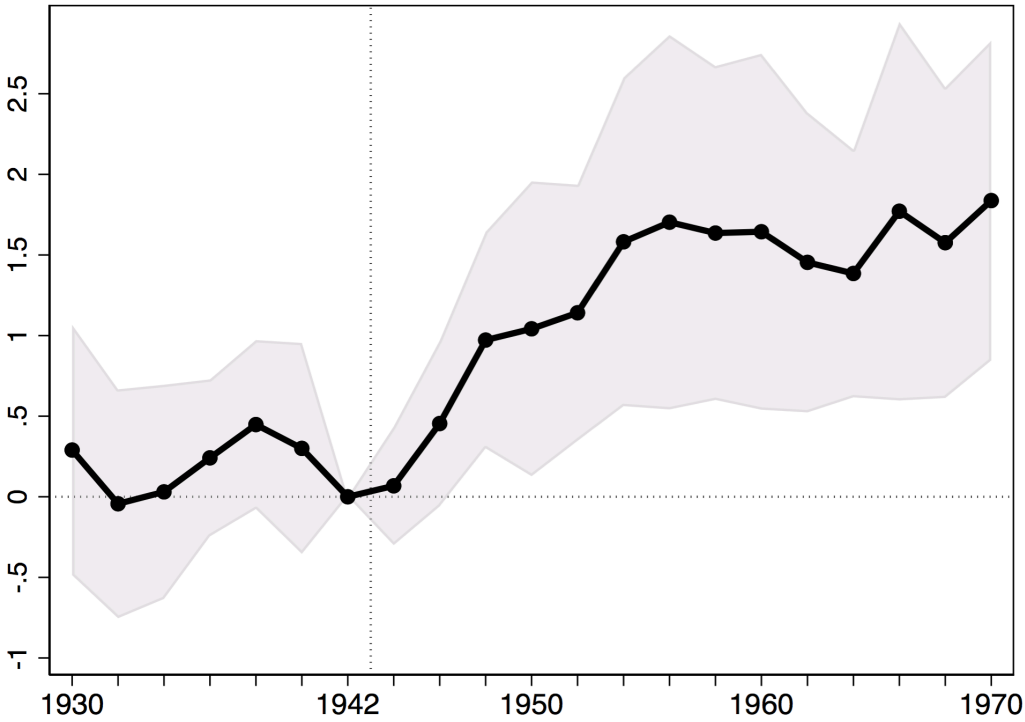

*Notes:* Data on the share of German-language operas collected from historical schedules of performances in the online archives of the Metropolitan Opera in New York (Moser 2012). *German composers* include Carl Maria von Weber, Engelbert Humperdinck, Friedrich Handel, Friedrich von Flotow, Giacomo Meyerbeer, Hermann Goetz, Jacques Offenbach, Ludwig van Beethoven, Max von Schillings, Peter Cornelius, Richard Strauss, and Richard Wagner. *German-language composers* further include Austrian composers Wolfgang Amadeus Mozart, Ernst Krenek, Franz von Suppé, Johann Strauss Jr. and Franz Schubert and the Bohemian Christoph von Gluck. Composers are assigned to ethnicities based on their country of birth, which means that Beethoven and Handel are counted as German, even though Beethoven was also active in Vienna and Handel in London.

FIGURE A3 – CITATIONS BY NEW PUBLICATIONS PER YEAR –
*METHODEN DER MATHEMATISCHEN PHYSIK* (1931) BY R. COURANT AND D. HILBERT




*Notes*: Citations *Methoden der Mathematischen Physik* (1931) by new scientific publications (book and articles) per year. Citations data from Google Scholar (http://scholar.google.com) between July 1st and September 25th, 2014. We restrict the data to new publications that cite the original German language versions of BRP books, and exclude citations to English translations (here, *Methods of Mathematical Physics*, 1966).

FIGURE A4 – TIME-VARYING EFFECTS OF CHANGES IN PRICE
ENGLISH VS. NON-ENGLISH CITATIONS TO BRP VS. SWISS BOOKS




*Notes*: Estimates of $\theta_s$ with a 95-percent confidence interval in the OLS regression $cites_{ilt} = \alpha_1 English_l + \alpha_2 English_l * post_t + \beta_1 BRP_i * English_l + \beta_2 English_l * post_t + \beta_3 BRP_i * English_l * post_t + \beta_4 BRP_i * post_t * + \Delta p_i + \Sigma_s \theta_s \Delta p_i * English_l * BRP_i * \tau_s + book_i + \square_{ft} + \tau_t + \varepsilon_{ilt}$ for two-year intervals 1920-21,…,1969-70, with years 1941-42 as the excluded period. The dependent variable $cite_{ilt}$ counts citations to book *i* in language *l* and year *t.* The indicator *English* equals 1 for citations from English-language authors. The indicator *BRP* equals 1 for 214 books that were licensed to US publishers under the 1942 Book Republication Program (BRP). The control group covers 39 Swiss books that were not available for licensing due to Switzerland's neutrality during the war. $Book_i$ is a vector of book fixed effects; $\square_{ft}$ are field-by-year fixed effects, and $\tau_t$ indicates year fixed effects. The variable $\Delta p$ 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 A5A – CITATIONS TO BRP BOOKS BY ÉMIGRÉS VS OTHER BRP BOOKS

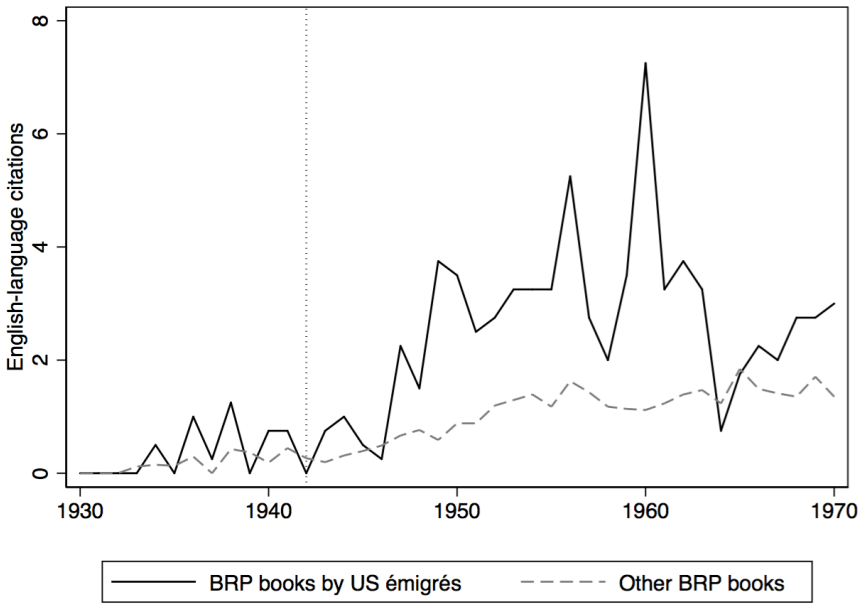
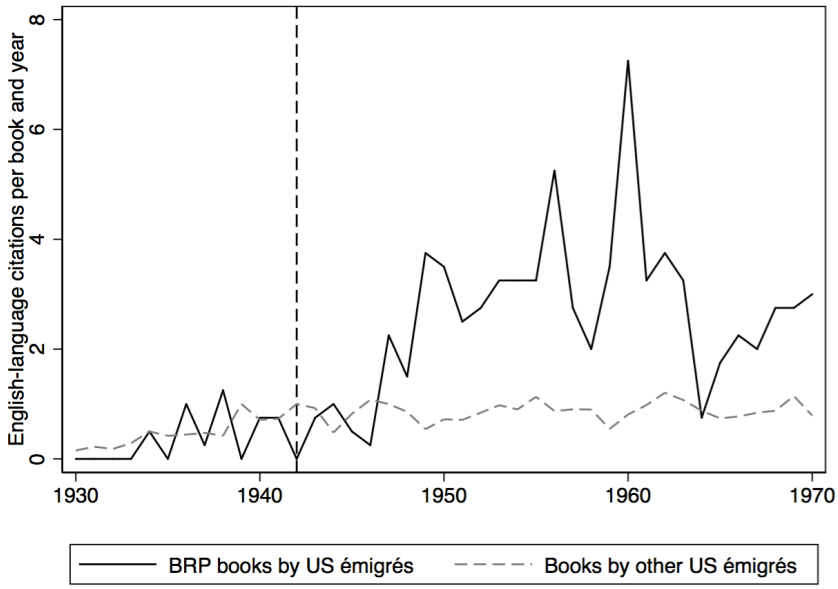



FIGURE A5B – CITATIONS TO BRP BOOKS BY ÉMIGRÉS VS OTHER BOOKS BY ÉMIGRÉS

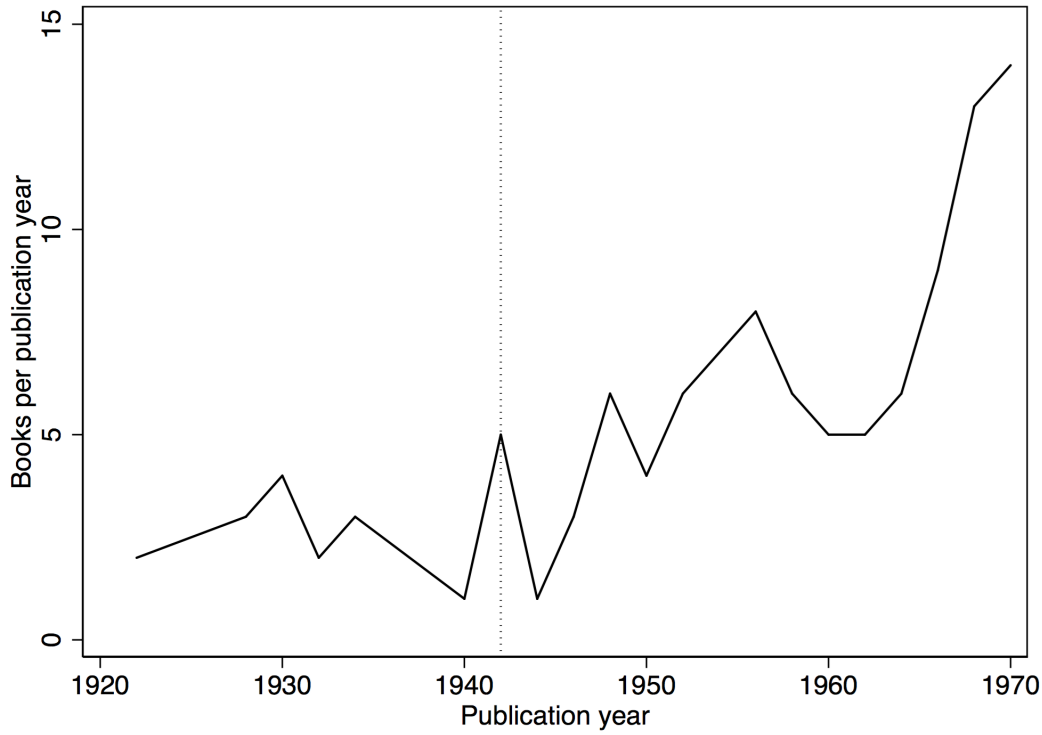



*Notes*: Panel A shows English-language citations per year to five BRP books by English-language citations per book and year for five BRP books by seven mathematicians who emigrated to the United States after 1932 (*BRP books by US emigres*, black line) and by all other BRP books (*Other BRP books,* grey dashed line). Panel B shows English-language citations to the same *BRP books by US emigres* (black line) and by other 115 German émigrés to the US whose work was not included in the BRP (*Books by other émigrés*). Data on émigrés from the *Dictionary of Central European Émigrés* (Straus et al. 1983), the *American Men of Science* (Cattell 1956), and the Mathematics Genealogy Project.

FIGURE A6 – CITATIONS TO BRP BOOKS BY ENGLISH-LANGUAGE AUTHORS PER BOOK AND YEAR: MATHEMATICS (TOP PANEL) AND CHEMISTRY (BOTTOM PANEL)

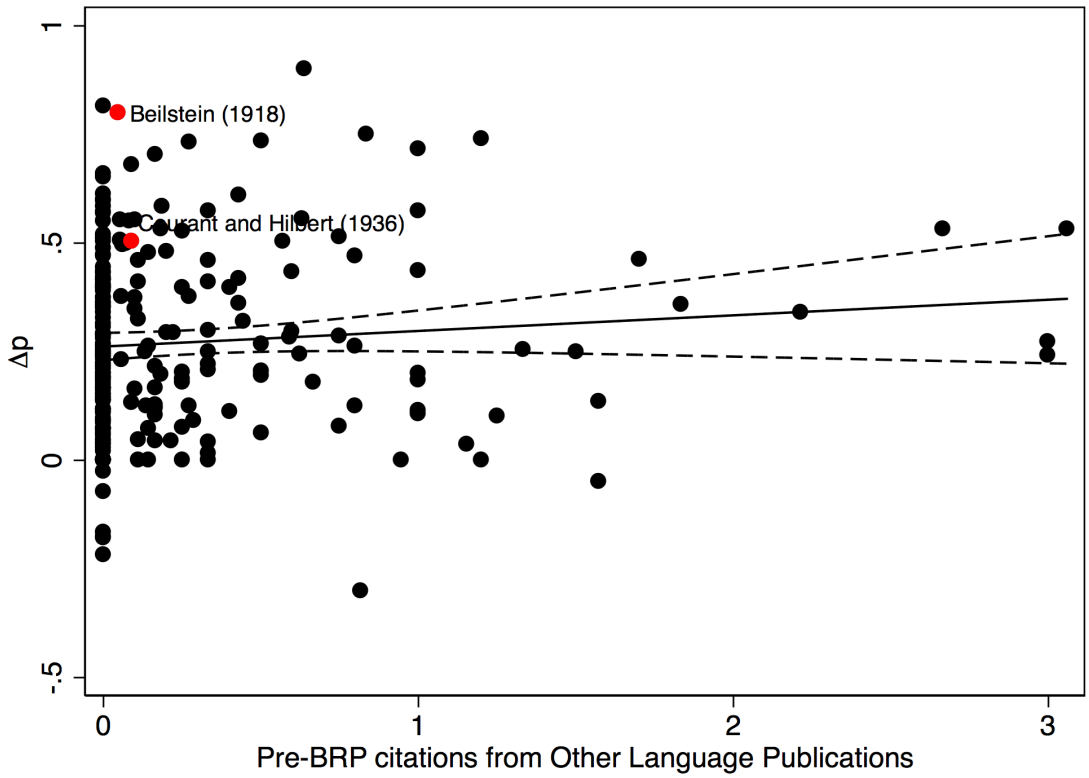

*Notes*: Citations per book and year for 55 mathematics books (bottom panel) and 228 BRP chemistry books (top panel) by new scientific publications in English compared with citations to BRP books by new publications in other languages (which did not benefit directly from the BRP). Citations collected from Google Scholar (http://scholar.google.com, accessed July 1st-September 25th, 2014).

FIGURE A7– PUBLICATION YEARS FOR POTENTIAL SUBSTITUTES FOR BRP BOOKS



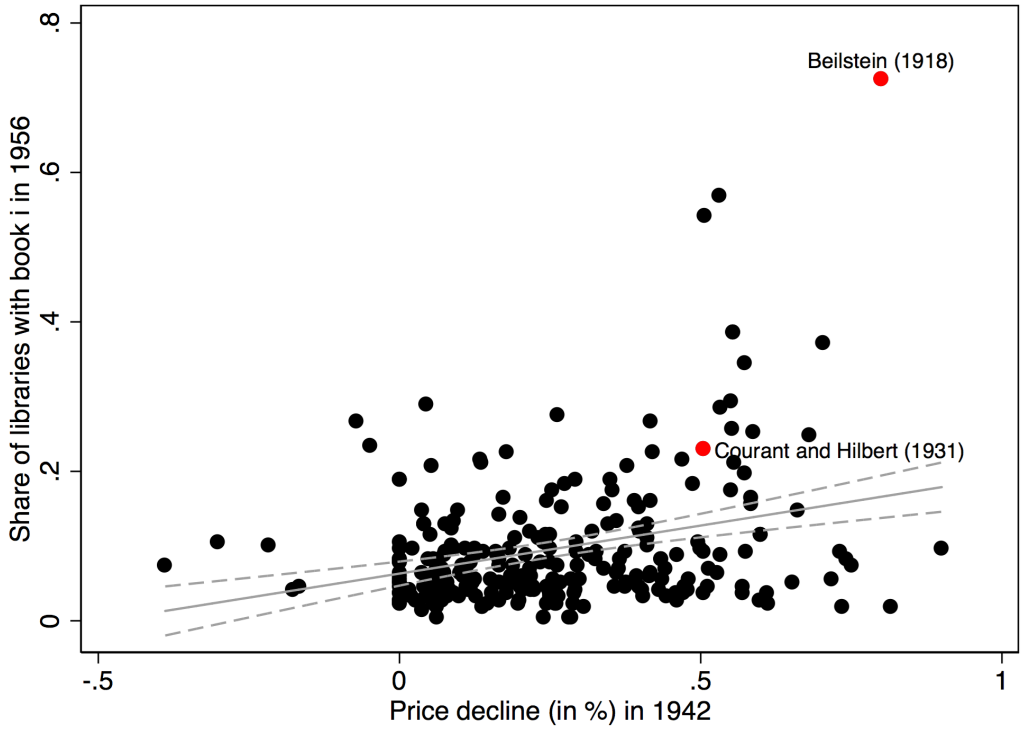

*Notes:* Books that customers on Amazon who bought BRP books "also bought" or "frequently bought together" with BRP books by the publication year of their first edition. For the four most highly cited BRP books in mathematics: Courant and Hilbert (1931) *Methoden der Mathematischen Physik,* Alexandroff and Hopf (1935), van der Waerden (1931), *Moderne Algebra*, Nevanlinna (1936), *Eindeutige analytische Funktionen* (R. Nevanlinna, 1936). Data collected from www.amazon.com, accessed September 21-30, 2016).

FIGURE A8 – DECLINE IN PRICE FOR BRP BOOKS
WITH FEW AND MANY PRE-BRP CITATIONS BY AUTHORS PUBLISHING IN OTHER LANGUAGES




*Notes*: The vertical axis shows the percentage decline in price $\Delta p$ (calculated as the difference between the original price and the BRP price divided by the original pre-BRP price). The horizontal axis shows the pre-BRP counts of citations per year to the same BRP book by publications in other languages. The solid line plots the linear relationship between $\Delta p$ and pre-BRP citations; the dashed lines denote 5 percent confidence intervals. One additional citation by a non-English publication before the BRP is associated with an additional 3.6 percentage point decline in price (with a p-value of 0.18).

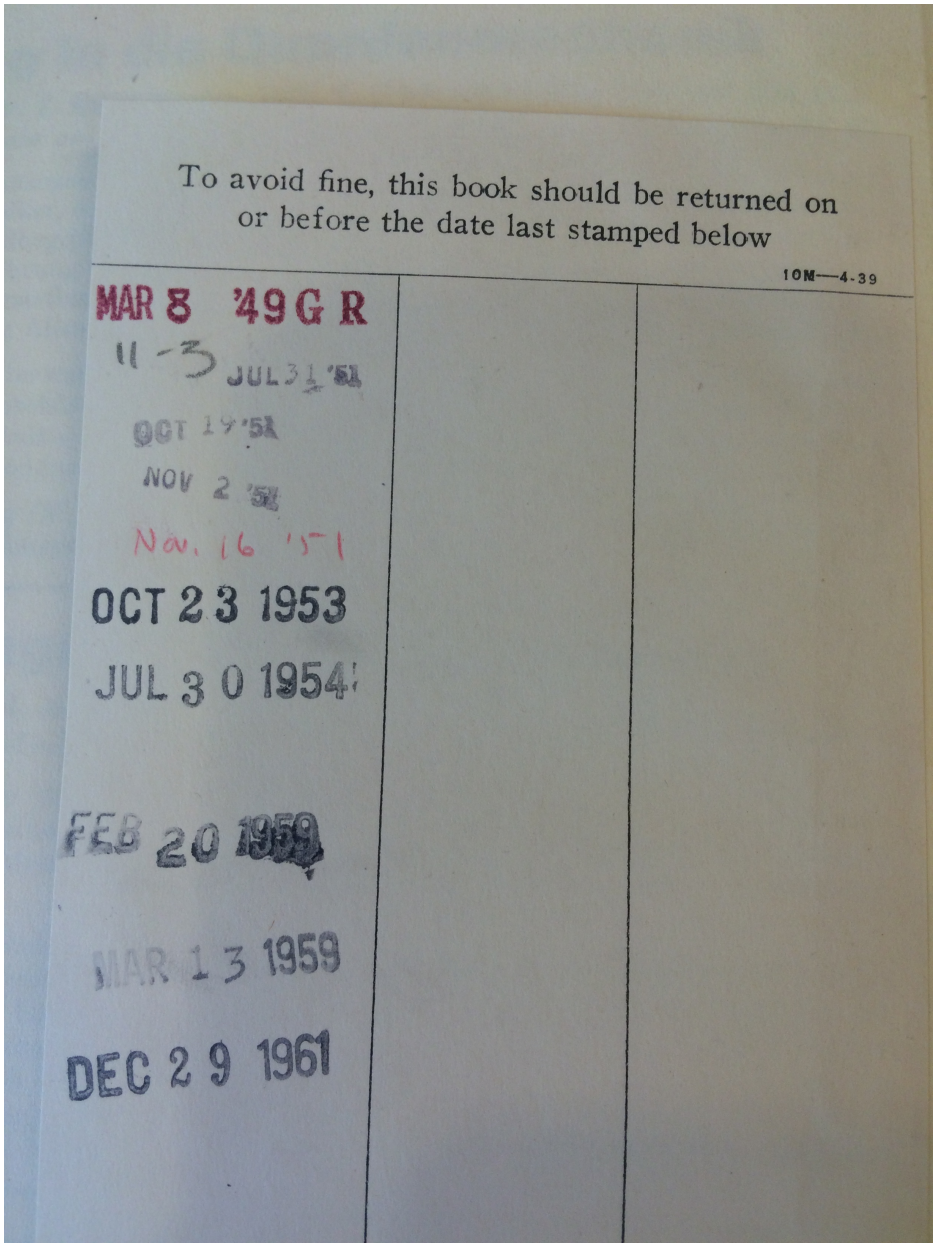
FIGURE A9 – SHARE OF LIBRARIES THAT HAD ACQUIRED A BRP BOOK BY 1956 VS ITS PRICE DECLINE IN 1942




*Notes*: The share of libraries that had acquired a BRP book *i* by 1956 against the decline in price for the same book in 1942. 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). We constructed data on libraries holdings of BRP books a physical copy of the National Union Catalog (Mansell 1968-1981), which is available in the Hoover Institution Library and Archives.

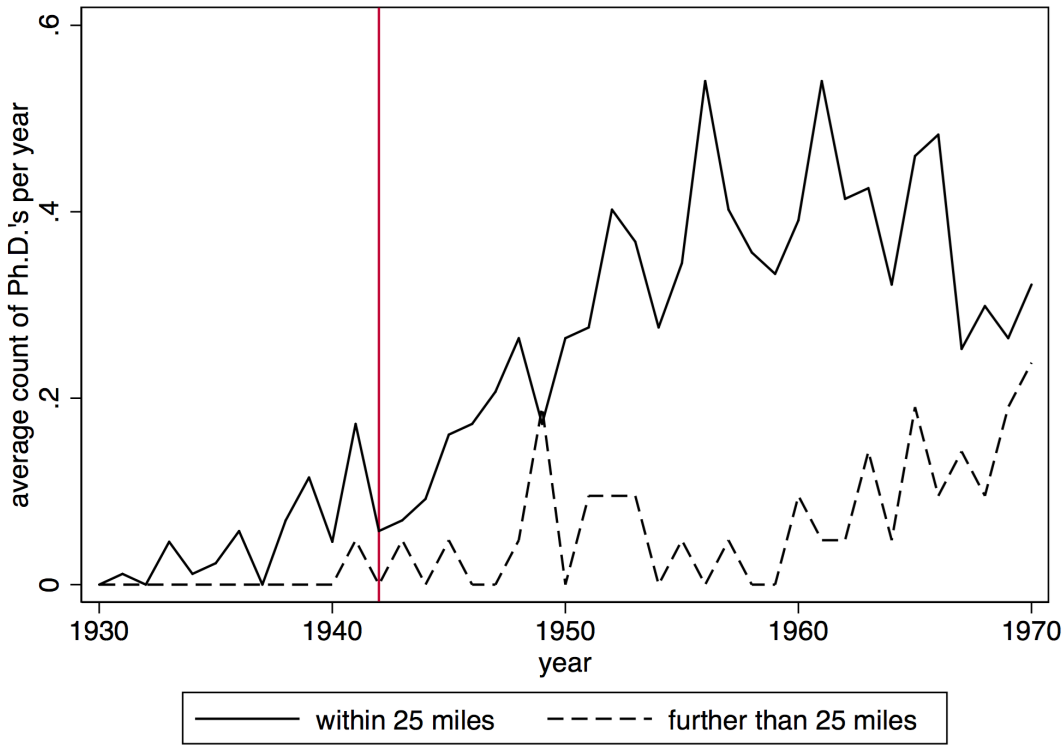
.

FIGURE A10 – CHECK-OUT SHEETS FOR ONE BRP BOOK




*Notes*: Check-out sheets included in the back of the BRP book "Grundlagen Und Anwendungen Ihrer Theorie" by H.C.F von Weizsäcker. Stanford University Library, June 2016.

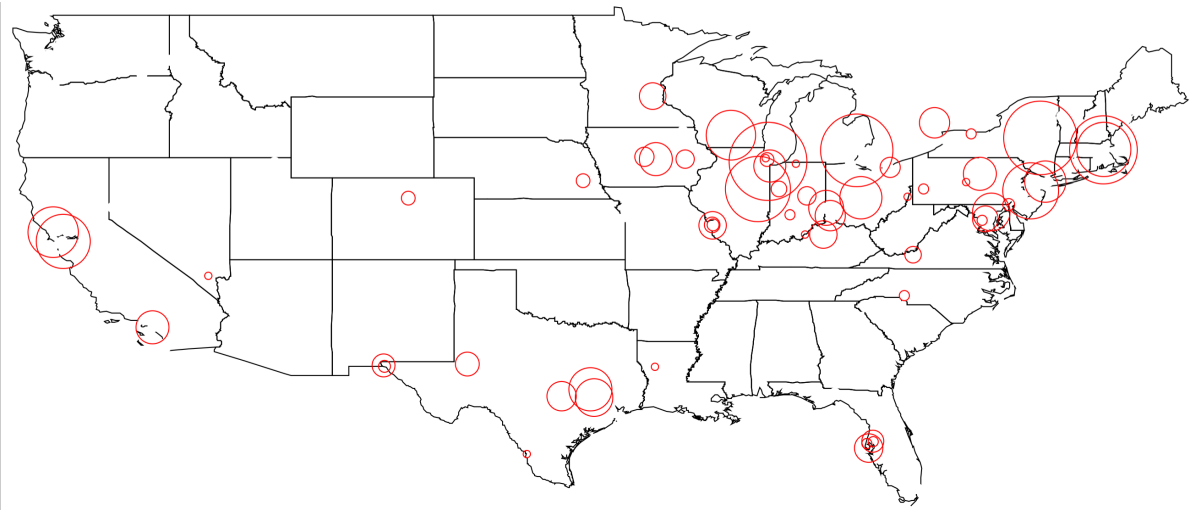
FIGURE A11 – NEW CITATIONS PER YEAR, BY DISTANCE OF LOCATION FROM BRP LIBRARY



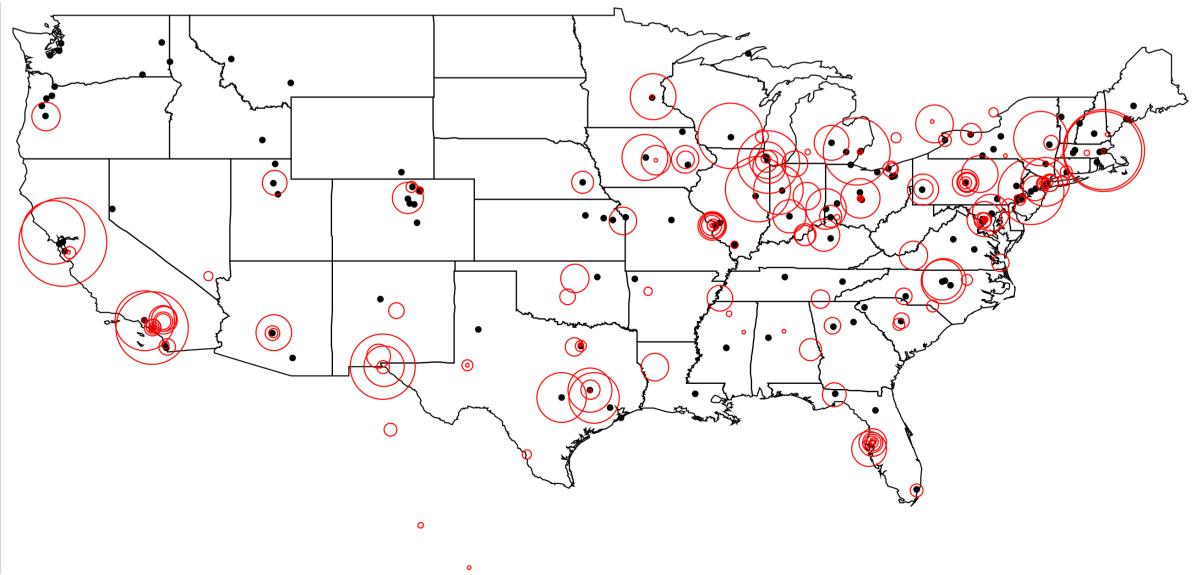

*Notes*: Citations by scientific publications per book and citation year for 55 BRP math books., by distance of the author from a library holding at least one BRP book. We have collected data on the geographic locations of authors from records of PhD granting institution of advisors and advisees in the Mathematics Genealogy Project (available at http://www.genealogy.ams.org, accessed January 28th-March 10, 2016). Data on libraries holdings were constructed from the records of the National Union Catalog (Mansell 1968-1981) at the Hoover Institution Library and Archives.

FIGURE A12 – LOCATIONS OF NEW PHDS AND BRP BOOKS IN MATH

1920-1941

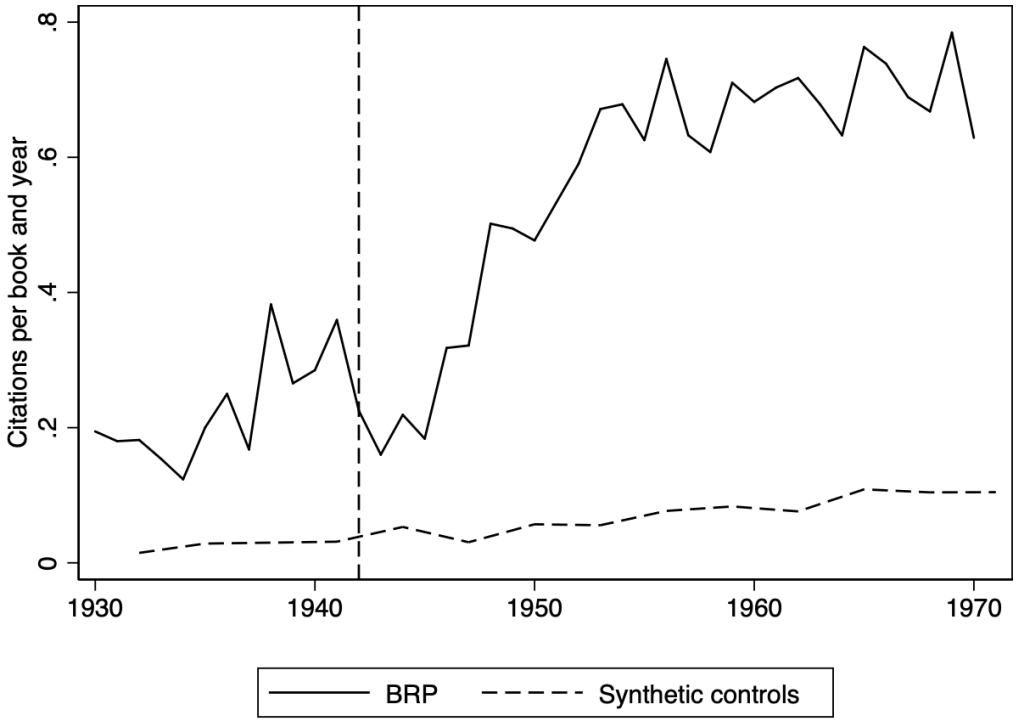


1942-1970



*Notes*: Black circles map the locations of US libraries where BRP math books had become available by 1956. Red circles show the locations of PhD-granting institutions; the size of the red circle represents the number of citations from a location. We have collected data on the geographic locations of authors from records of PhD granting institution of advisors and advisees in the Mathematics Genealogy Project (http://www.genealogy.ams.org, accessed January 28th-March 10, 2016).

FIGURE A13 – CITATIONS TO BRP BOOKS AND THEIR SYNTHETIC CONTROLS




*Notes*: Citations per book and year for 283 BRP books and a sample of synthetic controls. based on Swiss books by new scientific publications in English compared with citations to BRP books by new publications in other languages (which did not benefit directly from the BRP). The synthetic control for each BRP book is obtained using non-English citations as the covariate and searching among Swiss books in the same field (math and chemistry). Citations collected from Google Scholar (http://scholar.google.com, accessed July 1st-September 25th, 2014).

## APPENDIX B – A SIMPLE MODEL OF KNOWLEDGE PRODUCTION

We build a simple model to highlight the economic mechanisms by which copyrights for scientific content may help to shape the creation of new knowledge. Two identical generations of researchers produce new knowledge in periods $t-1$ and $t$. 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 $t-1$. Normalizing the price of new knowledge $y_t$ to equal 1, scientists receive a sure payoff $y_t$ if they produce new knowledge; this payoff can take the form of a money, peer recognition, or any other 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 $p$ could also be viewed as an access fee for a compilation of knowledge 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 $p$ 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 creating new 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

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

*Complementarities with Physical Capital*

The benefits of capital may vary across disciplines according to their dependence on other factors of production (and in particular physical capital) in addition to pre-existing knowledge. To examine these effects, we first extend the knowledge production function to allow for heterogeneous effects across disciplines. Let $y_{m,t} = g(y_{m,t-1}, k_t)$ represent a discipline

in which knowledge creation depends primarily on human capital, such as mathematics. Let $y_{c,t} = z(y_{c,t-1},k_t)$ be a discipline in which knowledge production requires physical capital (such as laboratory space for chemical research). The elasticity of knowledge production with respect to physical capital is $e^c(y_{c,t-1},k_t) = z_k(y_{c,t-1},k_t)\, k_t / z(y_{c,t-1},k_t)$ for chemistry and $e^m(y_{c,t-1},k_t) = g_k(y_{m,t-1},k_t)\, k_t / g(y_{m,t-1},k_t)$ for mathematics. This elasticity is smaller for mathematics than for chemistry, so that $e^m(y_{m,t-1},k_t) < e^c(y_{c,t-1},k_t)$ for every $\{y_{m,t-1}, y_{c,t-1}, k_t\}$. Then, the threshold prices for existing knowledge (above which scientists choose not to invest in follow-on research) become

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

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 cumulative knowledge with respect to physical capital:

$$\frac{dp'}{de(y_{t-1},k^*)} = -f(y_{t-1},k^*) \leq 0 \quad \text{if} \quad f(y_{t-1},k^*) \geq 0 \qquad (7)$$

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

$$\frac{dp'}{d\alpha} = \alpha^{\frac{\alpha}{1-\alpha}} y\, r^{\frac{\alpha}{\alpha-1}} \frac{1}{1-\alpha} \log(\alpha/r) \leq 0 \quad \text{if} \quad \alpha \leq r$$

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