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

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Is compulsory licensing an effective antitrust remedy to increase innovation? To answer this question, we analyze the 1956 consent decree which settled an antitrust lawsuit against Bell, a vertically integrated monopolist charged with foreclosing the telecommunications equipment market. Bell was forced to license all its existing patents royalty-free, including those not related to telecommunications. We show that this led to a long-lasting increase in innovation but only in markets outside the telecommunications industry. Within telecommunications, where Bell continued to exclude competitors, we find no effect. Compulsory licensing is an effective antitrust remedy only if incumbents cannot foreclose the product markets.

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# I. Introduction

With market concentration on the rise in many industries, so are concerns that this may lead to a slowdown of innovation.[1] One frequently voiced worry is that dominant incumbents use their patent portfolio strategically to foreclose the market by denying potential entrants access to key technologies.[2] As innovation typically builds on prior inventions protected by patents, such anti-competitive behavior could stifle technological progress and economic growth (Baker, 2012). One potential remedy available to the antitrust authorities is to impose compulsory licensing of the blocking patents, in order to give potential entrants access to the technology of the incumbent. But up to now, there is little empirical evidence on whether or not this instrument is indeed effective in promoting innovation in an antitrust context.

In this paper, we analyse compulsory licensing as an antitrust remedy and provide causal evidence on its effect on innovation. We investigate whether compulsory licensing is an effective antitrust instrument to foster follow-on innovation in competitive settings where patents are the only barrier to entry and in settings where the incumbent can also use other exclusionary devices such as exclusive contracts. We examine both short-run direct effects as well as long-run effects, including effects on the holder of patents subject to this antitrust remedy.

We study compulsory licensing in the context of the 1956 consent decree against the Bell System, one of the most important antitrust rulings in U.S. history. Although the paramount significance of this consent decree for the development of the U.S. economy post-World War II is widely recognized (Grindley and Teece, 1997), this paper is the first to provide an empirical analysis of its causal impact on U.S. innovation. The 1956 consent decree settled a seven-year old antitrust lawsuit that sought to break up the Bell System, the dominant provider of telecommunications services in the U.S., because it allegedly monopolized "the manufacture, distribution, and sale of telephones, telephone apparatus, and equipment" (Antitrust Subcommittee, 1958, p.1668). Bell was charged with having foreclosed competitors from the market for telecommunications equipment because its operating companies had sourced most of their supplies from its manufacturing subsidiary Western Electric and because it used exclusionary practices such as the refusal to license its patents.

The consent decree contained two main remedies. The Bell System was obligated to

[1] Among others: Derek Thompson, "America's Monopoly Problem", The Atlantic, Oct. 2016; Robert B. Reich, "Big Tech Has Become Way Too Powerful," The New York Times, Sept. 18, 2015, p. SR3; Thomas Catan "When Patent, Antitrust Worlds Collide," Wall Street Journal, Nov. 14, 2011.

[2] Among others: "Patents should spur bursts of innovation; instead, they are used to lock in incumbents' advantages." The Economist, Aug. 8, 2015 "Time to fix patents"; "The Patent, Used as a Sword." The New York Times, Oct. 7, 2012.

license all its existing patents royalty-free, and it was barred from entering any industry other than telecommunications. As a consequence, 7,820 patents or 1.3% of all unexpired U.S. patents in a wide range of fields became freely available in 1956. Most of these patents covered technologies from the Bell Laboratories (Bell Labs), the research subsidiary of the Bell System, arguably the most innovative industrial laboratory in the world at the time. The Bell Labs produced path-breaking innovations in telecommunications such as the cellular telephone technology or the first transatlantic telephone cable. But more than half of its patents were not related to telecommunications because of its commitment to basic science and because of its part in the war effort in World War II. Researchers at Bell Labs are credited with the invention of the transistor, the solar cell, the radar, and the laser, among other things.

The unique set-up of this case enables us to address two key challenges for the evaluation of compulsory licensing in antitrust settings. First, it allows us to study the impact of compulsory licensing without any confounding changes in the market structure. In many antitrust cases, the authorities impose compulsory licensing together with structural remedies such as divestitures, which makes it difficult to separate the innovation effects arising from changes in the market structure from those arising from changes in the licensing regime. In the case of Bell, no structural remedies were imposed, even though this had been the original intention of the Department of Justice - arguably because the Department of Defense considered Bell vital for national defense purposes and strongly lobbied for the dismissal of the case.

Second, the Bell case permits us to study the effect of intellectual property rights in different competitive settings relevant for antitrust, including settings where patents are used in combination with other exclusionary practices and settings where this is not the case. This is possible because Bell's broad patent portfolio was compulsorily licensed in its entirety. 43% of Bell's patents were related to the telecommunications industry, where Bell was de facto a vertically integrated monopolist who foreclosed rivals by denying access to its technology and its customers. The remaining 57% had its main application in industries outside of telecommunications, where Bell was not an active market participant and where the consent decree ruled out that it would ever become one. In these markets, we observe no universal use of exclusionary practices on the product market.

Our analysis shows that compulsory licensing can increase follow-on innovation - but only in markets where incumbents do not engage in other exclusionary practices. We find that in the first five years, follow-on innovation measured by patent citations increased by 16% per year. But the effects are very heterogeneous. In telecommunications, there are no significant effects on follow-on innovation, even though this was the explicit aim of the regulatory intervention. The fact that it was not effective in the telecommunications market is consistent with historical records that Bell continued to use exclusionary practices after the consent decree took effect and that these exclusionary practices impeded innovation (Wu, 2012). In fields unrelated to the telecommunications industry, the effects are positive - even in highly concentrated markets - with follow-on innovation increasing by 20%. 60% of this increase is driven by young and small companies, suggesting that patents held by a dominant firm can indeed act as a barrier to entry for small firms (Lanjouw and Schankerman, 2004; Galasso, 2012). In an in-depth case study, we show that the antitrust lawsuit also accelerated the diffusion of the transistor technology, one of the few general-purpose technologies of the post-World War II period.

In addition to the short-run direct effects, we show that the consent decree had a lasting positive effect on long-run U.S. innovation, measured by the number of patents. This increase is again driven by small and young companies outside the telecommunications industry. We find no increase in the number of patents related to the production of telecommunications equipment. The increase in long-run innovation is only partially offset by a small decrease in patenting by Bell, then the powerhouse of U.S. innovation. The quality of Bell's patents seemed to have been fairly stable before and after the consent decree. Bell did not significantly reduce its innovation activities, most likely because it was a monopolist subject to rate-of-return regulation. However, the consent decree changed the direction of Bell's research. Bell focused more on telecommunications research; the only business it was allowed to be active in. On balance, our results suggest that market foreclosure slows down technological progress and that antitrust enforcement can have a lasting positive impact on the long-run rate of technological change if market entry is not hindered by exclusionary practices.

Our paper contributes to the literature on antitrust and innovation by providing the first empirical assessment of the overall causal innovation effect of compulsory licensing used as an antitrust remedy. While this topic has been discussed extensively in the theoretical literature, the empirical literature is mostly descriptive, and concerned primarily with the effects of compulsory licensing on the licensor, not on the licensees.[3] We provide causal evidence on the effect of compulsory licensing both on the potential licensees and the patent holder subject to compulsory licensing. Acemoglu and Akcigit (2012) argue theoretically that

[3] Tandon (1982), e.g., studies theoretically the use of compulsory licensing as an instrument to deal with the monopoly problem associated with the patent system. See Scherer (1977) for an early cross-sectional study of compulsory licensing imposed by antitrust consent decrees. He finds no negative relation between compulsory licensing and the R&D behavior of licensors. Chien (2003) provides anecdotal evidence from six cases of pharmaceutical compulsory licensing in the context of mergers in the 1980s and 1990s, finding no negative impact on the innovation activities of the companies forced to license their patents. Compulsory licensing is also studied in the context of TRIPS agreements between developed and developing countries.

compulsory licensing can foster innovation because it enables more companies to compete for becoming the leader in an industry.[4] Others have emphasized that antitrust measures need to focus on exclusionary practices and the protection of start-ups (Segal and Whinston, 2007; Baker, 2012; Wu, 2012). Our empirical findings exemplify the relevance of both of these theoretical arguments. The Bell case shows that by providing free state-of-the-art technology to all U.S. companies, including a large number of entrants, compulsory licensing increased U.S. innovation and fostered the growth of new markets. But it did so only in markets where access to customers was not foreclosed by exclusionary practices. Access to technology alone is not sufficient to stimulate innovation if there is insufficient access to the product market. In other words, our results support the apprehension that "from the perspective of innovation promotion, exclusion is the real supreme evil [in antitrust]"(Wu, 2012).

Our study also contributes to the recent literature on intellectual property and its effect on follow-on innovation.[5] For example, Galasso and Schankerman (2015) study the innovation effect of patent invalidation and find an average increase of 50%.[6] Sampat and Williams (2015) study whether the granting of a gene patent reduces follow-on innovation and find no effect. Murray and Stern (2007) and Moser and Voena (2012) report an overall impact of a patent removal on follow-on innovation of 10-20% in biotech and chemistry. We find that the impact of compulsory licensing depends on the anti-competitive practices employed by the patent holder. This suggests that in order to evaluate the benefits and costs of the patent system we need to better understand how the specificities of the competitive setting affect the impact of patenting on innovation.

We also show that compulsory licensing changes the direction of research of the patent holder subject to compulsory licensing, and that it increases innovation in the long run by fostering market entry. These second-round effects should be taken into account when designing intellectual property rights policies. Policy makers should pay special atttention to the effects of intellectual property on entrepreneurship as market entry appears to be the most important margin to increase long-run innovation.

Finally, we contribute to the literature on the history of U.S. innovation with the first

[4]In the model of Acemoglu and Akcigit (2012), compulsory licensing also makes innovation less profitable because leaders are replaced more quickly. In the case of Bell, compulsory licensing was selectively applied to only one company which was not active in the newly created industries. This suggests that there was no disincentive effect and that our empirical set-up cleanly measures the effects of an increase in competition on innovation.

[5]For a recent survey, see Williams (2017).

[6]Litigated patents are selected by importance and by the virtue of having a challenger in court. Thus, the blocking effects of these particular patents might be larger than the average effect for the broad cross-section of patents.

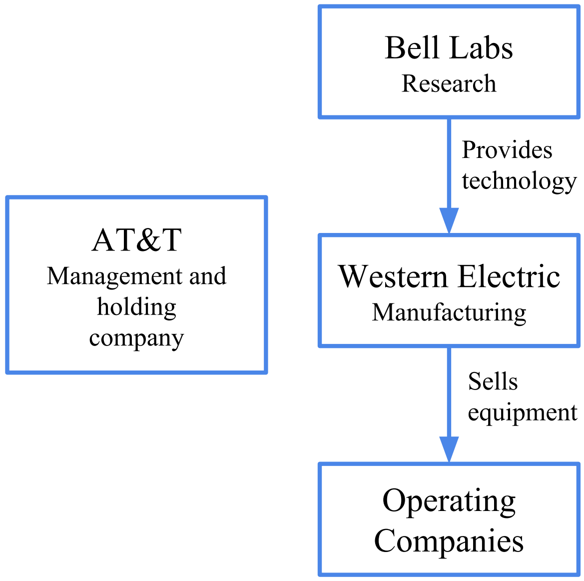
empirical analysis of the innovation effects of the 1956 Bell consent decree. In the immediate aftermath, the consent decree was criticized as an ineffective antitrust remedy because it failed to end Western Electric's position as an effectively exclusive supplier of the Bell operating companies. This ultimately led to another antitrust lawsuit and the break up of the Bell System in 1984. In later years, however, many observers pointed out that the consent decree was decisive for U.S. post-World War II innovation because it spurred the creation of whole industries. Gordon Moore, the co-founder of Intel, stated that "[o]ne of the most important developments for the commercial semiconductor industry (...) was the antitrust suit filed against [the Bell System] in 1949 (...) which allowed the merchant semiconductor industry "to really get started" in the United States (...) [T]here is a direct connection between the liberal licensing policies of Bell Labs and people such as Gordon Teal leaving Bell Labs to start Texas Instruments and William Shockley doing the same thing to start, with the support of Beckman Instruments, Shockley Semiconductor in Palo Alto. This (...) started the growth of Silicon Valley" (Wessner et al., 2001, p. 86). Similarly, Peter Grindley and David Teece opined that "[AT&T's licensing policy shaped by antitrust policy] remains one of the most unheralded contributions to economic development – possibly far exceeding the Marshall plan in terms of wealth generation it established abroad and in the United States" (Grindley and Teece, 1997). Our empirical findings substantiate this narrative. In the telecommunications sector, innovations continued to be impeded by Bell's use of exclusionary practices until the eventual break up of Bell in 1984, despite the 1956 consent decree. But in all other fields, the consent decree did have a large positive causal impact on long-run innovation.

The remainder of this paper is organized as follows. Section II describes the antitrust lawsuit against Bell and the consent decree. In Section III we describe the data and the empirical strategy. In Section IV we show that compulsory licensing increased follow-on innovation, we examine the heterogeneity of the effects for different competitive settings, and we present auxiliary results and robustness checks. Section V provides a case study of the licensing strategy Bell employed for its transistor technology. In Section VI we present the long-run effects of the consent decree on U.S. patenting, including the effects on Bell patenting. Section VII concludes.

# II. The Bell System and the Antitrust Lawsuit

In this section, we describe the Bell System and the antitrust lawsuit against Bell. We then discuss the unique features of the case that make it ideally suited for studying the effectiveness of compulsory licensing as an antitrust remedy.

Figure 1: The Structure of the Bell System




## A. The Bell System

In 1956, American Telephone & Telegraph (AT&T) was the dominant provider of telecommunications services in the U.S. Through its operating companies, it owned or controlled 98% of all the facilities providing long distance telephone services and 85% of all facilities providing short distance telephone services. These operating companies bought more than 90% of their equipment from Western Electric, the manufacturing subsidiary of AT&T. Western Electric produced telecommunications equipment based on the research done by the Bell Laboratories, the research subsidiary of AT&T and Western Electric. All these companies together were known as the Bell System, stressing its vertical integration (figure 1). 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).

The Bell System held patents on many key technologies in telecommunications, as well as a large number of patents in many other fields. Between 1940 and 1970, Bell filed on average ~503 patents or 1% of all U.S. patents each year. Around 70% of the patents protected inventions of the Bell Laboratories (Bell Labs), arguably the most innovative industrial laboratories in the world at the time.

The Bell Labs were unique in their commitment to basic research. When the Bell Labs were founded in 1925, no one knew which part of science might yield insights into the problems of electric communication (Rosenberg, 1990; Nelson, 1962, p.31). As a result, the

Bell System decided that - besides supporting the day-to-day need of the System - the Bell Labs would engage in basic science, assuming it would eventually yield products for some part of the large Bell System (Gertner, 2012; Nelson, 1959; Arora, Belenzon, and Patacconi, 2017).[7]

The Bell Labs produced path-breaking basic and applied research. Scientists at Bell are credited with the development of radio astronomy (1932), the transistor (1947), cellular telephone technology (1947), information theory (1948), solar cells (1954), the laser (1957), and the Unix operating system (1969). 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.[8]

## B. The Antitrust Lawsuit

On January 14, 1949, the United States Government filed an antitrust lawsuit with the aim to split AT&T from Western Electric.[9] The complaint charged that Western Electric and AT&T had been engaged in the monopolization of the manufacture, distribution, and sale of telecommunications equipment in violation of the Sherman Antitrust Act of 1890 (Antitrust Subcommittee, 1959, p.31). According to the complaint, Bell was closing the market to all other buyers and sellers of telecommunications equipment by exclusionary practices including exclusive contracts and the refusal to license patents.[10]

The government sought three main remedies. First, Western Electric was to be separated

[7] According to the first head of basic and applied research at Bell Labs, Harold Arnold, his department would include "the field of physical and organical chemistry, of metallurgy, of magnetism, of electrical conduction, of radiation, of electronics, of acoustics, of phonetics, of optics, of mathematics, of mechanics, and even of physiology, of psychology and meteorology." This broad focus led to major advances in basic science, but also to a large number of unused patents. For example, an investigation of the FCC in 1934 reported that Bell owned or controlled 9,255 patents but actively used only 4,225 patent covered inventions (Antitrust Subcommittee, 1958, p.3842).

[8] 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.

[9] This account of facts follows largely the final report to the Antitrust Subcommittee of the House on the Bell Consent Decree Program (Antitrust Subcommittee, 1959).

[10] For example, Bell allegedly forced competitors "engaged in the rendition of telephone service to acquire AT&T patent license under threat of (...) patent infringement suits," or refused "to issue patent licenses except on condition" to be able to control the telephone manufacturer or by "refusing to authorize the manufacture (...) of telephones (...) under patents controlled by (...) the Bell System" or by "refusing to make available to the telegraphy industry the basic patents on the vacuum tube" that are essential for telegraphy to compete with telephone or by refusing to purchase equipment "under patents which are not controlled by Western or AT&T, which are known to be superior" (Antitrust Subcommittee, 1958, p.3838).

from AT&T, split into three competing companies, and to transfer all of its shares of the research subsidiary Bell Laboratories to AT&T. Second, AT&T was to buy telephone equipment only under competitive bidding and all exclusive contracts between AT&T and Western were to be prohibited. Third, the Bell System was to be forced to license all its patents for reasonable and non-discriminatory royalties (Antitrust Subcommittee, 1959, p.33).[11]

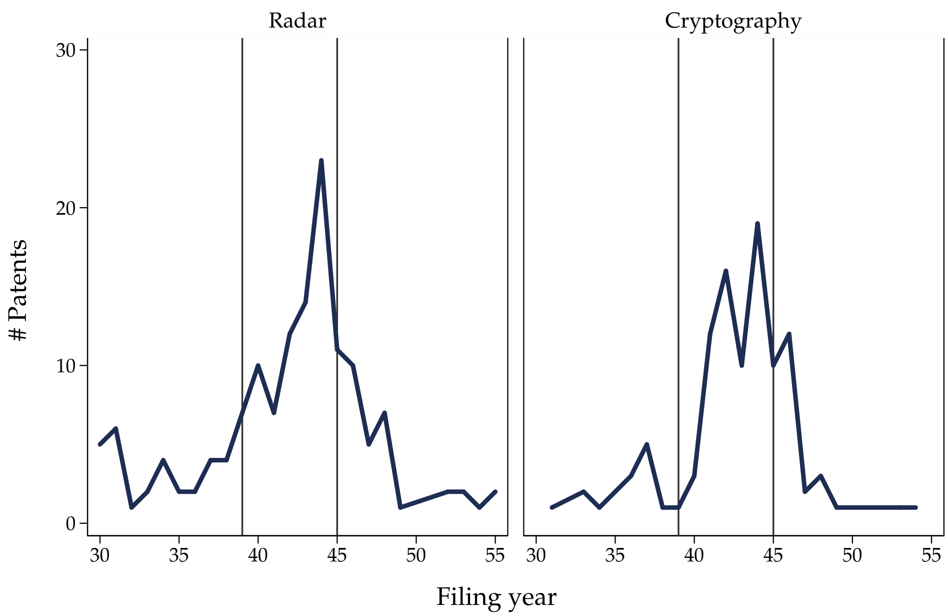
After the complaint was filed in January 1949, Bell sought and obtained a freeze of the antitrust lawsuit in early 1952 with the support of the Department of Defense (DoD), on the grounds that the DoD relied on the research of Bell Labs for the war effort in Korea. In World War II, the Bell Labs had 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 2 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 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 our 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

[11] There were two minor remedies: First, AT&T was not to be allowed to direct the Bell operating companies which equipment to purchase and, second, all contracts that eliminated or restrained competition were to be ceased.

Figure 2: War-Related Technologies Created by Bell Labs




*Notes:* 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 data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

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.

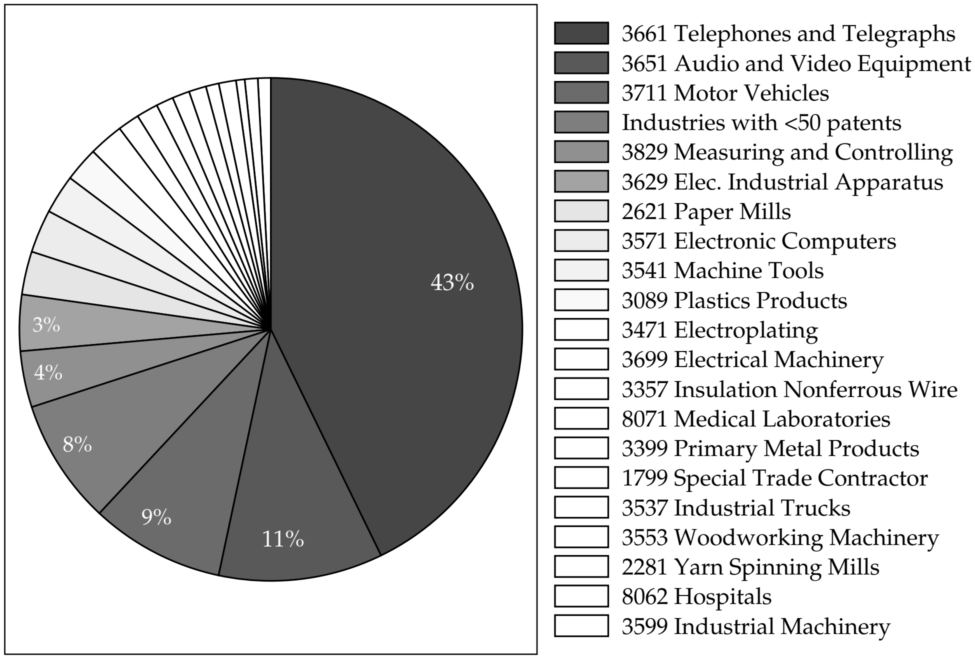
## C. Advantages of the Bell Case for the Empirical Set-Up

The Bell case has two features that make it ideally suited to measure the innovation effects of compulsory licensing as an antitrust remedy.

First, the consent decree did not impose any structural remedies for the telecommunications market. This allows us to isolate the innovation effect of compulsory licensing without any confounding changes in market structure. The reason why the Department of Justice did not impose any structural remedies is unclear. The final conclusion of the Antitrust Subcommittee blamed the lack of intent by the Attorney General to pursue Bell and the intense lobbying of the Department of Defense for the fact that no structural remedies were imposed (Antitrust Subcommittee, 1959, p.292).

Second, due to Bell Labs' commitment to basic science and its role in the war effort, Bell held a large number of patents unrelated to telecommunications. These patents were used in industries in which Bell was not an active market participant and was explicitly banned from ever entering by the consent decree. This gives us the opportunity to measure the effectiveness of compulsory licensing as an antitrust remedy in different competitive settings. In the telecommunications industry, Bell was more or less vertically integrated and allegedly foreclosed rivals by denying access to its technology and to its customers. In all other industries, Bell was only a supplier of technology. These markets cover a wide range of market structures as measured by their concentration ratios, including some with high concentration ratios. Thus we can assess the impact of intellectual property rights on innovation in different competitive settings, with different concentration ratios and with different uses

Figure 3: Compulsorily Licensed Patents by Industry




*Notes:* The pie chart shows the distribution of compulsorily licensed patents by most likely industry. We assign patents to the most likely 4-digit SIC industry using the data of Kerr (2008). The data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

of exclusionary practices. Understanding this interaction of intellectual property rights and competitive settings is a first order concern for the use of compulsory licensing in antitrust that so far has received no attention in the literature.

To visualize the broad patent portfolio of Bell we use the data of Kerr (2008) to assign the most likely 4-digit SIC industry group to each USPC class (figure 3).[12] Around 43% of Bell's patents have their most likely application in Bell's core business of producing telephones and telegraphs (SIC 3661). The remainder is spread across a large number of fields; with an emphasis on electronics, industrial machinery, and computer equipment.[13]

# III. Data and Empirical Strategy

For our estimation, we use comprehensive patent data for the U.S. from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office. In this data, we identify

[12]We thank Bill Kerr for sharing his data.

[13]In figure 11 in Appendix A.A. we show the 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 and the remaining patents are spread over 34 other subcategories.

all compulsorily licensed patents of the Bell System with the help of a list of patent numbers published in the "Hearings before the Antitrust Subcommittee" of the U.S. Congress on the consent decree of Bell in May 1958 (Antitrust Subcommittee, 1958).[14]

To measure follow-on innovations building on Bell patents, we use patent citations. Bell patents could be freely licensed after the consent decree, but patents that built on licensed Bell patents still had to cite them. Thus, we can use patent citations as a measure for follow-on innovations even though patents had lost their power to exclude competitors (Williams, 2015). The advantage of this measure is that, in contrast to most alternative measures such as new products or R&D spending, citations are consistently available from 1947 onward.[15] Citations have the additional advantage that they have a high frequency, which allows a precise measurement of effects. The caveat is that some citations might have been added by the patent examiner, which adds noise to the measure (Alcacer and Gittelman, 2006; Alcacer, Gittelman, and Sampat, 2009).

To construct a counterfactual for the compulsorily licensed Bell patents, we use as control group *all* other patents that are published in the same year, that have the same total number of citations as the Bell patents in the five years before 1949, and that are in the same USPC technology class. Thus we employ exact matching. By conditioning on the publication year, we control for the fact that, on average, young patents are cited more often. By conditioning on prior citations, we control for how much a patent is used by other companies. By conditioning on the same technology class, we control for the number of companies that are active in the same field (i.e., for the number of potential follow-on inventors) and for technology-specific citation trends.

We can interpret our results as causal effect of the consent decree under the assumption that in the absence of the consent decree Bell patents would have received the same number of citations as the control patents did (parallel trend assumption). More specifically, the identifying assumption is that conditioning on the control variables removes any systematic difference in follow-on citations between Bell and the control patents that is not due to compulsory licensing. Note, that this assumption *does not* imply that Bell and control patents necessarily have the same underlying scientific quality or monetary value. It only

[14]The list is the complete list of all patents owned by the Bell System in January 1956. Of these patents, we drop all that have assignee names other than companies of the Bell System. The list also includes patents of Typesetter Corp., which were explicitly excluded from compulsory licensing in Section X of the consent decree. We assume that these patents are unaffected.

[15]In 1947, the USPTO started to publish citations of prior art on the front page of the patent (Alcacer, Gittelman, and Sampat, 2009). The first patent to include prior art was issued on February 4, 1947. Yet, inventions were evaluated against the prior art already since the passage of the Patent Act of 1836. Before 1947, however, the prior art was available only from the "file history" of the issued patent, which is not contained in Patstat.

implies that in the absence of the consent decree both patents would have continued to have the same number of follow-on citations.

One potential concern about this identification strategy might be that the antitrust authorities chose to compulsorily license Bell patents because of their high potential for follow-on research of these patents. According to the complaint and historical records, compulsory licensing was imposed because Bell used patents to block competitors in the field of telecommunications equipment. If in the absence of compulsory licensing these blocking patents would have experienced particularly strong follow-on innovation, then we might overestimate the effect of the consent decree.

Yet, this does not appear to be likely. In the absence of compulsory licensing, Bell's telecommunication patents would have continued to block competitors because the consent decree did not contain any other remedies aimed at restoring competition. Consequently, in absence of any changes it seems fair to assume that the blocking patents would have continued to receive the same number of citations as the control patents that have the same number of citations in the five years before 1949.

Furthermore, this concern does not apply to the 57% of patents Bell held outside the field of telecommunications. These patents were included in the compulsory licensing regime of the consent decree not because they were blocking, but purely due to their association with the Bell System. Hence, there is no reason to expect any confounding effects.

To strengthen the point that the parallel trend assumption is plausible, we show in Section IV.A. that the number of citations of Bell and control patents was the same before the terms of the consent decree became known. In Section IV.D. we also show that companies that did not benefit from compulsory licensing did not start to cite Bell patents more after the consent decree. Thus, the control patents are a plausible counterfactual for patents both inside and outside of telecommunications. Finally, in VI.B. we estimate the effect of the consent decree on innovation without relying on citation data and find similar results.

Another concern might be that Bell's patenting strategy may have changed after the complaint became known. This is why we focus on patents *published* before 1949, the year the lawsuit against Bell started. The consent decree stated that only patents published before 1956 were to be compulsorily licensed royalty-free. As a consequence of this cut-off date, more than 98% of the patents affected by the consent decree were filed before 1953, and more than 82% earlier than 1949. This implies that the characteristics of the majority of the affected patents were fixed before the Department of Justice filed its initial complaint. To be on the safe side, we use only patents granted before 1949, but the results do not change when we use all patents affected by the consent decree's stipulation of royalty-free compulsory licensing. We start our sample with the publication year 1940 because patents issued in 1939 would expire during 1956.[16] Thus; the expiration would coincide with the consent decree. Patents published in 1940 expired during 1957, while patents issued in 1948 - the last year in our main sample - expired in 1965.

Out of the 7,262 Bell patents published from 1940 to 1955, 4,196 patents were published before 1949. Of these patents, we delete the 425 patents that were published with delay due to secrecy orders during World War II (Gross, 2019). For 3,602 of the remaining 3,771 patents (i.e., for 96%) we find in total 54,405 control patents that fulfill the criteria specified above. This implies that every Bell patent has potentially more than one control patent.[17] In our main specification we re-weight the sample to account for the different number of control patents per Bell patent.

Table 1 shows summary statistics of the unweighted raw data. In column (1), we report the summary statistics for all patents that are not Bell patents. In column (2), we report the summary statistics of all Bell patents that were published from 1940 to 1955 and hence affected by the compulsory licensing rule. The average non-Bell patent in our data set receives 3.3 citations per patent while Bell System patents receive on average 4.4 citations. In column (3), we report the summary statistics for our baseline sample of Bell patents published from 1940 to 1948. In columns (4) and (5), we do so separately for patents in telecommunications versus outside telecommunications.[18] In our baseline sample the average Bell patent receives around 3.9 citations.

# IV. Results

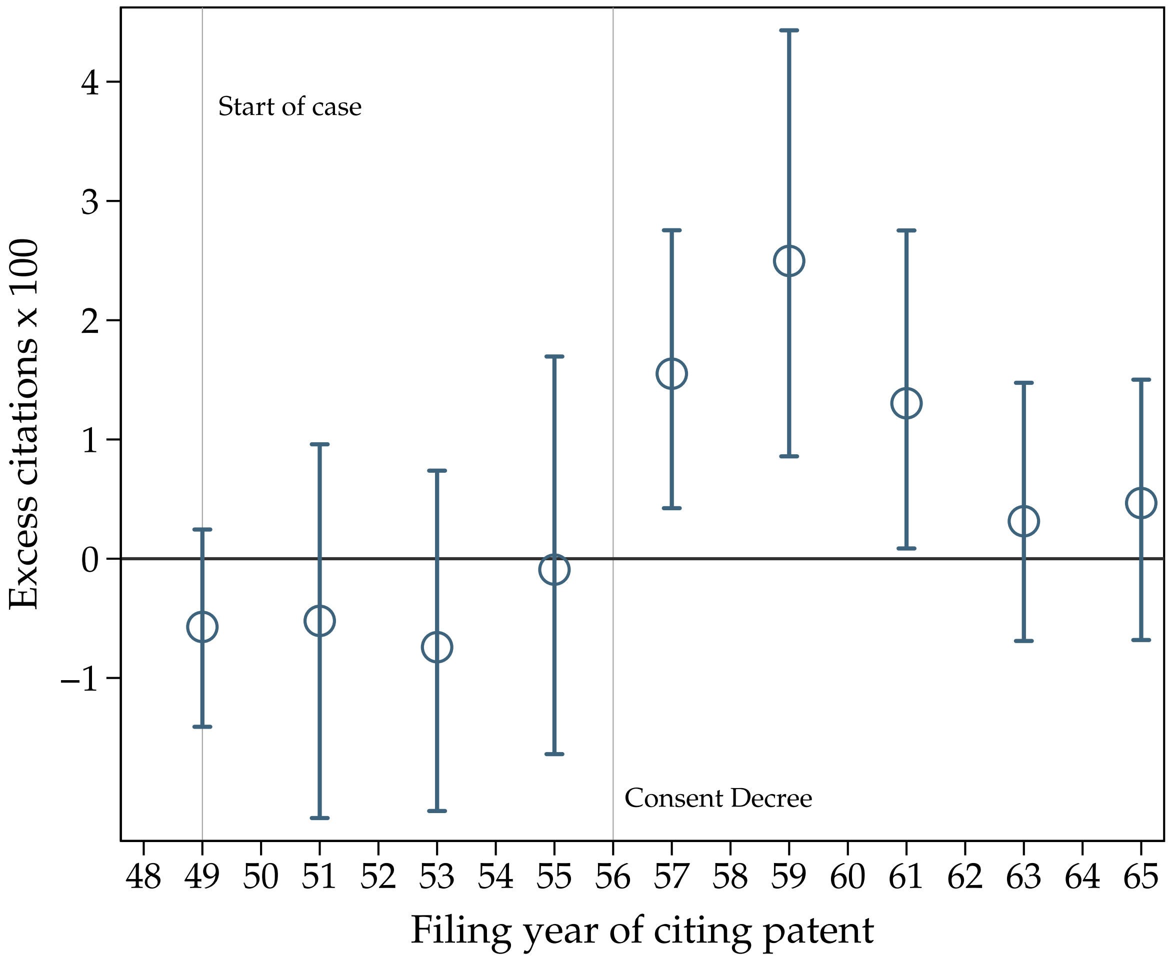
Before the consent decree, Bell licensed its patents to around 700 companies at royalty rates of 1% - 6% of the net sales price. Lower rates applied if a cross-license was agreed upon (Antitrust Subcommittee, 1958, p. 2685). The consent decree lowered these rates to zero and made licensing available without having to enter into a bargaining process with Bell. In this section, we estimate whether and if so by how much this compulsory licensing increased follow-on innovation inside and outside of telecommunications.

Table 1: Summary Statistics

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | Non-Bell | Bell System | | | |
| | | All (40-55) | Baseline Sample (40-48) | | |
| | | | All | Telecommunications | Others |
| | mean | mean | mean | mean | mean |
| Filing Year | 1944.9 | 1944.0 | 1940.9 | 1940.6 | 1941.0 |
| Publication Year | 1948.1 | 1947.0 | 1943.3 | 1942.7 | 1943.5 |
| # Years in patent protection after 1956 | 9.1 | 8.0 | 4.3 | 3.7 | 4.5 |
| Total cites | 3.5 | 5.1 | 4.6 | 4.9 | 4.4 |
| Citations by others | 3.3 | 4.4 | 3.9 | 3.9 | 3.9 |
| Self Citations | 0.2 | 0.7 | 0.7 | 1.0 | 0.6 |
| Citations by others prior to 1949 | 0.4 | 0.9 | 1.6 | 2.0 | 1.4 |
| Observations | 172464 | 6685 | 3771 | 1121 | 2650 |

*Notes:* The table reports the average filing and publication year, the average number of years until patent expiration and citation statistics for published patents as follows: Column (1) describes all patents published from 1940 to 1955 of non-Bell System companies in technologies where a Bell System company published at least one patent. Column (2) describes all Bell patents published from 1940 to 1955. Column (3) describes all Bell patents published from 1940 to 1948, the baseline sample of most of our regressions. Columns (4) and (5) split all Bell patents published from 1940 to 1948 according to their use in telecommunications. We classify a patent as a telecommunications-related patent if in its patent class patents have at least a 15% likelihood of being used in the production of telecommunications equipment according to the data of Kerr (2008). A citation is identified as a self-cite if the applicant of the cited and citing patent is the same. The data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

Figure 4: Effect of Compulsory Licensing on Subsequent Citations




*Notes:* This graph shows the average number of excess citations over two years of patents affected by the consent decree ("Bell patents") relative to their control patents. To estimate the average treatment effect on the treated $\tau_{t-1\wedge t}$, we use the following estimator:

$$\hat{\tau}_{t-1\wedge t} = \frac{1}{N}\sum_i (\#Citation_{i,t-1\wedge t} - \overline{\#Citation_{ci,t-1\wedge t}})$$

where $\#Citation_{i,t-1\wedge t}$ is the average number of citations to Bell patent $i$ in years $t-1$ and $t$. $\overline{\#Citation_{ci,t-1\wedge t}}$ is the average number of citations to all control patents assigned to patent $i$ in years $t-1$ and $t$. A patent is a control patent for patent $i$ if it has the same three-digit U. S. Patent Classification (USPC) primary class of a patent, the same number of citations up to 1949 and the same publication years. $N$ is the number of Bell patents. We correct for self-citations. The bars represent the 95% confidence bands for the estimated coefficient. Standard errors are bootstrapped over three-digit technology classes. The sample under consideration contains 3,602 Bell patents and 54,405 control patents. There are 169 Bell patents that we cannot match to control patents. The data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

## A. The Impact of the Consent Decree on Follow-on Innovation

We start by investigating whether compulsory licensing had any effect on innovation at all. A priori, it is not obvious why it should. As Green and Scotchmer (1995) show theoretically, patent rights should not prevent value-enhancing follow-on innovation as long as bargaining between the parties is efficient. We estimate the average impact on patent citations across all industries, looking at the time period 1948-1965. Figure 4 shows the average treatment effect on the treated of compulsory licensing on citations, i.e. the average number of excess citations of Bell patents relative to control patents. To calculate this treatment effect non-parametrically, we assign each Bell patent control patents with the same technology class, number of citations up to 1949, and publication year. Then we take the average difference of the number of citations over a two year period to each Bell patent and the average number of citations to all assigned control patents.We average the citations over a two year period to reduce the noise in the estimates. In Appendix B.B. we show the same results using yearly coefficients. 95% confidence intervals are constructed using bootstrapped standard errors clustered on patent class level. This accounts for a potential serial correlation in citations within technology class.

From 1949 to 1955, the average number of citations of treatment and control patents tracks each other very closely, speaking for parallel trends in citations to Bell patents and the control patents. After 1956, the average number of excess citations of other companies to Bell patents increases and becomes statistically significantly different from zero. The number of excess citations of Bell and Control patents converges again in 1961. Note that 1961 is the average expiration date of the treated Bell patents in our sample, and by 1965 all treated patents in our sample have expired. The coefficients from 1956 to 1961 are significantly different from zero.[19]

To observe a statistically significant effect right after 1956 is plausible in view of the fact that compulsory licensing was agreed upon in early 1954 (Antitrust Subcommittee, 1959, p.59). A memorandum of the Bell management dated March 1954 summarizes a meeting between the Attorney General and the Bell management and suggests that the

[16]From 1861 to 1994, the term of the patent was 17 years from issuance.

[17]Each treated patent has on average around 15 control patents. The median number of control patents is 7. The first affected patents start to expire by 1957 (424 patents). On average, each patent is in our main sample for 11.27 years, with a median of 11 years. The control patents are in our sample for an average of 11.37 years, with a median of 11 years.

[18]To make the statistics comparable for affected and not affected patents, we only consider technology classes in which Bell is active.

[19]In Appendix B.A. we graphically compare the average yearly number of citations to Bell and to control patents and find the same results. In Appendix B.C. we estimate the same picture with time-varying regression coefficients.

parties had come to a common understanding on how to resolve the Bell case (Antitrust Subcommittee, 1958, p. 1956). On May 28, 1954, Bell formally proposed a consent decree including the compulsory licensing of Bell System patents as described in Section II. The first media mentioning of the consent decree against Bell was on May 13, 1955 in the New York Times. Public officials confirmed that top level negotiations were ongoing "looking towards a settlement of the AT&T case."

We would expect an immediate reaction to news about the agreement on the consent decree. Due to the nature of the patent race, companies had an incentive to act quickly and patent the most important follow-on innovations as soon as they learned about the proposed consent decree. They could then wait with the production of goods based on the new patents and with the licensing of Bell's technology required for this production until after the consent decree was implemented.

The cumulative abnormal stock returns for AT&T stocks shown in figure 5 suggest that the agreement reached in 1954 was known to a substantial group of people.[20] 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. There is no more persistent positive or negative change in the cumulative abnormal return until 1959. In particular, the consent decree itself in 1956 did not seem to have had any more informational value.

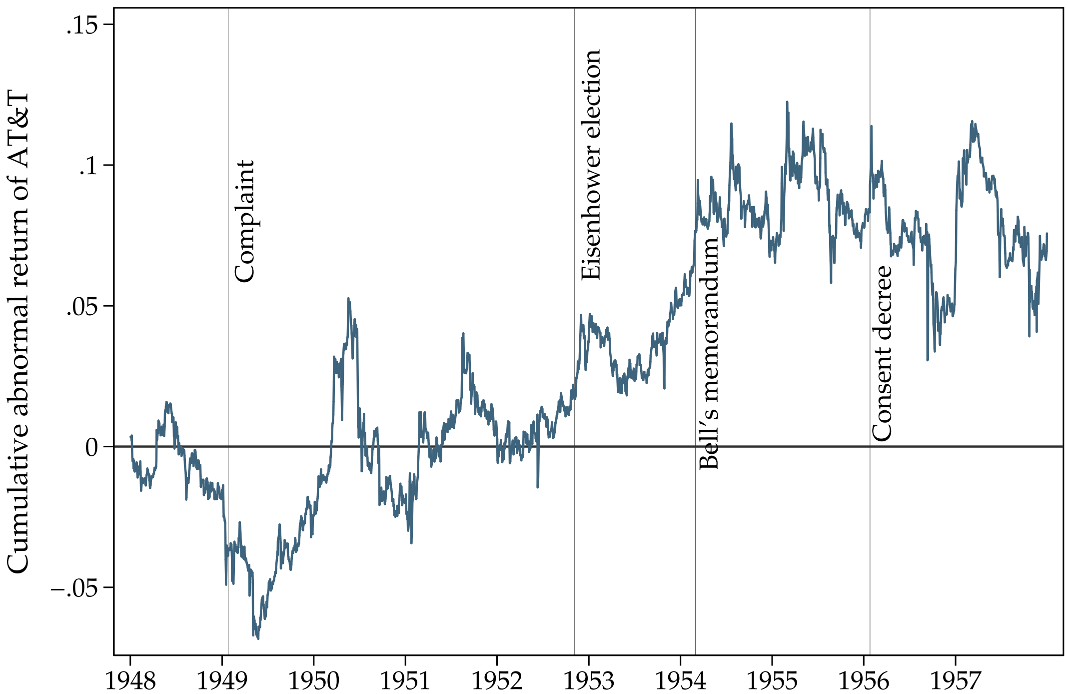
We can also infer from Bell's behavior that as early as the first half of 1955, compulsory licensing was expected. According to the consent decree, all patents had to be licensed for free if they were published before January 24, 1956. If they were published after this cut-off date, they were licensed 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 6, we show these hazard rates of publishing in a particular year for the filing years 1949 and 1953.[21] 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

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

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

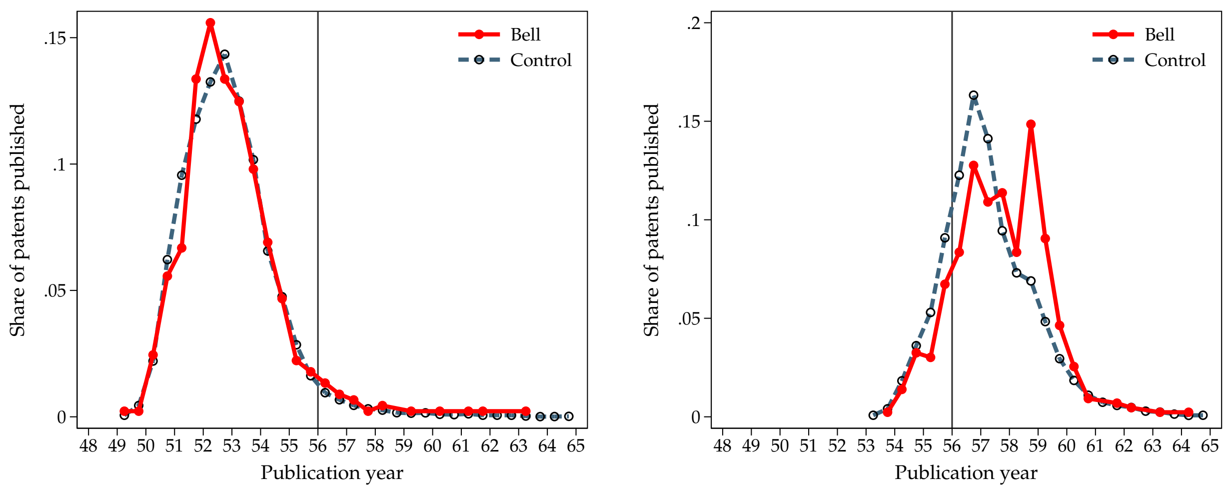
Figure 5: Cumulative Abnormal Stock Returns of AT&T




*Notes:* 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 (CRSP).

Figure 6: Hazard Rates for Publication of Patents by Filing Year

(a) Filing Year 1949 (b) Filing Year 1953




*Notes:* 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 data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

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.[22]

To summarize, our estimates show that the consent decree increased follow-on innovation on average. This result is consistent with the findings of Moser and Voena (2012), who study compulsory licensing after the first World War, and with those by Galasso and Schankerman (2015), who show that patents that are invalidated after they are challenged in court prevent follow-on innovation by other companies. What is special about our set-up is that compulsory licensing was implemented as an antitrust remedy with the specific aim to end market foreclosure in the telephone equipment market. To determine whether or not this attempt was successful, i.e. whether or not compulsory licensing stimulates innovation even in settings where further exclusionary practices are used, we need to go beyond the average effects and look at the effects in different markets separately.

[22]One concern is that Bell patents have a higher innate quality and this higher quality is reflected in citations only with a time lag. In unreported results, we find that the increase in citations does not depend on the age of the patent. Older and younger patents show a synchronized increase in 1956. This makes it unlikely that Bell patents would have experienced an increase in citations without the consent decree due to their potentially higher innate quality. The results are available from the authors on request.

## B. Effects Inside and Outside of Telecommunications

To analyze whether or not compulsory licensing indeed had a stimulating effect in the telecommunications industry, we group patent citations according to how likely it is that the citing patents are used for the production of telecommunications equipment.[23] We use the concordance of Kerr (2008) to determine the probability for each USPC technology class that a patent in this technology class is used in the production of telecommunications equipment (SIC 3661). We then assign this probability to each citing patent belonging to this technology class. We group these probabilities into five different bins, representing five different levels of closeness to the production of telecommunications equipment. We construct a different dependent variable for each of these five different levels, summing up the citations for each level. In the last step, we estimate for each level of closeness $c$ the following difference-in-differences regression:

$$\#Citations_{i,t,c} = \beta_{1,c} \cdot Bell_i + \beta_{2,c} \cdot Post_t + \beta_{3,c} \cdot Bell_i \cdot Post_t + \varepsilon_{i,t,c} \tag{1}$$

where $Bell_i$ is an indicator if the patent $i$ was filed by any company in the Bell System and $Post_t$ is an indicator for the period from 1956 till the expiration of the patent.

This estimate tells us how much the consent decree increased citations on average per year in markets that are close to the production of telecommunications equipment and in markets unrelated to it. In figure 7 we show the average treatment effect, $\beta_{3,c}$, for the five different levels of closeness to the production of telecommunications equipment. We find a strong negative relation between the closeness to telecommunications and excess citations. Almost all excess citations come from patents that have no relation to telecommunications. These results suggest that compulsory licensing was ineffective in increasing innovation in the telecommunications industry, but effective in others.[24][25]

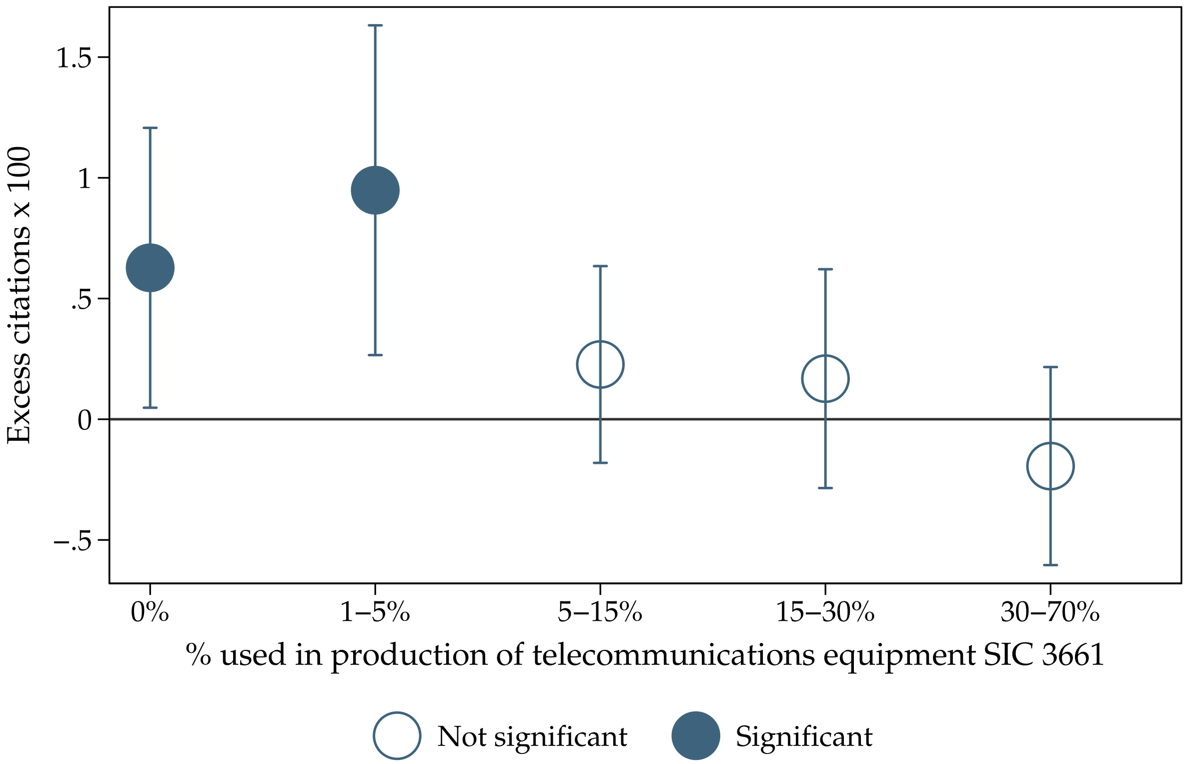
In table 2, we show the regression coefficients that underlie figure 7. For this table, we group citations in two bins, one with citations from telecommunications-related patents and one with citations unrelated to telecommunications. We classifiy a citing patent as a telecommunications-related patent if in its patent class, patents have at least a 15% likelihood of being used in the production of telecommunications equipment. These

[23] We also analyze the reverse case, focusing on how close the cited patents are to telecommunications. Results are similar and are available from the authors on request.

[24] Another explanation for the observed null effect might be that there was a lack of innovation potential in the telecommunications sector after 1956. To rule out this hypothetical possibility we compare the development of patents in the telecommunications sector with that of patents in other fields and show results in figure 15 in Appendix B.D. We show that the number of citations to Bell's telecommunications patents had a similar trend as to Bell's patents outside of telecommunications and that the number of Bell's newly filed telecommunications patents shows no signs of abating after the consent decree.

[25] In Appendix B.F., we report several robustness checks for this result.

Figure 7: Excess Citations by Patents with Varying Likelihood of Being Used in the Production of Telecommunications Equipment




*Notes:* This figure shows results from a difference-in-differences specification in Equation 1 of the impact of the consent decree on follow-on patent citations, with 1956 until patent expiration as the treatment period. We report $\beta_3$ 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"). Relevance is measured by the likelihood that a patent is used in industry SIC 3661, using the data of Kerr (2008). A solid circle implies that the coefficient is significant at the 5% level. The data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

telecommunications-related patents are captured by the final three bins in figure 7. Otherwise, we classify it as unrelated.[26] In column (1) of table 2, we report the results for our baseline regression, showing that the overall patent citations increased by 16%.[27] We find no effect in telecommunications (column 3), but a 20 percent increase in citations in other fields, unrelated to telecommunications (column 5).[28]

Back-of-the-envelope calculations suggest that the additional patents for other companies in other fields directly induced by the consent decree had a total value of up to $5.8 billion. To calculate this number we use estimates for the average patent dollar value derived from Kogan et al. (2017) to weight each citing patent.[29] According to these estimates, each compulsorily licensed patent created on average an additional value of $99,400 annually in the treatment period (column 6). Assuming homogeneous effects for all 7,820 patents in the treatment group, the consent decree led to around $5.8 billion dollars in economic value between 1956 and the expiration of the patents, which was on average 7.52 years after 1956. These calculations represent an upper bound because they assume that without the additional citations induced by the consent decree the patent would not have been invented (i.e., that the compulsorily licensed patent was strictly necessary for the citing invention).

To shed more light on the mechanism, we analyze the impact on citations from young and small assignees in the telecommunications industry and in all other markets. An assignee is either a company or an individual inventor. We define an assignee as young if its first patent was filed less than ten years before it cited the Bell patent and we define it as small if it had less than ten patents before 1949.[30] We find that compulsory licensing failed to stimulate innovation from young and small firms in the telecommunications sector (column 4), whereas they account for 60% of the increase in innovation in all other fields (column 7). This suggests that in particular newly entering companies benefitted from compulsory licensing. This is plausible since larger companies with a larger patent portfolio might have found it

[26]Our results are robust when using other cut-off values but the cut-off value is not arbitrary. In Appendix B.G. we show that for patent classes for which patents have at least a 15% likelihood of being used in the production of telecommunications equipment the most likely industry of all patents in this patent class is the production of telecommunication equipment (SIC 3661). In all other patent classes, some patents have their most likely application in other industries.

[27]Without compulsory licensing, we would expect that a Bell patent gets on average 0.112 citations (0.164-0.048-0.004) per year till expiration. With compulsory licensing, the average increase in citations is 0.018. This is an increase of 16.07% in citations.

[28]In Appendix B.H., we show that the timing of the increase in Other Fields is the same as in our main result (Figure 4). We see no increase in telecommunication. In Appendix B.H., we also show that the average quality of follow-on innovation did not drop after the consent decree.

[29]Kogan et al. (2017) measure the value of a patent using abnormal stock returns around the publishing date of the patent. We use this data to calculate the average dollar value for a patent in each technology class and publication year.

[30]In Appendix B.I., we use different definitions for young and small companies and find that the effect is mainly driven by inventors who file their first patent and by young & small companies ("start-ups").

relatively easier to license technology from Bell even before the consent decree because they could engage in cross-licensing (Lanjouw and Schankerman, 2004; Galasso, 2012; Galasso and Schankerman, 2015). Patents seem to act as a barrier to entry predominantly for start-ups.

## C. The Role of Exclusionary Practices

The telecommunications market was special in two ways: it was highly concentrated and more or less vertically integrated, with Western Electric being the near-monopolist for telephone equipment, and the Bell operating companies buying most of their supplies from Western Electric. In this section, we aim to shed light on the question which of these two features is responsible for the observed null response to compulsory licensing. In the telecommunications market, we cannot separate these two features. Outside of the telecommunications market, we can observe whether compulsory licensing increases innovation in highly concentrated markets. This informs us about whether concentration per-se is detrimental for follow-on innovation.

In columns (8) and (9) of table 2, we split the citations from patents not related to telecommunications in two groups, one with citations coming from patents in highly concentrated markets and one with citations from patents in markets with low concentration. To classify patents as belonging to a highly concentrated market we use again the concordance of Kerr (2008). This gives us for each patent class and each industry classified by four-digit SIC code a likelihood that a patent in this class is used in this industry. We multiply this likelihood with the 8-firm market share in an industry that we get from the U.S. Census and aggregate the product on the patent class level.[31] Thus, we get for each patent class the weighted average 8-firm market share in the industry in which the patent is used. In the last step, we classify a citing patent as being used in a highly concentrated industry if the average 8-firm market share is above 60%, which is the 75th percentile.[32]

We find a positive and significant increase in follow-on innovation, both in low and highly concentrated markets. This also holds for newly entering companies (columns 10 and 11). Both results suggest that compulsory licensing can be profitably employed in concentrated markets to foster entry by innovative start-ups and to increase follow-on innovation. This is prima facie evidence that compulsory licensing can work as an antitrust remedy.

Why did compulsory licensing not work in telecommunications? When the merits of the consent decree were discussed in the Congressional hearings, both the public and an-

[31] The data is available on http://www.census.gov/epcd/www /concentration92-47.xls. We use data for the years prior to the consent decree where available. If the industry is missing we use the earliest non-missing observation.

[32] The minimum average 8-firm market share across patent classes is 30%, the median is 53%, and the maximum is 82%.

Table 2: The Effect of Compulsory Licensing on Subsequent Citations

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Telecommunications | | Other Fields | | | | | | |
| | | Up to 1956 | All | Young & Small | All | Dollar weighted | Young & Small | High Conc | Low Conc | Y&S High Conc | Y&S Low Conc |
| Bell | -0.4 | 0.1 | 0.3 | -0.1 | -0.7 | -1.4 | -0.7*** | 0.1 | -0.8* | -0.1 | -0.6** |
| | (0.4) | (0.2) | (0.3) | (0.4) | (0.4) | (2.6) | (0.3) | (0.3) | (0.5) | (0.1) | (0.2) |
| Post | -4.8*** | -5.3*** | -1.6*** | -0.4 | -3.3*** | 4.9** | -0.1 | -1.7*** | -1.5*** | -0.3*** | 0.1 |
| | (0.5) | (0.9) | (0.5) | (0.3) | (0.7) | (2.0) | (0.2) | (0.4) | (0.5) | (0.1) | (0.1) |
| Bell x Post | 1.8*** | 1.7*** | -0.0 | 0.1 | 1.8*** | 9.9*** | 1.1*** | 0.8* | 1.0** | 0.5*** | 0.7*** |
| | (0.6) | (0.5) | (0.3) | (0.2) | (0.5) | (3.4) | (0.3) | (0.5) | (0.5) | (0.1) | (0.2) |
| Constant | 16.4*** | 19.7*** | 3.4*** | 1.2** | 13.0*** | 60.8*** | 4.6*** | 4.8*** | 8.2*** | 1.4*** | 3.2*** |
| | (1.0) | (1.6) | (1.2) | (0.6) | (2.0) | (9.1) | (0.7) | (0.8) | (1.5) | (0.2) | (0.6) |
| # treated | 3602 | 6645 | 3602 | 3602 | 3602 | 3602 | 3602 | 3602 | 3602 | 3602 | 3602 |
| Clusters | 207 | 243 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| Obs. | 659137 | 1488416 | 659137 | 659137 | 659137 | 659137 | 659137 | 659137 | 659137 | 659137 | 659137 |

*Notes:* 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. The estimation equation is:

$$\#Citations_{i,t} = \beta_1 \cdot Bell_i + \beta_2 \cdot Post_t + \beta_3 \cdot Bell_i \cdot Post_t + \varepsilon_{i,t}$$

where $Post_t$ is an indicator variable for the treatment period from 1956 until patent expiration. *Bell* is an indicator variable equal to one if a patent is published by a Bell System company before 1949. 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. 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. In the second column, we extend our sample of affected patents to 1956. In columns (3) and (4), the dependent variable is citations by patents in fields related to telecommunications. We classify a citing patent as a telecommunications-related patent if in its patent class patents have at least a 15% likelihood of being used in the production of telecommunications equipment, using the data of Kerr (2008). Column (4) shows results for this dependent variable using the citations by young and small companies. We define an assignee as young if its first patent was filed less than ten years before it cited the Bell patent and as small if it had less than ten patents before 1949. All remaining columns show the results for citations from patents in all other fields. Column (5) repeats the baseline specification for Other Fields. In column (6), we weight each citation by the average dollar value of a patent in the same publication year and technology class derived from the values provided by Kogan et al. (2017). Column (7) shows patent citations from young and small assignees as described before. In columns (8) and (9) we classify citing patents as belonging to a highly or lowconcentrated market. To this end, we again use the concordance of Kerr (2008) that gives us for each patent class and each industry classified by four-digit SIC code a likelihood that a patent in this class is used in this industry. We multiply this likelihood with the average 8-firm market share in an industry that we get from the U.S. Census and aggregate the product on the patent class level. In the last step, we classify a citing patent as being used in a highly concentrated industry if the average 8-firm market share is above 60%, which is the 75th percentile. Columns (10) and (11) use as the dependent variable citations from patents from young and small assignees in markets with high or low concentration as described before. 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.

titrust officials suspected that compulsory licensing would help only companies outside the telecommunications field because of Bell's unchallenged position as a vertically integrated monopolist. They attributed it to the foreclosure of the product market. A witness in the Congressional hearings put it succinctly: "while patents are made available to independent equipment manufacturers, no market for telephone equipment is supplied (...). It is rather a useless thing to be permitted to manufacture under patent if there is no market in which you can sell the product on which the patent is based." In the final report, the Antitrust Subcommittee concluded that "[t]he patent and technical information requirement have efficacy only so far as they permit independent manufacturers to avail themselves of patents in fields that are unrelated to the common carrier communication business carried on by the Bell System companies, and nothing more."

In the years after the consent decree, the Bell System faced repeated allegations of exclusionary behavior. By the 1960s and 1970s, a range of new firms was eager to enter the telecommunications market, but Bell implemented measures to make entry expensive or impossible (Wu, 2012). This led to a number of regulatory actions, in 1971, for example, forcing interconnections of Bell's telephone system to the entering competitor MCI, who provided long distance services using microwave towers (Temin and Galambos, 1987; Gertner, 2012, p. 272). Eventually, the continued exclusion of competitors in the telecommunications market by Bell resulted in the 1974 antitrust lawsuit. The lawsuit mirrored almost scene by scene the case of 1949. Again, Bell was charged with foreclosing competitors from the market for telecommunications equipment. Again, the Department of Defense intervened on the grounds of national defense. But the Reagan administration was not as accommodating as the Eisenhower administration had been, and the Department of Justice was keen on going after Bell. The case ended with the break-up of the Bell System in 1984, opening up the telecommunications equipment market for competition. In Appendix B.J., we show that after Bell was split up and market foreclosure ended, innovation increased in telecommunications relative to other fields.

Compulsory licensing is a frequent remedy in antitrust. It is allegedly "[f]orcing firms to share the sandbox" and considered a viable alternative for divestiture in merger cases and in non-merger cases with "extraordinary level of market dominance and a demonstrated history of monopolization and resistance to reform" (Delrahim, 2004). Our results suggest that compulsory licensing is ineffective in stimulating innovation if dominant companies can engage in exclusionary practices. If exclusion is not a concern, compulsory licensing fosters innovation. While in traditional antitrust analysis collusion is thought to be the "supreme evil", our results second the view that when it comes to innovation, exclusionary practices should be the main concern of antitrust authorities (Wu, 2012; Baker, 2012).

## D. Auxiliary Results and Robustness Checks

One concern for the identification of the effect is that 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 compulsory licensing because they expected that there would be strong technological progress in the technology fields of Bell. If exogenous technological progress rather than 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 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 3. 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.[33] 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.[34] Foreign companies could license for free but did not receive any technical description or assistance from Bell.[35] 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).

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

[33]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 on conventional levels. However, the p-Value of this test is 0.25. Thus, an estimate this low still is rather unlikely.

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

[35]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 (...)." As foreign citation we define every citation from a patent whose publication authority is not the United States.

patents might have received a favorable shock. To show that this is not the case, we first split our sample in high-quality and low-quality patents in columns (6) and (7) of table 3. We define a high-quality patent as a patent with a value of more than 3.07 million dollars, 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 (see Section V.). 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.

Historical accounts also report that there was an exodus of important Bell researchers from Bell Labs around the time of the consent decree. For example, in 1953 Gordon Teal, 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 thus to more follow-on innovation by small and young companies.

To investigate whether this was indeed 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 (10) and (11) of Table 3. We find a positive effect on the citations of unrelated inventors and a negative effect on the citations of related inventors.[36] This pattern does not suggest that the increase in follow-on innovation was driven by former Bell employees.

In further robustness checks in Appendix B.K., we show that the effect is also not driven by citation substitution; i.e., it is not driven by companies citing royalty-free Bell patents instead of other, potentially more expensive technologies. Finally, in Appendix B.L., we vary the construction of control groups and show that our results are not driven by the particular

[36]The estimated yearly coefficients for excess citations of former Bell inventors and of unrelated inventors are available from the authors upon request.

Table 3: The Effect of Compulsory Licensing on Subsequent Citations by Company Type and Field

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base line | B-2 Comp. | For- eign | Prior License Yes | No | Quality High | Low | without Transistor | without IBM and RCA | Former Bell? Yes | No |
| Bell | -0.4 | 0.2 | -0.1 | 0.5** | -0.9** | -0.3 | -0.5 | -0.5 | -0.5 | 0.7*** | -1.1** |
| | (0.4) | (0.1) | (0.1) | (0.2) | (0.4) | (0.6) | (0.7) | (0.4) | (0.4) | (0.2) | (0.5) |
| Post | -4.8*** | -0.6*** | -2.0*** | -1.0*** | -3.9*** | -4.9*** | -4.7*** | -4.8*** | -4.7*** | -0.4*** | -4.4*** |
| | (0.5) | (0.2) | (0.3) | (0.2) | (0.4) | (0.7) | (0.4) | (0.5) | (0.4) | (0.1) | (0.5) |
| Bell x Post | 1.8*** | 0.0 | 0.1 | 0.7** | 1.1** | 2.2*** | 1.4** | 1.8*** | 1.7*** | -0.6*** | 2.4*** |
| | (0.6) | (0.1) | (0.2) | (0.3) | (0.5) | (0.8) | (0.6) | (0.6) | (0.5) | (0.2) | (0.6) |
| Constant | 16.4*** | 1.2*** | 2.8*** | 2.6*** | 13.8*** | 16.9*** | 15.9*** | 16.4*** | 15.7*** | 0.9*** | 15.5*** |
| | (1.0) | (0.3) | (0.2) | (0.2) | (1.0) | (1.1) | (1.0) | (1.0) | (0.9) | (0.1) | (1.0) |
| # treated | 3602 | 3602 | 3602 | 3602 | 3602 | 1759 | 1843 | 3557 | 3602 | 3602 | 3602 |
| Clusters | 207 | 207 | 207 | 207 | 207 | 181 | 170 | 207 | 207 | 207 | 207 |
| Obs. | 659137 | 659137 | 659137 | 659137 | 659137 | 418671 | 387687 | 658649 | 659137 | 659137 | 659137 |

Notes: 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 sample into high-quality and low-quality patents. We define a high-quality patent as a patent with a value of more than 3.07 million dollars, the median dollar value of a Bell patent according to Kogan et al. (2017). In column (8), 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 (9), 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. In columns (10) and (11), 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.

choice of matching variables.

# V. Case Study: The Diffusion of the Transistor Technology

The case of the transistor, arguably the most important invention of Bell Labs, gives the most vivid illustration of how important open and standardized licensing can be for follow-on innovation. The invention of the transistor earned John Bardeen, Walter Brattain, and William Shockley the Nobel Prize in Physics in 1956. They filed patents in June 1948 and announced the invention on July 1 of the same year. The patents were published in 1950 and 1951. Bell, the military, and the research community at large immediately understood the importance and value of the transistor.

In contrast to all other Bell patents, the open and standardized licensing of transistor patents started already in 1952. Due to the ongoing antitrust lawsuit, Bell's management was reluctant to draw attention to its market power by charging high prices for transistor licenses (Mowery, 2011). To appease the regulator, Bell's top managers agreed to share and license the transistor device with standardized non-discriminatory licensing contracts (Gertner, 2012, p.111). In addition, Bell decided to actively promote the transistor by organizing conferences to explain the technology. A first symposium was held at Bell Labs in September 1951, and over 100 representatives from 40 companies gathered for a second nine-day Transistor Technology Symposium in April 1952. After the conference, 30 companies decided to license the transistor technology for a non-refundable advance payment of $25,000 ($\sim$ $220,000 in today's dollars) that was credited against future royalty payments (Antitrust Subcommittee, 1958, p.2957). Royalty rates amounted to 5% of the net selling price of the transistor in 1950, which were reduced to 2% in 1953 (Antitrust Subcommittee, 1959, p. 117).

To be able to separately analyze the effects of the transistor licensing we identify among the patents affected by the consent decree all patents related to the original transistor inventor team.[37] There are two main transistor patents: Patent # 2,524,035 with the title "Three-Electrode Circuit Element Utilizing Semiconductive Materials" granted in 1950 to John Bardeen and Walter Brattain and Patent # 2,569,347 with the title "Circuit Element Utilizing Semiconductive Material" issued to William Shockley in 1951. To these two patents, we add all patents of all researchers who actively worked towards the development

[37] Researchers whom we classify to have actively contributed to the transistor at Bell Labs were in alphabetical order Bardeen, Becker, Brattain, Buehler, Gomperez, Green, Haynes, Little, Morgan, Ohl, Pearson, Pfann, Scaff, Shive, Shockley, Sparks, Storks, Teal, Theurer amd Zinc (Nelson, 1962; Buehler, 1983).

of the transistor at Bell Labs. We identify 164 "transistor" patents affected by the consent decree (i.e., held by Bell Labs). 104 of those were published up to 1952. 76 were published until 1949 and thus are also contained in our baseline sample. This sample is most likely a super-set of all transistor patents. For example, it also includes patent # 2,402,662 with the title "Light Sensitive Device" granted to Russell Ohl, the original patent of the solar cell.

To repeat our main regressions in this subsample of transistor patents, we extend our baseline sample to patents published up to 1951. For our control group, we use patents with the same number of citations up to 1951 while all other criteria stay the same. Out of the 77 non-secret transistor patents published by 1951, we can find control patents for 64 patents.

Figure 8 panel (a) shows the yearly excess citations of transistor patents relative to the control group patents. The impact of licensing is measurable starting in 1953 and lasts for at least 15 years. This suggests that standardized licensing had a positive impact on follow-on innovation. The fact that the impact does not strongly increase after 1956, when the consent decree reduced licensing fees to zero, suggests instead that the price reduction had little further impact. What mattered was access to standardized licensing.

In a next step, we distinguish the effects of standardized licensing for patents with a different likelihood of being used in the production of telecommunications equipment. Figure 8 panel (b) presents the results. Again, we find a negative relation between the closeness to telecommunications and excess citations. All excess citations come from patents that have no or little relation to telecommunications. We show the results from estimating a difference-in-difference specification for the transistor subsample in Appendix C.

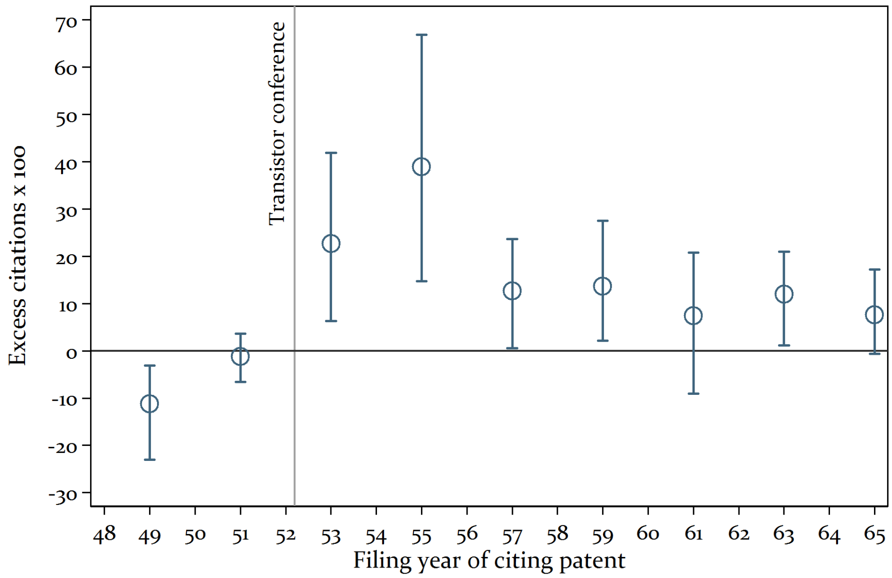
Transistors are the classical example of a general-purpose technology that has the potential of having a large scale impact on the economy (Helpman, 1998). If it had not been for the antitrust lawsuit against Bell, the odds are that Bell's licensing policy would have been less accommodating and the follow-on innovations stimulated by the transistors less dramatic than they were.

# VI. The Long-Run Effects on U.S. Innovation

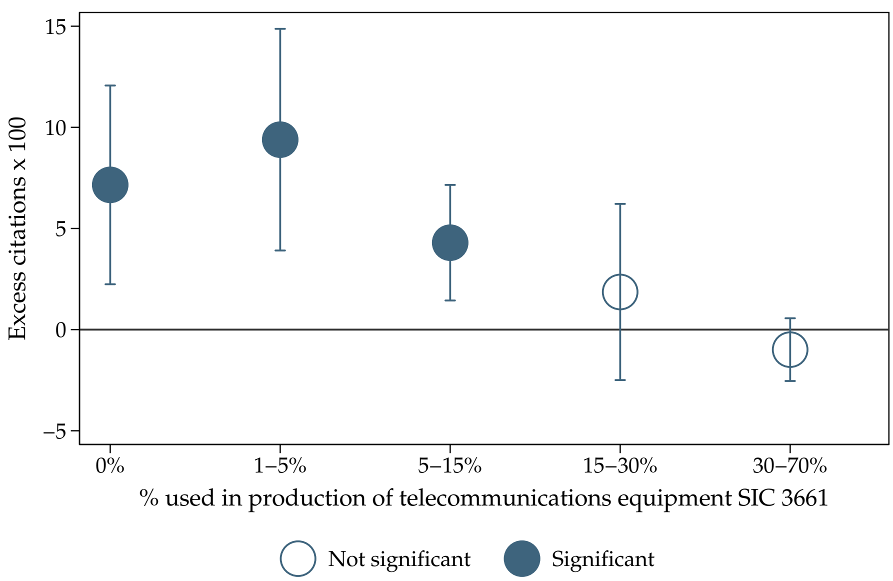
We have shown in Section IV. that compulsory licensing is effective in stimulating innovation, even in highly concentrated markets, provided market entry is not jeopardized by the use of exclusionary practices. However, to assess the merits of compulsory licensing as a tool in antitrust enforcement, it is important to take into consideration the potential costs and side-effects that may result from such a massive intervention in intellectual property rights and to weigh them against the long-term benefits. The advantage of the Bell case is that we can observe both Bell's reaction and the reactions of other companies over a longer horizon.

Figure 8: Annual Treatment Effects on Excess Citations of Transistor Patents

(a) Two-Yearly




(b) Average Effects Across Markets




*Notes:* Panel (a) shows the average number of excess citations in year $t$ and $t-1$ of transistor patents published before 1952 affected by the consent decree relative to patents with the same publication year, in the same three-digit U.S. Patent Classification (USPC) primary class and with the same number of citations up to 1951. We correct for self-citations. The solid line represents the 95% confidence bands for the estimated coefficient. Standard errors are bootstrapped over technology classes. The sample under consideration contains 104 transistor patents 77 of which were not affected by the secrecy program. We can match 64 transistor patents to 1,900 control patents. In Panel (b), we show results from a difference-in-differences estimation of the impact of the consent decree on follow-on patent citations. We report separate treatment effects using as dependent variables citations from patents with a different likelihood of the production of telecommunication equipment (SIC 3661 - "Telephone and Telegraph Apparatus") according to the data of Kerr (2008). A solid circle implies that the coefficient is significant at the 5% level.

This allows us to evaluate the overall merits of this antitrust intervention.

## A. The Effects on Bell

At the time of the consent decree, Bell held patents with an estimated value of around 30 billion in today's dollars.[38] The consent decree devalued these patents by forcing Bell to license them for free, while all future patents had to be licensed for reasonable terms. This change in Bell's intellectual property rights protection might have reduced the incentive of Bell to engage in innovation.

Yet, Bell's subsequent innovation output measured by the number of patents seems to have been little affected by the consent decree. To see this, we compare the patent output of a synthetic Bell with the actual output of the Bell System. To construct a synthetic Bell, we first calculate the share of Bell's patents of all patents in each technology subcategory for the years 1946, 1947, and 1948. Then we assume that Bell's patent growth would have been in line with the growth of other companies that existed before 1949 in these technology subcategories so that Bell would have held its patent share in each subcategory constant for the following years.[39] Results are presented in figure 9a. It shows that Bell's patenting is on average smaller than the patenting of the synthetic control, but not by much.[40]

Regarding patent quality, the evidence is inconclusive but does not speak for a marked decline in the quality of Bell's innovation after the consent decree. Bell continued to produce path-breaking innovations, e.g., the laser technology (1957), the communications satellite (1962) or the Unix operating system (1969-1972). In figure 9b we plot the share of patents Bell had in the upper 5% of the citation distribution and in the upper 5% of the value distribution for each year. In both cases, we define the 5% cut-off by filing year of the patent and by technology class. In 1950, around 7.3% of Bell's telecommunications patents were in the top 5% in terms of citations and around 6.6% in the top 5% in terms of dollar value. Ten years later, in 1960, 5.7 % of all Bell patents were in the top 5% of the citation distribution and 16.5% in the top 5% of the value distribution. The interpretation of these numbers is difficult as patents published before 1956 were compulsorily licensed and thus received more

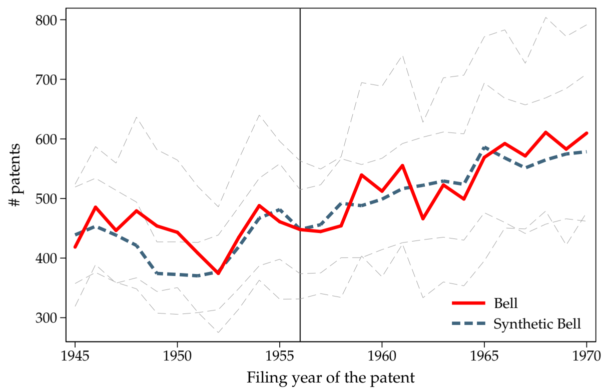
[38] To calculate these numbers we use the data of Kogan et al. (2017). When using only non-missing values in the data we arrive at estimates of $31.4 billion and at estimates of $34.4 billion if we use average patent values per publication year and technology class. All dollar values are in 2010 U.S. dollars.

[39] Instead of assuming the same patent growth for each technology subcategory, we could have constructed a synthetic Bell based on the assumption of the same patent growth for each USPTO Patent Class, or for each IPC Class or Category. Results are similar. The results for alternative constructions of a synthetic Bell are available from the authors on request.

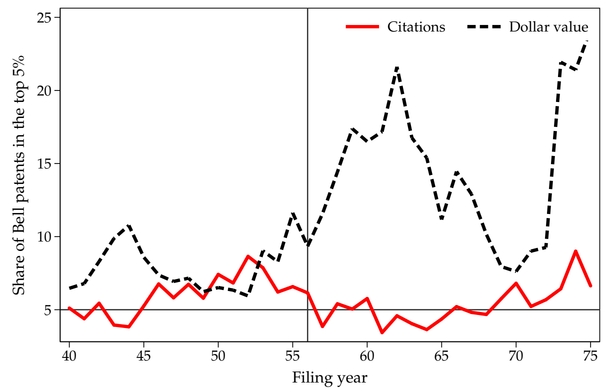
[40] In figure 24 in the Appendix D.A., we compare the patenting output of Bell with other control companies and find that Bell's patent growth is in line - but at the lower end - of similar companies. The only exception is the growth of General Electric which is much larger, highlighting the problem of constructing a counterfactual for a single company.

Figure 9: Innovation and R&D in the Bell System After the Consent Decree

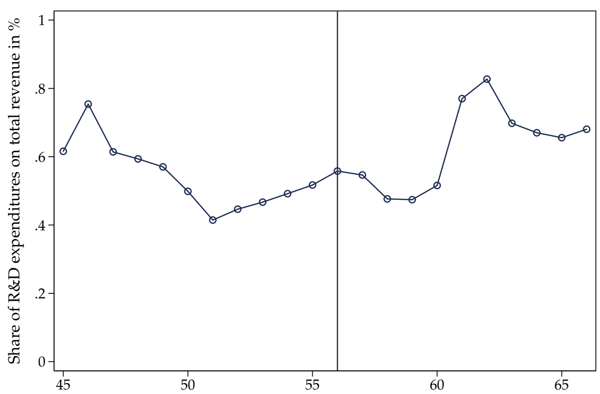
(a) Patenting Over Time: Bell System and Synthetic Bell



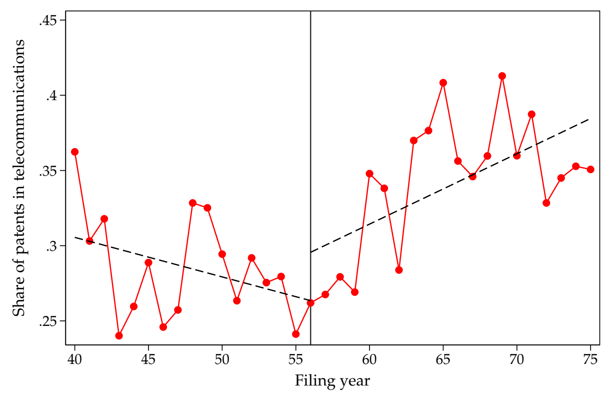

(b) Share of Top Patents




(c) R&D Spending by AT&T




(d) Share of Telecommunications Patents




*Notes:* Panel (a) shows the total number of patents filed by the Bell System compared to a synthetic Bell. To construct the synthetic Bell, we calculate the share Bell's patents had in each NBER technology subcategory relative to all patents of companies that had at least one patent before 1949. We then assume that in the absence of the consent decree, Bell's patenting would have grown in each subcategory at the same pace as the patenting of all other companies. As a consequence, Bell's share in each technology subcategory is held constant. In the last step, we add the number of patents up to a yearly sum. Panel (b) shows the share of Bell patents in the top 5% as defined by citations and as defined by the average dollar value of a patent in the same publication year and technology class derived from the values provided by Kogan et al. (2017). In both cases, we define the 5% cut-off by filing year of the patent and by technology class. The patent data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office. Panel (c) shows the ratio of R&D expenditures relative to total R&D of American Telephone & Telegraph. The data are from the annual reports of AT&T. Panel (d) shows the share of patents related to telecommunications relative to all patents filed by Bell. We classify a patent as a telecommunications-related patent if in its patent class patents have at least a 15% likelihood of being used in the production of telecommunications equipment, using the data of Kerr (2008). In Appendix D.B., we show the change in direction of research using NBER subcategories and most likely SIC industries.

citations. This made it more likely that a Bell patent ended up in the top 5% of the citation distribution. Interpreting the increase in dollar values in this period as causal is also not straightforward, as Kogan et al. (2017) use stock-market values to infer patent values, and the conclusion of the antitrust case might have influenced the value of AT&T on the stock exchange.

Bell's continued investment in research is in line with the incentives the consent decree and the regulators provided. The consent decree did not significantly alter the profitability of new patents. It mandated that Bell could demand "reasonable" licensing fees for all patents published after January 1956. The royalty rates Bell charged for patents published after the consent decree were not much different from the pre-decree royalties (Antitrust Subcommittee, 1959, p.111). The only difference was that Bell could no longer refuse to grant a license.

Bell also had little incentive to reduce investment in R&D because it was subject to a rate of return regulation following the Communications Act of 1934. According to annual reports, AT&T had a stable ratio of R&D to operating revenue of 0.5% from 1949 to 1960 (figure 9c).[41] For the entire Bell System, the share of R&D to total turnover stayed almost constant at 2%-3% from 1966 to 1982 (Noll, 1987). However, the absolute level of R&D effort increased as the Bell System grew. Operating revenues increased from $3.2 billion in 1950 to $5.3 billion in 1955, to $7.3 billion in 1960, and to $11 billion in 1965, while the staff at Bell Labs grew from 6,000 in 1950, to 10,000 in 1955, to 12,000 in 1960, and 15,000 in 1965 (Temin and Galambos, 1987).

While the consent decree offered no reason for Bell to downsize its R&D investment, it offered incentives to redirect its research budget. Before the consent decree, Bell had the option of expanding to other businesses. After the consent decree, Bell's commercial future was restricted to common carrier telecommunications. The company correspondingly refocused its research program on its core business and increased its share of patents in fields related to the production of telecommunications equipment, which had been decreasing in the two decades before (figure 9d).

These results are consistent with the study of Galasso and Schankerman (2018) on patent invalidations. They show that large companies on average do not reduce follow-on innovation significantly if they lose a patent due to litigation. The only exception is if the large company loses a patent outside of its core-fields. Then it reduces innovation in the field of the patent under consideration and reacts by redirecting future innovation to a different but related field.

[41] We do not know whether the consolidated balance sheet also includes the Bell Labs and Western Electric. It seems that at least some parts of the Bell System are not consolidated in the annual reports of AT&T.

## B. Long-Run Impact on Other Companies

The results presented in Section IV. captured only the immediate impact of compulsory licensing, i.e., first-round effects on follow-on innovation citing Bell patents. To assess the overall impact of the consent decree, we need to take into account the cumulative impact of further rounds of effects, due for instance to the market entry of new firms and follow-on innovation building on their innovations.[42] For this purpose, we study the long-run impact on the patent activities of firms patenting in the U.S. To quantify the effect, we compare the increase in the total number of patents in a USPC technology subclass with a compulsorily licensed Bell patent relative to subclasses without a Bell patent. Our sample consists of 200 classes with 2,915 subclasses of which 874 are treated.[43] Within each technology class, we aggregate the subclasses into one treated and one untreated subclass.[44]

In figure 10, we plot the average difference of the total number of patents in treated and untreated subclasses within a class per year. We subtract the average difference in 1949 in each year. In panel (a), we use all 200 patent classes, and in panel (b), we restrict the sample to the 174 patent classes that do not contain a transistor patent. The standard errors are bootstrapped using the patent class as the cluster variable.

In panel (a), the number of patents in technology subclasses where Bell patents were compulsorily licensed increased relative to subclasses without Bell patents starting in 1953, and it continued to do so beyond 1960, even after the last of Bell patents affected by the consent decree expired. The increase in 1953 coincides with the licensing of the transistor patents in 1952, as described in Section V. If we drop all 26 patent classes that have at least one patent that is related to the transistor, the increase is significantly positive for the first time in 1957, and consistently so after 1962. This suggests that the consent decree had a long-lasting positive effect on long-run U.S. innovation.[45]

To quantify the effect, we estimate the average yearly effect of the consent decree on the total number of patent applications for the time period 1949-1970. We employ the following difference-in-differences model:

$$\#Patents_{c,s,t} = \beta \cdot Treat_s \cdot I[1956 - 1970] + YearFE_t + ClassFE_c + \varepsilon_{c,s,t} \tag{2}$$

where the dependent variable $\#Patents_{c,s,t}$ is the number of patents in class $c$, subclass $s$ in year $t$. $Treat_s$ is an indicator function that is equal to one if there is at least one Bell

[42] Holbrook et al. (2000) tells four case studies of companies that build on the transitor patents of Bell.

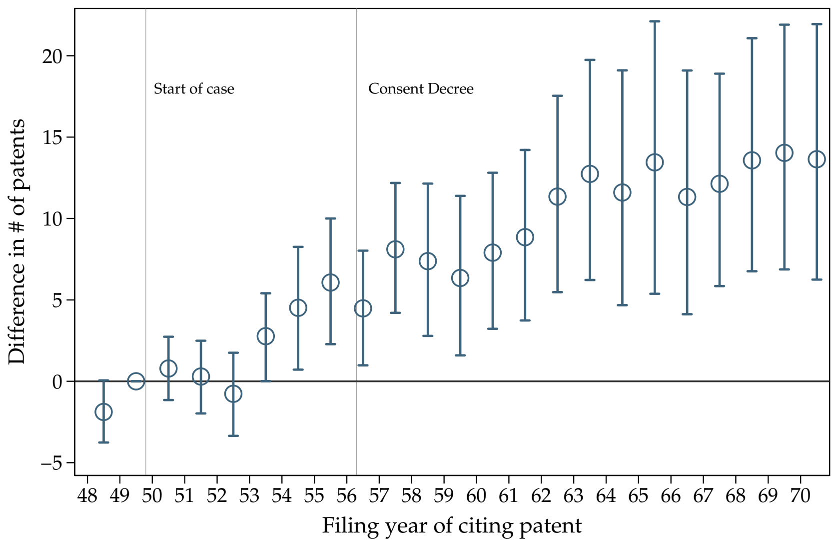
[43] We include only patent classes that contain both treated and control subclasses.

[44] The number of subclasses of the highest level varies between two and 77 across USPC classes. Aggregating these subclasses to two per class gives each class equal weight in the average.

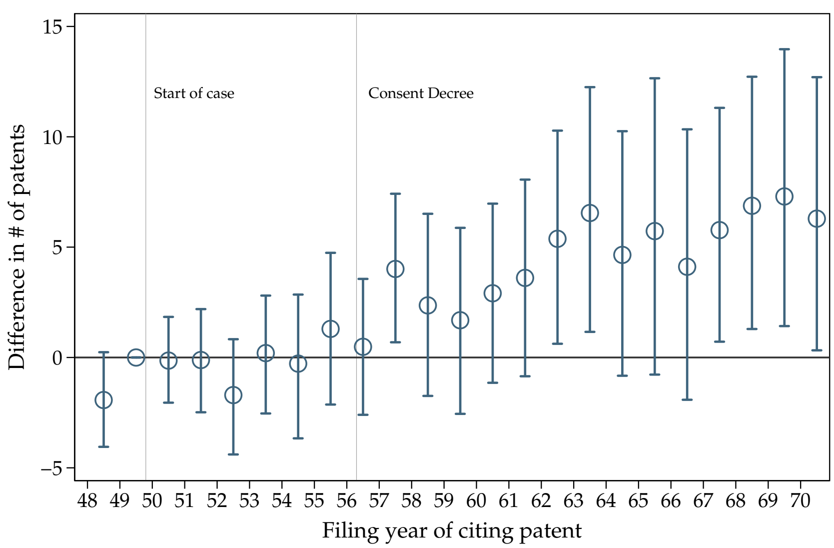
[45] In Appendix D.C. we plot the average number of patents of treatement and control patents for classes with and without transistor patents separately.

Figure 10: Annual Treatment Effects on the Number of Patent Applications

(a) All Patents




(b) Without Transistor Classes




*Notes:* These graphs show the total number of yearly excess patents in subclasses with a compulsorily licensed Bell patent relative to subclasses within the same technology class without compulsorily licensed patent, along with 95% confidence bands. Standard errors are bootstrapped over three-digit technology classes. In panel (a) we use all 200 patent classes while in panel (b) we use only the 174 patent classes that do not contain a patent related to the invention of the transistor. To estimate the average treatment effect for year $t$, $\tau_t$, we use the estimator

$$\hat{\tau}_t = \frac{1}{N} \sum_i (\#Patents^T_{i,t} - \#Patents^C_{i,t})$$

where $\#Patents^T_{c,t}$ is the total number of patents in subclasses of patent class $i$ with at least one compulsorily licensed patent, and $\#Patents^C_{i,t}$ is the total number of patents in subclasses without a compulsorily licensed patent. $N$ is the number of USPC technology classes with at least one treated and one untreated subclass. For these graphs we use patents of other companies, i.e., excluding patents of the Bell System.

patent in subclass $s$, and Post is an indicator function for the years 1956 to 1970. $\beta$ measures the number of excess patents in treated relative to untreated subclasses. All coefficients are reported in table 4.

In column (1), we present results using as dependent variable the number of all patent applications in a subclass, including applications from the Bell System. We find a strong increase in the number of patents even when taking into account the reaction of the Bell System. In columns (2) - (8), the dependent variable captures the number of patent applications from other companies only. Similar to what we have observed for the direct effects on citations reported in Section IV., the increase in patenting is restricted to technologies unrelated to the production of telecommunications equipment (columns 2 and 3).[46] This highlights again that the fields in which Bell continued to operate and dominate experienced relatively slower technological progress than markets where entry of start-ups was possible.

To check to what extent this increase in long-run innovation was driven by Bell's most important invention, the transistor, which had an enormous impact on the computer industry, we repeat our analysis for other fields excluding the transistor-related patents (columns 4-8). While the treatment effect is around 25 percent smaller, it is still highly significant. The effects are again positive and significant for both highly and low concentrated markets (columns 5 and 6). They are mostly driven by young and small assignees (column 7), while the other firms experience no increase in patenting (column 8).

Thus, overall we find that the consent decree led to a long-lasting increase of innovation outside the telecommunications field. This positive effect is consistent with the theoretical argument by Acemoglu and Akcigit (2012) who build on the step-by-step innovation model of Aghion et al. (2001) to analyze the effects of compulsory licensing on innovation. Acemoglu and Akcigit consider the case where all current and future patents in the economy are compulsorily licensed for a positive price and identify two main effects. On the one hand, compulsory licensing helps technological laggards to catch up and brings more industries to a state of intense competition. This "composition effect" increases innovation, because companies in industries with intense competition invest more in R&D in order to become the industry leader. On the other hand, compulsory licensing reduces the time a technology leader keeps its profitable position. This "disincentive effect" reduces the innovation and growth in the economy.

In our case, compulsory licensing was selectively applied to one company that did not participate in any market other than the telecommunications market. This enabled many

[46]We use again the 15% cut-off to classify telecommunications-related technologies. In Appendix D.D. we report the results for a finer classification. In unreported regressions we use citation-weighted patents instead of the absolute number of patents and find the same results. Results are available from the authors upon request.

Table 4: Patent Applications per Subclass and Year by Company Type and Field

| | (1) All | (2) Telecom-munica-tions | (3) Other Fields | (4) Other Fields without Transistor | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | with Bell | All | All | All | High Conc | Low Conc | Young & Small | Oth-ers |
| Treated x I(56-70) | 3.2*** | -0.0 | 3.6*** | 2.9*** | 2.6** | 2.9*** | 2.9*** | -0.0 |
| | (0.5) | (0.5) | (0.5) | (0.4) | (1.0) | (0.4) | (0.3) | (0.2) |
| Constant | 2.7*** | 0.8 | 2.9*** | 3.1*** | 3.6*** | 3.0*** | 0.6*** | 2.5*** |
| | (0.4) | (1.1) | (0.4) | (0.3) | (0.6) | (0.4) | (0.2) | (0.2) |
| with Transistor | Yes | Yes | Yes | No | No | No | No | No |
| N Cluster | 200 | 10 | 190 | 168 | 31 | 137 | 168 | 168 |
| Observations | 64130 | 2464 | 61666 | 53966 | 8448 | 45518 | 53966 | 53966 |

*Notes:* The dependent variable is the total number of patent applications per year that are either in a treated or untreated subclass within a USPC technology class. A subclass is in the treatment group if it contains at least one Bell patent that was subject to compulsory licensing. This treatment variable is interacted with an indicator that is equal to one for the period after 1956 to 1970. The panel includes subclasses that had at least five patent application from 1940 to 1948 and whose classes contain both treated and untreated subclasses. Column (1) shows the baseline estimates. Column (2) restricts the dependent variable to citations from telecommunications-related patents. We classify a citing patent as a telecommunications-related patent if in its patent class patents have at least a 15% likelihood of being used in the production of telecommunications equipment, using the data of Kerr (2008). Column (3) and all remaining columns use the citations from patents from all other fields. Starting with column (4), we additionally 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. Columns (5) and (6) classify patents as belonging to a highly or low concentrated market. For this classication, we use again the concordance of Kerr (2008) that gives us for each patent class and each industry classified by four-digit SIC code a likelihood that a patent in this class is used in this industry. We multiply this likelihood with the 8-firm market share in an industry that we get from the U.S. Census and aggregate the product on the patent class level. In the last step, we classify a patent as being used in a highly concentrated industry if the 8-firm market share is above 60%, which is the 75th percentile. Column (7) uses citations from young and small assignees, i.e., assignees whose first patent was granted less than ten years ago and who had less than ten patents in 1949. Column (8) uses patents from all other assignees. The regressions include class and year fixed effects and standard errors are clustered on the class level. *, **, *** denote statistical significance at the 10%, 5% and 1% level, respectively.

new companies to enter markets with state-of-the-art technology and to compete for the industry leadership with the full patent protection of future inventions intact (Holbrook et al., 2000). Thus, in all industries but the telecommunications industry, we measure the pure composition effect without the counteracting disincentive effect. The interpretation that the consent decree helped to open up new markets and enabled start-ups to compete is consistent with historical accounts of the growth of the electronics and computer industry in the 1950s and 1960s (Grindley and Teece, 1997).

# VII. Conclusion

In this paper, we show that compulsory licensing can be an effective antitrust remedy to foster innovation in highly concentrated markets. But it is ineffective if product markets are foreclosed. Several antitrust scholars have argued that antitrust enforcement should pay special attention to exclusionary practices because of their negative influence on innovation (Baker, 2012; Wu, 2012). Our study seconds this view.

Compulsory licensing is often imposed in merger cases where the market structure changes endogenously (Delrahim, 2004; Sturiale, 2011). We would expect that if the newly merged company is able to foreclose the product market, compulsory licensing is not an effective remedy. More empirical studies are needed to assess whether the negative effect of market foreclosure on innovation is a first order concern for merger and acquisition cases.

For our analysis, we study an important antitrust lawsuit from the 1950s. Using a historical setting has the advantage that we can draw on a large number of detailed historical accounts and that we can conduct a long run evaluation many years after the case. At the same time, it may seem unclear whether the size of the effects of compulsory licensing would be similar today. Jaffe and Lerner (2011) suggest that many negative effects of the patent system discussed today are related to regulatory changes surrounding the establishment of the Court of Appeals for the Federal Circuit in 1982. The reforms led to a significant broadening and strengthening of the rights of patent holders and consequently to a surge in the number of patents granted. This makes us think that the effects of compulsory licensing might be even larger today.

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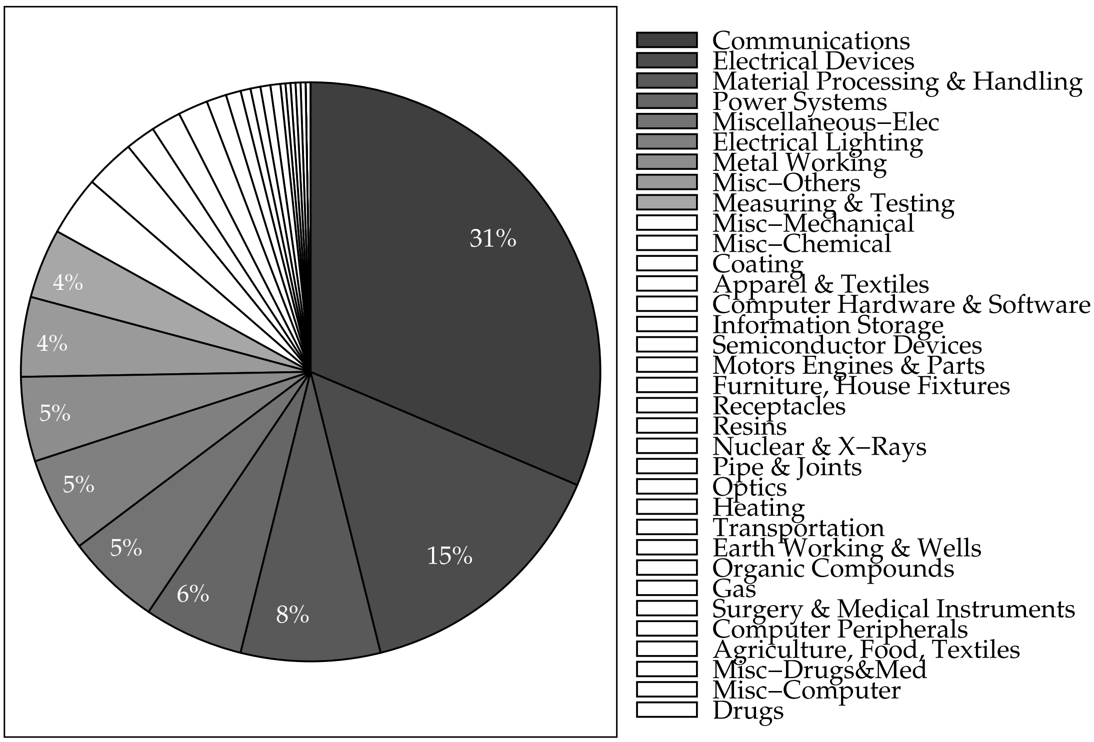
APPENDICES: FOR ONLINE PUBLICATION
(UNLESS REQUESTED OTHERWISE BY REFEREES/EDITOR)

# A Appendix to Section II.

## A. Compulsorily Licensed Patents by NBER Technological Subcategory

Figure 11: Compulsorily Licensed Patents by NBER Technological Subcategory



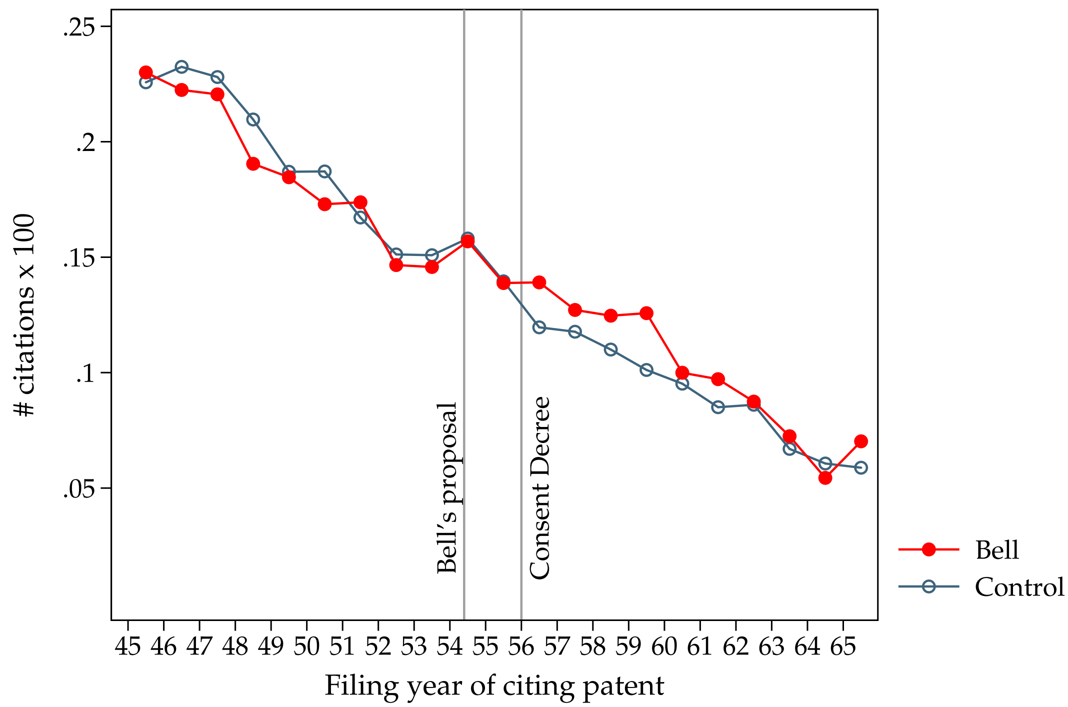

*Notes:* The pie chart shows the distribution of compulsorily licensed patents over 35 NBER technological subcategories. The legend is sorted from largest to smallest share. The categorization in technological subcategories is based on U.S. patent classifications, following Hall, Jaffe, and Trajtenberg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

# B Appendix to Section IV.

## A. Comparing the Average Number of Citations of Treatment and Control Patents

In figure 12, we compare the evolution of patent citations to Bell patents and control patents in the same publication year and the same four digit technology class and with the same number of citations up to 1949. We use the weights proposed of Iacus, King, and Porro (2009) to adjust for the different number of control patents for each Bell patent. From 1949 to 1955, the average numbers of citations of treatment and control patents track each other very closely. This implies that the Bell patents and the control patents exhibit a parallel trend in citations in the first 6 years after the beginning of the lawsuit. The two lines diverge in 1956, with Bell patents receiving relatively more citations than control patents, and they converge again in 1962/1963.

Figure 12: Average Number of Citations to Bell and Control Patents Published before 1949




*Notes:* This figure shows average patent citations of patents published before 1949 in every year after publication. The line with solid circles shows patent citations of the treated patents (Bell patents) and the line with empty circles shows patent citations of control patents, with the same publication year and the same four digit technology class as the Bell patents. For aggregation, we use the weights of Iacus, King, and Porro (2009) to adjust for a different number of control patents for each Bell patent. The data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

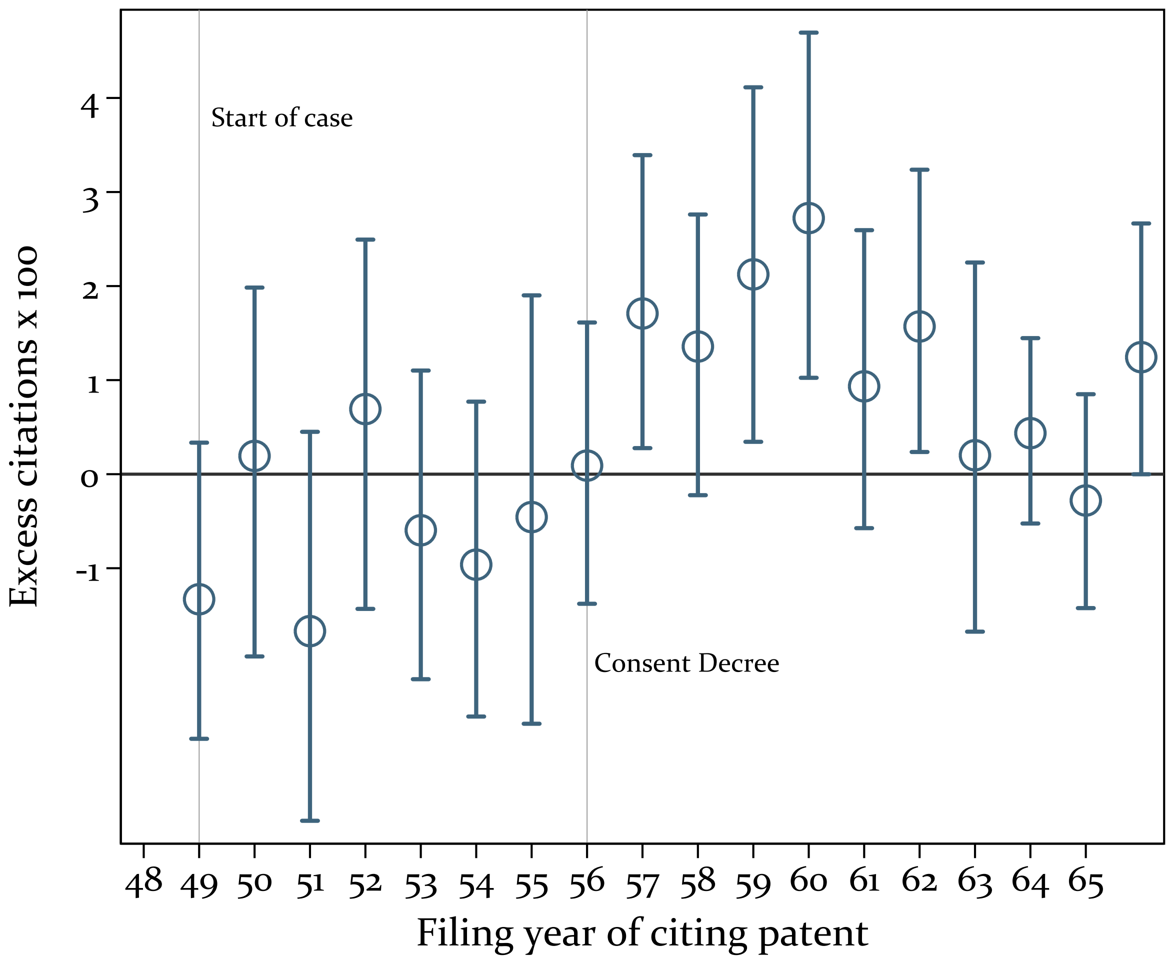
## B. Yearly coefficients

In Figure 13 we repeat our estimation in Figure 4 for each year in the sample. The size of the coefficient is quantitatively the same.

## C. Estimating Average Effects with Time-Varying Coefficients

In Section IV.A. of the paper, we estimate treatment effects non-parametrically with a cell estimator. In this section, we estimate the impact of the compulsory licensing on citations looking at the time period 1945-1970 with a regression framework. We employ the following specification:

Figure 13: Effect of Compulsory Licensing on Subsequent Citations - Yearly




*Notes:* This graph shows the average number of yearly excess citations of patents affected by the consent decree ("Bell patents") relative to their control patents. To estimate the average treatment effect on the treated $\tau_t$, we use the following estimator:

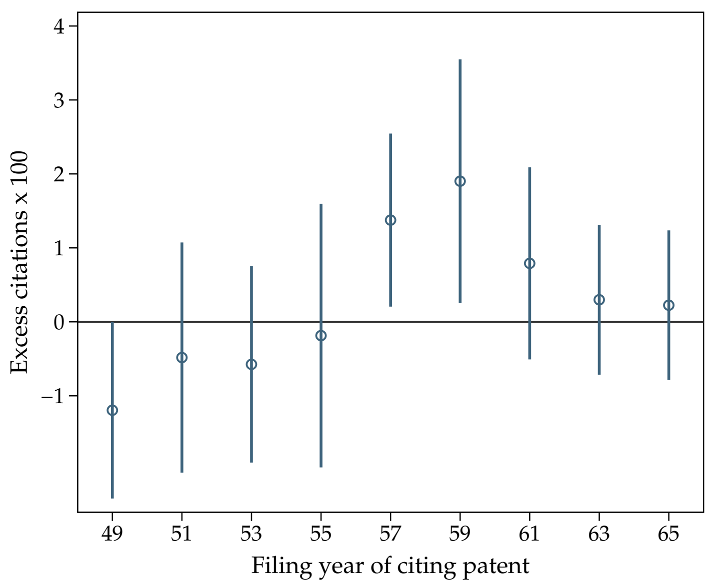
$$\hat{\tau}_t = \frac{1}{N}\sum_i(\#Citation_{i,t} - \overline{\#Citation_{ci,t}})$$

where $\#Citation_{i,t}$ is the average number of citations to Bell patent $i$ in years $t-1$ and $t$. $\overline{\#Citation_{ci,t}}$ is the average number of citations to all control patents assigned to patent $i$ in year $t$. A patent is a control patent for patent $i$ if it has the same three-digit U. S. Patent Classification (USPC) primary class of a patent, the same number of citations up to 1949 and the same publication years. $N$ is the number of Bell patents. We correct for self-citations. The bars represent the 95% confidence bands for the estimated coefficient. Standard errors are bootstrapped over three-digit technology classes. The sample under consideration contains 3,602 Bell patents and 54,405 control patents. There are 169 Bell patents that we cannot match to control patents. The data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

$$\#Citations_{i,t} = \alpha + \sum_{\tau=45}^{70} \beta_\tau \cdot Bell_i + YearFE_t + \varepsilon_{i,t} \tag{3}$$

where $\#Citations_{i,t}$ is the number of follow-on citations of other companies to patent $i$ in year $t$. $Bell_i$ indicates whether the patent i is owned by the Bell System and is therefore treated. We also include fixed effects for each year ($YearFE_t$). The results are reported in figure 14 and they are identical to our main specification.

Figure 14: Effect of Compulsory Licensing on Subsequent Citations



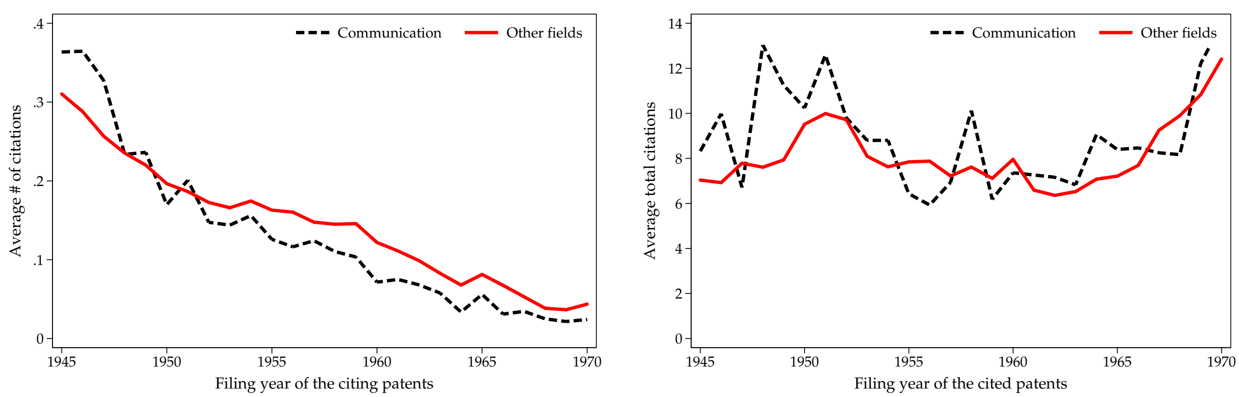

*Notes:* This graph shows the estimated number of yearly excess citations of patents affected by the consent decree ("Bell patents") relative to patents with the same publication year, in the same three-digit U. S. Patent Classification (USPC) primary class and with the same number of citations up to 1949. For these estimates, we regress the number of citations in each year on an indicator variable that is equal to one if the patent under consideration is affected by the consent decree, and year fixed effects (Equation 3). We correct for self-citations. The blue lines represent the 95% confidence bands for the estimated coefficient. 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). The data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

## D. 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 15 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 outside of communication. This speaks against a low quality of compulsorily licensed patents as a reason for the 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 16 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.

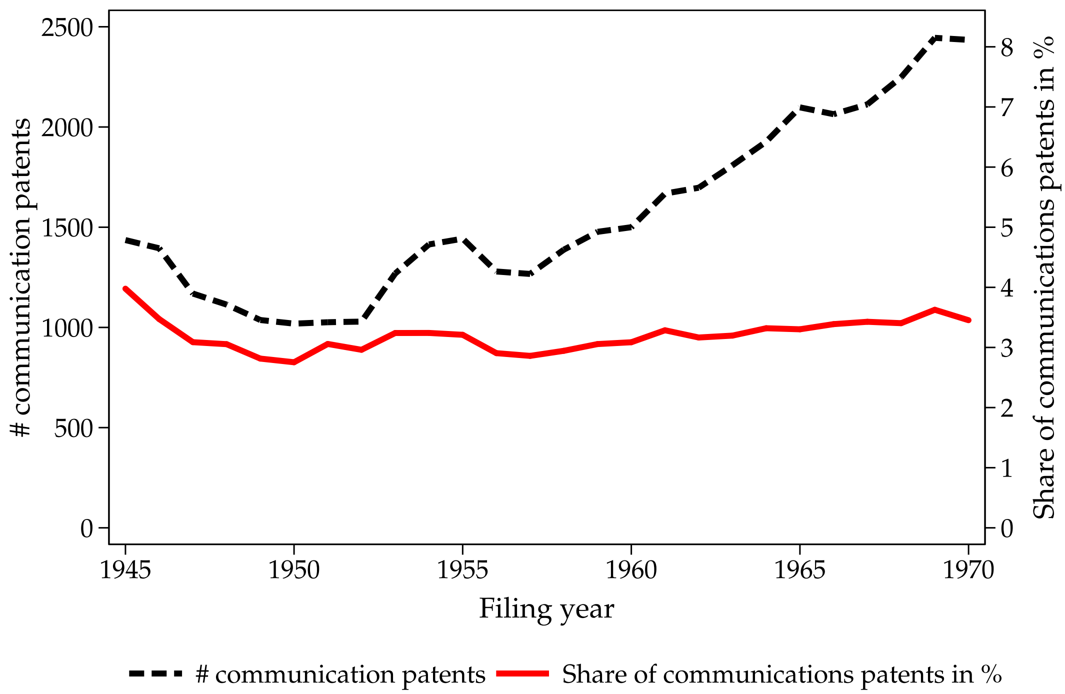
Figure 15: Number of Citations to Bell Patents Inside and Outside of Telecommunications

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




Note: Panel (a) shows the average number of citations per year for all Bell patents 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). 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 data stem from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

Figure 16: Number and Share of Telecommunications Patents



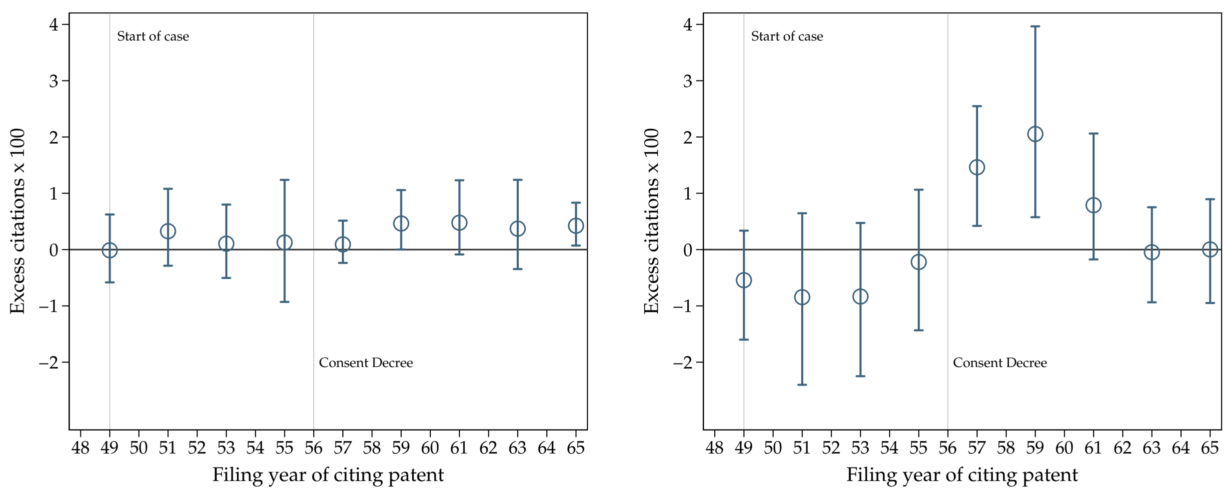

*Note:* This figure shows the total number of telecommunications patents in the U.S. economy (black and dashed line) and the share of telecommunications patents relative to all U.S. patents. We classify a patent as a telecommunications patent if it has a higher than 15% likelihood to be used in the production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

# E. Event-study: Telecommunications vs. Other Fields

Figure 17 shows an event study of citations from telecommunication patents (Panel a) and of citations of patents of other fields (Panel b). We classify a citing patent as a telecommunications-related patent if in its patent class patents have at least a 15% likelihood of being used in the production of telecommunications equipment, using the data of Kerr (2008). We find that the timing of the effect in other fields is the same as in our main results graph in Figure 4. In telecommunications we do find any effect.

Figure 17: Event-study: Telecommunications vs. Other Fields

(a) Telecommunications (b) Other Fields




Note: Panel (a) shows the average number of excess citations from telecommunications patents over a two years period of patents affected by the consent decree ("Bell patents") relative to their control patents. Panel (v) shows the average number of excess citations from patents in other fields over a two years period of patents affected by the consent decree ("Bell patents") relative to their control patents. 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).

# F. Further Results: Telecommunications vs. Other Fields

In this section, we address four potential concerns regarding our results that we do not find any innovation effect of 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 18a. 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 18b 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 18c, 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.

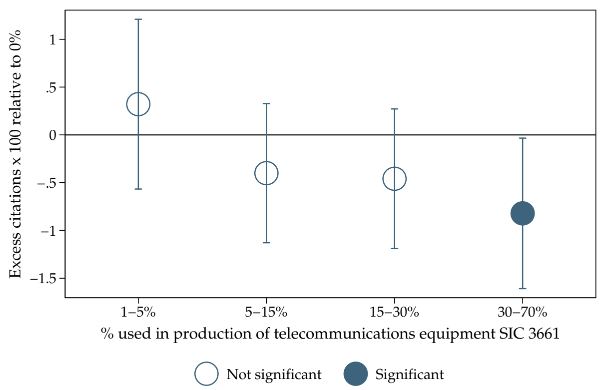
A last concern might be that the continuous measure for closeness to telecommunications might not be adequate. In figure 18d, we estimate our main treatment effect separately for citations of patents in different NBER technology subcategories and plot it against the size of Bell's patent portfolio in 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.

## G. Delineating Telecommunications vs. Other Fields

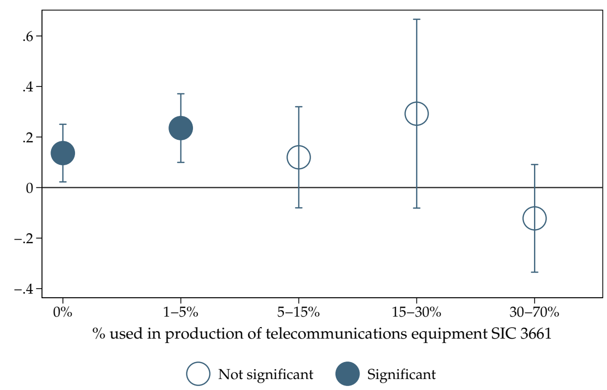
In Section IV.B., we split the sample into telecommunications vs. other fields, using a cut-off value of 15% likelihood that a patent class is used in the production of telecommunications equipment. The cut-off value is not arbitrary, and our results are robust when using other cut-off values. In figure 19, we assign to each 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 18: Excess Citations by Patents with Varying Likelihood of Being used in Production of Telecommunications Equipment

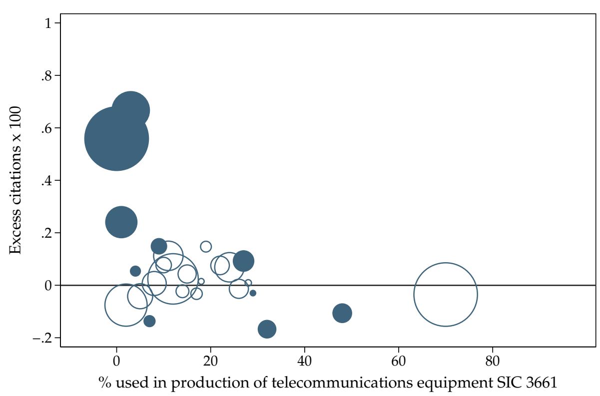
(a) Triple-Difference Relative to 0% Telecommunications



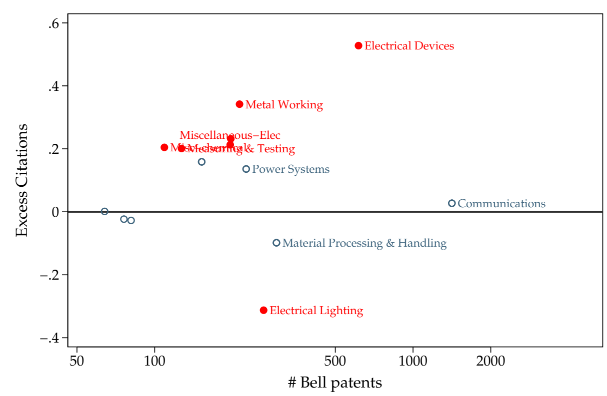

(b) Percent Changes




(c) Individual Levels of Likelihood

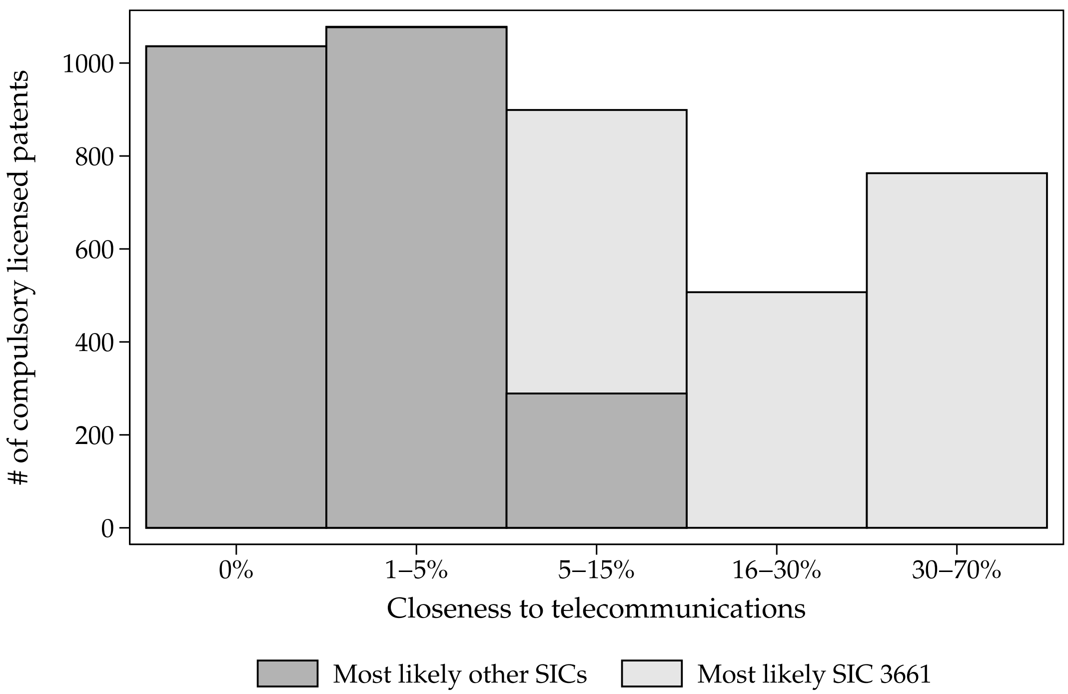



(d) By NBER Classification for Technological Subcategories




*Notes:* This figure shows results from estimating a difference-in-difference 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 data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

Figure 19: Patent Portfolio: Closeness vs. Most Likely Use




*Notes:* The chart shows the distribution of compulsorily licensed patents by the level of closeness to 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).

## H. Quality of Follow-On Innovation was not Significantly Lower after Compulsory Licensing

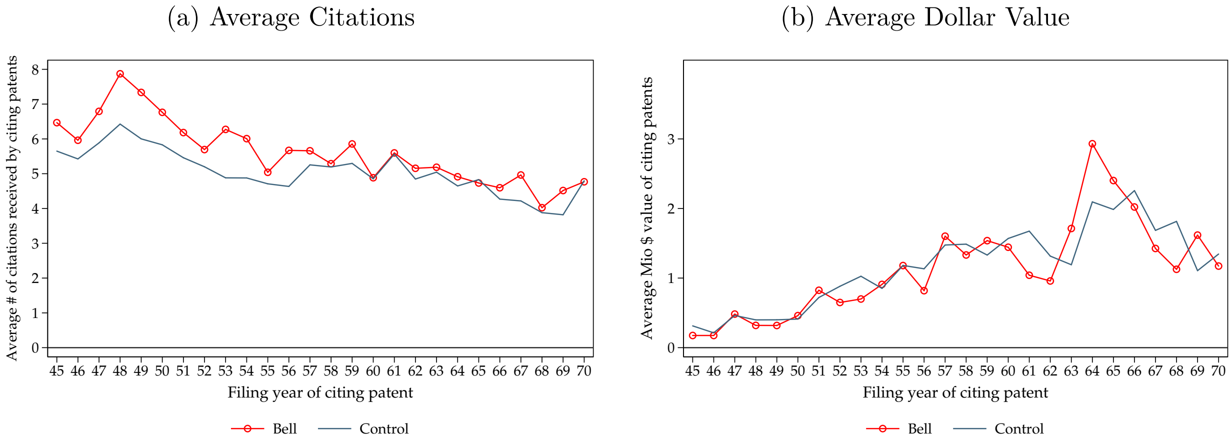
When assessing the overall impact of the consent decree, one concern might be that the innovation induced by compulsory licensing was of lower quality than the quality of follow-on innovation building on Bell patents prior to the consent decree. In figure 20, we measure the quality of the patents citing 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).[47] 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.

## I. Effects for Different Definitions of Young and Small Assignees

In figure 21, 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 21a), and by

[47]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.

Figure 20: Quality of Citing Patents




Notes: 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.

young companies and individual inventors, i.e., assignees that are less than one year old at the time of the citations (figure 21b). The majority of all citations comes from companies and in particular from young and small companies (Figure 21c). 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.

## J. The Break-Up of the Bell System in 1984

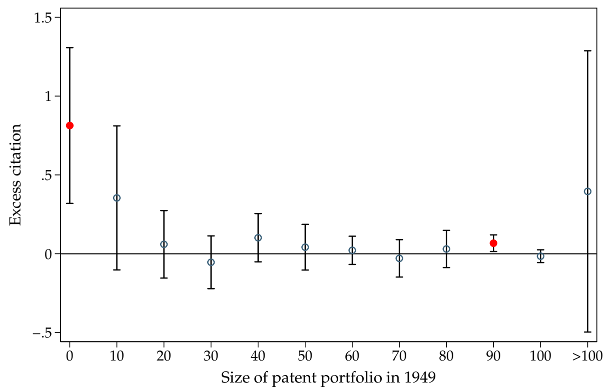
### Historical Background

On November 20, 1974, the Federal Government filed a complaint charging AT&T to have monopolized the telecommunications markets in violation of Section 2 of the Sherman Act. The suggested remedy was the break-up of the Bell System. There were four main accusations. According to these, first, Bell had prevented the interconnection of long-distance service providers with the Bell telephone system. Second, the Operating Companies had bought their equipment from Western Electric even when cheaper equipment was available from other companies. Third, Bell had cross-subsidized Western Electric with the monopoly profits of the operating companies. Fourth, Bell had given Western Electric earlier access to technical information and standards, so that Western Electric had more time for development than competitors.

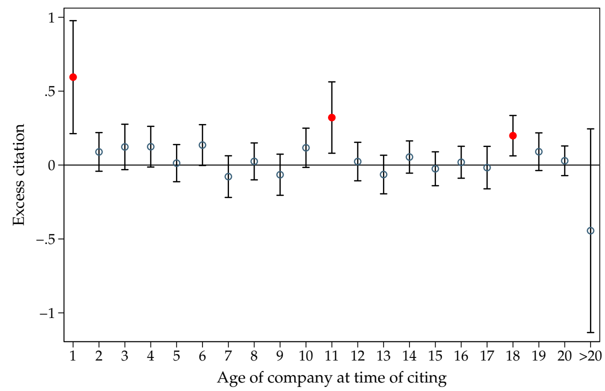
After a seven-year long battle, AT&T and the U.S. Department of Justice signed the Modified Final Judgment, the 1982 Consent Decree on January 8, 1982. As a consequence, the Bell Operating Companies were separated from the Bell System and reorganized into seven Bell Regional Operating Companies (Baby Bells). The Baby Bells had to provide equal access to the local telephone network to all long-distance providers and were banned

Figure 21: Sample Split by Characteristics of Citing Firm

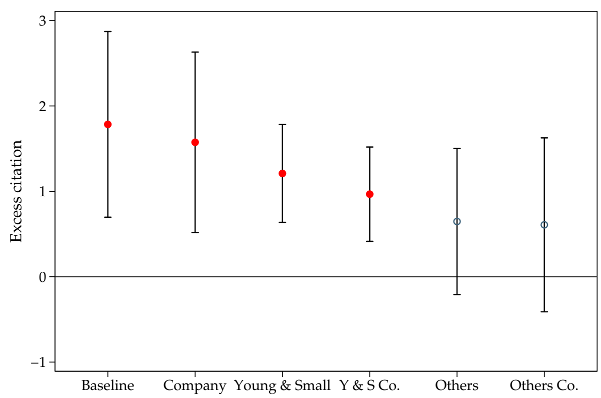
(a) By Size of Patent Portfolio in 1949




(b) By Age of Company at Citation




(c) By Company Type




*Notes:* 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. The data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

from the manufacturing of telecommunications equipment. In exchange, the consent decree of 1956 and all entailing restrictions were declared null and void. The implementation of the 1982 consent decree led to the largest corporate re-organization in history. It was completed on January 1st, 1984.

**Empirical Model and Identification**

To examine if the break-up of the Bell System influenced follow-on innovation we use data for 3,582 patents of the Bell Labs published in the years from 1967 to 1973. As the break-up of Bell affected the entire telecommunications sector, it potentially influenced follow-on innovation to every patent in the economy. Thus, we cannot identify a set of untreated patents as a control group.

To estimate the effect of the restructuring of the telecommunications sector on follow-on innovation we use a different approach. We compare for every year and for every patent the number of citations this patent receives from patents related to telecommunications with the number of citations this patent receives from patents in other fields:

$$\hat{\tau}_t = \frac{1}{N}\sum_i (\#Citation_{i,t}^{Telco} - \#Citation_{i,t}^{Others}). \tag{4}$$

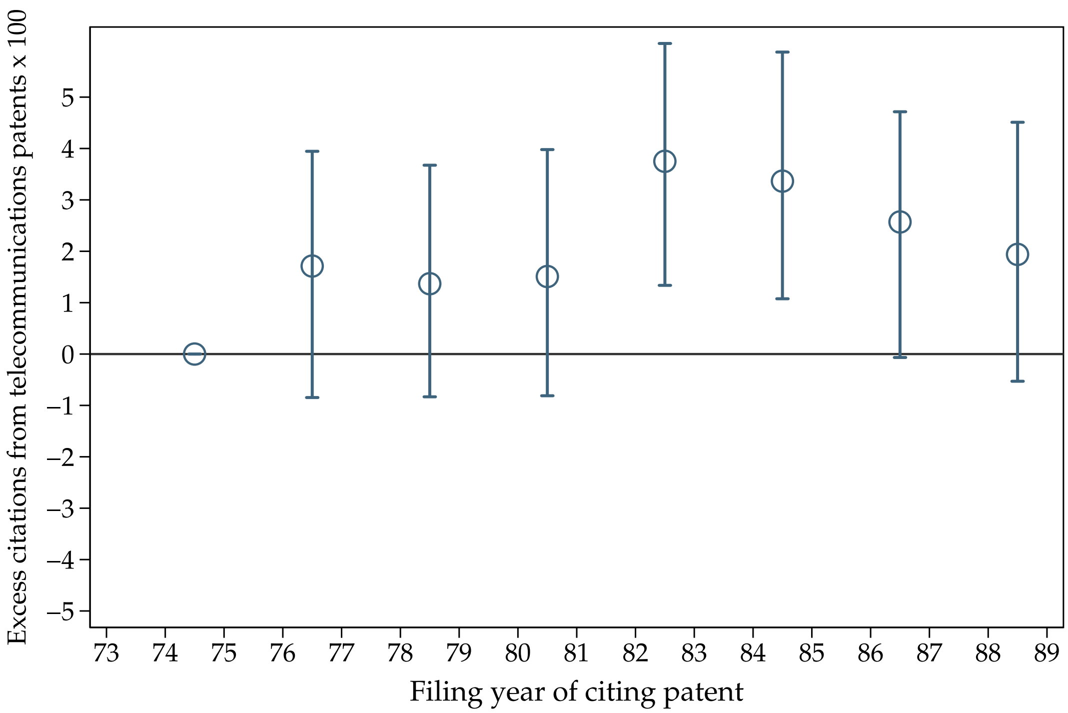
$\#Citation_{i,t}^{Telco}$ is the number of citations from patents that have a more than 10% likelihood of being used in the production of telecommunications equipment.[48] $\#Citation_{i,t}^{Others}$ is the total number of citations from patents in other fields.

The sequence of estimates $\hat{\tau}_t$ for all $t$, shows how the direction of research changed after restructuring under the condition that the trend of citations inside and outside of telecommunications would have been the same in the absence of the break-up. If in addition the number of citations outside of telecommunications, $\#Citation_{i,t}^{Others}$, was unaffected by the break-up of Bell, this estimate also measures the increase or decrease in the number of follow-on inventions in telecommunications.

**Results**

In figure 22, we show the results from estimating Equation 4 for all years after the start of the lawsuit in November 1974. We normalize all differences by the difference in 1973 to highlight the changes after the beginning of the antitrust case. From 1974 to 1980, the direction of follow-on research is stable, i.e. the number the citations in telecommunications relative to other fields does not change on average. Beginning in 1982, there are 0.03 more citations from telecommunications patents than from patents in other fields. This suggests that the direction of U.S. innovation changed to telecommunications after the break-up of the Bell System.

Figure 22: The Break-Up of Bell and Follow-On Innovation




*Notes:* This figure shows the average yearly difference between the number of citations from telecommunications patents and the number of citations from other fields, along with 95% confidence intervals. The differences are normalized by the average difference in citations in 1973. We use 3,582 patents of the Bell Labs published between 1967 and 1973.

Table 5: Auxiliary Regressions

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | | Pseudo Treatment | | | Diff. Control Group | | |
| | Baseline | B-2 Comp. | Control: Same USPC diff IPC | Control: Same IPC diff USPC | Control: Same IPC diff 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) |
| Constant | 16.4*** | 19.4*** | 12.8*** | 14.5*** | 18.2*** | 16.1*** | 16.9*** |
| | (1.0) | (0.8) | (0.5) | (0.5) | (0.9) | (0.8) | (0.7) |
| # treated | 3602 | 6538 | 33506 | 37966 | 3660 | 3565 | 3721 |
| Clusters | 207 | 152 | 191 | 214 | 217 | 216 | 211 |
| Obs. | 659137 | 659421 | 574709 | 645216 | 247664 | 400028 | 895445 |

*Notes:* 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. The 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.

## K. 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.[49] To see if 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 5, 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 5, 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 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.

## L. Effects are Robust to Different Matching Strategies

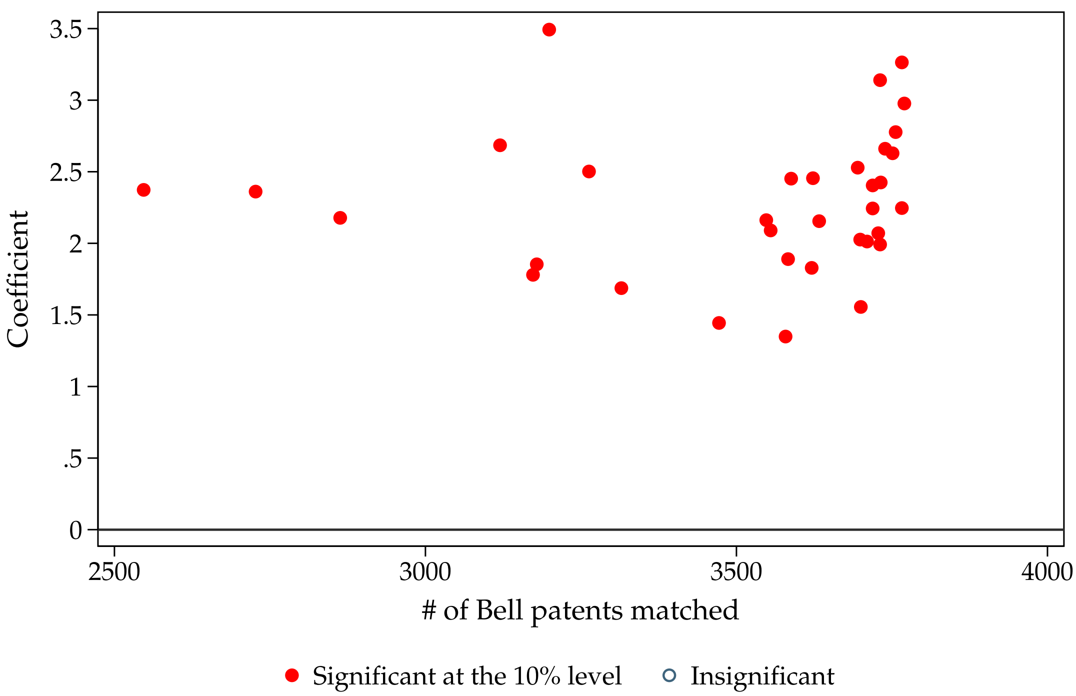
In columns (5) - (7) of Table 5 and in figure 23, we report results from using several alternative matching variables. In the main specification, we use the age (measured by the publication year), the technology (measured by USPC class) and the quality of a patent (measured by the number of citations 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.[50] In all three cases the size of the effects is similar to the one in the main specification. In figure 23, 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.

[48] We use a 10% cut-off instead of 15% because this equalizes the pre-citations from patents in telecommunications and from patents in other fields.

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

[50] 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 23: Treatment Effects for Different Matching Variables




*Notes:* 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. The data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

## C Appendix to Section V.

In table 6, we report the results from repeating our baseline regression for the transistor patents published up to 1951. The treatment period is now defined to start in 1953 and to last until the expiration of the patent. We find that yearly excess citations to the transistor patents increase by more than 100% (column 1).[51] We find no positive effect on excess citations for transistor patents closely related to the telecommunications industry (column 2) and also not for young and small assignees (column 3). In fields outside telecommunications instead, the effect is large and statistically significant (column 4), and particularly so for young and small assignees where the relative effect exceeds 150% (column 5) .

[51]The large magnitude of the effect should not be taken at face value. The identifying assumption of this regression is that the control patents would have had the same number of citations as the transistor patents. In our regression, this is true for 1952, but given the exceptional nature of the invention of the transistor, it is fair to assume that this trend might have diverged in later years. Furthermore, it is not absolutely clear from the historical records why Bell decided to license the transistor patents. If the licensing decision was taken because of the expectation of important follow-on research, our estimate might give an upper bound on the effect. For example, Jack Morton, the leader of Bell Labs effort to produce transistors at scale, advocated the sharing of the transistor to benefit from advances made elsewhere. Source: http://www.computerhistory.org/siliconengine/bell-labs-licenses-transistor-technology/ (last accessed July 4, 2018).

Table 6: The Transistor Subsample

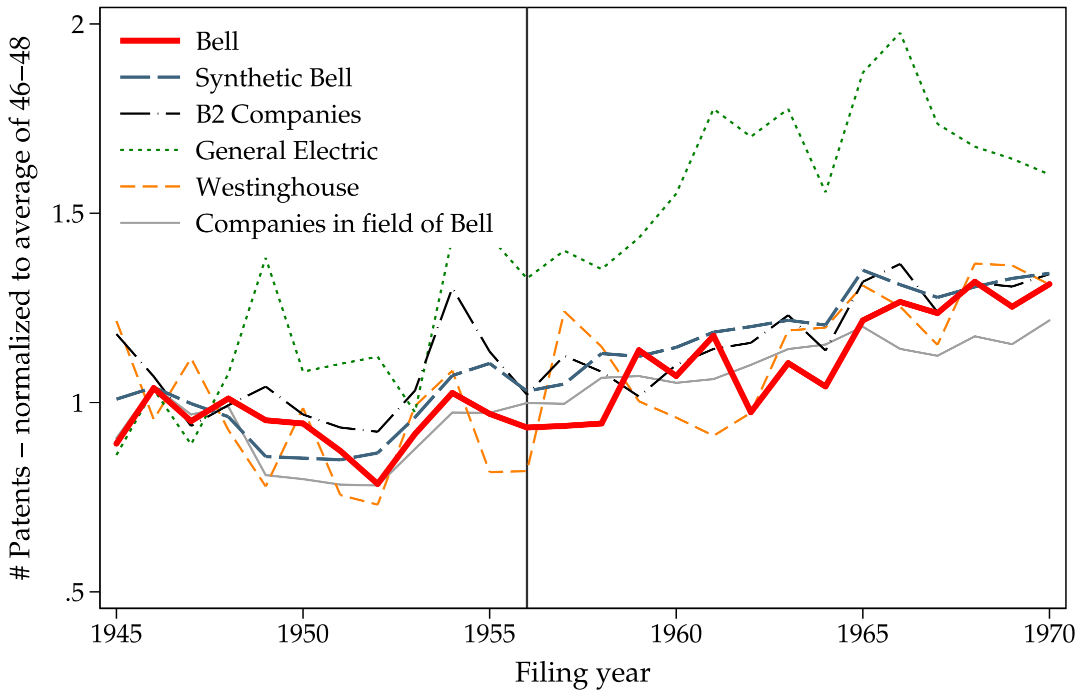
| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | | Telecommunications | | Other Fields | |
| | All | All | Young & Small | All | Young & Small |
| Bell | 0.5 | 3.8 | 0.2 | -3.4 | -1.4 |
| | (2.6) | (2.5) | (0.6) | (3.4) | (1.1) |
| Post | -1.2 | 0.8 | 1.2 | -1.9 | 1.6** |
| | (4.3) | (2.5) | (1.0) | (2.6) | (0.7) |
| Bell x Post | 21.1*** | 0.3 | -0.4 | 20.7*** | 6.2* |
| | (5.6) | (1.8) | (0.7) | (5.3) | (3.0) |
| Constant | 20.2*** | 4.3* | 0.7 | 16.0*** | 3.7*** |
| | (4.4) | (2.1) | (0.5) | (3.2) | (0.8) |
| # treated | 64 | 64 | 64 | 64 | 64 |
| Clusters | 28 | 28 | 28 | 28 | 28 |
| Obs. | 25736 | 25736 | 25736 | 25736 | 25736 |

Note: This table shows the results from difference-in-differences estimations with transistor patents. As the dependent variable, we use all citations by companies other than the filing company. We define the treatment period as starting in 1953. Bell is an indicator variable equal to one if a patent is affected by the consent decree. 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. We classify a patent as a transistor patent if it was filed by a member of the original transistor team. We use all patents with a publication year before 1952 and we match all citations up to and including 1951. Column (1) shows our baseline specification using this sample. Columns (2) and (3) use citations from patents closely related to the telecommunications industry. We classifiy a citing patent as a telecommunications-related patent if in its patent class patents have at least a 15% likelihood of being used in the production of telecommunications equipment, according to the data of Kerr (2008). Columns (4) and (5) use citations from patents from all other fields. Columns (3) and (5) use citations from assignees that are young and small, defined as having applied for their first patent no more than ten years ago and having less than ten patents overall. 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.

# D Appendix to Section VI.

## A. Patenting Behavior of Bell Relative to Comparable Companies

Figure 24: Patenting of Bell System and B-2 Companies without RCA

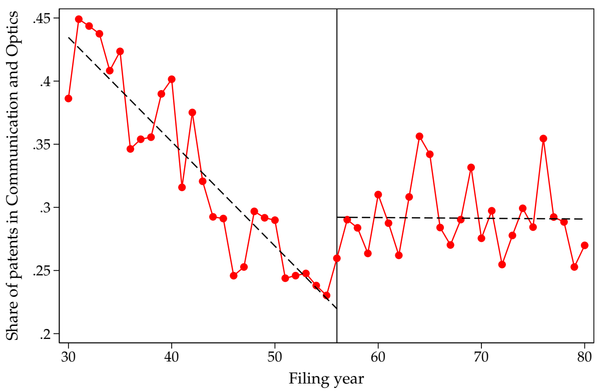



*Notes:* In this figure we compare Bell's total patenting to a synthetic Bell, the number of patents filed by the B-2 companies (General Electric, Westinghouse, RCA and ITT), General Electric and Westinghouse separately and all companies that existed before 1949 and had at least 100 patents in any field 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 data are from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office.

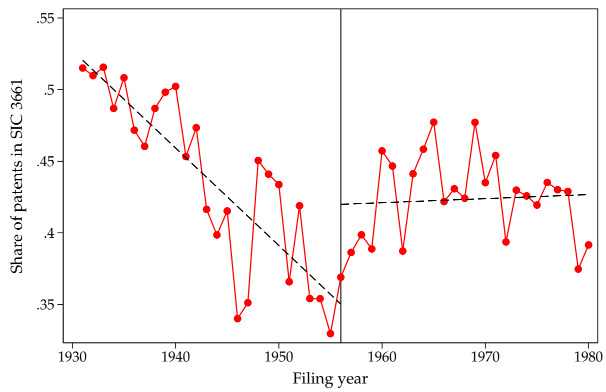
## B. Redirection of Bell Research: Share of Telecommunications Patents

Figure 25: Share of Telecommunications Patents

(a) By NBER Subcategory



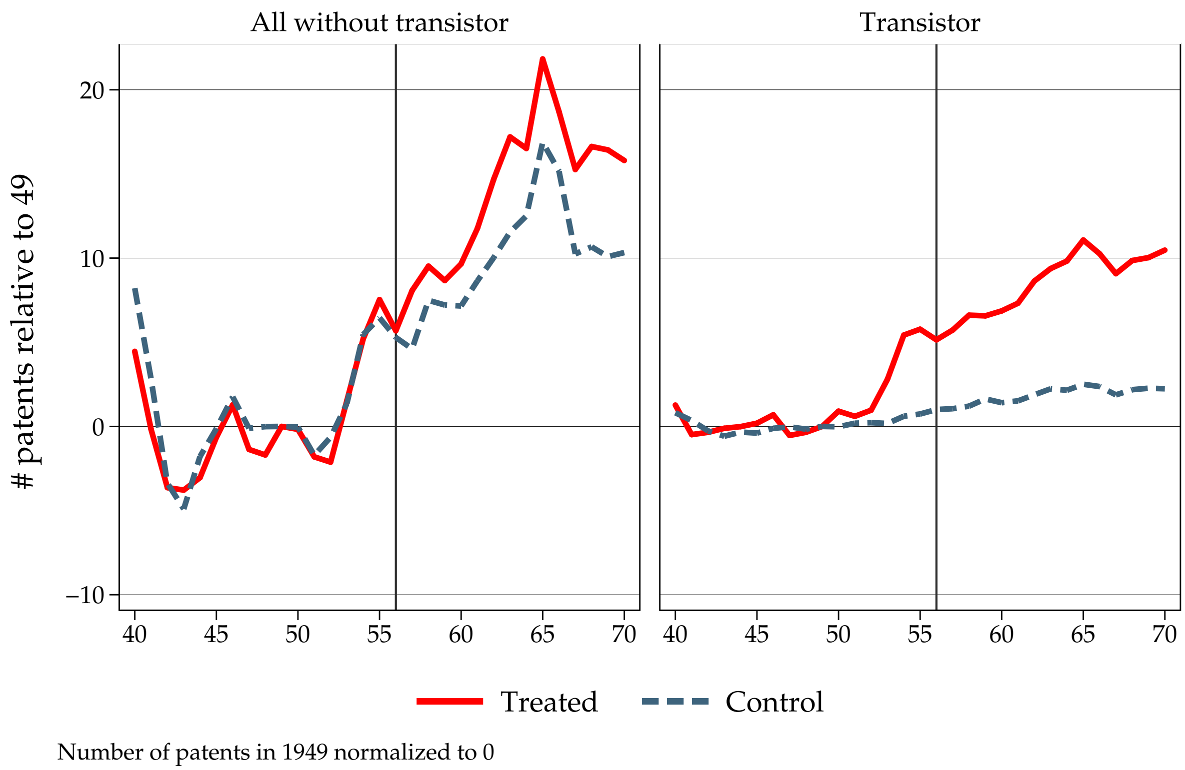

(b) By Most Likely SIC




*Notes:* 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) to assign SIC codes to patents.

## C. Change in Total Number of Patents - Averages

Figure 26: Average Change in Number of Patents Relative to 1949

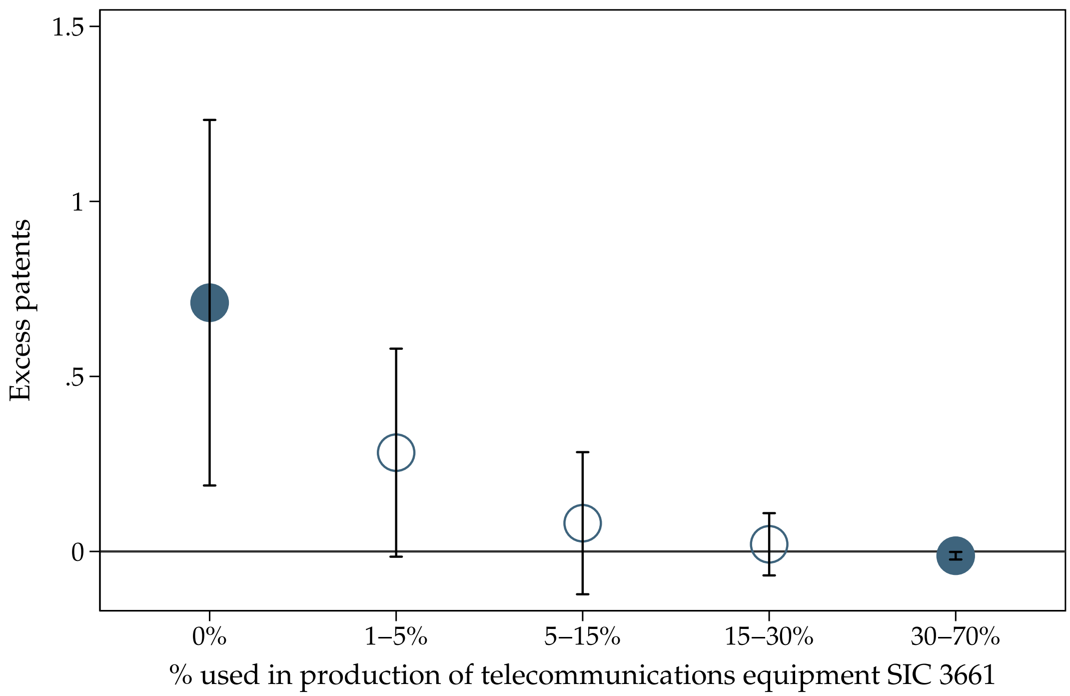



*Notes:* This figure shows the average change in the number of patents in subclasses with a compulsorily licensed Bell patent (red solid lines - "Treated") and without a compulsorily licensed patent (blue dashed lines - "Control") relative to 1949. In the left part of the figure, we use all 174 patent classes without any transistor patent, and in the right part of the figure, we use only the 26 patent classes with a transistor patent.

## D. Increase in Total Number of Patents: Telecommunications vs Other fields

In figure 27, we estimate the number of excess patents for different levels of closeness to telecommunications following the approach employed in Subsection B.. We find that the total number of patents increases most in fields with 0% closeness, i.e., no connection to telecommunications.

Figure 27: Excess # of Patents with Varying Likelihood of Being used in the Production of Telecommunications Equipment




*Notes:* This figure shows results from a difference-in-differences estimation following the empirical model in Equation 2 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). A solid circle implies that the coefficient is significant at the 5% level. The regressions include year fixed effects and standard errors are clustered on the class level.