How Antitrust Enforcement Can Spur Innovation: Bell Labs and the 1956 Consent Decree

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Online Appendix

Appendix to Section I

A1. The History of the Bell System and the Antitrust Lawsuit

As described in Section I, the Bell System was the dominant provider of telecommunications services in the United States. In terms of assets, AT&T was by far the largest private corporation in the world in 1956. AT&T, together with all companies in the Bell system, employed 746,000 people with a total revenue of $5.3 billion or 1.9% of the U.S. GDP at the time (Antitrust Subcommittee, 1959; Temin and Galambos, 1987). It was also one of the most innovative companies in the world: Between 1940 and 1970, Bell filed on average ∼503 patents or 1% of all U.S. patents each year. The 1950 staff of Bell Labs alone consisted of four future Nobel Laureates in physics, one Turing Award winner, five future U.S. National Medals of Science recipients, and ten future IEEE Medals of Honor recipients. In 1950, Bell Labs employed 6,000 people, one-third of whom were professional scientists and engineers (Nelson, 1962; Temin and Galambos, 1987). This was 1% of the entire science and engineering workforce in the U.S. at the time.[1]

After the complaint was filed in January 1949, Bell sought and obtained a freeze of the antitrust lawsuit in early 1952 with the support of the Department of Defense (DoD), on the grounds that the DoD relied on the research of Bell Labs for the war effort in Korea. In World War II, the Bell Labs had been instrumental in inventing the superior radar systems of the Allies. They also engaged in around a thousand different war-related projects, from tank radio communications to enciphering machines for scrambling secret messages (Gertner, 2012, p.59 ff.). In Figure A1, we show two examples of Bell's war-related technologies: radar and cryptography. In these two technologies, Bell filed a total of 251 patents. In the following years, Bell Labs continued to work for the DoD, for example by operating the Sandia National Laboratories, one of the main development facilities for nuclear weapons.

In January 1953, after Dwight D. Eisenhower took office, Bell began to lobby for the dismissal of the case on the grounds that the Bell System was too important for national defense and thus should be kept intact. The government followed this argument, and the Attorney General Herbert Brownell Jr. asked Bell to submit

[1]According to the National Science Foundation, the number of workers in S&E occupations was 182,000 in the U.S. in 1950. Source: https://www.nsf.gov/statistics/seind12/c3/c3h.htm - last accessed June 4, 2017.

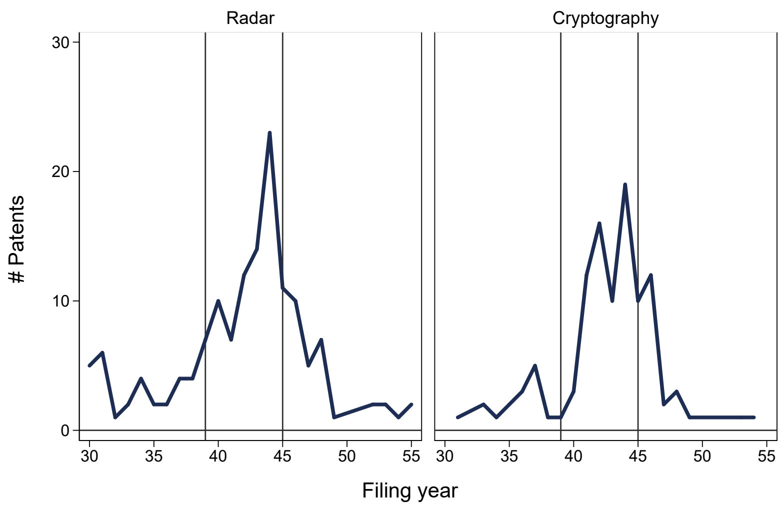


Figure A1. : War-Related Technologies Created by Bell Labs

Note: This figure shows the yearly number of Bell patents related to radar and cryptography, two technologies relevant for World War II. We identify both technologies by their USPC class. We use the class 342 titled "Communications: directive radio wave systems and devices (e.g., radar, radio navigation)" to classify radar and class 380 titled "Cryptography" to classify cryptography. The patent data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

concessions with “no real injury” that would be acceptable to settle (Antitrust Subcommittee, 1959, p.55). In May 1954, AT&T presented and in June 1954 submitted to the Department of Justice a checklist of concessions that would be an acceptable basis for a consent decree. The only major remedy suggested was the compulsory licensing of all Bell patents for reasonable royalties. To support this position, Charles Erwin Wilson, the Secretary of Defense, wrote Herbert Brownell Jr., the Attorney General, a memorandum to the effect that the severance of Western Electric from Bell would be “contrary to the vital interests of the Nation” (Antitrust Subcommittee, 1959, p. 56). In December 1955, the Department of Justice communicated with AT&T that it was ready to consider a decree of the “general character suggested (by A. T. & T.) in its memorandum (...) dated June 4, 1954” (Antitrust Subcommittee, 1959, p.92). Bell agreed.

The case ended with a consent decree on January 24, 1956, containing two remedies. First, the Bell System had to license all its patents issued prior to the decree royalty-free to any applicant, with the exception of RCA, General Electric, and Westinghouse, who already had cross licensing agreements with Bell (the so-called B-2 agreements). All subsequently published patents had to be licensed for reasonable royalties. As a consequence of the consent decree, 7,820 patents in 266 USPC technology classes and 35 technology subcategories or 1.3% of all unexpired U.S. patents became freely available. Second, the Bell System was barred from engaging in any business other than telecommunications.

According to Stanley N. Barnes, the presiding Judge over the Bell Case, the consent decree and in particular compulsory licensing was a suitable remedy to restore competition. He argued that “[t]he patent relief in itself opens wide the door to hundreds of small businesses to attempt to supply these companies” (Antitrust Subcommittee, 1959, p.317). The Judge rejected the charge brought by the prosecutors that Western Electric used exclusive contracts to keep competitors out. Moreover, he argued, a regulator overseeing the accounting system of Bell would make foreclosure impossible because he would prohibit the operating companies from buying equipment from Western Electric if cheaper and higher quality products were available from alternative suppliers.

A2. Free Compulsorily Licensed Patents by NBER Technological Subcategory

In Figure A2 we show the free compulsorily licensed patents split by technology subcategories following (Hall, Jaffe and Trajtenberg, 2001). Only 31% of all Bell patents are in the field of telecommunications while the remaining patents are spread over 34 other subcategories.

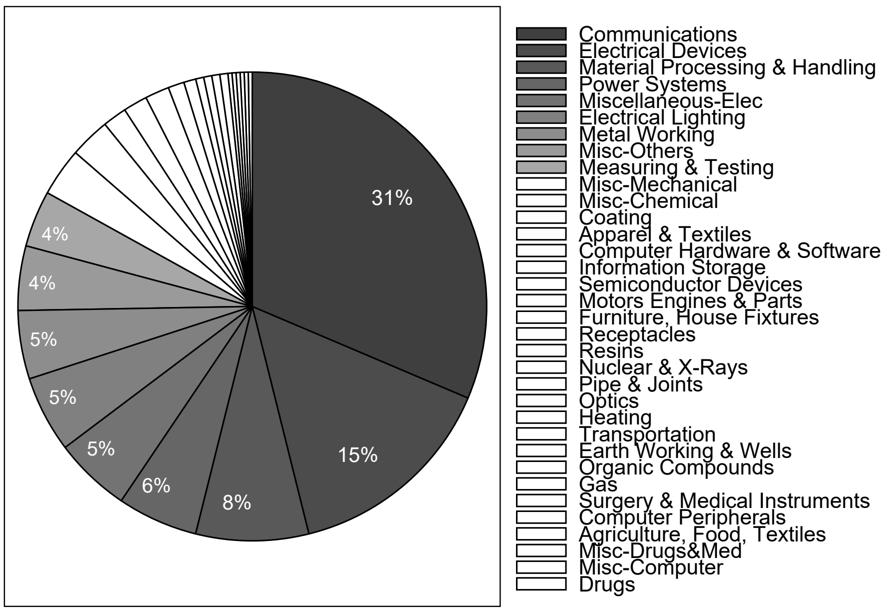


Figure A2. : Free Compulsorily Licensed Patents by NBER Technological Subcategory

Note: The pie chart shows the distribution of free compulsorily licensed patents over 35 NBER technological subcategories. The legend is sorted from largest to smallest share. The categorization in technological subcategories is based on U.S. patent classifications, following Hall, Jaffe and Trajtenberg (2001). The patent data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

Appendix to Section II

B1. Timing the News on the Consent Decree

The cumulative abnormal stock returns for AT&T stocks shown in Figure B1 suggest that the agreement reached in 1954 between the Attorney General and the Bell management was known to a substantial group of people.[2] Up to the election of Dwight Eisenhower, cumulative abnormal returns were centered around zero. At the beginning of 1954, cumulative abnormal returns strongly increased to around 11%. The large uptick in March 1954 is exactly synchronized with the Bell memorandum of this month, which summarized the meeting between the Attorney General and the Ball management. There is no more persistent positive or negative change in the cumulative abnormal returns until 1959. In particular, the consent decree itself in 1956 did not seem to have had any more informational value.

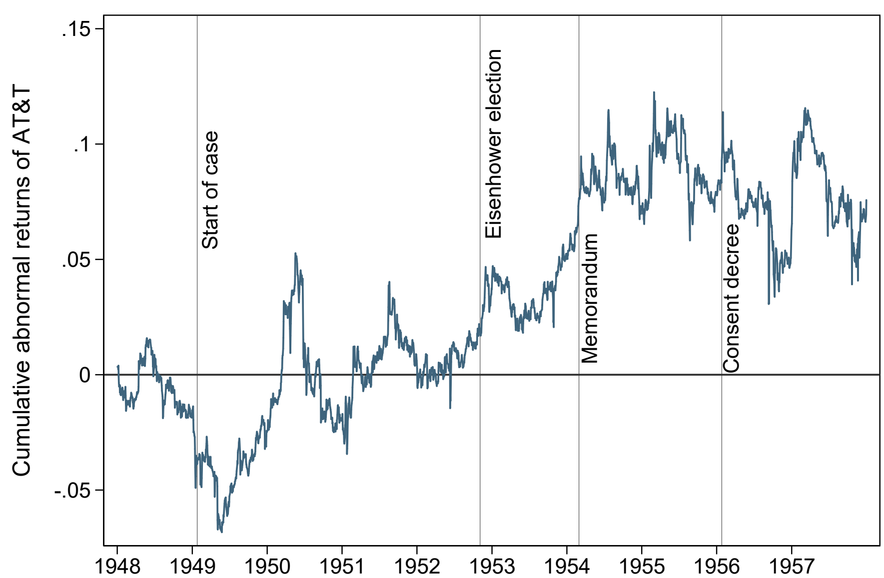
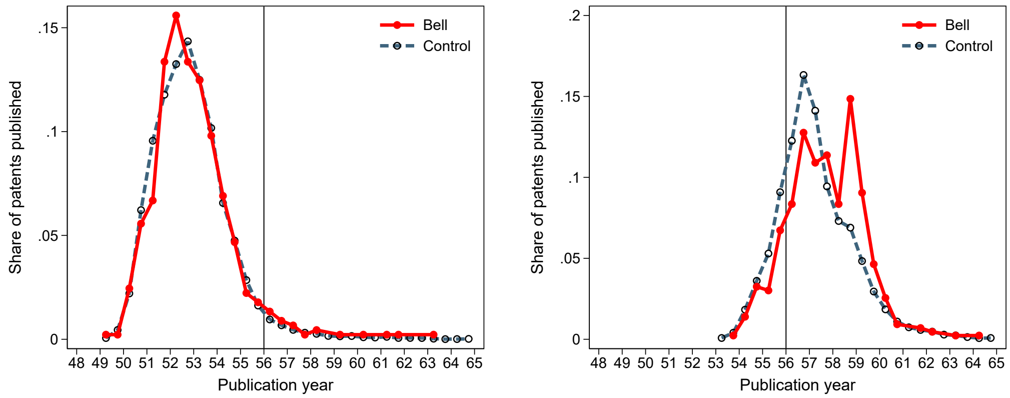


Figure B1. : Cumulative Abnormal Stock Returns of AT&T

Note: This figure shows the cumulative abnormal stock returns of AT&T compared to other companies in the Dow Jones index, beginning in January 1948. The events marked in the graph are the beginning of the antitrust lawsuit on January 14, 1949, the presidential election on November 4, 1952, Bell's memorandum summarizing a meeting between the Attorney General and the Bell management in March, 1954, and the consent decree on January 25, 1956. The data are from the Center for Research in Security Prices (Center for Research in Security Prices, 2015).

[2]The historical stock market data is from the Center for Research in Security Prices (CRSP).



(a) Filing Year 1949

(b) Filing Year 1953

Figure B2. : Hazard Rates for Publication of Patents by Filing Year

Note: These figures show the hazard rates for publication of patents that were filed by Bell (solid line) and others (dotted line). Panel (a) shows hazard rates for patent applications filed in 1949, Panel (b) for applications filed in 1953. The patent data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

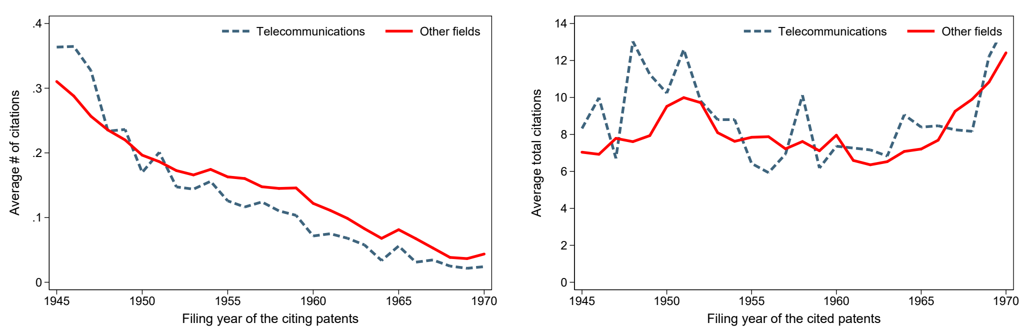
We can also infer from Bell's behavior that as early as the first half of 1955, compulsory licensing was expected. According to the consent decree, all patents had to be licensed for free if they were published before January 24, 1956. If they were published after this cut-off date, they were licensed on a reasonable and non-discriminatory basis. So starting from the date when Bell became aware of the clause it had an incentive to delay the publication of its patents beyond the cut-off date.

According to the data, Bell indeed started to delay its patents at the patent office beginning in the first half of 1955. To pin down the date, we compare the propensity of a Bell patent to be published with the propensity that control patents are published for a given filing year. In Figure B2, we show these hazard rates of publishing in a particular year for the filing years 1949 and 1953.[3] For the filing year 1949, the publishing rates per year are very similar for Bell patents and patents from other companies. If at all, Bell patents were published a bit earlier. For the filing year 1953, this picture is reversed. Starting in the first half of 1955, Bell patents had a significantly lower probability of being published. This is consistent with Bell trying to delay the publications of its patents and having credible information about the general outline of the consent decree in the first half of 1955 at the latest.

[3]Hazard rates for all other years are available from the authors upon request.

B2. No Lack of Follow-on Innovation in Telecommunications

This section presents evidence that the null effect in telecommunications was not due to a lack of potential follow-on innovation in the telecommunications market. To do this, we look at the total number of citations, the sum of citations of other companies and self-citations, to Bell patents inside and outside of telecommunications. In panel (a) of Figure B3, we plot the average number of total citations to Bell patents related to telecommunications and related to other fields. We use the concordance of Kerr (2008) to assign to each Bell patent the likelihood that it is used in the production of telecommunications equipment (SIC 3661). We classify a patent as a telecommunications patent if this likelihood is above 15%. The total number of citations to telecommunications patents of Bell are at least as high as to patents unrelated to telecommunications. This speaks against a lack of follow-on innovation in telecommunications. Furthermore, in panel (b), we show that the total number of patent citations to Bell's patents inside and outside of telecommunications were almost identical before and after the consent decree. In Figure B4, we show that neither the total number nor the share of telecommunications patents declined substantially after the consent decree. All these results together suggest that after the consent decree the potential for follow-on innovation was not significantly lower in telecommunications than in other fields.



(a) Up to 1949 (b) All Bell Patents

Figure B3. : Number of Citations to Bell Patents Inside and Outside of Telecommunications

Note: Panel (a) shows the average number of citations per year to all Bell patents published up to 1949 that are related to the production of telecommunications equipment (SIC 3661) and that are used in any other industry. We classify a patent as a telecommunications patent if it has more than a 15% likelihood to be used in the production of telecommunications equipment (SIC 3661) according to the data of Kerr (2008) and of Acemoglu, Akcigit and Kerr (2015). Panel (b) shows the total number of citations to Bell patents inside and outside of telecommunications filed in a particular year. In this graph, we use total citations, the sum of citations from other companies and from Bell to its own patents. The patent data stem from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

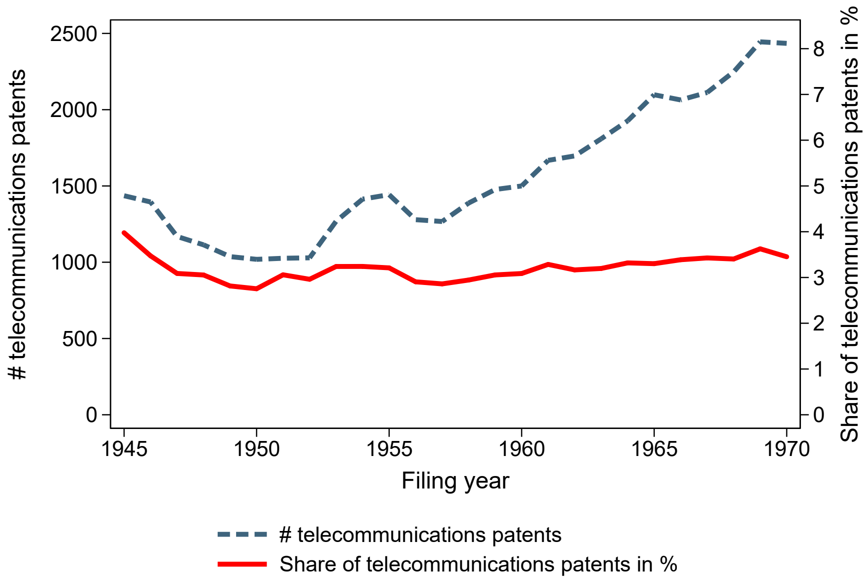


Figure B4. : Number and Share of Telecommunications Patents

Note: This figure shows the total number of telecommunications patents in the U.S. economy (blue dashed line) and the share of telecommunications patents relative to all U.S. patents. We classify a patent as a telecommunications patent if it has a higher than 15% likelihood to be used in the production of telecommunications equipment (SIC 3661), according to the data of Kerr (2008).

B3. Further Results: Telecommunications vs. Other Fields

In this section, we address four potential concerns regarding the fact that we do not find any innovation effect of free compulsory licensing in telecommunications, while we find strong increases in other fields. First, we show that the effects are indeed statistically different inside and outside of telecommunications. To show this, we use a triple-difference model. Results are presented in Figure B5a. Relative to a level of closeness to telecommunications of zero, there are significantly fewer follow-on citations in fields with a level of closeness to the production of telecommunications equipment higher than 30% than with a level of closeness lower than 30%.

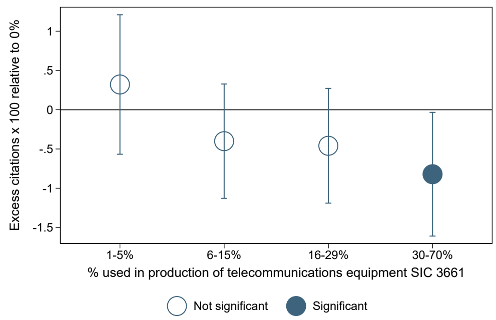
A second concern might be that comparing coefficients across different levels of closeness may not be meaningful because the baseline rates of follow-on innovation could be different. In Figure B5b, we use a negative binomial model to measure percent changes in citations in the different categories. We observe a similar negative relationship between the level of closeness and excess citations as with absolute changes.

A third concern might be that the grouping of citations with different levels of closeness in five bins could hide important information. In Figure B5c, we use citations from each level of closeness to telecommunications separately as the dependent variable. Each coefficient is weighted by the number of patents Bell has in each field. There is again a strong negative relationship.

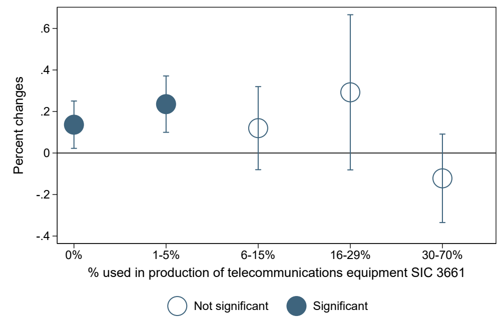
A last concern might be that the continuous measure for closeness to telecommunications might not be adequate. In Figure B5d, we estimate our main treatment effect separately for citations of patents in different NBER technology subcategories and plot it against the size of Bell's patent portfolio in each category. The increase in citations comes mainly from technologies related to electrical components, in particular from "Electrical Devices", but also from "Metal Working" and chemical patents. Yet, there is no increase in citations by patents in the subcategory of "Communication". These results corroborate the finding in our main text that there is no increase in follow-on innovation in industries concerned with the production of telecommunications equipment, the core business of Bell.

B4. Excess Citations by Patents with Varying Likelihood of Being Used in the Production of Telecommunications Equipment

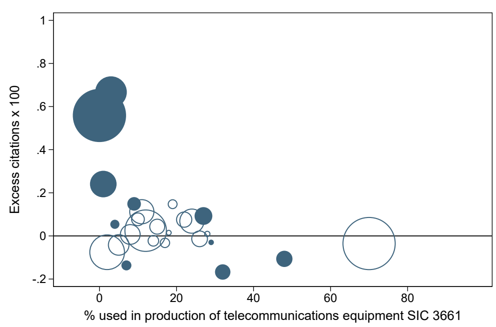
In Figure 4 in the main part of the paper, we group citations in two and five bins to classify the closeness of the citing patent to telecommunications. To show that our conclusions do not depend on the number of bins, we group citations into consecutively finer bins in Figure B6. Panels a) and b) show our baseline results, panels c) to e) show 7, 10, 20 and all 28 bins available in our data. Note first that there is a strongly negative relationship between the bins' impact of the consent decree on follow-on innovation and the bins' closeness to telecommunications.



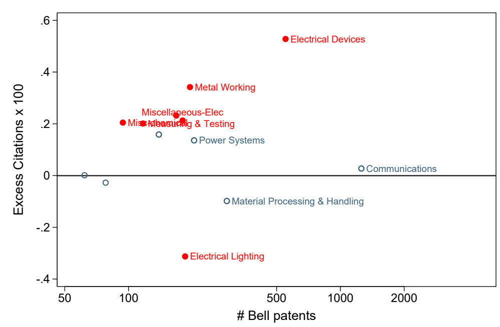
(a) Triple-Difference Relative to 0% Telecommunications



(b) Percent Changes



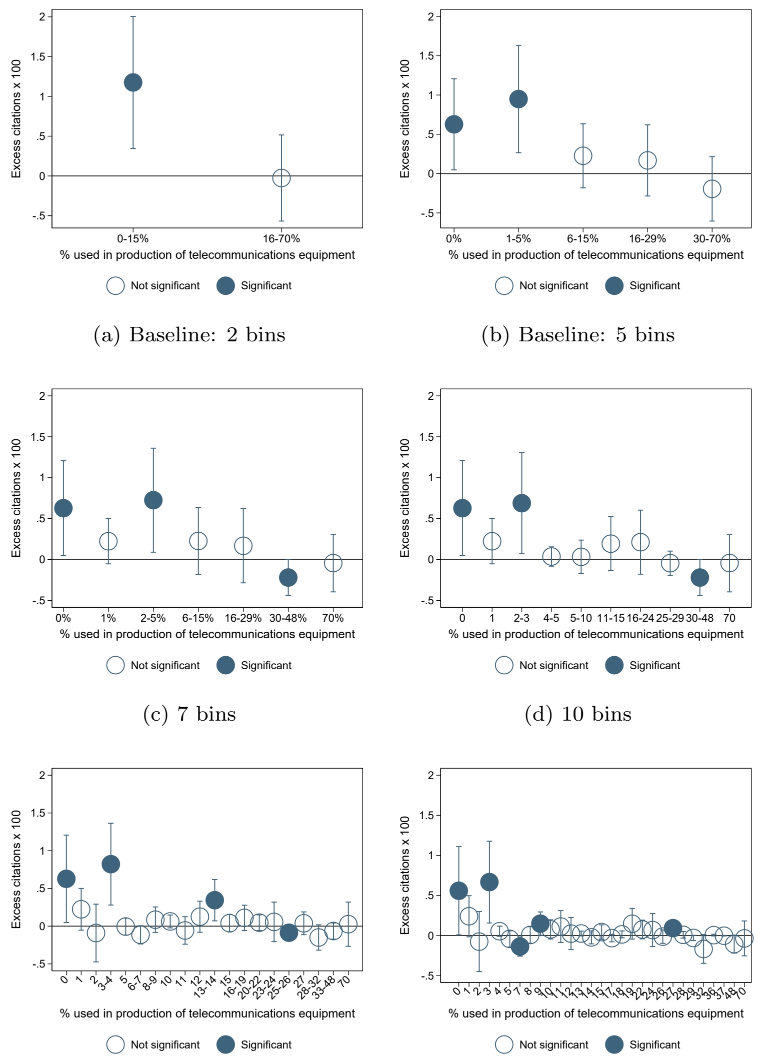
(c) Individual Levels of Likelihood



(d) By NBER Classification for Technological Subcategories

Figure B5. : Excess Citations by Patents with Varying Likelihood of Being Used in Production of Telecommunications Equipment

Note: This figure shows results from estimating a difference-in-differences specification of the impact of the consent decree on follow-on patent citations with 1949-1955 as the pre-treatment period and 1956 till patent expiration as the treatment period, controlling for year fixed effects. In Panel (a), we use a triple-difference interaction to estimate the increase in follow-on innovation for different levels of closeness to telecommunications relative to the left-out category of 0% closeness. In Panel (b), we use a negative binomial model to estimate percent changes. In Panel (c), we estimate the increase in citations for each level of closeness separately. In Panel (d), we estimate the increase in follow-on innovation for each NBER technology subcategory of Hall, Jaffe and Trajtenberg (2001). The patent data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office. All coefficients are multiplied by 100 for better readability.



(a) Baseline: 2 bins

(b) Baseline: 5 bins

(c) 7 bins

(d) 10 bins

(e) 20 bins

(f) All bins

Figure B6. : Different Number of Bins

Note: This figure shows results on follow-on citations by varying likelihood of the compulsorily licensed patent to be used in telecommunications. In Panels (a) to (f), we group the citing patents according to the probability that a patent in this technology class is used in the production of telecommunications equipment (SIC 3661) into different number of bins. We then construct a different dependent variable for each of these different bins, summing up the citations from patents in each bin to Bell patents and to control patents. In the last step, we use these different outcome variables and estimate for each level of closeness a difference-in-differences regression adapting equation (1). We report the treatment effect along with 95% confidence intervals separately for citations from patents with differing relevance for the production of telecommunications equipment (SIC 3661 - "Telephone and Telegraph Apparatus"). All coefficients are multiplied by 100 for better readability.

Also, the significantly positive effects are generally below the cut-off of 15% used in the main part of our paper to define non-telecommunications related patents.

B5. Delineating Telecommunications vs. Other Fields

In Section III.B, we split the sample into telecommunications vs. other fields, using a cut-off value of 15% likelihood that a patent class is used in the production of telecommunications equipment. The cut-off value is to some extent arbitrary, and our results are robust when using other cut-off values (see Appendix B.B4). In Figure B7, we assign to each free compulsorily licensed patent its most likely SIC code and its closeness to the production of telecommunications equipment (SIC 3661). All patents with a likelihood higher than 15% are also most likely used in SIC 3661. Patents with a likelihood below 5% are most likely used in other SIC codes. Between 5% and 15%, the patents are in between.

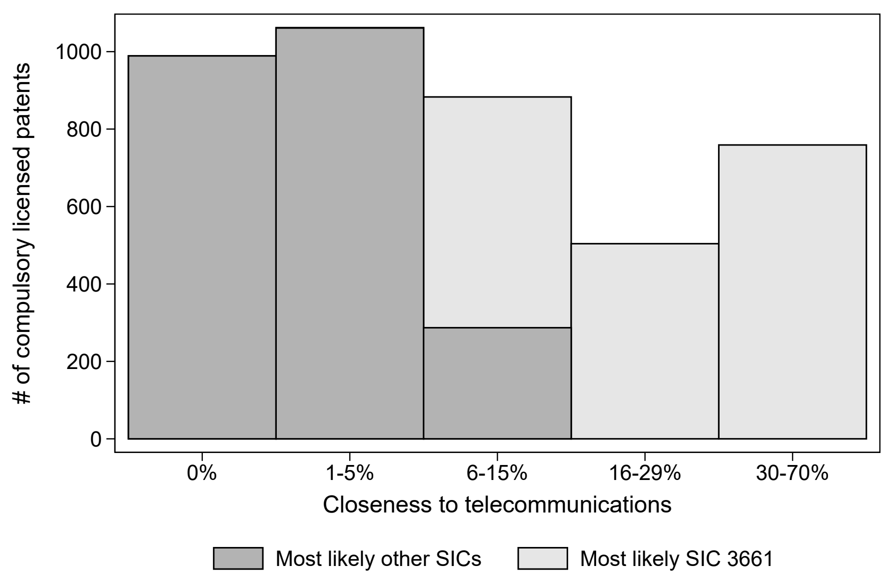
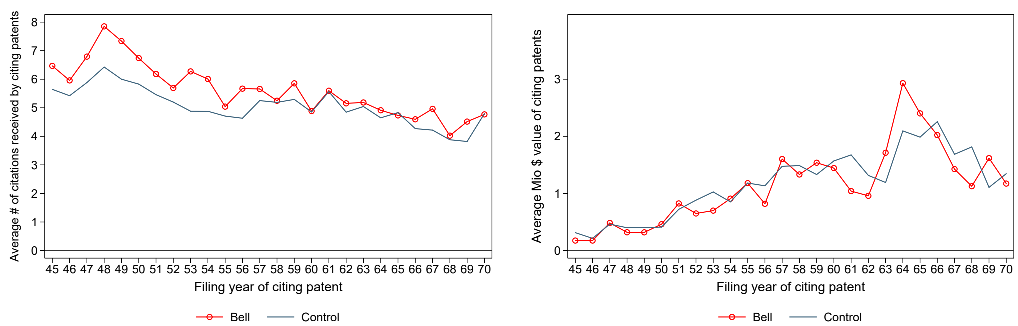


Figure B7. : Patent Portfolio: Closeness vs. Most Likely Use

Note: The chart shows the distribution of free compulsorily licensed patents by the level of closeness to the production of telecommunications equipment (SIC 3661) and by its most likely SIC code. To assign a patent to its most likely SIC codes and to different levels of closeness to telecommunications, we use the data of Kerr (2008) and of Acemoglu, Akcigit and Kerr (2015).

B6. Quality of Follow-On Innovation not Significantly Lower after Free Compulsory Licensing

When assessing the overall impact of the consent decree, one concern might be that the innovation induced by free compulsory licensing was of lower quality than the quality of follow-on innovation building on Bell patents prior to the consent decree. In Figure B8, we measure the quality of the patents citing Bell and control patents in each year by their average number of citations and by their average dollar values assigned by Kogan et al. (2017).[4] We do not see a decline of the quality of patents citing Bell patents relative to the average quality of the patents citing control patents.



(a) Average Citations

(b) Average Dollar Value

Figure B8. : Quality of Citing Patents

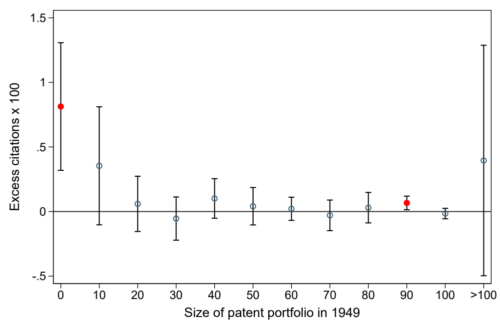
Note: Panel (a) shows the average number of citations per year for all patents citing Bell patents and for all patents citing control patents. Control patents are in the same patent class, have the same publication year and the same number of citations up to 1949 as Bell patents. Panel (b) shows the average value of the citing patents according to the data of Kogan et al. (2017). We impute a value of zero for all unavailable patent values.

B7. Effects for Different Definitions of Young and Small Assignees

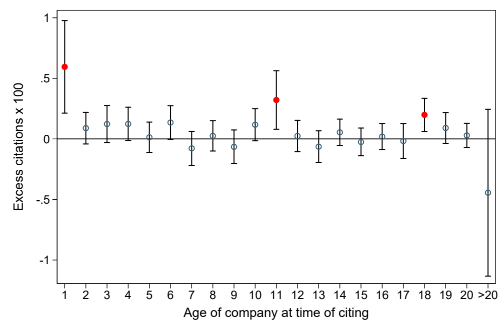
In Figure B9, we estimate the main treatment coefficient separately for different size and age groups of assignees. We find that the effect is driven mainly by small companies and individual inventors; i.e. by assignees without patents before 1949 (Figure B9a), and by young companies and individual inventors; i.e., assignees that are less than one year old at the time of the citations (Figure B9b). The majority of all citations comes from companies and in particular from young and

[4]We impute a value of zero dollar for to all patents without valuation. Note that in our main text we use average values across publication year and patent class to calculate the increase in the value of follow-on innovation. If we use this data we see no decline, either.

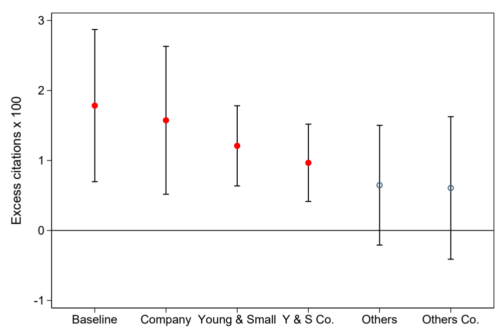
small companies (Figure B9c). We classify an assignee as a company if it was never an inventor. Our results are robust to defining companies as having Inc., Corp., Co. or similar abbreviations in their name.



(a) By Size of Patent Portfolio in 1949



(b) By Age of Company at Citation



(c) By Company Type

Figure B9. : Sample Split by Characteristics of Citing Firm

Note: These panels show results from a difference-in-differences estimation with the years 1949-1955 as pre-treatment period and 1956 till the expiration of the patent as treatment period, controlling for year fixed effects. As dependent variable, we use all citations by companies other than the filing companies with a specific size of their patent portfolio (panel a) and a specific company age (panel b) as indicated in the figure. In panel (c) we report results separately for citations from all, from companies, from young and small assignees, from young and small companies and from all others. As control patents, we use all patents that were published in the U.S. matched by publication year, primary USPC technology class, and the number of citations up to 1949. All coefficients are multiplied by 100 for better readability. The patent data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

B8. Auxiliary Results and Robustness Checks

In this part of the appendix, we provide and discuss the results summarized in Section III.C. In this section, we noted as one potential concern for the identification of the effect that the impact of free compulsory licensing on subsequent citations might be driven by an unobserved shock that increased follow-on innovation to Bell patents and was correlated with the consent decree. For example, the antitrust prosecutors might have chosen to press for free compulsory licensing because they expected that there would be strong technological progress in the technology fields of Bell. If exogenous technological progress rather than free compulsory licensing drives the increase in follow-on innovation, then companies that are less affected by the consent decree should react in the same way as companies profiting from free compulsory licensing.

To see whether this is the case, we analyze the citation patterns of companies that were relatively less affected by the consent decree. The 1956 consent decree singled out three companies that were explicitly excluded from the free compulsory licensing of Bell patents: the General Electric Company, Radio Corporation of America, and Westinghouse Electric Corporation. The reason was that these companies already had a general cross-licensing agreement, the "B-2 agreements" dated July 1, 1932.

We repeat our baseline analysis, but use only the citations of the B-2 companies as the dependent variable and report the results in column (2) of Table B1. We find no significant effect. This suggests that the measured effects are not due to a common technology shock. As these companies in total make up around 8% of all citations to Bell patents, this null effect is not due to a lack of measurability.[5] There are also two other groups of companies that were to a lesser degree affected by the consent decree: foreign companies and companies that already had licensing agreements in place.[6] Foreign companies could license for free, but did not receive any technical description or assistance from Bell.[7] We do not find a measurable effect for foreign companies (column 3). Similarly, we find that companies that had at least one license before the consent decree increased follow-on innovation less than companies without (columns 4 and 5).

Historical accounts also report that there was an exodus of important Bell researchers from Bell Labs around the time of the consent decree. In 1953, for example, Gordon Teal, the inventor of a method to improve transistor performance, joined the then small Texas Instruments Inc. Similarly, William Shockley, one of the inventors of the transistor, left Bell in 1956 to start Shockley Semiconductors Laboratory. So, secular changes at the Bell Laboratories unrelated to the consent decree might have led to more spin-offs and, consequently, to more follow-on innovation by small and young companies. To investigate whether this was indeed

[5]We additionally test whether the coefficient for the B-2 companies is larger or equal to a constant reflecting a proportional effect to the main estimate. Due to the standard errors being relatively large, we cannot reject this hypothesis at conventional levels. However, the p-Value of this test is 0.25. Thus, an estimate this low still is rather unlikely.

[6]All companies with a license agreement are listed in the hearing documents (Antitrust Subcommittee, 1958, p. 2758).

[7]Verbatim in the consent decree "The defendants are each ordered and directed (...) to furnish to any person domiciled in the United States and not controlled by foreign interests (...) technical information relating to equipment (...)" (United States District Court for the District of New Jersey, 1958, p. 112). As foreign citation we define every citation from a patent whose publication authority is not the United States.

the case, we separately look at patent citations by inventors who were at some point associated with or close to Bell; i.e., former Bell employees, co-inventors of Bell employees, and their co-inventors, and compare with citations by all remaining unrelated inventors. In our data, there are 5,613 former Bell employees with 35,589 patents, 4,477 co-inventors of former Bell employees with 28,569 patents, and 12,068 co-inventors of co-inventors who were never active at Bell and who filed 87,148 patents in total. The results are reported in columns (6) and (7) of Table B1. We find a positive effect on the citations of unrelated inventors and a negative effect on the citations of related inventors. This pattern suggests that the increase in follow-on innovation was even negative for former Bell employees.

Table B1—: The Effect of Free Compulsory Licensing on Subsequent Citations by whether Citing Party was Affected by Decree

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Base line	B-2 Companies	For-eign	Prior License Yes	No	Former Bell? Yes	No
Bell	-0.4	0.2	-0.1	0.5**	-0.9**	0.7***	-1.1**
	(0.4)	(0.1)	(0.1)	(0.2)	(0.4)	(0.2)	(0.5)
Post	-4.8***	-0.6***	-2.0***	-1.0***	-3.9***	-0.4***	-4.4***
	(0.5)	(0.2)	(0.3)	(0.2)	(0.4)	(0.1)	(0.5)
Bell x Post	1.8***	0.0	0.1	0.7**	1.1**	-0.6***	2.4***
	(0.6)	(0.1)	(0.2)	(0.3)	(0.5)	(0.2)	(0.6)
Mean Dep.	14.6	1.0	2.1	2.3	12.3	0.8	13.8
# treated	3602	3602	3602	3602	3602	3602	3602
Clusters	207	207	207	207	207	207	207
Obs.	659137	659137	659137	659137	659137	659137	659137

Note: This table shows the results from a difference-in-differences estimation with 1949-1955 as the pre-treatment period and 1956 until patent expiration as the treatment period. The variable Bell is an indicator variable equal to one if a patent is filed by a Bell System company before 1949 and therefore subject to the consent decree. As control patents, we use all patents with the same publication year, primary three-digit USPC technology class, and the same number of citations up to 1949 as Bell patents. To adjust for the different number of control patents per treated patent, we use the weights suggested by Iacus, King and Porro (2009). As the dependent variable, we use all citations by companies other than the filing companies in column (1). In column (2), we use only citations from patents by General Electric Company, Radio Corporation of America and Westinghouse Electric Corporation, the three companies exempt from the consent decree. Column (3) uses citations from patents of foreign assignees as the dependent variable. Foreign companies could license for free but did not receive any technical description or assistance from Bell. In columns (4) and (5), we split the citations according to whether the assignee on the citing patent had previously held at least one license for Bell patents. In columns (6) and (7), we split the citations according to whether inventors ever patented for Bell or ever were co-authors with Bell inventors. All coefficients are multiplied by 100 for better readability. Standard errors are clustered on the primary three-digit USPC technology class level. *, **, *** denote statistical significance on 10%, 5% and 1% level, respectively.

These findings suggest that the results are not driven by a general technology shock. But, potentially, only a subset of patents was affected by the shock. For instance, high-quality patents might have received a favorable shock. To show that this is not the case, we first split the sample of treated Bell patents into high-quality and low-quality patents in columns (2) and (3) of Table B2. Then we match control patents based on technology class, filing year and the number of citations up to 1949. This is the only analysis where we do a sample split with respect to Bell patents, not with respect to the dependent variable. We define a high-quality patent as a patent with a value of more than \$3.07 million, the median dollar value of a Bell patent according to Kogan et al. (2017). We find that the treatment effect is similar for high and low-quality patents. Next, we drop all patents related to the transistor, the most important invention of Bell. Dropping these patents does not change the results. Lastly, the effect might be due to other secular changes, either in the economy at large or at Bell Labs. For example, shortly after the Bell consent decree there were two other consent decrees issued that used compulsory licensing as a remedy: IBM in 1956 and of RCA in 1958. To show that these consent decrees do not drive the results, we drop all citations from patents that also cite either the patents of RCA or the patents of IBM and report the results in column (9). We find that the effects are the same.

B9. Pseudo Treatment: Citation Substitution is Small

One potential concern might be that our estimates do not capture an increase in follow-on innovation, but merely reflect a substitution effect. Due to the free availability of Bell technology, companies might have substituted away from other, potentially more expensive technologies. If this were the case, we should find a negative impact of the consent decree on citations of similar patents of other companies.[8] To see whether this is the case, we assign a pseudo treatment to the patents of GE, RCA, Westinghouse, which were part of the B-2 agreement. These companies were among the largest patenting firms in the ten technology classes in which Bell had most patents from 1940 to 1948. Results are reported in Table B3, column (2). We find no effect, implying that the citation substitution is either small or homogeneous to patents of these companies and the control group.

For a second approach, we exploit the fact that a patent's technology is classified twice: once in the USPC system, which has a technical focus, and once in the IPC system, which reflects more closely the intended industry or profession ("usage") (Lerner, 1994). In columns (3) and (4) of Table B3, we assign a pseudo-treatment to all patents that have the same USPC class and the same IPC class as the Bell patents. As control group, we use in column (3) patents with the same USPC, but a different IPC classification as Bell patents. In column (4), we use as a control group patents with the same IPC, but a different USPC classification as Bell patents. Thus, we compare patents that are arguably more similar to the Bell

[8]This approach is suggested by Imbens and Rubin (2015).

Table B2—: The Effect of Free Compulsory Licensing on Subsequent Citations: Robustness

	(1)	(2)	(3)	(4)	(5)
	Base-line	Quality of Bell patent High	Low	without Transistor	without IBM and RCA
Bell	-0.4	-0.3	-0.5	-0.5	-0.5
	(0.4)	(0.6)	(0.7)	(0.4)	(0.4)
Post	-4.8***	-4.9***	-4.7***	-4.8***	-4.7***
	(0.5)	(0.7)	(0.4)	(0.5)	(0.4)
Bell x Post	1.8***	2.2***	1.4**	1.8***	1.7***
	(0.6)	(0.8)	(0.6)	(0.6)	(0.5)
Mean Dep.	14.6	15.0	14.2	14.6	14.0
# treated	3602	1759	1843	3557	3602
Clusters	207	181	170	207	207
Obs.	659137	418671	387687	658649	659137

Note: This table shows the results from a difference-in-differences estimation with 1949-1955 as the pre-treatment period and 1956 until patent expiration as the treatment period. The variable Bell is an indicator variable equal to one if a patent is filed by a Bell System company before 1949 and therefore subject to the consent decree. As control patents, we use all patents with the same publication year, primary three-digit USPC technology class, and the same number of citations up to 1949 as Bell patents. To adjust for the different number of control patents per treated patent, we use the weights suggested by Iacus, King and Porro (2009). As the dependent variable, we use all citations by companies other than the filing companies in column (1). In columns (2) and (3), we split the sample of Bell patents into high-quality and low-quality patents. Then we match control patents based on technology class, filing year and the number of citations up to 1949. This implies that the same control patent might be matched both to a high quality and to a low quality patent. We define a high-quality patent as a patent with a value of more than $3.07 million, the median dollar value of a Bell patent according to Kogan et al. (2017). In column (4), we drop all patents related to the transistor. We define patents as transistor patents if they were filed by a member of the original transistor team or one of their co-authors. In column (5), we exclude all citations by patents of IBM and RCA and all patents that cite IBM and RCA patents. IBM had a consent decree with a compulsory licensing of patents in 1956 as well, and RCA had a consent decree in 1958. All coefficients are multiplied by 100 for better readability. Standard errors are clustered on the primary three-digit USPC technology class level. *, **, *** denote statistical significance on 10%, 5% and 1% level, respectively.

Table B3—: Auxiliary Regressions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
		Pseudo Treatment			Different Control Group		
	Baseline	B-2 Companies	Control: Same USPC different IPC	Control: Same IPC different USPC	Control: Same IPC different USPC	Control: Same IPC	Loose
Treatment	-0.4	-1.3**	0.3	-0.7	-1.2	-0.3	0.2
	(0.4)	(0.5)	(0.3)	(0.7)	(1.4)	(0.6)	(0.7)
Post	-4.8***	-5.8***	-1.7***	-2.5***	-5.9***	-4.6***	-5.4***
	(0.5)	(0.7)	(0.5)	(0.4)	(0.8)	(0.4)	(0.4)
Treat x Post	1.8***	0.1	-0.5	-0.1	2.2**	1.8***	1.9***
	(0.6)	(0.4)	(0.6)	(0.5)	(0.9)	(0.7)	(0.7)
Mean Dep.	14.6	17.0	12.2	12.9	15.9	14.4	14.9
# treated	3602	6538	33506	37966	3660	3565	3721
Clusters	207	152	191	214	217	216	211
Obs.	659137	659421	574709	645216	247664	400028	895445

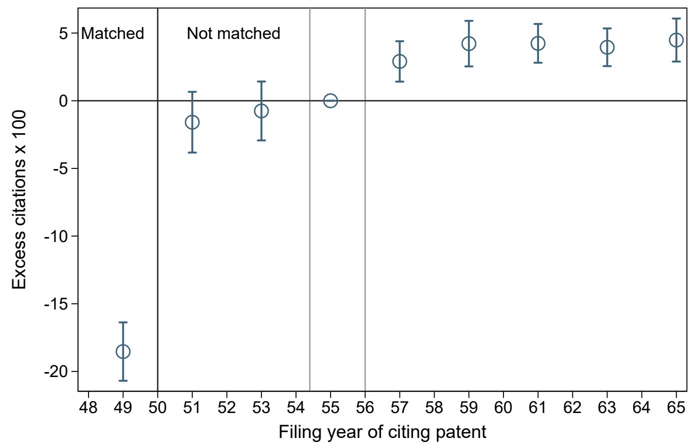
Note: This table shows the results from a difference-in-differences estimation with years 1949-1955 as pre-treatment period and 1956 till the expiration of the patent as treatment period, controlling for year fixed effects. As the dependent variable, we use all citations by companies other than the filing company. As control patents, we use all patents that were published in the U.S. matched by publication year, primary USPC technology class, and the number of citations up to 1949. In all columns, we match the control patents on publication year and the number of citations prior to 1949. In columns (2) - (4), we assign pseudo treatments. In column (2), we define patents of the B-2 companies (GE, RCA, and Westinghouse) as treated and match the control patents on the USPC class. In column (3), we assign all patents that have the same USPC and different 3-digit IPC technology class as treated, and in column (4), we assign patents with the same IPC and different USPC classification as treated. In column (5), we use as controls patents in the same IPC 3 class but in a different USPC class than the Bell patents. In column (6,) we use as controls patents with the same 4-digit IPC class as the Bell patents. In column (7), we coarsen the publication year to two-year windows and sort all pre-citations into ten equally sized bins to match a larger number of patents. All coefficients are multiplied by 100 for better readability. The patent data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office. All coefficients are multiplied by 100 for better readability. Standard errors are clustered at the three-digit USPC technology class level. *, **, *** denote statistical significance on 10%, 5% and 1% level, respectively.

patents to two different control groups. We find a small, negative but statistically insignificant effect. Again, this speaks in favor of limited citation substitution or - alternatively - a homogeneous citation substitution to all control groups.

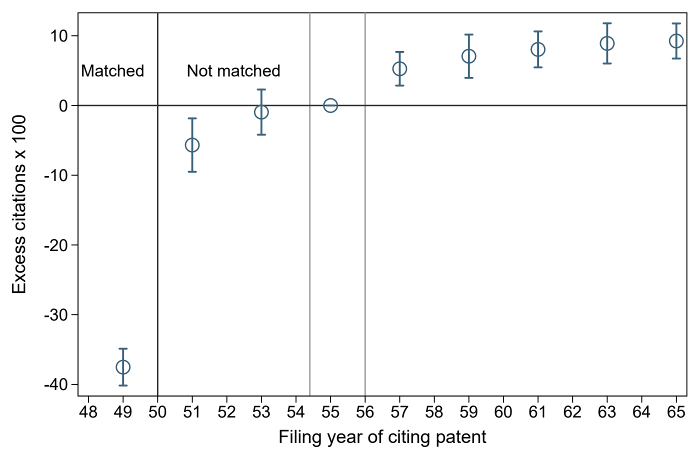
B10. *Effects are Robust to Matching on Higher Pre-Citations*

One potential concern is that Bell patents received too little citations relative to their quality before the consent decree. For example, inventors might choose to strategically under-cite Bell patents or AT&T might have taken measures to suppress the use of their intellectual property before the consent decree. In this case, the surge in citations might not reflect an increase in invention, but is an artifact of matching patents with too few pre-citations. To address this concern, we use in this section patents with higher pre-citations than the Bell patents as a control group. The results are shown in Figure B10 and Table B4. In Panel a) of Figure B10, we present the results using a control group with one more pre-citation than the Bell patents. Adding one pre-citation is a substantial increase as the average number of pre-citations for Bell patents is 1.4. To adjust for the level shift in average citations, we include a fixed effect in 1953. Note that between 1945 and 1949, the number of citations is by construction lower for the treatment patents than for the control patents. Between 1950 and 1956, the trend in citations is the same for the Bell and the control patents. In 1957, citations of Bell patents increase relative to citations of control patents, but in contrast to our main results the effect does not vanish in the 1960s. We repeat this exercise in Panel b), now adding two instead of one pre-citations. We see qualitatively the same picture. If anything, the coefficients are even larger than in our baseline regression. This suggests that when matching on higher pre-citations, the measured effect is driven predominantly by Bell patents with lower pre-citations because Bell patents with higher pre-citations are now less likely to have a matching control patent and thus less likely to be included in the sample. This sample selection might bias upward the estimated effect. In sum, both estimations, matching with one added pre-citation and matching with two added pre-citations, are consistent with parallel trends of Bell patents and control group patents in the years 1950 to 1956 and an increase in citations afterwards.

In Table B4, we show the corresponding regression results using a matching on higher citation counts. Column (1) repeats our baseline specification. In columns (2) and (3), we match Bell patents to control patents that have one and two more citations up to 1949, respectively. Matching on higher citation counts increases the magnitude of the measured effect relative to the baseline. In column (4), we match Bell patents to patents having the same citation rates *after* the consent decree in 1956. If, in contrast to our identification assumption, Bell patents indeed have a higher counterfactual citation trend than the matched patents with the same number of pre-citations, then it seems plausible that these Bell patents should have the same citation trend before the consent decree as control patents with the same number of post-citations. Yet, this is not the case. Similar to



(a) +1 pre-citation



(b) +2 pre-citations

Figure B10. : Matching to Higher Citation Counts

Note: Panel (a) and Panel (b) show the number of two-yearly excess citations of patents affected by the consent decree ("Bell patents") relative to control patents estimated using the specification in equation (2). In Panel (a), we use as control patents for each Bell patent non-Bell patents with the same publication year, with the same three-digit USPC primary class and with one more citation up to 1949 than the Bell patent. In Panel (b), we use as control patents for each Bell patent non-Bell patents with the same publication year, with the same three-digit USPC primary class and with two more citations up to 1949 than the Bell patent. The blue lines represent the 95% confidence bands calculated from standard errors clustered on the three-digit technology class level. To adjust for the different number of control patents per treatment patent in each stratum, we use the weights suggested by Iacus, King and Porro (2009). To adjust for the level shift in average citations we include a fixed effect in 1953. All coefficients are multiplied by 100 for better readability.

Table B4—: The Effect of Compulsory Licensing on Subsequent Citations Using Different Matching Procedures

	(1)	(2)	(3)	(4)
Matching:	Baseline	Higher Citations +1	Higher Citations +2	Post-1956
Bell	-0.4	-6.6***	-14.2***	-1.9**
	(0.4)	(0.9)	(1.0)	(0.8)
Post	-4.8***	-7.9***	-11.5***	-7.6***
	(0.5)	(0.5)	(0.8)	(0.5)
Bell x Post	1.8***	4.3***	7.8***	1.9**
	(0.6)	(1.1)	(1.1)	(0.8)
Mean Dep.	14.6	19.3	23.7	15.7
# treated	3602	3242	3013	3648
Clusters	207	193	190	207
Obs.	659137	295387	166748	774064

Note: This table shows the results from a difference-in-differences estimation with 1949-1955 as pre-treatment period and 1956 until patent expiration as the treatment period. As control patents we use all patents that were published in the U.S., matched by publication year, primary three-digit USPC technology class, and the number of citations up to 1949 in column (1). In column (2), we use the same procedure, but add one citation to the number of citations up to 1949 for Bell patents. In column (3), we again use the same procedure, but add two citations to the number of citations up to 1949 for Bell patents. In columns (2) and (3), we add an additional fixed effect for the period 1950 to 1955 for Bell patents to the estimation equation to account for mechanical changes in citation rates due to the different matching before 1950. In column (4), we use the same procedure, but use the number of citations after the consent decree in 1956 instead of the number of citations up to 1949. To adjust for the different number of control patents per treatment patent, we use the weights suggested by Iacus, King and Porro (2009). As dependent variable, we use all citations by companies other than the filing company. Column (1) is our baseline specification. All coefficients are multiplied by 100 for better readability. Standard errors are clustered on the three-digit USPC technology class level. *, **, and *** denote statistical significance at the 10%, 5% and 1% levels, respectively.

our main result, the size of the estimated effect is around 2 using this alternative matching strategy.

B11. Effects are Robust to Different Matching Strategies

In columns (5) - (7) of Table B3 and in Figure B11, we report results from using several alternative matching variables. In the main specification, we use the age (measured by the publication year), the technology (measured by USPC class) and the quality of a patent (measured by the number of citations up to 1949). In column (6), we use patents in the same IPC but different USPC class instead of using those in the same USPC class. In column (7), we match on the IPC classification, independent of the USPC class. Finally, in column (8), we do a coarsened exact matching in order to match all Bell patents.[9] In all three cases, the size of the effects is similar to the one in the main specification. In Figure B11, we show the size of the treatment effects for different combinations of background variables as proxy for age, technology and quality. On the vertical axis, we plot the number of matched patents. The coefficient is mostly around the main estimate.

[9]Coarsened exact matching was proposed by Iacus, King and Porro (2012). In this specification, we match on one of five publication-year categories that contain two years each and one of ten prior-citation categories.

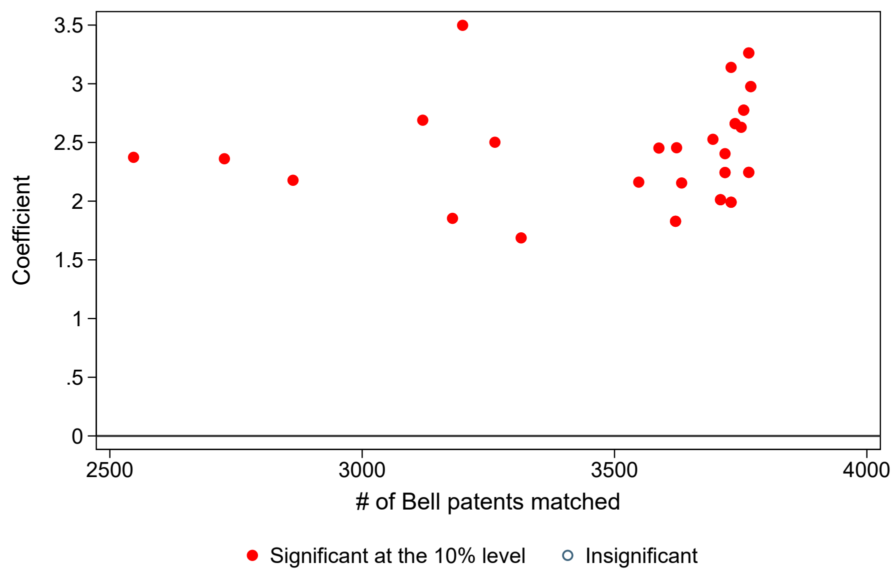


Figure B11. : Treatment Effects for Different Matching Variables

Note: In this figure, we plot the parameter estimates from difference-in-differences estimations of the impact of the consent decree for different matching strategies, controlling for year fixed effects. As the dependent variable, we use all citations by companies other than the filing company. In all regressions, we use a measure for the age, the technology and the quality of a patent for matching. As measures for the age of a patent, we alternatively use application year, publication year or both. For technology, we use the USPC, the USPC with subclasses, the three and the four digit IPC. As a measure of quality, we use the number of pre-citations as exact numbers, coarsened to steps of five citations, and an indicator for at least one citation prior to 1949. The horizontal axis displays the number of matched Bell patents. Empty circles denote that the coefficients are insignificant, solid circles denote coefficients that are significant at the 10% level. All coefficients are multiplied by 100 for better readability. The patent data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

Appendix to Section IV

C1. Increase in Total Number of Patents: Telecommunications vs Other Fields

In Figure C1, we estimate the number of excess patents for different levels of closeness to telecommunications following the approaches employed in Section IV and Subsection III.B. We find that the total number of patents increases most in fields with 0% closeness; i.e., no connection to telecommunications.

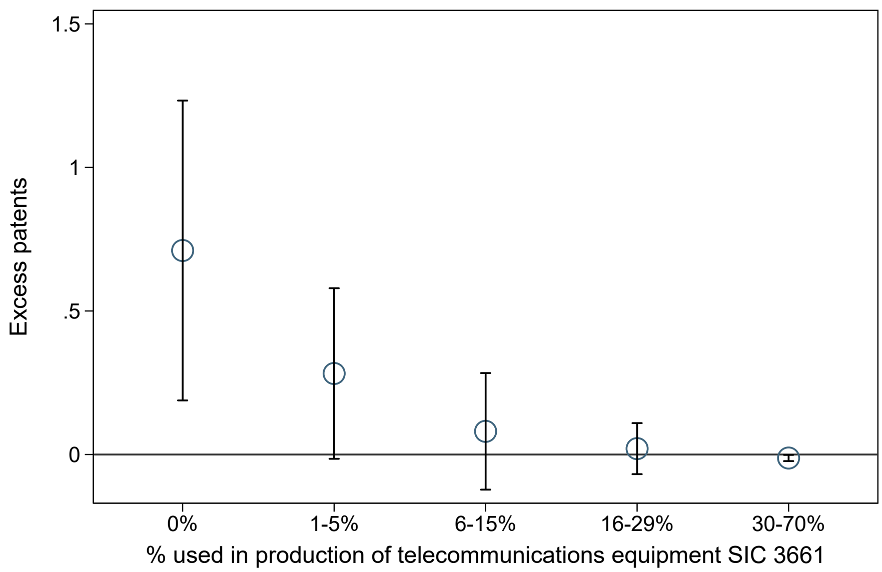


Figure C1. : Excess Number of Patents with Varying Likelihood of Being Used in the Production of Telecommunications Equipment

Note: This figure shows results from a difference-in-differences estimation following the empirical model in equation (3) of the impact of the consent decree on the number of patents in a treated technology subclass relative to an untreated technology subclass, along with the 95% confidence intervals. We calculate the number of excess patents separately for technology classes with a different likelihood of being used in industry SIC 3661, as defined by the data of Kerr (2008). The regressions include year fixed effects and standard errors are clustered on the class level.

C2. *Change in Total Number of Patents - Averages*

In Figure C2 we show the impact of the consent decree on the number of patents in subclasses with a free compulsorily licensed Bell patent relative to subclasses within the same technology class without free compulsorily licensed patents.

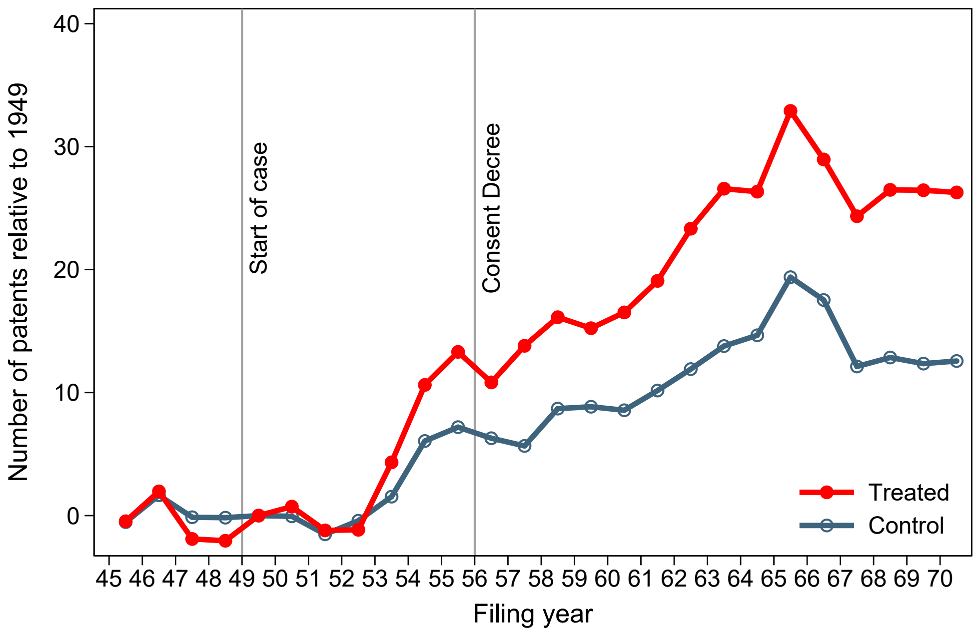


Figure C2. : Average Change in Number of Patents Relative to 1949

Note: This figure shows the average change in the number of patents in subclasses with a free compulsorily licensed Bell patent (red solid lines - "Treated") and without a free compulsorily licensed patent (blue dashed lines - "Control") relative to 1949. This graph includes all transistor-related subclasses.

C3. Patenting Behavior of Bell Relative to Comparable Companies

In Figure C3 we compare the patenting output of Bell with other control companies. These include the B-2 companies, General Electric and Westinghouse separately, and all companies that existed before 1949 and had at least 100 patents in any field in which Bell was active.

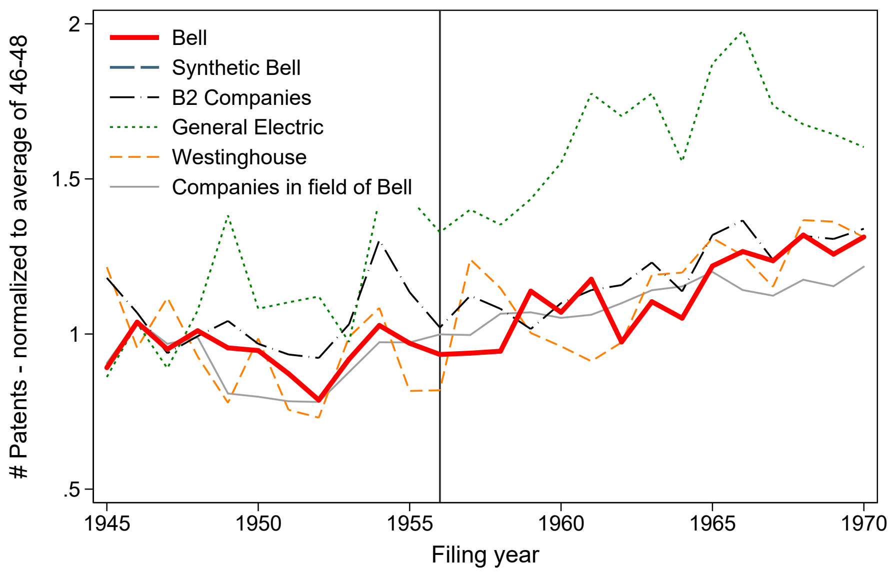
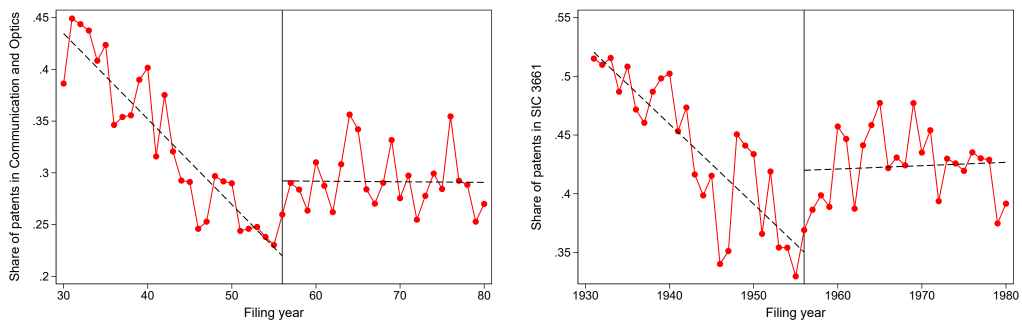


Figure C3. : Patenting of Bell System and B-2 Companies Without RCA

Note: In this figure, we compare Bell's total patenting to a synthetic Bell, the number of patents filed by the B-2 companies (General Electric, Westinghouse, RCA and ITT), General Electric and Westinghouse separately and all companies that existed before 1949 and had at least 100 patents in any field in which Bell was active. The number of patents are normalized to the average number of patents from 1946-1948. We show General Electric and Westinghouse separately, because RCA had a consent decree involving patents in 1958 and thus might have changed its behavior. The patent data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

C4. Redirection of Bell Research: Share of Telecommunications Patents

In Figure C4, we show the change in the direction of research of Bell using NBER subcategories (Hall, Jaffe and Trajtenberg, 2001) and most likely SIC industries (Kerr, 2008; Acemoglu, Akcigit and Kerr, 2015).



(a) By NBER Subcategory (b) By Most Likely SIC

Figure C4. : Share of Telecommunications Patents

Note: Panel (a) shows the share of patents related to telecommunications relative to all patents filed by Bell. We define technologies related to telecommunications as the NBER subcategories "Communication" and "Optics" (Hall, Jaffe and Trajtenberg, 2001). We include "Optics" because after the invention of the laser at Bell Labs in 1958, Bell officials predicted correctly that optics might be crucial for the future of telecommunications (Gertner, 2012, p. 253). Panel (b) shows the share of patents in Bell's patent portfolio whose most likely industry classification is SIC 3661, the production of telecommunications equipment. We use the data of Kerr (2008) and of Acemoglu, Akcigit and Kerr (2015) to assign SIC codes to patents.

*

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