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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 that 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 identify the effect of the consent decree on follow-on innovations building on Bell patents by using exactly matched non-Bell patents as control group. We show that the consent decree led to a lasting increase in innovation but only in markets outside the telecommunications sector. (*JEL* D45, K21, L12, L24, L63, O31, O34)

With market concentration on the rise in many industries, there is a growing concern that this could lead to a slowdown in innovation activity.[1] One frequently voiced worry is that dominant incumbents will strategically use their patent portfolio to foreclose the market by denying potential market entrants access to key technologies.[2] Since innovation typically builds on earlier patented inventions, such anticompetitive behavior could stifle technological progress and

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[1] See, among others, Derek Thompson, "America's Monopoly Problem," *The Atlantic*, October 2016; Robert B. Reich, "Big Tech Has Become Way Too Powerful," *The New York Times*, September 18, 2015, SR3; Thomas Catan, "When Patent, Antitrust Worlds Collide," *Wall Street Journal*, November 14, 2011.

[2] See, among others, "Patents Should Spur Bursts of Innovation; Instead, They Are Used to Lock In Incumbents' Advantages." *The Economist*, August 8, 2015; "The Patent, Used as a Sword." *The New York Times*, October 7, 2012.

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 this instrument is indeed effective in promoting innovation in an antitrust context.

In this paper, we analyze compulsory licensing as an antitrust remedy and provide causal evidence on its effect on innovation. More specifically, we study the effects of royalty-free compulsory licensing in the context of the 1956 consent decree against the Bell System, one of the most important antitrust rulings in US history. Although the paramount significance of this ruling for the development of the US economy after 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 US innovation. We examine both direct effects on follow-on innovation, measured by patent citations, as well as the overall effects on US innovation, measured by the number of patents. Furthermore, we study how this ruling affected the subsequent innovation efforts of Bell, the holder of the patents subject to this antitrust remedy.

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 United States, because it allegedly monopolized “the manufacture, distribution, and sale of telephones, telephone apparatus and equipment” (Antitrust Subcommittee 1958, 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 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 percent of all unexpired US 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 pathbreaking innovations in telecommunications, such as the cellular telephone technology and the first transatlantic telephone cable. But more than half of its patents were not related to telecommunications, because of Bell’s commitment to basic science and 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 setup 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 to antitrust, including settings where patents may have been used in combination with other exclusionary practices. This is possible because Bell's broad patent portfolio was compulsorily licensed in its entirety. Note that 43 percent of Bell's patents were related to the telecommunications industry, where Bell was a de facto vertically integrated monopolist that allegedly foreclosed rivals by denying access to its technology and its customers. The remaining 57 percent had their main application in industries outside of telecommunications, where Bell was not an active market participant and the consent decree ruled out that it would ever become one.

To estimate the effect of the royalty-free compulsory licensing of patents on follow-on innovation, we use two complementary empirical strategies. In our main specification, we measure follow-on innovations building on Bell patents by using 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. To identify the effect of the consent decree on the number of follow-on innovations building on Bell patents, we use as a control group exactly matched non-Bell patents with the same filing year, the same technology class, and the same number of citations up to the start of the case in 1949. As a complementary approach to our main specification, we investigate the impact of the consent decree on the number of patents. More specifically, we compare within each technology class the change in the total number of patents in technology subclasses with compulsorily licensed Bell patents to the change in the total number of patents in subclasses without them before and after the consent decree.

Our analysis shows that royalty-free compulsory licensing can increase follow-on innovation. We find that in the first five years, follow-on innovation measured by patent citations increased by around 12 percent per year relative to the mean. But the effects are very heterogeneous across industries. In telecommunications, there are no significant effects on follow-on innovation, even though this was the explicit aim of the regulatory intervention. A subsequent congressional commission of the Antitrust Subcommittee blamed the lack of effect of the consent decree in the telecommunications market on the fact that Bell continued to use exclusionary practices after the consent decree took effect (Wu 2012, Antitrust Subcommittee 1959). In fields unrelated to the telecommunications industry, the effects are positive—even in highly concentrated markets—with follow-on innovation increasing by 15 percent. Sixty percent 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).

Complementary to the direct effects on follow-on innovations measured by patent citations, we show that the consent decree had a substantial positive effect on US innovation, increasing the overall number of patents in technology classes with compulsorily licensed Bell 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.

A full assessment of the consent decree requires understanding its effect on innovation by Bell itself, which at the time was the powerhouse of US innovation. We find that the increase in innovation outside of Bell is only partially offset by a small decrease in patenting by Bell. The quality of Bell's patents seems 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.

Our paper contributes to the literature on antitrust and innovation by providing the first empirical assessment of the overall causal innovation effect of royalty-free 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 the licensees.[3] We provide evidence on the effect of royalty-free compulsory licensing both on the potential licensees and the patent holder subject to the antitrust remedy. Acemoglu and Akcigit (2012) argues theoretically that 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 illustrate the relevance of both of these theoretical arguments. The Bell case shows that by providing free state-of-the-art technology to all US companies, including a large number of entrants, free compulsory licensing increased US innovation and fostered the growth of new markets. But it did not do so in the telecommunications market, where, according to historical accounts, access to customers continued to be foreclosed by exclusionary practices. Thus, access to technology is necessary but may not be sufficient to stimulate innovation.

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) studies the innovation effect of patent invalidation and finds an average increase of 50 percent.[6] Sampat and Williams (2019) studies whether the granting of a gene patent reduces follow-on innovation and finds 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 percent in biotech and chemistry. We find that the impact of free compulsory licensing depends on the specifics of the case. This suggests that

[3] For example, Tandon (1982) 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. It 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 The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreements between developed and developing countries.

[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, free compulsory licensing was selectively applied to only one company that was not active in the newly created industries. This suggests that there was no disincentive effect and that our empirical setup 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.

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 the number of innovations by fostering market entry. These second-round effects should be taken into account when designing intellectual property rights policies. Policymakers should pay special attention to the effects of intellectual property on entrepreneurship, as market entry appears to be the most important margin to increase innovation.[7]

Finally, we contribute to the literature on the history of US innovation with the first 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 post-World War II US innovation because it spurred the creation of whole industries. Gordon Moore, the cofounder 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 2001, 86)

Similarly, Peter Grindley and David Teece opined that "[AT&T's licensing policy shaped by antitrust policy] remains as one of the most unheralded contributions to economic development—possibly far exceeding the Marshall Plan in terms of the wealth generation capability it established abroad and in the United States" (Grindley and Teece 1997, 13). Our empirical findings substantiate this narrative for the fields outside the telecommunications sector. In the telecommunications sector, despite the 1956 consent decree, innovations by competitors continued to be impeded, possibly by Bell's dominant position and its use of exclusionary practices, until the eventual break up of Bell in 1984. But in all other fields, the consent decree did have a large positive causal impact on innovation.

The remainder of this paper is organized as follows. Section I describes the antitrust lawsuit against Bell and the consent decree. In Section II, we describe our empirical strategy and the data. In Section III, we show that free compulsory licensing increased follow-on innovation as measured by patent citations, and we analyze the heterogeneity of these effects. We then present the effects of the consent decree on US patenting in Section IV. Section V studies the impact of the consent decree on

[7] In line with this, Reimers (2019) shows that copyright protection decreases the availability of different editions per book title.

Bell's subsequent innovation activities. Section VI discusses our results and relates them to the interpretation of the case discussed at the time. Section VII concludes.

I. 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.[8]

A. *The Bell System*

In 1956, American Telephone and Telegraph (AT&T) was the dominant provider of telecommunications services in the United States. Through its operating companies, it owned or controlled 98 percent of all the facilities providing long-distance telephone services and 85 percent of all facilities providing short-distance telephone services. These operating companies bought more than 90 percent 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 1956, AT&T was by far the largest private corporation in the world in terms of assets. Together with all companies in the Bell System, AT&T employed 746,000 people, with a total revenue of $5.3 billion, or 1.9 percent of the US GDP (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. Around 70 percent 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 (Nelson 1962, Rosenberg 1990). As a result, the Bell System decided that—besides supporting the day-to-day needs—the Bell Labs would engage in basic science, expecting it would eventually yield products for some part of the large Bell System (Nelson 1959; Gertner 2012; Arora, Belenzon, and Patacconi 2017).[9] The Bell Labs produced pathbreaking basic and applied research. Scientists at Bell are, for example, 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

[8] More details on the Bell System and the antitrust lawsuit may be found in online Appendix A1.

[9] According to Harold Arnold, the first head of basic and applied research at Bell Labs, the department would include "the fields 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 of meteorology" (Gertner 2012). 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 Federal Communications Commission in 1934 reported that Bell owned or controlled 9,255 patents but actively used only 4,225 patent covered inventions (Antitrust Subcommittee 1958, 3842).

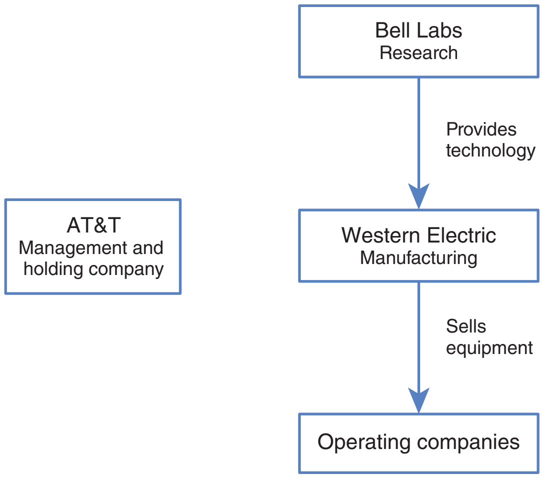

Figure 1. The Structure of the Bell System

Laureates in physics, one Turing Award winner, five future US National Medals of Science recipients, and ten future Institute of Electrical and Electronics Engineers Medals of Honor recipients.

B. *The Antitrust Lawsuit*

On January 14, 1949, the United States Government filed an antitrust lawsuit with the aim to split Western Electric from AT&T.[10] 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, 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.[11]

The government sought three main remedies. First, Western Electric was to be separated from AT&T, be split into three competing companies, and 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

[10] 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).

[11] For example, Bell allegedly forced competitors "engaged in the rendition of telephone service to acquire AT&T patent licenses 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, 3838–41).

to be forced to license all its patents for reasonable and nondiscriminatory royalties (Antitrust Subcommittee 1959, 33).[12]

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 January 1953, after Dwight D. Eisenhower took office, Bell began to lobby for the dismissal of the case, arguing that the Bell System was too important for national defense and thus should be kept intact. The government followed this argument, and Attorney General Herbert Brownell Jr. asked Bell to submit concessions with "no real injury" that would be acceptable to settle the lawsuit (Antitrust Subcommittee 1959, 55). In May 1954, AT&T presented and in June 1954 submitted to the Department of Justice a list 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, which was supported by the Secretary of Defense (Antitrust Subcommittee 1959).

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

C. *Advantages of the Bell Case for the Empirical Setup*

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 free 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, 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 free compulsory licensing as an antitrust remedy in different competitive settings. In the telecommunications industry, Bell

[12] 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.

was 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. Understanding this interplay of intellectual property rights and competitive conditions is a first-order concern for the assessment of the use of compulsory licensing in antitrust cases, a topic that has so far received no attention in the literature.

To visualize the broad patent portfolio of Bell, we use the data of Kerr (2008) and of Acemoglu, Akcigit, and Kerr (2015) to assign the most likely four-digit SIC industry group to each USPC class (Figure 2).[13] Around 43 percent 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.[14]

II. Estimation Frameworks and Data

In this section, we present and discuss our main empirical strategy, which relies on comparing follow-on citations to Bell patents to follow-on citations to exactly matched patents by inventors outside of the Bell system. Then we present a complementary empirical strategy, which compares within technology classes the change in the number of patents in technology subclasses that were affected by the royalty-free compulsory licensing of Bell patents to the change in the number of patents in technology subclasses that were unaffected by the consent decree.

A. *Main Empirical Strategy: Impact on Citations to Bell Patents*

To estimate the effect of royalty-free compulsory licensing on follow-on innovations, we need to compare the number of follow-on innovations building on Bell patents after the consent decree with what would have happened had the consent decree not been enacted. In our main specification, we measure follow-on innovations building on Bell patents using 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 2015a). The advantage of this measure is that it gives a direct link between follow-on innovations and the compulsorily licensed Bell patents. Another advantage is that citations are consistently available from 1947 onward, in contrast to most alternative measures such as new products or R&D spending.[15] Citations have the additional advantage of

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

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

[15] In 1947, the United States Patent and Trademark Office (USPTO) started to publish citations of prior art on the front page of the patent (Alcácer, Gittelman, and Sampat 2009). The first patent to include prior art was issued

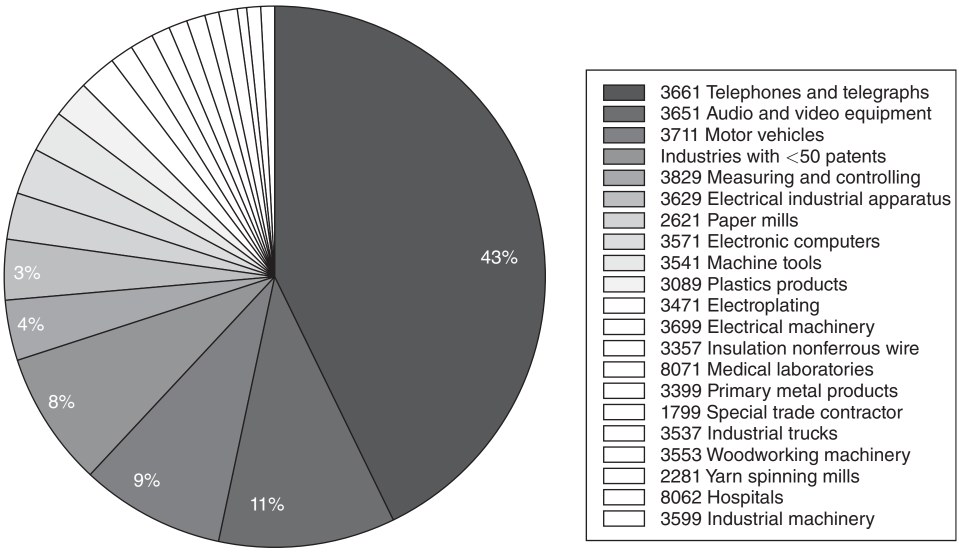

Figure 2. Compulsorily Licensed Patents by Industry

Notes: The pie chart shows the distribution of compulsorily licensed patents by most likely industry. We assign patents to the most likely four-digit SIC industry using the data of Kerr (2008) and Acemoglu, Akcigit, and Kerr (2015).

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

having 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 (Alcácer and Gittelman 2006; Alcácer, 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, have the same total number of citations as the Bell patents in the five years before 1949, and 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.

To compare the number of patent citations to Bell patents and to control patents before and after the consent decree, we employ the following regression specification:

$$\#Citations_{i,t} = \beta_1 \cdot Bell_i + \beta_2 \cdot Post_t + \beta_3 \cdot Bell_i \cdot Post_t + \varepsilon_{i,t}, \quad (1)$$

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.

where $\#Citations_{i,t}$ is the number of follow-on citations of other companies to patent i in year t in the treatment period from 1956 until patent expiration. The variable $Bell_i$ indicates whether patent i is owned by the Bell System and is therefore treated. $Post_t$ is an indicator for whether year t is in the treatment period. The coefficient of interest is β_3, which reflects the increase in patent citations to Bell relative to the control patents.

We can interpret our results as causal effects 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 trends 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 free compulsory licensing. This assumption *does not* imply that Bell and control patents necessarily have the same underlying scientific quality or monetary value. It only implies that in the absence of the consent decree, both treatment and control patents would have continued to have the same number of follow-on citations.

To see whether the parallel trends assumption is plausible, we estimate a version of equation (1) with time-varying coefficients. This specification allows for a visual inspection of pretrends. Specifically, we estimate the following equation:

$$\#Citations_{i,t} = \sum_{\tau=1945}^{1965} \beta_{3\tau} \cdot Bell_i + YearFE_t + \varepsilon_{i,t}, \tag{2}$$

where $YearFE_t$ is a fixed effect for the citing year. We show in Section IIIA that the number of citations to Bell and control patents was the same before the terms of the consent decree became known, which is in line with the parallel trends assumption. In the online Appendix, we also show that companies that did not benefit from free compulsory licensing did not increase citing Bell patents after the consent decree. Thus, the control patents are a plausible counterfactual for Bell patents.

There are three main concerns with this empirical setup. A first concern about this identification strategy might be that the antitrust authorities chose to compulsorily license Bell patents royalty-free because of their high potential for follow-on research. According to the complaint and historical records, free compulsory licensing was imposed because Bell used patents to block competitors in the field of telecommunications equipment. If, in the absence of free compulsory licensing, these blocking patents would have experienced particularly strong follow-on innovation, then we might overestimate the effect of the consent decree. This does not appear to be likely. In the absence of free 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 the 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 received the same number of citations in the five years before 1949. Furthermore, this concern does not apply to the 57 percent 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.

A second concern might be that Bell's patenting strategy may have changed after the complaint became known. This is why we restrict our analysis to 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 cutoff date, more than 98 percent of the patents affected by the consent decree were filed before 1953, and more than 82 percent earlier than 1949. We start our sample with the publication year 1940 because patents issued in 1939 expired during 1956, coinciding with the implementation of the consent decree. 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 percent), we find in total 54,405 control patents that fulfill the criteria specified above. This implies that every Bell patent potentially has more than one control patent.[16] In our main specification, we reweight the sample to account for the different number of control patents per Bell patent.

A third concern might be that the matching approach by definition limits the possibility to analyze the effect of the consent decree on the diffusion of extraordinary inventions. The Bell Laboratories were known for their one-of-a-kind inventions, such as solar cells and the transitor. Finding a control patent for these inventions is difficult, which results in a number of unmatched Bell patents. Our estimates are therefore best interpreted as the average treatment effect on the treated for the more normal patents produced by Bell. This focus on patents with common characteristics might aid the external validity of our findings but provide only an imprecise lower bound for the effect of the consent decree on follow-on inventions.

B. *Complementary Empirical Strategy: Impact on Number of Patents*

To complement our analyses using patent citations, we additionally analyze the impact of the consent decree on the number of innovations. More specifically, we compare within technology classes the change in the total number of patents in a USPC technology subclass with a compulsorily licensed Bell patent to the change in the total number of patents in subclasses without before and after the consent decree. To do this, we employ the regression model

$$(3) \quad \#Patents_{c,s,t} = \beta \cdot Treat_s \cdot I\big[1956\text{–}1970\big] + YearFE_t + ClassFE_c + \varepsilon_{c,s,t},$$

where the dependent variable $\#Patents_{c,s,t}$ is the number of non-Bell patents in class c, subclass s in year t. The variable $Treat_s$ is an indicator that is equal to one if there is at least one free compulsorily licensed Bell patent in subclass s, and $I[1956\text{–}1970]$ is an indicator function for the years 1956 to 1970. The coefficient β measures the number of excess patents in treated relative to untreated subclasses.

[16] Each treated patent has on average around 15 control patents. The median number of control patents is seven. 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.

We control for technology class fixed effects to account for permanent differences in patenting rates between technology classes and for year fixed effects to account for developments in patenting activity in the United States that are common across technology classes. We include only patent classes that contain both treated and control subclasses. The resulting data consists of 200 classes with 2,915 subclasses, of which 874 are treated. Within each technology class, we aggregate the subclasses into one treated and one untreated subclass.[17]

We can interpret the estimates from this specification as causal if, in the absence of the consent decree, the patenting rates in treated and untreated classes would have developed in the same way (parallel trends assumption). One potential concern could be that Bell selected itself into technology classes that would have also grown in the absence of the consent decree. The parallel trend assumption is untestable but supported by evidence provided in Section IV, where we estimate equation (3) with time-varying coefficients and find that the trends of treated and untreated classes are parallel up to the consent decree. In addition, we restrict the sample to the 174 patent classes that do not contain a transistor patent because the transistor technology is one of the few general-purpose technologies of the post-World War II period and thus likely exhibits very different trends.[18]

When we observe an increase in the number of patents after the consent decree, we cannot say for sure to what extent this increase is caused by the access to royalty-free compulsorily licensed Bell patents (patents published before the consent decree) and to what extent by the access to Bell patents that could be licensed at reasonable rates (patents published after the consent decree). Thus, the estimated coefficient on the patent class level requires a nuanced interpretation. It might pick up not only the effect of the royalty-free compulsory licensing but also the effect of licensing at reasonable rates. This empirical strategy thus captures the overall effect of the consent decree but does not allow us to separate the two potential effects of licensing royalty-free and at reasonable rates.

The empirical strategy based on patent counts complements our first empirical strategy based on patent citations in several ways. First, it does not rely on matching Bell patents to other patents. Thus, there is no concern that results might be driven by inventors who might have strategically undercited Bell patents before the consent decree. Second, we do not need to worry about potential substitution between similar patents, e.g., due to the salience of Bell patents after the consent decree, since we estimate the net growth in the number of patents. Lastly, citations capture only the immediate impact of royalty-free compulsory licensing (i.e., first-round effects on follow-on innovations citing Bell patents). Patent counts might give us a more comprehensive picture, as they also include second-round effects.

[17] The number of subclasses of the highest level varies between 2 and 77 across USPC classes. Aggregating these subclasses to two per class gives each class equal weight in the average.

[18] We also drop subclasses that had less than five patents from 1940 to 1948 to avoid changes in the composition of classes over time.

C. *Data*

For all of our estimations, we use comprehensive patent data for the United States from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office (European Patent Office 2016). In this data, we identify 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 US Congress on the consent decree of Bell in May 1958 (Antitrust Subcommittee 1958).[19]

Table 1 shows summary statistics of the unweighted raw data. In column 1, we report the summary statistics for all patents in our estimation sample that are not Bell patents but are in the same technology classes as Bell patents. Column 2 describes all non-Bell patents published from 1940 to 1948, the time period of our baseline regressions. Columns 3 and 4 split all non-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 a probability higher than 15 percent of being used in the production of telecommunications equipment according to the data of Kerr (2008). Columns 5 through 8 present the equivalent summary statistics for Bell patents. The average non-Bell patent in our dataset receives 3.3 citations per patent, while Bell System patents receive on average 4.4 citations by others. In our baseline sample, the average Bell patent receives around 3.9 citations, slightly above the 3.1 citations that patents of non-Bell inventors received.

III. Main Results: The Impact of the Consent Decree on Follow-On Innovation

Before the consent decree, Bell licensed its patents to around 700 companies at royalty rates of 1–6 percent of the net sales price. Lower rates applied if a cross-license was agreed upon (Antitrust Subcommittee 1958, 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 free compulsory licensing increased follow-on innovation inside and outside of telecommunications.

A. *Baseline Results*

We start by investigating whether royalty-free compulsory licensing had any effect on follow-on innovation at all. A priori, it is not obvious why it should have. As Green and Scotchmer (1995) shows theoretically, patent rights should not prevent value-enhancing follow-on innovation as long as bargaining between the parties is efficient. Yet, if there are any impediments to efficient bargaining between Bell and follow-on inventors, such value-enhancing follow-on innovations may be suppressed. If this is the case, royalty-free compulsory licensing potentially increases follow-on innovation.

[19] 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.

Table 1—Summary Statistics

	Non-Bell System patents				Bell System patents			
	All ('40–'55)	Baseline sample ('40–'48)			All ('40–'55)	Baseline sample ('40–'48)		
		All	Telecom-munications	Others		All	Telecom-munications	Others
	Mean (1)	Mean (2)	Mean (3)	Mean (4)	Mean (5)	Mean (6)	Mean (7)	Mean (8)
Filing year	1944.9	1940.8	1940.5	1940.8	1944.0	1940.9	1940.6	1941.0
Publication year	1948.1	1943.4	1943.4	1943.4	1947.0	1943.3	1942.7	1943.5
Number of years in patent protection after 1956	9.1	4.4	4.4	4.4	8.0	4.3	3.7	4.5
Total cites	3.5	3.3	4.4	3.2	5.1	4.6	4.9	4.4
Citations by others	3.3	3.1	4.0	3.0	4.4	3.9	3.9	3.9
Self-citations	0.2	0.2	0.4	0.2	0.7	0.7	1.0	0.6
Citations by others prior to 1949	0.4	0.9	1.9	0.8	0.9	1.6	2.0	1.4
Observations	172,464	75,739	5,120	70,619	6,685	3,771	1,121	2,650

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 (from here: "non-Bell patents"). Column 2 describes all non-Bell patents published from 1940 to 1948, the baseline sample of most of our regressions. Columns 3 and 4 split all non-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 more than a 15 percent likelihood of being used in the production of telecommunications equipment according to the data of Kerr (2008). Columns 5 through 8 repeat the same figures for Bell patents. A citation is identified as a self-cite if the applicant of the cited and citing patent is the same.

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

In Figure 3, panel A, we compare the evolution of patent citations to Bell patents and to control patents in the same publication year and the same three-digit technology class with the same number of citations, up to 1949. We use the weights proposed by 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 six 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 start to converge again in 1960–1961.

This difference in mean patenting rates motivates our analysis of the average impact of the consent decree on patent citations across all industries. Figure 3, panel B shows the two-yearly coefficients of estimating equation (2). We average the citations over a two-year period to reduce the noise in the estimates. From 1945 to 1955, the average number of citations of treatment and control patents track each other very closely, resulting in no excess citations to Bell patents relative to control patents. This speaks again 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 starts to converge again in 1961. Note that 1961 is the average expiration date of the treated Bell patents in our sample. By 1965 all treated patents in our sample had expired.

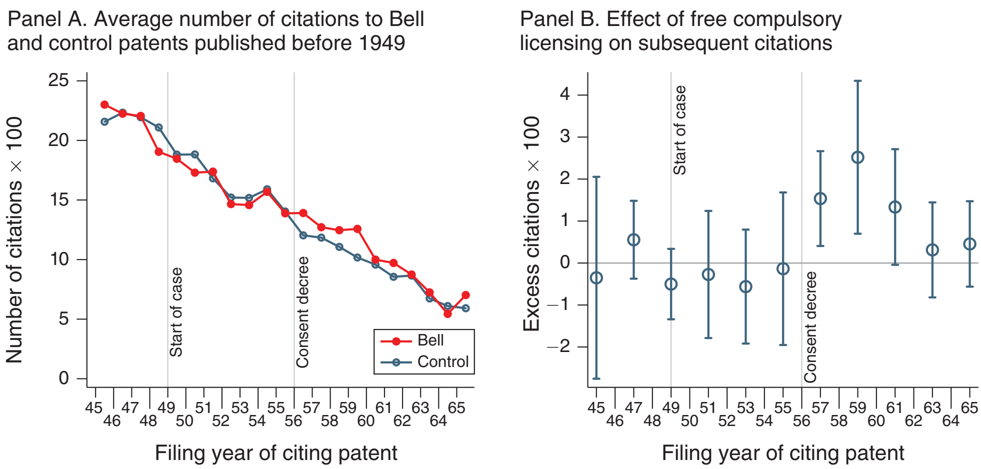

FIGURE 3. MAIN RESULT

Notes: Panel A shows the average number of citations to 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 three-digit technology class as the 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). Panel B shows the number of two-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 US Patent Classification (USPC) primary class and with the same number of citations up to 1949, estimated using the specification in equation (2). We correct for self-citations. The blue lines represent the 95 percent confidence bands calculated from standard errors clustered on the three-digit technology class level. To adjust for the different number of control patents per treated patent, we use the weights suggested by Iacus, King, and Porro (2009). All coefficients are multiplied by 100 for better readability.

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, 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 parties had come to a common understanding on how to resolve the Bell case (Antitrust Subcommittee 1958, 1956). On May 28, 1954, Bell formally proposed a consent decree including the compulsory licensing of Bell System patents as described in Section I. In online Appendix B1, we show that the cumulative abnormal stock returns for AT&T stocks suggest that the agreement reached in 1954 was known to a substantial group of people. The returns experience a large uptick in March 1954, when Bell suggested the memorandum. In the same Appendix, we also time the date on which Bell knew about the upcoming consent decree by analyzing the lags between patent application and patent publication for Bell patents versus those of control patents. According to the consent decree, all patents had to be licensed for free if they were published before January 24, 1956, while they were licensed at reasonable rates if they were published after this date. This created incentives for Bell to delay the publication of their patents. The data shows that Bell started to shift the publication of patents to after the consent decree, starting in 1953. The first media mention 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 and "looking toward a possible 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 on the production of goods based on the new patents and on the licensing of Bell's technology required for this production until after the consent decree was implemented.

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), which studies compulsory licensing after World War I, and with those of Galasso and Schankerman (2015), which shows that when patents were invalidated after being challenged in court, follow-on innovation by other companies increased. What is special about our setup is that free compulsory licensing was implemented as an antitrust remedy with the specific aim to end market foreclosure in the telephone equipment market. To determine whether this attempt was successful, we need to go beyond the average effects and look at the effects in different markets separately.

B. *Effects Inside and Outside of Telecommunications*

To analyze whether free compulsory licensing 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.[20] We use the concordance of Kerr (2008) to determine, for each USPC technology class, the probability that a patent in this 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 from patents at each level to Bell patents and to control patents. In the last step, we use these different outcome variables and estimate, for each level of closeness, a difference-in-difference regression adapting equation (1). The resulting 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 4, panel A, we show the average treatment effect 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 free compulsory licensing was ineffective in increasing innovation in the telecommunications industry but effective

[20] 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.

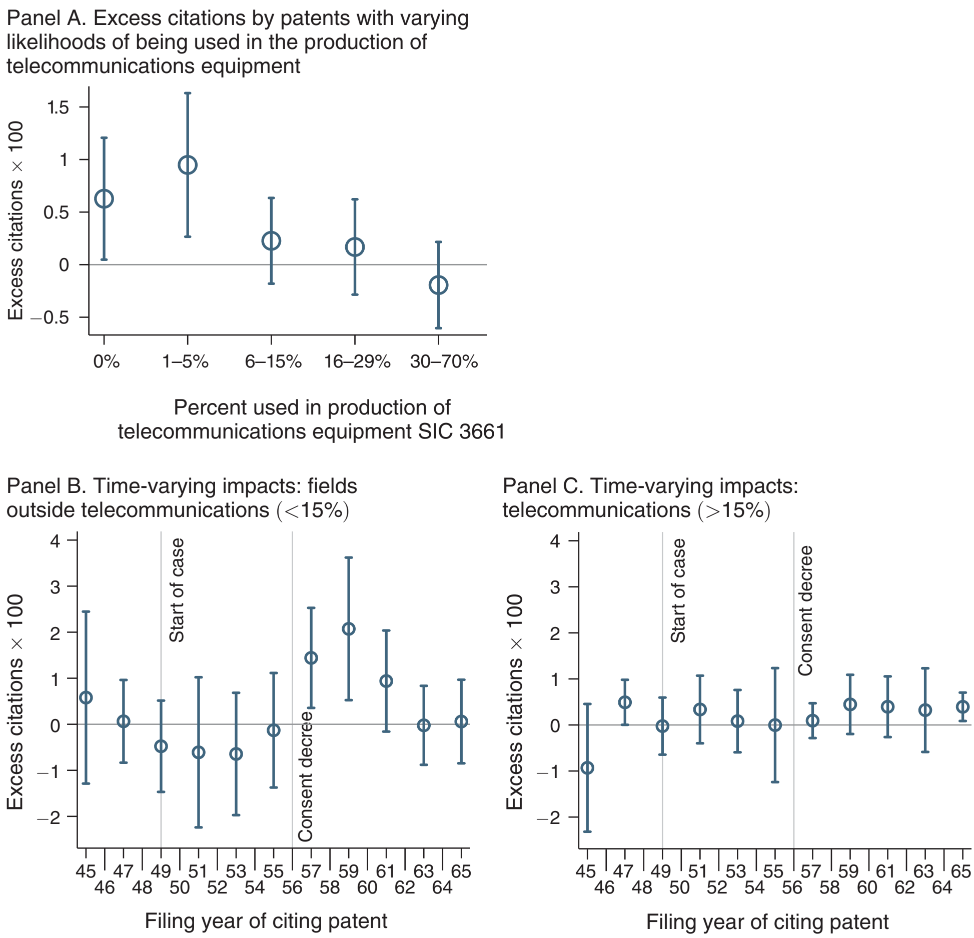

Figure 4. The Impacts of the Consent Decree on Follow-On Innovation by Closeness to Telecommunications

Notes: This figure shows results on follow-on citations by varying likelihood of the citing patent to be used in telecommunications. Relevance is measured by the likelihood that a patent is used in industry SIC 3661, using the data of Kerr (2008). Panel A shows results from the difference-in-difference specification of the impact of the consent decree on follow-on patent citations by closeness to telecommunications, with 1956 until patent expiration as the treatment period. We report the treatment effect, along with 95 percent confidence intervals separately, for citations from patents with differing relevance for the production of telecommunications equipment (SIC 3661—"Telephone and Telegraph Apparatus"). The bins labeled 0 percent, 1–5 percent, 6–15 percent, 16–29 percent, 30–70 percent aggregate citations of 367, 75, 28, 17, and 7 technology classes, respectively. Panel B shows the average number of excess citations from patents in fields outside telecommunications over a two-year period of patents affected by the consent decree ("Bell patents") relative to their control patents. Panel C shows the average number of excess citations from patents in telecommunications over a two-year 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 percent likelihood to be used in the production of telecommunications equipment (SIC 3661) according to the data of Kerr (2008). In all panels, the blue lines represent the 95 percent confidence bands calculated from standard errors clustered on the three-digit technology class level. All coefficients are multiplied by 100 for better readability.

in others.[21] In online Appendix B3, we report several robustness checks for this result.

Figure 4 also shows an event study of citations from patents outside of telecommunications (panel B) and telecommunications patents (panel C). For this figure, we group citations in two bins, one with citations from telecommunications-related patents and one with citations unrelated to telecommunications. This means that we split the dependent variable by relatedness, holding the unit of observation, the cited patent, constant. We classify a citing patent as a telecommunications-related patent if in its patent class, patents have a probability higher than 15 percent of being used in the production of telecommunications equipment, based on the data of Kerr (2008).[22] These telecommunications-related patents are captured by the final two bins in Figure 4, panel A. Otherwise, we classify the patent as unrelated to telecommunications.[23] We find that the timing of the effect in other fields is the same as in our main results graph in Figure 3, panel B. In telecommunications, we do not find any effect.

Table 2 shows the corresponding results from estimating equation (1). In column 1 of Table 2, we report the results for our baseline regression, showing that the overall patent citations increased by 12 percent relative to the mean of the dependent variable. We find no effect in telecommunications (column 3) but a 15 percent increase in citations relative to the mean in other fields unrelated to telecommunications (column 5).[24]

Back-of-the-envelope calculations suggest that the additional patents for other companies in fields unrelated to telecommunications 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.[25] 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 (i.e., including patents published until 1956 and patents under secrecy), the consent decree led to around \$5.8 billion in economic value between

[21] 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 B3 in online Appendix B2. 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.

[22] The bin containing patents with zero percent likelihood of being used in telecommunications includes citations from patents from 367 different technology classes. For the other bins, we aggregate citations of patents from 7 to 75 technology classes.

[23] The cutoff values above are to some extent arbitrary, and our results are robust to using others. In online Appendix B4, we report the estimations for different bin sizes, with qualitatively similar results. In online Appendix B5, we show that for patent classes for which patents have at least a 15 percent 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.

[24] In online Appendix B6, we show that the average quality of follow-on innovation did not drop after the consent decree.

[25] Kogan et al. (2017) measures 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.

Table 2—The Effect of Free Compulsory Licensing on Subsequent Citations in Telecommunications and in Other Fields

			Telecommunications		Other fields		
	Baseline (1)	Up to 1956 (2)	All (3)	Young and small (4)	All (5)	Dollar weighted (6)	Young and small (7)
Bell	−0.4	0.1	0.3	−0.1	−0.7	−1.4	−0.7
	(0.4)	(0.2)	(0.3)	(0.4)	(0.4)	(2.6)	(0.3)
Post	−4.8	−5.3	−1.6	−0.4	−3.3	4.9	−0.1
	(0.5)	(0.9)	(0.5)	(0.3)	(0.7)	(2.0)	(0.2)
Bell × post	1.8	1.7	−0.0	0.1	1.8	9.9	1.1
	(0.6)	(0.5)	(0.3)	(0.2)	(0.5)	(3.4)	(0.3)
Mean dep.	14.6	16.8	2.8	1.1	11.8	62.8	4.5
Number treated	3,602	6,645	3,602	3,602	3,602	3,602	3,602
Clusters	207	243	207	207	207	207	207
Observations	659,137	1,488,416	659,137	659,137	659,137	659,137	659,137

Notes: This table shows the results from a difference-in-difference estimation with 1949–1955 as the pretreatment period and 1956 until patent expiration as the treatment period. The estimation equation is equation (1). As control patents, we use all patents that were published in the United States, 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 the 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 more than a 15 percent 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). In column 7, we use citations by young and small companies as the dependent variable. Standard errors are clustered on the three-digit USPC technology class level.

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 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.[26] We find that free compulsory licensing failed to stimulate innovation from young and small firms in the telecommunications sector (column 4), whereas they account for 60 percent of the increase in innovation in all other fields (column 7). This suggests that in

[26] In online Appendix B7, 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 and small companies ("start-ups").

particular, newly entering companies benefited from free compulsory licensing. This is plausible since larger companies with a larger patent portfolio might have found it 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.

The telecommunications market was special in two ways: it was highly concentrated and 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 the telecommunications market, we cannot separate these two features. Outside of the telecommunications market, we can observe whether free compulsory licensing increases innovation in highly concentrated markets. This informs us about whether concentration per se is detrimental for follow-on innovation.

We investigate this in Table 3. In column 1, we repeat the baseline result for citations from patents not related to telecommunications. In columns 2 and 3, we split the citations into 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 eight-firm market share in an industry that we get from the US census (Federal Trade Commission 1992) and aggregate the product on the patent class level.[27] Thus, we get, for each patent class, the weighted-average eight-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 eight-firm market share is above 60 percent, which is the seventy-fifth percentile.[28]

We find a positive and significant increase in follow-on innovation in both low and highly concentrated markets. This also holds for newly entering companies (columns 4 and 5). Both results suggest that free compulsory licensing can be successfully employed in concentrated markets to foster entry by innovative start-ups and increase follow-on innovation.

C. *Auxiliary Results and Robustness Checks*

One concern for the identification of the effect is that the impact of free compulsory licensing on subsequent citations might be driven by an unobserved shock that increased follow-on innovation to Bell patents and was correlated with the consent decree. For example, the antitrust prosecutors might have chosen to press for free compulsory licensing because they expected that there would be strong

[27] Until recently, the data was available at http://www.census.gov/epcd/www/concentration92-47.xls and is included in the data repository. We use data for the years prior to the consent decree where available. If the industry is missing, we use the earliest nonmissing observation.

[28] The minimum average eight-firm market share across patent classes is 30 percent, the median is 53 percent, and the maximum is 82 percent.

Table 3—The Effect of Free Compulsory Licensing on Subsequent Citations in Other Fields (Outside Telecommunications) by Market Concentration

	All	All Concentration		Young and small Concentration	
		High	Low	High	Low
	(1)	(2)	(3)	(4)	(5)
Bell	−0.7	0.1	−0.8	−0.1	−0.6
	(0.4)	(0.3)	(0.5)	(0.1)	(0.2)
Post	−3.3	−1.7	−1.5	−0.3	0.1
	(0.7)	(0.4)	(0.5)	(0.1)	(0.1)
Bell × post	1.8	0.8	1.0	0.5	0.7
	(0.5)	(0.5)	(0.5)	(0.1)	(0.2)
Mean dep.	11.8	4.2	7.6	1.3	3.2
Number treated	3,602	3,602	3,602	3,602	3,602
Clusters	207	207	207	207	207
Observations	659,137	659,137	659,137	659,137	659,137

Notes: This table shows the results from a difference-in-difference estimation with 1949–1955 as the pretreatment period and 1956 until patent expiration as the treatment period. The estimation equation is equation (1). As control patents, we use all patents that were published in the United States, 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 the dependent variable, we use all citations by companies other than the filing company and unrelated to telecommunications. We classify a citing patent as a telecommunications-related patent if in its patent class, patents have more than a 15 percent likelihood of being used in the production of telecommunications equipment, using the data of Kerr (2008). In columns 2 and 3, we classify citing patents as belonging to a market with high or low concentration. To this end, we again use the concordance of Kerr (2008), which 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 eight-firm market share in an industry that we get from the US census (Federal Trade Commission 1992), and we 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 eight-firm market share is above 60 percent, which is the seventy-fifth percentile. Columns 4 and 5 use as the dependent variable citations from patents from young and small assignees in markets with high or low concentration as described before. 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 coefficients are multiplied by 100 for better readability. Standard errors are clustered on the three-digit USPC technology class level.

technological progress in the Bell's technology fields. If exogenous technological progress, rather than free compulsory licensing, drives the increase in follow-on innovation, then companies that are less affected by the consent decree should react in the same way as companies profiting from free compulsory licensing.

We provide a variety of robustness checks to document that this is not the case. In the following, we present an overview of the results, while details are presented in online Appendix B8. First, we analyze the citation patterns of companies that were relatively less affected by the consent decree. Most importantly, the General Electric Company, Radio Corporation of America, and Westinghouse Electric Corporation were explicitly excluded from the free compulsory licensing of Bell patents. We find no significant effect of the consent decree on citations of these companies. This suggests that the measured effects are not due to a common technology shock. In addition, we find no significant effect for foreign companies, which could license Bell's patents for free but did not receive any technical description or assistance from Bell. We also find much weaker effects for companies that already had licensing agreements in place. Second, we split the compulsorily licensed patents by their quality as measured through the dollar value based on Kogan et al. (2017). We find that the treatment effects are similar for high- and low-quality patents. Third, we drop all patents related to the transistor, the most important invention of Bell. Dropping these patents does not change the results. Next, we drop all citations from patents that also cite either the patents of RCA or the patents of IBM, two companies that also experienced compulsory licensing of their patents. Again, our results do not change. Finally, we separately look at patent citations by inventors who were at some point associated with or close to Bell (i.e., former Bell employees, coinventors of Bell employees, and their coinventors) and compare their citations with citations by all remaining unrelated inventors. We find a positive effect on the citations of unrelated inventors and a negative effect on the citations of related inventors.

In further robustness checks in online Appendix B9, we show that the effect is 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. We also show that our results are robust to the use of a matched control group that has higher citations before the start of the antitrust lawsuit in online Appendix B10. Finally, in online Appendix B11, we vary the construction of control groups and show that our results are not driven by the particular choice of matching variables.

IV. Complementary Results: The Impact of the Consent Decree on US Innovation

The results presented in Section III captured the immediate impact of royalty-free compulsory licensing, i.e., first-round effects on follow-on innovation citing Bell patents. In this section, we complement this analysis by studying the impact of the consent decree on overall US patent activities. This allows us to assess the cumulative impact of further rounds of effects, including patenting by new firms entering the market and follow-on innovation building on their innovations.[29] The empirical strategy used in this section differs from the one in the previous section by using both a different outcome variable and a different identification strategy. More specifically, we compare within technology classes the increase in the total number of patents in USPC technology subclasses containing a Bell patent subject to royalty-free compulsory licensing to the increase in the total number of patents in subclasses without a Bell patent.

In Figure 5, we plot the total number of patents and the average difference in the total number of patents in treated and untreated subclasses within a class per year. In panel A, we see that the total number of patents relative to 1949 develops similarly in affected and unaffected subclasses until 1955. Starting with the consent decree in 1956, subclasses that contain a free compulsorily licensed Bell patent show a higher patenting rate than subclasses that were unaffected by the decree. In panel B, we show that the number of patents in technology subclasses containing Bell patents that were compulsorily licensed increases relative to subclasses without Bell patents. The increase starts in 1957. The effects do not decrease over time, which suggests that the consent decree had a lasting positive effect on US innovation.

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

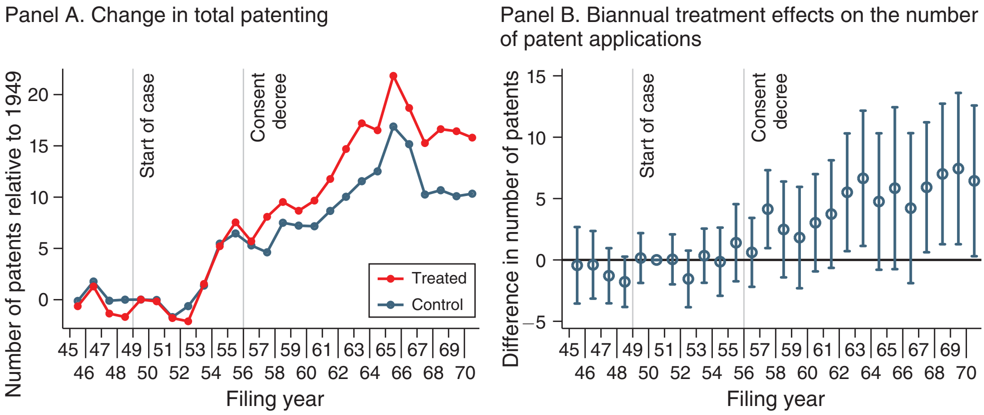

FIGURE 5. THE EFFECT OF FREE COMPULSORY LICENSING ON THE NUMBER OF PATENTS

Notes: These graphs show the impacts of the consent decree on the number of patents in subclasses with a free compulsorily licensed Bell patent relative to subclasses within the same technology class without free compulsorily licensed patents. We only use the 174 patent classes that do not contain a patent related to the invention of the transistor and that had at least five patent applications from 1940 to 1948. Panel A shows the impact on the total number of yearly patents in affected relative to unaffected technology subclasses relative to 1949. For an analogous graph using all technology classes, see online Appendix C2. Panel B shows the average difference in total patenting between affected and unaffected subclasses adapting equation (3), along with 95 percent confidence bands. Standard errors allow for clustering within three-digit technology classes. Class hierarchies are from the US Manual of Classification File (United States Patent Office 2015).

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 1956–1970. We employ the difference-in-difference model outlined in equation (3). All coefficients are reported in Table 4.

In column 1, we present the results using the number of all patent applications in a subclass, including applications from the Bell System, as the dependent variable. We find a strong increase in the number of patents even though we are including applications from the Bell System, which were potentially negatively affected by the consent decree. In columns 2–8, the dependent variable captures the number of patent applications from other companies only. Similar to the direct effects on citations reported in Section III, the increase in patenting is restricted to technologies unrelated to the production of telecommunications equipment (columns 2 and 3).[30] This highlights again that the fields in which Bell continued to operate and dominate experienced relatively slower technological progress than other markets.

To check to what extent this increase in the number of US patents was driven by the transistor—Bell's most important invention, which had an enormous impact on the computer industry—we repeat our analysis for other fields but exclude the transistor-related patents (columns 4–8). While the treatment effect is smaller by

[30]We again use the 15 percent cutoff to classify telecommunications-related technologies. In online Appendix C1, 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—Number of Patent Applications per Year in Different Subclasses by Company Type and Field

	All	Telecom-munications	Other fields	Other fields without transistor				
					Concentration		Young	
	with Bell	All	All	All	High	Low	and small	Others
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treated × $I(56–70)$	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)
Mean dep.	6.8	3.8	6.9	6.2	7.3	6.0	2.7	3.5
With transistor	Yes	Yes	Yes	No	No	No	No	No
Number of clusters	200	10	190	168	31	137	168	168
Observations	64,130	2,464	61,666	53,966	8,448	45,518	53,966	53,966

Notes: This table shows the results from estimating equation (3). 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 free 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 patents from 1940 to 1948. Column 1 shows the baseline estimates. Column 2 restricts the dependent variable to patents from telecommunications-related subclasses. We classify a patent as telecommunications-related if in its patent class, patents have more than a 15 percent likelihood of being used in the production of telecommunications equipment, using the data of Kerr (2008). Column 3 and all remaining columns use subclasses 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 market with high or low concentration. For this classification, 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 eight-firm market share in an industry that we get from the US census, and we 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 eight-firm market share is above 60 percent, which is the seventy-fifth percentile. Column 7 uses patents 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. Standard errors are clustered on the three-digit technology class level. Class hierarchies are from the US Manual of Classification File (United States Patent Office 2015).

around 25 percent, it is still statistically significant. The effects are again positive and significant for markets with both high and low concentration, respectively (columns 5 and 6). They are mostly driven by young and small assignees (column 7), while the other firms do not increase their patenting (column 8).

Thus, overall we find that the consent decree led to an increase in the amount of patenting outside of telecommunications. This positive effect is consistent with the theoretical argument by Acemoglu and Akcigit (2012). Building on the step-by-step innovation model of Aghion et al. (2001), Acemoglu and Akcigit (2012) analyzes the effects of compulsory licensing on innovation. It considers the case where all current and future patents in the economy are compulsorily licensed for a positive price and identifies two opposing effects. On the one hand, compulsory licensing helps technological laggards 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 innovation and growth in the economy.

In our case, royalty-free compulsory licensing was selectively applied to one company that did not participate in any market other than telecommunications. This enabled many new companies to enter markets with state-of-the-art technology and 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 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).

V. 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.[31] The consent decree devalued these patents by forcing Bell to license them for free while all future patents had to be licensed at reasonable terms. This also meant that Bell could no longer refuse to license its patents to potential competitors. Moreover, the consent decree explicitly banned Bell from entering markets other than telecommunications. Both of these provisions may have reduced Bell's incentives 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 show 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 in 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.[32] Results are presented in Figure 6, panel A. We find that Bell's patenting is smaller on average than the patenting of the synthetic control, but not by much.[33]

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), and the Unix operating system (1969–1972). In Figure 6, panel B, we plot the share of patents Bell had in the upper 5 percent of the citation distribution and in the upper 5 percent of the value distribution for

[31] To calculate these numbers, we use the data of Kogan et al. (2017). When using only nonmissing values in the data, we obtain estimates of $31.4 billion, and if we use average patent values per publication year and technology class, estimates of $34.4 billion. All dollar values are in 2010 US dollars.

[32] 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.

[33] In Figure C3 in online Appendix C3, 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.

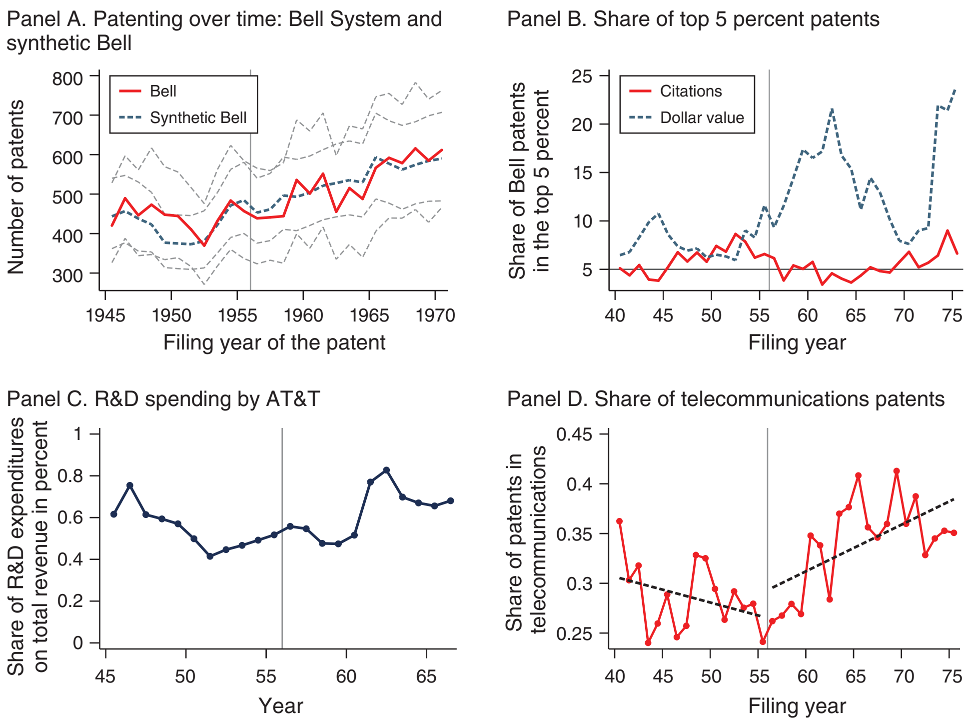

Figure 6. Innovation and R&D in the Bell System after the Consent Decree

Notes: Panel A shows the total number of patents filed by the Bell System per year compared to a synthetic Bell. To construct the synthetic Bell, we calculate the share that 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. Dashed lines indicate 90 percent confidence bounds. Panel B shows the share of Bell patents each year in the top 5 percent as defined by citations and 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 percent cutoff by filing year of the patent and by technology class. Panel C shows the ratio of yearly R&D expenditures relative to the total revenues of American Telephone and Telegraph. The data are from the annual reports of AT&T. Panel D shows the share of patents per year related to telecommunications relative to all patents filed by Bell per year. We classify a patent as a telecommunications-related patent if in its patent class, patents have more than a 15 percent likelihood of being used in the production of telecommunications equipment, using the data of Kerr (2008). In online Appendix C4, we show the change in direction of research using NBER subcategories and most likely SIC industries.

each year. In both cases, we define the 5 percent cutoff by filing year of the patent and by technology class. In 1950, around 7.3 percent of Bell's telecommunications patents were in the top 5 percent in terms of citations and around 6.6 percent in the top 5 percent in terms of dollar value. Ten years later, in 1960, 5.7 percent of all Bell patents were in the top 5 percent of the citation distribution, and 16.5 percent were in the top 5 percent of the value distribution. The interpretation of these numbers is difficult, as patents published before 1956 were compulsorily licensed and thus received more citations. This made it more likely that a Bell patent ended up in the top 5 percent of the citation distribution. Interpreting the increase in dollar values in this period as causal is also not straightforward, as Kogan et al. (2017) uses 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 that 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 that Bell charged for patents published after the consent decree were not much different from the predecree royalties (Antitrust Subcommittee 1959, 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 percent from 1949 to 1960 (Figure 6, panel C).[34] For the entire Bell System, the share of R&D to total turnover stayed almost constant at 2–3 percent 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 to 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 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 6, panel D).

These results are consistent with Galasso and Schankerman's (2018) study on patent invalidations. It shows 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.

VI. Compulsory Licensing as an Antitrust Remedy

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 nonmerger cases with "extraordinary level of market dominance and a demonstrated history of monopolization and resistance to reform" (Delrahim 2004). We showed in the previous sections that the royalty-free compulsory licensing imposed by the consent decree fostered innovation, even in markets with high concentration. But it was not effective in telecommunications, the market for which it was implemented in the first place.

[34] 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.

There are a variety of potential reasons why this may have been the case. The consent decree kept Bell's position as a regulated monopolist in the telecommunications market intact. Knowing Bell's dominant position in this industry may have kept potential newcomers away. Even more so since after the consent decree, Bell redirected its R&D efforts to the regulated telecommunications industry, as we have shown in the previous section. This may have caused other companies to avoid this technology space even more. Another explanation could be that Bell continued foreclosing the market for telecommunications equipment, which in turn discouraged newcomers to enter this market.

When the merits of the consent decree were discussed in the congressional hearings, both the public and antitrust officials suspected that free compulsory licensing would help only companies outside the telecommunications field because of Bell's unchallenged position as a vertically integrated monopolist. Commentators 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 a patent if there is no market in which you can sell the product on which the patent is based" (Antitrust Subcommittee 1959, 108). In the final report, the Antitrust Subcommittee concluded that "[t]he patent and technical information requirements have efficacy only so far as they permit independent manufacturers to avail themselves of patents in fields that are unrelated to the common carrier communications business carried on by the Bell System companies, and nothing more" (Antitrust Subcommittee 1959, 108).

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, Bell was forced to interconnect its telephone system to the entering competitor MCI, which provided long-distance services using microwave towers (Temin and Galambos 1987, Gertner 2012, 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. 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 breakup of the Bell System in 1984, opening up the telecommunications equipment market for competition.

VII. Conclusion

The 1956 consent decree against the Bell System provides a rare opportunity to learn about the workings of antitrust remedies concerning companies with enormous market power. It has been referred to repeatedly as an example of how to deal with such companies. In this paper, we provide evidence for the potential, but also the limits, of this remedy.

We show that free compulsory licensing can be effective in fostering innovation in highly concentrated markets. Our analysis provides the first rigorous evidence supporting the view, shared by other observers, that "Intel would have found it harder to develop microprocessors without a consent decree in 1956 that forced AT&T, then America's telephone monopoly, to agree to license all its past patent free of charge, including the ones for the transistor."[35] But we also demonstrate that forcing Bell to compulsorily license its patents was ineffective as an antitrust remedy in stimulating market entry and innovation in the telecommunications equipment market, the market for which the antitrust remedy was intended.

Recent mergers, like the ones between AT&T and Time Warner and between Disney and Fox, have put issues of vertical integration, market power, and potential foreclosure front and center in the current antitrust policy debate. The typical approach to deal with issues of market power and foreclosure in the case of vertical mergers is to impose behavioral remedies. Our paper cautions that this behavioral remedy may not always be sufficient to deal with market foreclosure resulting from vertical integration.

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