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JEL Classification: O30, K21, L40

Keywords: Antitrust, Innovation, Diversity, Exclusionary practices

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The Breakup of the Bell System and its Impact on US Innovation*

Martin Watzinger and Monika Schnitzer†

September 5, 2022

We analyze the effects of the 1984 breakup of the Bell System on the rate, diversity, and direction of US innovation. In the antitrust case leading to the breakup, AT&T, the holding company of the Bell System, was accused of using exclusionary practices against competitors. The breakup was intended to end these practices. After the breakup, the scale and diversity of telecommunications innovation increased. Total patenting by US inventors related to telecommunications increased by 19%, driven by companies unrelated to the Bell System. Patenting by Bell's successor companies decreased, but not the number of top inventions.

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1 Introduction

Section 2 of the Sherman Act makes it unlawful "to monopolize any part of the trade or commerce among the several States" through anticompetitive conduct, such as exclusionary or predatory practices. Several antitrust cases are currently pending in which companies are accused of using exclusionary practices to the detriment of consumers, raising prices, and decreasing innovation. In many of these cases, the breakup of the companies under investigation is discussed as a potential remedy.[1]

In theory, using structural remedies to prevent exclusionary practices can make sense, for example, when a vertically integrated company uses its control over an upstream "essential facility" (or "bottleneck" or "natural monopoly") to exclude competitors in a downstream market (Hart and Tirole, 1990; Rey and Tirole, 2007). Yet, there is little empirical evidence on the advantages and disadvantages of breakups of dominant companies (Crandall and Winston, 2003). This is unfortunate, since a breakup has potentially enormous costs for the involved company and should be implemented only if the benefits are substantial and cannot be achieved in a less costly way using other, less intrusive measures. We know comparatively little about the effects of breakups because they are so rare. In the last 100 years, the only breakup of a monopolist in the US under Section 2 of the Sherman Act was the 1984 divestiture of the Bell System, the US monopolist in telephone services (Crandall, 2001).

Before the breakup, the Bell System was a vertically integrated telecommunications company and the largest company in the US, with more than one million employees. It controlled more than 85% of all local telephone services through its Bell Operating Companies; it had a market share of over 85% in long-distance services through its subsidiary AT&T Long Lines and a 82% market share in telephone equipment through its subsidiary Western Electric (Commission et al., 1974). The Bell System was a well-known innovation leader, and its Bell Laboratories were one of the most productive industrial laboratories of all time.

In 1974, the Department of Justice filed an antitrust lawsuit in response to

[1]Two currently pending cases under Section 2 of the Sherman Act where a breakup was discussed are United States v. Google LLC (2020) and FTC v. Facebook Inc (2021).

repeated complaints from competitors that the Bell System had used its control over local telephone services to prevent other companies from entering its markets. The accusation was that in violation of Sherman Act Section 2, the Bell Operating Companies had refused to connect non-Bell telecommunications equipment to Bell's telephone network and to interconnect local telephone calls to non-Bell providers of long-distance services. The case ended in 1982 with a final ruling that imposed the structural separation of Bell's Operating Companies from the rest of the Bell System, effective January 1st, 1984.

In this paper, we analyze the effect of the breakup of the Bell System on the rate, diversity, and direction of US innovation in telecommunications. We focus on innovation because it is, after all, a powerful contributor to consumer surplus in high-tech sectors at the heart of today's antitrust cases against major technology companies. It also was a major concern in the Bell case. For example, on the day the breakup was completed, the New York Times wrote that new technologies would "rush forward" because of the breakup. But "the breakup could also impede innovation (...) [the] Bell Laboratories (...) might see its research funds shrink and its focus become more oriented toward short-term product development rather than the long-term research that has made it a national electronics resource."[2]

In the first part of our empirical analysis, we show that Bell's breakup significantly increased the rate of US innovation in telecommunications, i.e., in technologies, in which Bell was active before the breakup and which thus were affected by the divestiture. Using a difference-in-differences approach, we find that after the breakup, the number of patents in technologies in which Bell was active increased by 19.0% (95% CI: [7.0%; 31.1%]) per year relative to the number of patents in technologies that are similar but in which Bell was not active. In total, there is an increase of 1065 patents per year for the filing years 1982 to 1990, i.e. in the eight years after the breakup. To put this into perspective, on average 40,490 patents were granted in the USA to US inventors in the period from 1982 to 1990 per year. Thus,

[2] "Bell system breakup opens era of great expectations and great concern" By Andrew Pollack, New York Times January 1, 1984, Section 1, Page 12 (`https://www.nytimes.com/1984/01/01/us/bell-system-breakup-opens-era-of-great-expectations-and-great-concern.html`, last accessed 2022-08-06.)

1065 patents per year correspond to 2.6% of all US patents.[3]

This estimate captures the overall increase in patenting, taking into account a decline in patenting of the Bell System after the breakup. Using a synthetic control method, we find that Bell's patenting decreased by around 107 patents per year, or 24%. Moreover, contrary to the concerns of many observers at the time, we find that the number of high-quality and impactful Bell patents did not suffer from the breakup. While the negative effect of the breakup on Bell's overall patenting is substantial, it is too small to outweigh the much larger increase in patenting by other companies. The overall increase in patenting resulting from the breakup suggests that before, society had missed out on innovation, or, to put it differently, that in the counterfactual scenario if a breakup had been enforced earlier, society would have benefited from more innovations. It is also noteworthy that the average patent quality did not suffer from the increase in patent quantity after the breakup.

To complement these main results, we show that R&D spending in the telecommunications industry increased discontinuously after the breakup, suggesting that the observed increase in patents does not simply reflect a change in patenting strategies, but can be interpreted as an increase in innovation. We also show that the effect is unlikely to be the result of concurrent changes in the patent system or regulatory environment, and that the results are robust to a variety of different definitions of the empirical specification.

In the second part of our empirical analysis, we show that the breakup increased the diversity and changed the direction of US innovation. To study the diversity of innovation, we propose a novel approach that makes use of the technology classification system of the Patent Office. The Patent Office classifies the content of each patent according to its technology into a class, subclass, group, and subgroup. The lowest hierarchical level, that of subgroups, gives a fine-grained view of the technology in a patent. For example, the technology group "Data Switching Networks" (H04L 12) has the subgroups "Bus networks" (H04L 12/40), "Loop networks" (H04L 12/42), "Star or tree networks" (H04L 12/44) or "Interconnection of networks" (H04L 12/46).[4]

[3]The number of granted patents is from https://www.uspto.gov/web/offices/ac/ido/oeip/taf/us_stat.htm (last accessed 2021-10-02).

[4]All technology groups and subgroups of subclass H04L are listed here https://www.uspto.

We call subgroups in which at least one patent is filed in a given year "active." To capture innovation diversity, we count the number of active subgroups within a technology group. We call technology groups with a larger number of active subgroups "more diverse" than technology groups with a smaller number, since they cover a wider range of different technology approaches within one technology group. We compare the number of active subgroups for treated and control technology groups before and after the breakup. We find that the number of active subgroups in technology groups related to telecommunications increased by around 8.9% relative to control technology subgroups, suggesting an increase in diversity. Other approaches using text analyses and patent citations complement and support this finding. They show, for example, that the text of patents in affected technology groups became less similar to the text of earlier patents after the breakup.

In the last part, we round out our analysis of breakups by going further back into the past. In addition to the breakup of Bell, the most well-known and iconic breakup was that of Standard Oil in 1911. While the two cases differ in many respects, they are surprisingly similar in their economic structure. Prior to the breakup, Standard Oil used its control of oil transportation, the essential facility of the oil industry at the time, to exclude competitors in the oil refining and oil exploration industry. The breakup aimed at ending these exclusionary practices. Therefore, investigating whether we find similar results is instructive. Our empirical analysis shows that patenting in oil-related technologies increased by 14.9% (95% CI: [5.3%; 24.6%]) relative to control technologies after the breakup. This finding supports the notion that the positive impact of the breakup on innovation in the Bell case is not a coincidence or an exception, but actually reflects a causal effect.

Our paper contributes to the literature on antitrust and innovation by providing the first empirical assessment of the overall causal innovation effect of the vertical breakup of a monopolist.[5] The divestiture of the Bell system separated local telephone services, an essential facility, from the potentially competitive manufacture of telecommunications equipment and the provision of long-distance services. There-

gov/web/patents/classification/cpc/html/cpc-H04L.html (last accessed 2021-10-21).

[5]A concurrent study looking at the innovation effects of a horizontal breakup is Poege (2021), which deals with the breakup of IG Farben in Germany in 1952.

fore, the Bell breakup is the archetypical case in which economic theory concerned with leveraging of market power might justify a breakup (Laffont and Tirole, 2001; Rey and Tirole, 2007; Tirole, 2020). By focusing on innovation aspects, our work complements studies that consider the effect of the Bell breakup on prices, telephone penetration in the market, and productivity (e.g. Temin and Galambos, 1987; Hausman, Tardiff, and Belinfante, 1993; Olley and Pakes, 1996).

Our study of the breakup of Bell also contributes to the literature by shedding light on the relative merits of structural and behavioral remedies and regulation in fostering innovation. Prior to the breakup, the FCC had tried, for more than 60 years, all behavioral remedies at its disposal to encourage competition in the telecommunications equipment and long-distance services markets. For example, the settlement of the 1949 antitrust case against AT&T mandated Bell to make all its existing patents freely available through compulsory licensing, in order to foster competition in the equipment market (Watzinger et al., 2020). Our results indicate that the breakup in fact increased innovation in telecommunications over and above what had been achieved by a large number of behavioral remedies and regulatory measures. It thus contributes to the small but growing literature on the interrelation between regulation and antitrust remedies, and innovation (Bryan and Hovenkamp, 2020; Federico, Morton, and Shapiro, 2020; Gilbert, 2020; Cunningham, Ederer, and Ma, 2021).

Finally, we contribute to the literature by studying the innovation effects of the breakup of one of the most productive industrial laboratories of all time. The Bell System with its Bell Laboratories was the powerhouse of US innovation. Bell is credited with major innovations such as cellular telephone technology, the transistor, the solar cell, the communication satellite, and the Unix operating system (Nagler, Schnitzer, and Watzinger, 2021). Nine Nobel Prizes and four Turing Awards have been awarded for work at Bell Laboratories. Throughout the 1970s, the Bell system filed 0.5% to 1% of all US patents by US inventors each year. At the time, people worried that the breakup might destroy the Bell Laboratories, just as there are concerns today that antitrust cases might curtail the innovation capacity of the big technology companies. The Bell breakup is, therefore, arguably a worst-case situation, as the potential loss of innovation output of Bell Labs was substantial.

We find that the breakup indeed reduced patenting by the Bell Laboratories but not the number of important patents. Most importantly, the decrease in the number of Bell patents was more than compensated for by the increase in patenting of other companies.

2 The breakup of the Bell System

In this section, we describe the Bell System and the antitrust lawsuit against the Bell System that led to its breakup.

2.1 The Bell System

In the 1970s, the Bell System was the monopolistic provider of telephone services in the US. In 1974, it was the largest private company in the US by employment, with one million employees, or about 1.1% of the US workforce. It had revenue of $145.5 billion measured in 2020 US dollars, or 1.7% of US GDP. In terms of revenue relative to US GDP, the Bell System in 1974 was larger than Apple (1.3% of US GDP) and Alphabet (0.9% of US GDP) were in 2020, despite being a purely domestic company.[6]

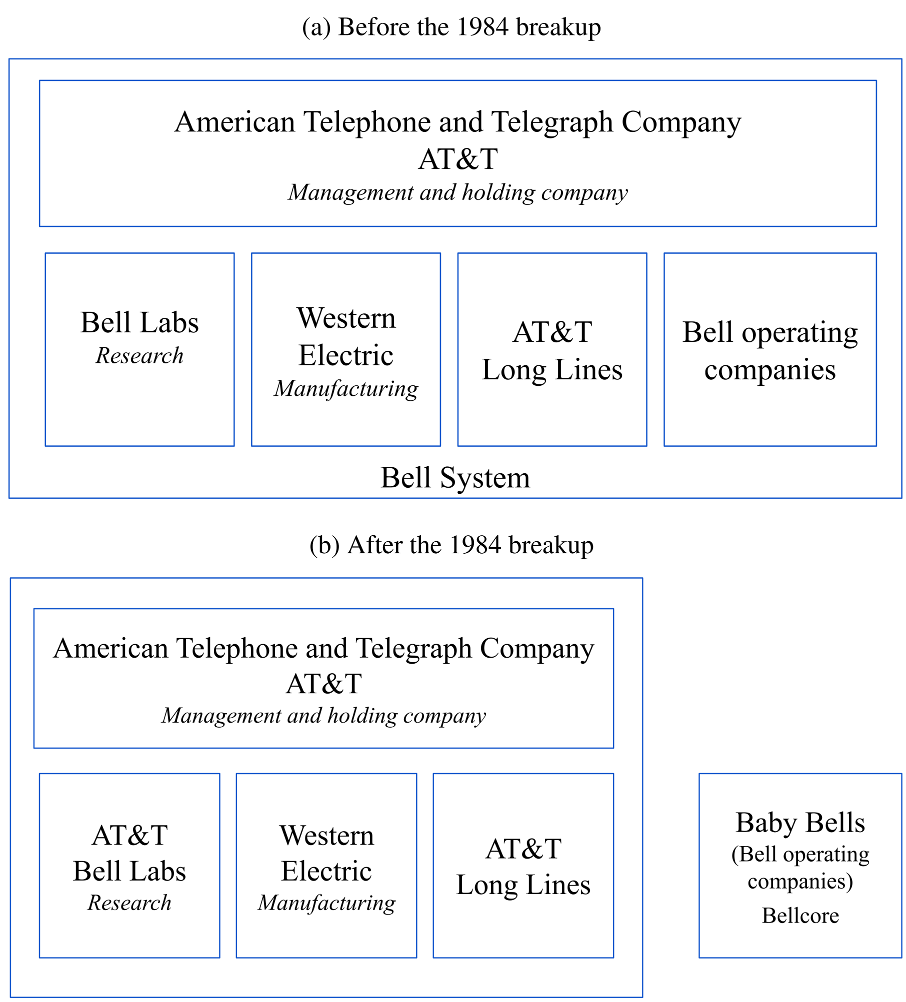
The structure of the Bell System in the 1970s is shown in Panel a) of Figure 1. AT&T was the management and holding company of the Bell System. The Bell Operating Companies provided local telephone services and were regulated at the state level, and they had a market share of more than 85% of all local telephone services. AT&T Long Lines provided long-distance services and was regulated at the federal level. It had a market share of 85% of all long-distance services in the US. Western Electric produced telecommunications equipment and had a 82% market share in the US (Commission et al., 1974). Bell Laboratories was the industrial laboratory of the Bell System.

Throughout its entire history, Bell was repeatedly accused of anti-competitive behavior. The key concern was vertical foreclosure. The Bell operating companies

[6]Employment numbers and the revenue of the Bell System are from the annual report of AT&T in 1974. The revenue of Apple and Alphabet are from the respective 10-K filings for 2020.

controlled local telephone networks, which were an essential facility (or bottleneck) for reaching customers for companies producing telephone equipment or providing long-distance services. Therefore, the Bell System had the ability to exclude competitors of Western Electric and AT&T Long Lines. Without the possibility to connect its equipment to the telephone network, producers of telephone equipment were simply unable to reach customers. Similarly, a long-distance service provider could not sell its services if the Bell operating companies refused to connect the

Figure 1: Structure of the Bell System



Notes: This figure shows the corporate structure of the Bell System before the 1984 breakup (Panel (a)) and after the 1984 breakup (Panel (b)).

provider to its local customers.

Whether or not Bell had an incentive for exclusionary conduct is debatable. On the one hand, tight regulation of local telephone rates and universal service obligations may have constrained the earning potential of Bell's operating companies. This may have created incentives for the Bell System to exclude competitors in less regulated downstream industries, in order to earn higher profits with its own subsidiaries (Laffont and Tirole, 2001). On the other hand, the FCC should have prevented such anti-competitive behavior of Bell through tailored regulation.

2.2 The Antitrust Lawsuit

During the 1960s and 1970, there were repeated complaints by competitors that Bell was using its control over the local telephone networks to exclude them. In 1974, the Department of Justice (DOJ) filed an antitrust lawsuit under Section 2 of the Sherman Act, that would lead to the breakup of the Bell System ten years later.

The complaint listed three main allegations: First, Bell had prevented the interconnection of competing long-distance service providers with Bell's local telephone system. Second, Bell had refused to connect non-Western-Electric telephone equipment to the Bell telephone system. Third, the Bell Operating Companies had directed the majority of Bell System telecommunications equipment purchases to Western Electric.[7]

The case commenced in 1981. The Assistant Attorney General in charge and Stanford Law Professor William Baxter resisted continuous pressure from the Department of Defense and the Reagan Administration to settle the lawsuit, and made it clear that he would litigate the case "to the eyeballs" (Schmalensee, 1998; Coll, 2017, p.215-219). Baxter's opposition was based on the conviction that regulation creates incentives to monopolize that are not present in unregulated sectors (Temin and Galambos, 1984, p.220-221). By the end of the year, AT&T directors authorized

[7]The complaint is filed under United States v. AT&T, Civil No. 74-1698 (D.D.C., filed Nov. 20, 1974). The press release of the complaint is available here: https://www.justice.gov/archive/atr/public/press_releases/1974/338834.pdf. The complaint is discussed in United States v. American Telephone & Telegraph Co., 461 F. Supp. 1314 (D.D.C. 1978), which is available here: https://law.justia.com/cases/federal/district-courts/FSupp/461/1314/2266659/.

the company to negotiate a settlement with the government.

On January 8th, 1982 AT&T agreed to a consent decree, the Modified Final Judgment. The decree stipulated that the Bell Operating Companies had to be separated from the rest of the Bell System and reorganized into seven Bell Regional Operating Companies ("Baby Bells"). The new structure is shown in Panel (b) of Figure 1. The Baby Bells were obliged to provide all long-distance service providers equal access to the local telephone network. They were also banned from manufacturing telecommunications equipment. The breakup of the Bell System, the largest corporate restructuring in history, was completed by January 1st, 1984.

The breakup changed the competitive situation in the telecommunications market in several ways. Most importantly, Western Electric and AT&T Long Lines could no longer rely on privileged access to Bell's operating companies as customers. Instead, the newly independent Baby Bells were free to buy their equipment and long-distance services from outside the Bell System and indeed did so (Crandall, 1991). For example, Olley and Pakes (1996) show that the share of telecommunications equipment purchased by the Bell System from Western Electric fell from 92% in 1982 to 58% in 1986. Correspondingly, the number of active companies in SIC 3661 "Telephone and telegraph apparatus" increased by 56% from 259 in 1982 to 403 in 1987.[8]

Thus, it seems that the breakup adressed the court´s main concern, that of exclusionary conduct. "AT&T has prevented competing for long-distance carriers, and competing equipment manufacturers from gaining access to the local network, thus placing them in an inferior position vis-a-vis AT&T's own services. (...) Some other remedy is plainly required; hence the divestiture of the local Operating Companies from the Bell System."[9]

[8]The scanned version of the Census of Manufacturers are available on `https://www.hathitrust.org/`. For example, the 1982 version is available here: `https://hdl.handle.net/2027/umn.31951d02881554v` (last accessed 2021-10-27).

[9]United States v. American Tel. and Tel. Co., 552 F. Supp. 131 (D.D.C. 1983) *223

3 Estimation Framework and Data

The aim of the breakup of the Bell System was to foster competition in the telecommunications market by separating the essential facility, the local operating companies, from the rest of the Bell System. To understand how this structural change in the telecommunications market influenced innovation related to this market, we need to compare the number of innovations after the breakup with what would have happened without the breakup. To implement this approach, we have to address three challenges: How to measure innovation consistently over a longer time period, how to identify innovations related to telecommunications, and how to construct the counterfactual.

To measure innovation consistently over the study period, we use the number of utility patents filed (and eventually granted) in a particular year. Patents are a noisy measure for innovation, as they capture only the disclosure of a novel, useful and non-obvious invention, not whether the invention is commercially valuable or successfully introduced in a market. The advantage of using patent data is that it is consistently available throughout our study period. In our main specification, we use patents from inventors residing in the US to measure US innovation. The reason to exclude foreign inventors is that these patents may not represent new inventive activity, but merely the transfer of technology previously developed for foreign markets to the United States.

To identify innovation related to telecommunications, our second challenge, we use the technology group classification of the Cooperative Patent Classification (CPC) scheme. The Patent Office uses the CPC scheme to organize patents according to the technical content. It is hierarchical and subdivided into sections, classes, subclasses, groups, and subgroups. For example, the US Patent 3,663,762 with the title "Mobile communication System" filed in 1970 by Edward J. Amos Jr. for Bell Laboratories - one of the defining patents for the cellular telephone technology - is classified according to the CPC as H04W 36/08. The section of this patent is H - "Electricity", the class is H04 - "Electric Communication Techniques", the subclass is H04W - "Wireless Communication Networks", the group is H04W 36 - "Handoff or reselecting arrangements." and the subgroup is H04W 36/08 - "Reselecting an access point." In our main analysis, the level of observation is the technology group.[10]

We define a technology group as telecommunications-related, if the Bell System received at least five patents in this technology group between 1965 and 1974, i.e., in the ten years prior to the filing of the lawsuit in November 1974.[11] At the time of the lawsuit, the Bell System was the largest US telecommunications company. In fact, Bell was barred from engaging in any business other than telecommunications by a consent decree, which settled an earlier antitrust lawsuit against AT&T (Watzinger et al., 2020). It thus seems plausible that Bell patented predominantly in technological fields that are potentially useful for telecommunications. Due to its commitment to basic science, inventors at Bell Laboratories also patented in other technology groups, but often only once. To filter out these idiosyncratic inventions, we require the Bell System to have patented at least five times in a technology group to designate it as related to telecommunications.[12] In total, the Bell System published 6406 patents during this time period.

Our third challenge is to construct a counterfactual; i.e., we need to determine what would have happened to patenting in telecommunications in the absence of the breakup. For this purpose, we again use the CPC technology classification system. We assign to each technology group classified as telecommunications-related ("treated technology groups") other technology groups as controls that are similar but not treated because they are not telecommunications-related. To ensure that control technology groups are similar, we use for every treated technology group

[10] This is the same level of observation as in Myers and Lanahan (2021), which analyses the impact of public R&D investment of the Department of Energy on the number of patents in a CPC group.

[11] We use patents *granted* from 1965 to 1974, instead of patents *filed* in this time period, to make sure that there is no bias due to a potential change in the patenting strategy of the Bell System when the antitrust case started.

[12] Appendix A.1 shows the Top 5 classes in the patent portfolio of Bell for patents published between 1965 and 1974.

only groups within the same technology subclass as a control.[13]

Our main sample has 232 treated groups and 6144 control groups within 75 technology subclasses.[14] The number of treated technology groups per subclass ranges from 1 to 9. To ensure that all technology subclasses receive equal weight in the estimate, we aggregate the number of patents in all treated and control technology groups into one treated and one control technology group per technology subclass.[15]

In our main specification, we compare the change in the number of patents in treated technology groups to the change in the number of patents in control technology groups within the same technology subclass before and after the breakup. For this purpose, we use the following regression model:

$$\begin{aligned} \#Patents_{s,g,t} &= \beta_1 \cdot Treat_g \cdot I[74-80] + \beta_2 \cdot Treat_g \cdot I[82-90] + \\ &\quad + Subclass_s \times Year\,FE_t + \varepsilon_{s,g,t} \end{aligned} \tag{1}$$

where the dependent variable $\#Patents_{s,g,t}$ is the number of patents in subclass s, group g and in filing year t. $Treat_g$ is an indicator function equal to one if group g is affected by the breakup and zero otherwise. We interact the treatment indicator $Treat_g$ with the time periods 1974 to 1980 and 1982 to 1990. All estimates are therefore relative to 1981, the year before the breakup was announced. β_1 measures the yearly number of excess patents in treated relative to untreated technology groups from the start of the antitrust case to the announcement of the breakup. β_2 measures the effect of the breakup on patenting.[16] We control for technology subclass x filing-year fixed effects to account for differences in patenting rates between technology

[13] Appendix A.2 shows as an example, the technology groups assigned to treatment and control for the subclass H04L - "Transmission of Digital Information."

[14] There are 639 subclasses in total. Thus, the Bell breakup affected 11.7% all subclasses.

[15] We show in Appendix B.6 that the results are robust if we do not aggregate.

[16] We use, as the start of the treatment period, the announcement date of the breakup, rather than the date of the actual breakup, because we cannot exclude the possibility that inventors reacted as soon as they knew of the breakup that was to be implemented later on.

subclasses over time. We include only patent subclasses that contain both treated and control technology groups.

As our main data source, we use the comprehensive patent data from PATSTAT (European Patent Office, 2016). The geolocation of the inventors is from Berkes (2018) and De Rassenfosse, Kozak, and Seliger (2019). We describe other data sources throughout the text. In Appendix A.3 we define each variable used in the analysis, describe its source and provide summary statistics.

4 The effect of the breakup on the US innovation rate

Through the breakup, the Bell System lost its control over the local telephone networks, reducing the scope for exclusionary practices. In this section, we estimate whether - and if so, by how much - the breakup increased the rate of telecommunications innovation of US inventors.

4.1 Baseline results

We start by investigating whether or not the breakup increased US innovation at all. Prima facie, it may not be obvious why it should have, because there are several countervailing effects (Shapiro, 2012). On the one hand, the breakup might have induced more innovation, because it increased the contestability of the market for long-distance services and telecommunications equipment, and thus encouraged market entry. There is strong pressure to innovate, even for the incumbent, if a firm can increase its market share by being innovative, or if it risks losing market share if it is not. On the other hand, the breakup might have reduced US innovation if innovation by the Bell System, the incumbent monopolist, suffered. Before the breakup, Bell Laboratories generated major breakthroughs in telecommunications research, as described above. The breakup may have reduced the ability of the Bell System to appropriate the returns of its own innovation activities and, as a consequence, lowered AT&T's incentive to invest in R&D. Also, the separation of the local telephone operating companies from Bell Laboratories may have reduced synergies within the Bell System. With less input from engineers who worked directly on the telephone networks, the R&D of the Bell System may have become less productive.

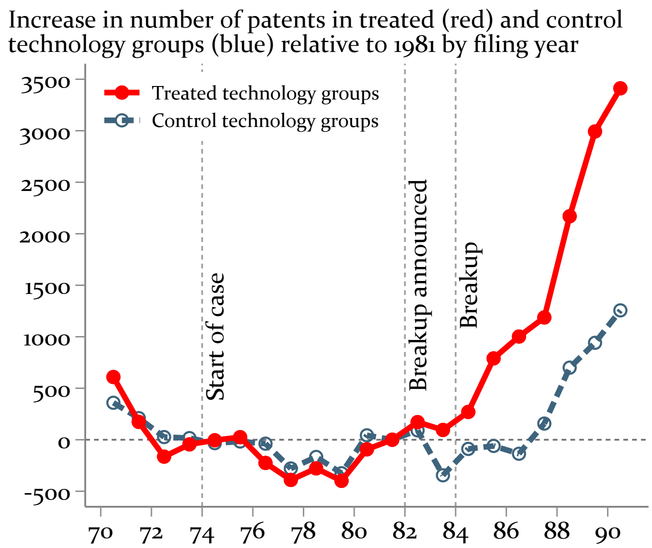
In Figure 2a, we compare the total number of patents of US inventors in treated technology groups (red solid line) with the total number of patents in control technology groups (blue dashed line), within the same CPC technology subclass before and after the breakup. To adjust for the higher levels of patenting in treated technology groups, we subtract the respective 1981 levels of patenting in treated and control groups. From 1970 to 1982, the total number of patents follow a very similar trend for treated and control groups. This implies that treatment and control technology groups exhibit a parallel trend in the number of patents in the first eight years after the beginning of the lawsuit in 1974. After 1982, the two lines begin to diverge. Starting in 1983, treated technology groups, i.e., technology groups in which Bell was active before 1974, show a higher patenting rate than control technology groups in the same subclass.

This difference in total patenting motivates our analysis of the average impact of the breakup on patenting across technology subclasses. Figure 2b shows the average yearly increase in the total number of patents in the period 1970 to 1990. We estimate these treatment coefficients along with their 95% confidence intervals, using a version of equation (1) with time-varying coefficients and convert the estimated absolute values into percentages. The baseline period is 1981, the year before the breakup was announced. From 1970 to 1980, the average number of patents relative to 1981 in treatment and control, track each other very closely, again suggesting parallel trends. After 1982, the excess number of patents in technology groups in which Bell was active increased. The effect does not decrease over time, which suggests that the antitrust case against Bell had a lasting positive effect on innovation by US inventors.

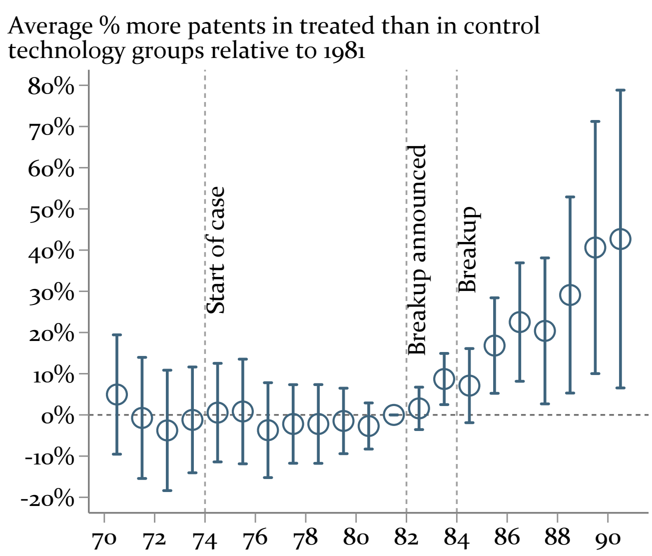
We estimate the effect of the breakup on the average yearly number of patents per technology group for the period 1974 to 1990, using the difference-in-differences model in Equation (1). We report the estimated coefficients and the 95% confidence intervals in Table 1. In columns (1) and (2), we report the results for our baseline regression, showing that after the breakup, the number of patents increases on average by 14.2 (95% CI: [4.5; 23.9]) or 19.0% (95% CI: [7%; 31.1%]) in treated technology groups relative to control technology groups. In this regression we use data on 75 technology subclasses, each with one aggregated treated and one

Figure 2: The effect of the breakup on patenting

(a) Total patenting



(b) Time-varying treatment effects



Notes: Panel a) shows the total number of patents in treated technology groups (red) relative to the total number of patents in control technology groups over time. Panel b) shows the impact of the breakup on the average difference in total patenting in terms of percent increases between treated and control technology groups within the same technology subclass. The 95% confidence intervals are based on standard errors that allow for clustering on the CPC technology subclass level. The time-varying treatment coefficients are estimated using a variant of Equation 1. All data is from PATSTAT.

Table 1: Quantifying the effect: Difference-in-Differences

	(1)	(2)	(3)	(4)	(5)	(6)
	US inventors		Without Bell inventors		Bell vs Synthetic Control	
	# patents	% increase	# patents	% increase	# patents	# impactful patents
Treat x I(74-80)	-1.0	-1.4	-0.9	-1.2		
	[-6.9,4.8]	[-9.0,6.2]	[-6.7,5.0]	[-9.3,6.8]		
Treat x I(82-90)	14.2	19.0	14.5	20.8	-107.2	15.8
	[4.5,23.9]	[7.0,31.1]	[4.7,24.3]	[7.7,34.0]	[-147.6, -66.9]	[12.7, 18.9]
Obs.	2550	2550	2550	2550	2615	2615

Notes: Columns (1) to (4) show the result of a difference-in-differences specification following Equation (1). The first column shows the result of an OLS regression of our baseline specification. The dependent variable is the count of all US patents with a US-based inventor in a treated or a control technology subgroup. We include technology subclass x year fixed effects. In column (2), we use the OLS estimates in (1), and transform them to percentage increases using the filing year 1981 and the treated group as baseline. In columns (3) and (4), we use the number of US patents with US inventors as outcome, but exclude patents of the Bell System. We report 95% confidence intervals. The confidence intervals in columns (1) to (4) are based on standard errors clustered on the subclass level. Column (5) shows the result using a synthetic control method to construct the number of patents for a counterfactual of the Bell System by filing year. In column (6), we also use the Synthetic Control Method to construct a counterfactual Bell, but we use the number of impactful patents as outcome. We define a patent as impactful if it is among the top 10% in terms of forward citations within its CPC subgroup and filing year. In columns (5) and (6), we use the placebo method standard errors described in Arkhangelsky et al. (2021).

aggregated control technology group. This means that our estimates imply a total increase of 1065 patents per year from 1982 to 1990.[17] In the period from 1982 - 1990, on average, 40,490 patents were issued in the US, so that 1065 patents per year represent 2.6% of all US patents.

One concern might be that this increase in patenting came at the expense of overall patent quality. In Figure A.7 in Appendix B.6 , we show that this is not the case. Using several different measures for patent quality, we find that the average quality of patents did not change after the breakup.

To summarize, our estimates show that the breakup increased patenting in

[17]The number of treated and control technology groups varies between technology subgroups. To give each subclass equal weight in the regression, we aggregate treated and control technology groups per subclass. We show in Appendix B.6 that the results are robust if we do not aggregate.

telecommunications on average. This suggests that the positive effect of increased contestability of the market for the long-distances service and telecommunications equipment outweighed the negative effect of a reduction in appropriability and innovation synergies for the Bell System. While the net effect is important for policy, we need to go beyond the average effect to understand the mechanisms behind this positive net effect. In the next section, we therefore analyze how the Bell System adapted its own innovative output, and which companies entered the market and contributed to the innovation increase.

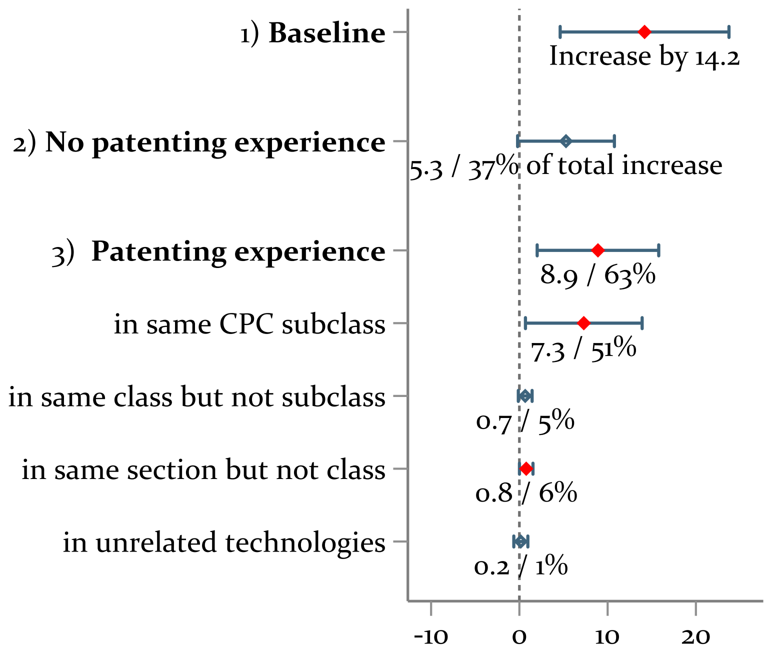
4.2 Effect on the Bell System versus non-Bell companies

To separate the effect of the breakup on Bell and non-Bell companies, we redo our difference-in-differences estimations in modified versions. We first drop all patents filed by the Bell System and its successor companies from our sample. The results are presented in Table 1, columns (3) and (4). When excluding Bell patents, the average effect is 14.5 extra patents (95% CI: [4.7; 24.3]) or an increase of 20.8% more patents (95% CI: [7.7%; 34.0%]). This confirms that non-Bell companies drive the increase in patenting.

To understand which type of firms increased their patenting we split the dependent variable further and report the result for the subsamples in Figure 3. The increase in patenting is driven primarily by firms with experience in the same technology class or subclass. Of the total increase of 14.2, about 37% or 5.3 patents is due to firms with no patenting experience; i.e., potentially new entrants, whereas 63% is due to firms with patenting experience (rows 2 and 3). 51% of the total increase in patenting (or 7.3 patents) is due to firms already active in the same technology subclass. The relatively larger role of incumbents for the innovation effect means that exclusionary behavior can be particularly harmful (and a breakup particularly beneficial), if many firms with technological experience are ready to enter the market.

Another way to investigate the consequences of increased contestability is to look at the entry of foreign companies. The prospect of access to the large US market may have encouraged innovation by foreign inventors (Schmookler, 1966; Acemoglu and

Figure 3: Other companies: Increase by companies with technology experience



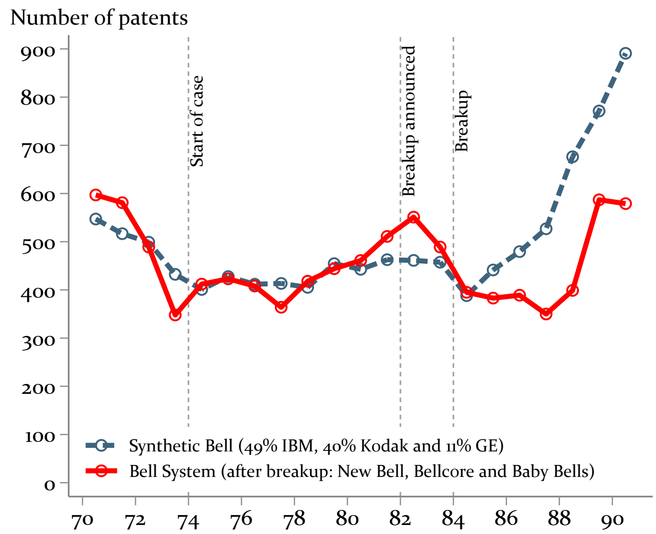
Notes: We analyze which companies increased patenting after the breakup. To do this, we split the outcome variable according to whether the assignees already patented before 1981 and in which technology class they patented. The 95% confidence intervals are based on standard errors that allow for clustering at the subclass level. The sources and definitions of all variables are shown in Appendix A.3.

Linn, 2004). In Appendix B.1, we include the US patents of foreign inventors in the outcome variable and find that the number of patents of foreign inventors also increases. Yet, at the time, foreign companies such as the Swedish Ericsson, the Japanese NTT or the Finnish Nokia were already producers of telecommunications equipment for their respective home markets. Therefore, some of the new patents granted to foreign inventors in the US may reflect a transfer of existing technology to the US, not the invention of new technology. This is why we exclude patents of foreign inventors in our main analysis.

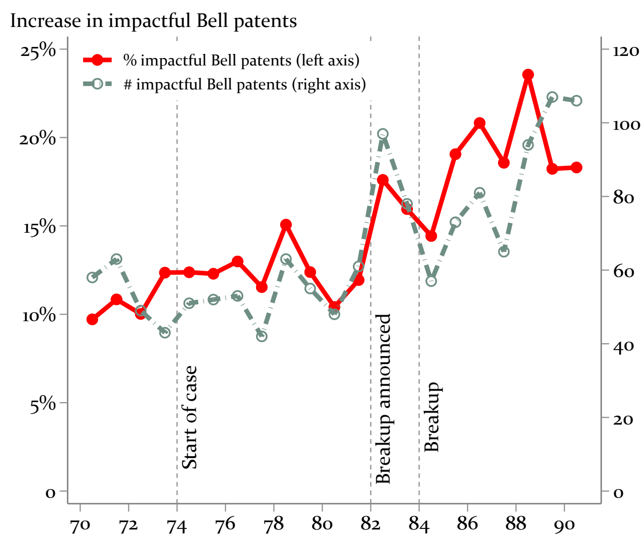
One key question for the evaluation of the breakup on innovation is whether innovation by the Bell System and most notably Bell Laboratories suffered, in terms of quantity and/or quality. Studying this question is difficult, because it requires us

Figure 4: Effect on Bell

(a) Synthetic control method - patent count



(b) Before and after comparison of impactful patents



Notes: Panel a) shows the evolution of the patenting of the Bell System, relative to a counterfactual Bell System constructed with the Synthetic Control Method. The red line shows the number of patents for the Bell System before the breakup and the number of patents for the successor companies of the Bell System after the breakup. The successor companies are the Baby Bells, Bellcore, and AT&T with its subsidiaries Western Electric, AT&T Long Lines, and the Bell Laboratories. The blue line shows the number of patents for the synthetic Bell System. In Panel b) we plot the number of impactful Bell patents and their share by filing year. We define a patent as impactful if it is among the top 10% in terms of forward citations within its CPC subgroup and filing year. All data is from PATSTAT.

to construct a counterfactual for a single firm. To do this, we employ the Synthetic Control Method (SCM) (Abadie and Gardeazabal, 2003; Abadie, Diamond, and Hainmueller, 2010; Abadie, 2021) and use patent counts per year up to 1981 as a matching variable. As the donor pool, we use all patent assignees with five or more patents before 1974. To construct the yearly patent count of the counterfactual Bell System, the SCM method gives us as the closest match 49% of the patent counts of IBM, 40% of Kodak, and 11% of General Electric.[18]

Figure 4a shows the results for patent quantity. After 1982, the number of patents for Synthetic Bell (blue dashed line) grows faster than the number of patents for the Bell System and its successors (red solid line). Results from the difference-in-differences estimation on the quantity effect are presented in Column (5) in Table 1. The Bell successor companies filed, on average, 107.2 fewer patents per year, compared to the synthetic Bell (95% CI [-147.6, -66.9]. This is a reduction of 23.9% relative to the average of 449.5 patents that the Bell System filed on average from 1970 to 1981.

In column (6), we use again the Synthetic Control Method but now use as outcome a measure for impactful patents. We define a patent as impactful if it is in the Top 10% of the forward citation distribution in a CPC technology subclass and filing year. By accounting for the technology subclass and filing year, we filter out trends in citations over technology and time. To construct the number of these highly impactful patents for the counterfactual Bell System we use the number of impactful patents per year up to 1981 as matching variable. The closest fit is achieved with the weighted sum of 30.2% General Motors, 23.2% DuPont, 22.2% Kodak, 13.3% General Electric and 6.5% IBM. Using the SCM method, we find that after the breakup, the Bell successor companies filed 15.8 (95% CI [12.7, 18.9]) more impactful patents per year. This is an increase of 37.1% relative to the average of 42.5 impactful patents that the Bell System filed per year between 1970 to 1981.

If overall patenting declined while the number of impactful patents increased, this suggests that Bell focused more on impactful patents. Figure 4b illustrates this

[18]IBM seems a plausible candidate for the counterfactual as it was also involved in an antitrust suit with the aim of a breakup. This lawsuit was dismissed on the same day the breakup of the Bell System was announced in January 1982. At the time, both GE and Kodak were R&D-intensive companies. In 1975, Kodak engineer Steven Sasson, for instance, invented the first digital still camera.

by showing the share of impactful patents among all Bell patents (red solid line, left axis) and the number of impactful patents (green dashed line, right axis) over time. There is a clear increase in influential patents as a percentage of all Bell patents after the breakup announcement.

In Appendix B.2, we show that the results are robust to the use of alternative measures of patent quality and the use of a synthetic difference-in-differences estimation method instead of the Synthetic Control Method.

The increase in impactful patents after the breakup suggests that before the breakup, Bell's incentive to innovate was dominated by the Arrow replacement effect (Arrow, 1962). This effect captures the fact that an incumbent has little incentive to cannibalize its own revenue by replacing existing products with new ones, and therefore invests less in innovation than a potential market entrant. One example from the Bell System that is consistent with the Arrow replacement effect is the suppression and concealment of the newly invented answering machine. Clarence Hickman developed the answering machine at the Bell Laboratories in 1934. Yet, the device was not patented and introduced to the market, but kept secret by the AT&T management, because it expected customers might fear a recording of their conversations and hence reduce their demand for telephone services (Clark, 1993; Wu, 2010).

In summary, the breakup increased overall innovation and does not seem to have kept the Bell Labs from engaging in pathbreaking basic science. One indication of this is that four Nobel Prizes and three Turing Awards were awarded for work done at the Bell Labs from 1982 to 1990.[19] This is also consistent with anecdotal evidence. Forbes Magazine wrote in 1989 about the consequences of the breakup:

> *"The industry has evolved into an entrepreneurial, freewheeling marketplace (...) Most important, the new competition has forced rapid technological change, in fact, a flowering of communications research.*

[19] The Nobel Laureates related to these four Nobel Prizes are Steven Chu (Physics 1997), Horst Störmer, Daniel Tsui and Robert Laughlin (Physics 1998), Eric Betzing (Chemistry 2014) and Arthur Ashkin (Physics 2018). The Turing Award winners are Robert E Tarjan (1986), Yann LeCun (2018) and Alfred V. Aho and Jeffrey Ullman (2020).

(...) Most fears about Bell Labs have turned out to be illusory. (...) [AT&T] has pumped up its R&D budget from about $2 billion annually at the breakup to about $2.7 billion in 1988 (...) AT&T continues to devote about 10% of the Labs' budget to basic research (...) Far more important for telephone users, competitive pressures are turning the concepts developed in the laboratory into products faster than before. About 30% faster, according to Ian Ross, president of Bell Labs. He says, "If you walk around the lab, there is a greater sense of urgency about implementing technology." Divestiture has clearly accelerated the pace of some crucial new communications developments. One major example: fiber optics, which provide more capacity and clearer transmissions."[20]

4.3 Auxillary Results and Robustness Checks

While our results indicate a strong positive effect of Bell's breakup on innovation, we need to ensure that we can rule out potential alternative explanations for the observed increase in US patenting. This section presents a series of analyses to show that our results are plausible and robust.

R&D spending increases in the telecommunications industry One potential concern might be that in our case, patent counts are not a suitable measure of innovation, because the propensity to patent may have changed at the time of the breakup. In particular, with more competition there might have been more need to protect inventions with patents. Also, concurrent changes in the patent system, such as the establishment of the United States Court of Appeal for the Federal Circuit in 1982, might have increased incentives to file for patents.

To see whether this concern is valid, we examine the development of R&D expenditures in industries related to telecommunications and compare this to the development in control industries. If the breakup increased innovation, not merely

[20]"Was breaking up AT&T a good idea? The answer, on balance, is yes. Five years after divestiture, many customers enjoy lower costs and more choices, the industry thrives, and the technology has advanced." (FORTUNE Magazine) By Kenneth Labich, January 2, 1989 (https://archive.fortune.com/magazines/fortune/fortune_archive/1989/01/02/71446/index.htm - last accessed 2021-09-24).

the propensity to patent, we would expect to also observe an increase in R&D as an input for the innovation process. As the data source we use the Compustat North America database and match it to the Compustat Historical Segment Data. We restrict the sample to the years 1976 to 1990, and include all companies in our dataset that have no missing R&D expenditure and sales in all years.[21] We exclude all companies related to the Bell System or its successor companies and drop "Telefonaktiebolaget LM Ericsson," as it is a predominately Swedish company. The final and balanced sample includes 78 companies over the 15 years.

Figure 5a shows the average R&D expenditure per company in the telecommunications industry group and the control industry group over time. We define the telecommunications industry group as SIC 3661 "Telephone and Telegraph Apparatus", SIC 3663 "Radio and Television Broadcasting and Communications Equipment", and SIC Code 481 - "Telephone Communications". As the control industry group, we use all other industries in the two-digit SIC code 36 - "Electronic and other Electrical Equipment and Components, except Computer Equipment" and 48 - "Communications" that are not in the telecommunications industry group. If a company is active in both the telecommunications and the control industry group in the same year, we attribute to each industry an equal share of the R&D expenditure of this company.

We find that after the breakup was announced in 1982, R&D spending in telecommunications companies increased relative to the control industries. To see whether an expansion in market size drives this effect, we normalize the R&D spending of a company by its sales (Figure 5b). The results again show an increase in R&D over sales in 1983 from 4% to about 6%. These results seem to suggest that not only innovation output measured by patents increased, but also innovation input.

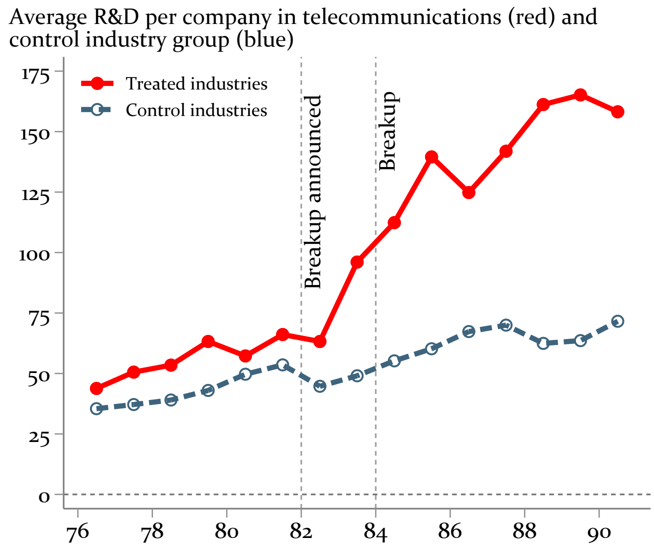
In Appendix B.3, we quantify the increase in R&D and R&D/sales using a difference-in-differences specification and show that the results are similar if we use an unbalanced sample that includes more companies.

Baseline effect not driven by introduction of software patents and changes in regulation of data services Another concern regarding our identification

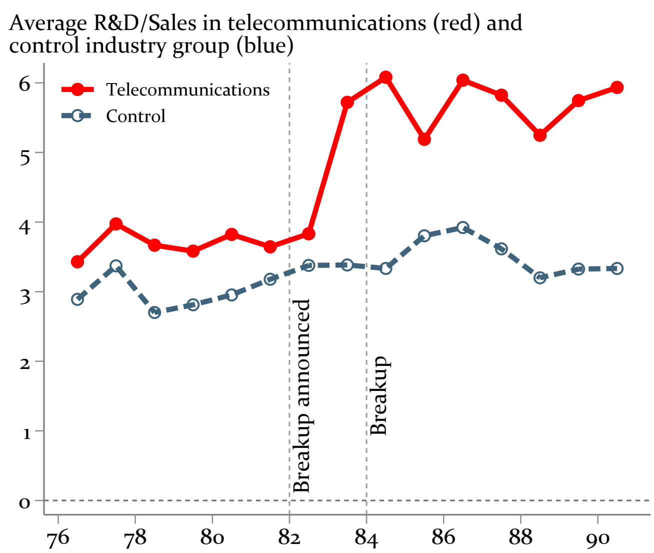
[21]The coverage of Compustat before 1976 appears to be significantly worse.

Figure 5: R&D expenditures over time

(a) Average R&D per company



(b) Average R&D over sales



Notes: Panel a) shows the average R&D per company in the telecommunications industry group compared to a control industry group over time. The telecommunications industry group is comprised of SIC 3661, SIC 3663, and SIC Code 481. The control industry group are all other industries in the two-digit SIC code 36 and 48. Panel b) shows the R&D to sales ratio. R&D and sales data is from Compustat North America. The industry classification is from the Compustat Historical Segment data.

of the effect is that the impact of the breakup on patenting might be driven by a contemporaneous shock. One such shock was the introduction of software patents in 1981. Furthermore, a new regulatory framework for data services called Computer II became effective in 1980. These regulatory changes might have increased the innovative potential of companies in the computer industry and also made the computer industry more attractive for Bell to enter, particularly as Bell already had extensive computer technology experience from manufacturingdigital switches. As noted above, an earlier consent decree restrained the Bell System from entering the computer market. This may have motivated Bell to agree to the breakup in order to get rid of these restrictions (Picker, 2020).

We show evidence suggesting that neither software patents nor the new regulatory framework for data services are the main driving forces behind our results. In columns (1) and (2) of Table 2, we repeat the results from our main difference-in-differences specification. In columns (3) and (4), we exclude software patents, in columns (5) and (6) we exclude data patents, and in columns (7) and (8) we exclude both. Software patents are 12.5% of our sample, data patents are 11.4% of our sample and the joint set are 16.8% of all patents in our sample. If we exclude software and data patents, we find that the increase in patenting after the breakup is, at 16.1%, of a similar size as in our full sample with 19.0% (columns 2 and 6). This suggests that after the breakup, patenting in all other technology fields grows at a rate similar to that of software and data patents.

Therefore, while software and data patents also increase after the breakup, they are not the only driver of the breakup effect. In Appendix B.5, we explain in detail how we determine software and data patents, give the historical background behind the regulatory changes and provide additional results.

Treatment assignment identifies telecommunications technologies A further issue might arise from our classification of telecommunications-related patents, based on the patent portfolio of Bell from 1965 to 1974. If for example scientists at the Bell Laboratories patented in fields unrelated to telecommunications, our estimates might pick up developments in these other fields that have nothing to do

Table 2: Quantifying the effect: Software and data-related patents

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	US inventors		Excl. software patents		Excl. data patents		Excl. software & data patents	
	# patents	% increase	# patents	% increase	# patents	% increase	# patents	% increase
Treat x I(74-80)	-1.0	-1.4	0.0	0.0	-0.2	-0.3	-0.2	-0.4
	[-6.9,4.8]	[-9.0,6.2]	[-5.1,5.1]	[-8.0,8.1]	[-5.0,4.6]	[-7.8,7.2]	[-5.0,4.5]	[-8.3,7.5]
Treat x I(82-90)	14.2	19.0	10.6	17.0	11.4	18.2	9.4	16.1
	[4.5,23.9]	[7.0,31.1]	[2.3,18.9]	[4.2,29.8]	[2.5,20.3]	[4.7,31.8]	[1.1,17.7]	[2.4,29.8]
Obs.	2550	2550	2550	2550	2550	2550	2550	2550

Notes: This table shows the result of a difference-in-differences specification following Equation (1). The first column shows the result of an OLS regression of our baseline specification. The dependent variable is the count of all US patents with a US-based inventor in a treated or a control technology subgroup. We include technology subclass x year-fixed effects. In column (2) we use the OLS estimates in (1) and transform them to percentage increases, using the filing year 1981 and the treated group as baseline. In columns (3) and (4), we exclude software patents from the analysis. In columns (5) and (6), we exclude data-related patents from the analysis. In columns (7) and (8), we exclude software and data-related patents from the analysis. We report 95% confidence intervals. The confidence intervals are based on standard errors clustered at the subclass level.

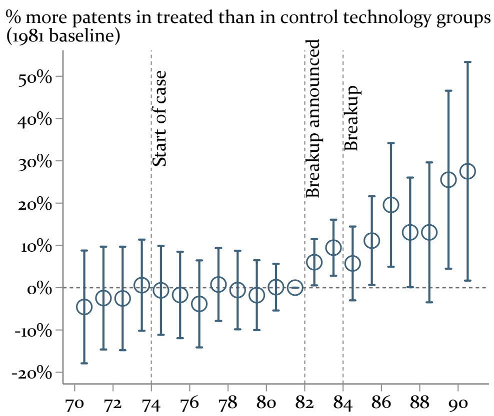
with the breakup. We provide a variety of robustness checks to document that this is unlikely.

First, we use an alternative way to define which technology groups are related to telecommunications and thus treated - not based on the Bell patents´ portfolio but on those of foreign telecommunications companies. The rest of the specification stays the same; i.e., as before, we use US patents as the outcome. If Bell patented in technologies outside of telecommunications because of their expected innovative potential and if this drives our main effect, we should not find any effect in our analysis, using the alternative treatment definition. To implement this analysis, we manually searched the worldwide patent record for companies that mainly produced telecommunications equipment and had at least 10 patents from 1965 to 1974. These are Nokia (Finland), NTT (Japan), Ericsson (Sweden), Standard Telephones and Cables (UK), Northern Telecom (Canada), Siemens Italy (Germany / Italy), Society Anonyme de Telecommunications (France), CIT (France) and Le Materiel Telephonique (France). Treatment is defined as having at least five patents filed in a non-US patent office in a technology group. Panel a) in Figure 6 shows that the results are very similar to our main specification in Figure 2a. In particular, the increase in patenting also starts in 1982, the year the breakup was announced.

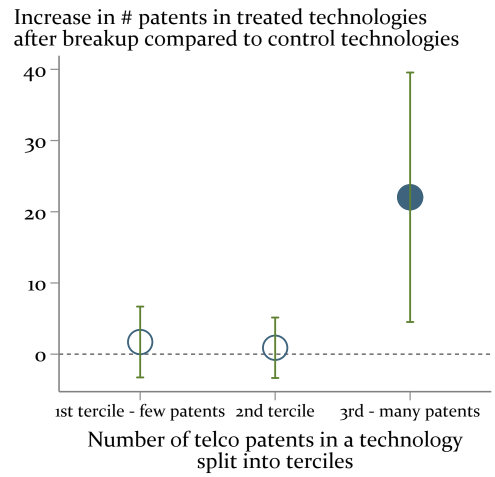
If in our main analysis we indeed observed the impact of the breakup, we should see a greater increase in patents in technologies that are more likely to be used in telecommunications than in technologies that are less likely to be used in telecommunications. To estimate the effect of the breakup for subclasses that are more or less central for telecommunications, we count the number of patents filed by the foreign telecommunications companies in the ten years prior to the antitrust case, that is between 1965 and 1974. We then split the technology subclasses by this patent count into terciles and redo the difference-in-differences analysis using each tercile as a separate sample. In Panel b) of Figure 6, we report the average impact of the breakup on patenting from 1982 to 1990 for each tercile. We find that the positive breakup effect on innovation is predominantly driven by technology subclasses that are more central to telecommunications. In Appendix B.4, we redo this exercise, but to split the sample into deciles, we use the count of Bell patents. We also provide results for a split into deciles. In both robustness checks, we find

Figure 6: Treatment defined by patents of foreign telecommunications companies in foreign patent offices

(a) Time-varying treatment effects



(b) Terciles split by the portfolio of foreign telecommunications companies



Notes: Panel a) shows the impact of the breakup on patenting in percent, using the patent portfolio of foreign telecommunications companies in foreign patent offices for the grant years 1965 to 1974, to define treatment. The foreign telecommunications companies are Nokia (Finland), NTT (Japan), Ericsson (Sweden), Standard Telephones and Cables (UK), Northern Telecom (Canada), Siemens Italy (Germany / Italy), Society Anonyme de Telecommunications (France), CIT (France) and Le Materiel Telephonique (France). Treatment is defined with five or more patents in a technology group. Panel b) shows the impact of the breakup on patenting after the breakup for different subsamples. To define the subsamples, we divide the patent portfolio of the foreign telecommunications companies into terciles, each containing 33 CPC technology subclasses. The 95% confidence intervals are based on standard errors that allow for clustering at the CPC technology subclass level.

consistent results, namely that the technology subclasses with more Bell patents, those more likely related to telecommunications, drive the result.

Robustness In Appendix B.6, we present several robustness checks using alternative treatment definitions, estimation methods, alternative samples, and outcome variables. We find similar results if we use the USPC instead of the CPC technology classification, if we use a different cutoff to define treatment, and if we do not aggregate treatment and control groups at the subclass level. We find similar results using the estimation method of Borusyak, Jaravel, and Spiess 2021 for the time-varying treatment effects, with Poisson pseudolikelihood regression instead of OLS. We re-calculate the standard errors of the event-study graph following Montiel Olea and Plagborg-Moller 2019. We also show that our results do not depend on a particular part of the sample, i.e., a specific CPC section, class, or subclass. Lastly, we use alternative outcome variables that account for patent quality and find that the number of quality-weighted patents increase overall.

5 The effect of the breakup on the diversity and direction of US innovation

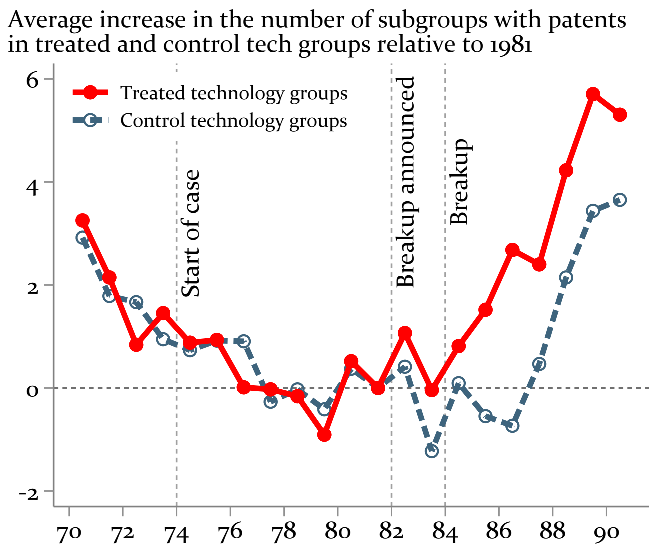
If the breakup had increased the number of inventors trying to come up with new ideas for telecommunications, this might have changed the diversity and direction of innovation. To determine whether this is in fact the case, we follow three different approaches. The results of our analysis are presented in Figure 7.

To study the diversity of innovation, we propose a novel approach that makes use of the technology classification system of the Patent Office. The Patent Office classifies the content of each patent according to its technology into a class, subclass, group, and subgroup. The lowest hierarchical level, subgroups, gives a fine-grained view of the technology in a patent.[22] For example, the patent for the first voicemail system (US 4,371,752, filed in 1979) is classified in the CPC subclass H04M "Telephonic communication" and in the technology group "Automatic or semi-automatic exchanges" (H04M 3). Its subgroup is "Centralised arrangements for recording messages for absent or busy subscribers" (H04M 3/50). But there are also 58 other subgroups within group H04M 3, such as "Arrangements for automatic redialing" (subgroup 424), "Arrangements for recalling a calling subscriber when the wanted subscriber ceases to be busy" (subgroup 48), or "Arrangements for providing information services, e.g. recorded voice services or time announcements" (subgroup

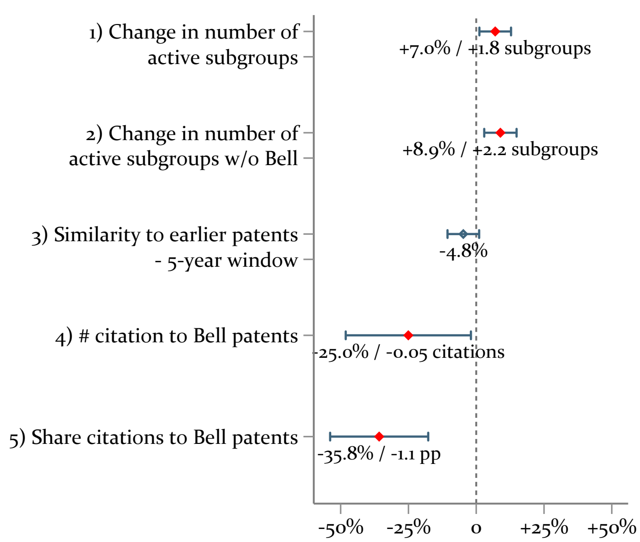
[22] All technology groups and subgroups of subclass H04L are listed here `https://www.uspto.gov/web/patents/classification/cpc/html/cpc-H04L.html` (last accessed 2021-10-21). Every patent is classified according to the newest version of the CPC classification. So if a new category enters into the classification system old patents are reclassified.

Figure 7: Direction and diversity of innovation

(a) Number of active subgroups over time



(b) Changes in various measures of diversity and direction of innovation



***Notes**:* Subfigure a) shows the change in the average number of technology subgroups with at least one patent in a filing year in treatment (red) and control technology groups (blue) relative to 1981 over time. In lines 1) and 2) of Subfigure a), we use the difference-in-differences specification to estimate the impact of the breakup on the number of subgroups. In lines 3) of Subfigure a), we use the 5-year backward similarity of Kelly et al. (2021) as the outcome for the same analysis. In lines 4) and 5) of Subfigure b), we estimate the impact of the breakup on the number and share of backward citations to Bell System patents. The sources and definitions of all variables are shown in Appendix A.3.

487).[23]

We call subgroups in which at least one patent is filed in a given year "active." To capture how innovation diversity was affected by the breakup, we count the number of active subgroups within a technology group and compare this number for treated and control technology groups before and after the breakup. Counting the number of subgroups with at least one patent in a year, the number of active subgroups, therefore allows us to capture the diversity of innovation on a fine level.

The results showing the average number of active subgroups in treated and control technology groups over time are presented in Subfigure a) of Figure 7. After the breakup, the average number of subgroups with at least one patent increases more in treated technology groups than in control technology groups. In Subfigure b), we use a difference-in-differences specification to quantify the effect. We find that the average increase in the number of active subgroups is +7.0% (95% CI [1.2%, 12.8%]) or 1.8 subgroups (95% CI [0.3, 3.2]). This suggests that after the breakup, the diversity of innovation increases.

We next exclude Bell patents from the sample and report results in row 2 of Subfigure b). After the breakup, we find that the average increases in the number of active subgroups is +8.9% (95% CI [3.9%, 14.9%]) or 2.2 subgroups (95% CI [0.8, 3.6]). This suggests that the increase in diversity is not driven by the Bell System.

To investigate the change in direction, we examine as a second approach, whether after the breakup, the text of patents in treated technology groups becomes less similar to all past patents, relative to those in the control group compared to before the breakup. For our analysis, we use the 5-year backward similarity measure of Kelly et al. (2021), which gives us the text-similarity of the full text of a patent to the full text of all patents filed in the five years preceding the filing year of the patent. The results are presented in row 3). After the breakup, the backward text similarity declines by 4.8% (95% CI [-10.6%, 1.1%]), suggesting that the text of patents changes. This implies that after the breakup, more new or different words are used in the patents of the treated technology groups than in the patents of the

[23] Subgroups have a hierarchy, called the dot-hierarchy. The first level of subgroups is zero-dot, also called the "main group". There are 12 hierarchical levels below the subclass level. We aggregate all subgroups to second highest level, the "two-dot" level. The figures for all dot-levels are shown in the Appendix C.1.

control groups.

Our third approach provides an alternative way to capture a potential change in the direction of innovation. For this purpose, we examine whether patents cited Bell patents to the same degree before and after the breakup, and report the results in rows 4) and 5) of Subfigure b). Each patent must disclose all prior art on which it is based by citing all relevant prior patents. Therefore, if patents relied less on the technologies of the Bell System after the breakup than before the breakup, we should see fewer citations to Bell patents, indicating a change in the direction of innovation activity. This is indeed what we find. After the breakup, patents in treated technology groups cite fewer Bell System patents, both in absolute numbers and in the percentage of all backward citations.

Taken together, the evidence points to an increase in the diversity, and a change in the direction of innovation after the breakup. This suggests that before the breakup, the Bell System, with its Bell Laboratories, tried too few different approaches in the field of telecommunications, relative to the competitive benchmark.

6 The breakup of Standard Oil 1911

On the day the settlement between AT&T and the Department of Justice was announced, the New York Times wrote that "The A.T.& T. agreement (...) would be the largest and most significant antitrust settlement in decades. It is likely to be compared with the 1911 settlement that divided the Rockefeller family's Standard Oil Company..."[24] Indeed, the Standard Oil case and the Bell case have many similarities. Similar to the Bell case, Standard Oil was accused of vertical foreclosure, and the case was also brought under Section 2 of the Sherman Act, also ending with a vertical breakup. Below, we analyze the breakup of Standard Oil to see whether it led to a similar increase in patenting as in the Bell case.

Standard Oil Co. was the dominant American company engaged in oil-production, transporting, refining, and marketing at the beginning of the 20th century. It reached

[24] Holsendolph, Ernest. "US settles phone suit, drops IBM case; AT &T. to split up." New York Times (1982): 8-9. (https://www.nytimes.com/1982/01/09/us/us-settles-phone-suit-drops-ibm-case-at-t-to-split-up-transforming-industry.html, last accessed 2022-07-13)

and maintained its dominant position by cartelizing oil transportation through exclusionary contracts with railroad companies and direct control over pipelines, the essential facilities for producing petroleum products, during the 1870s and 1880s (Granitz and Klein, 1996; Baker, 2012).

In 1909, the Department of Justice filed a federal antitrust lawsuit against Standard Oil under Section 2 of the Sherman Act. After eight months of deliberations, the judge concluded that Standard Oil's control of petroleum transportation had "the purpose of excluding others from the trade" (Lamoreaux, 2019). To end the exclusionary conduct, the court ordered the breakup of Standard Oil into 34 different companies. After the breakup, none of the oil companies would control the oil pipelines or have enough buying power vis-a-vis the railroad companies to implement exclusionary contracts. Standard Oil appealed the decision to the US Supreme Court but lost in 1911.

To estimate the effect of the breakup of Standard Oil on innovation, we compare the number of patents in technology fields related to the oil industry after the breakup with what would have happened without the breakup. Due to data limitations of the patent data before 1910, we adapt the methodology used for the Bell case in three ways. First, we use the grant date instead of the filing date of the patent as the time dimension, as the latter is usually not available before 1910. Second, we use the USPC technology classification system instead of the CPC system. This means that treatment and control are now specified at the subclass level instead of the technology group level. Third, we define treatment differently: A patent subclass is treated if the word "oil" is in the name of the assignee or the title of at least one patent filed in this subclass in the ten years from 1931 to 1940; i.e., twenty years after the breakup of Standard Oil.[25] For every treated technology subclass, we use the other subclasses within the same USPC technology class as control. In total, we have 169 technology classes with 644 treated subclasses and 4083 control subclasses. To give each technology class equal weight in the estimate, we aggregate the number of patents in all treated and control subclasses into one treated and one control subclass

[25] Before 1910, the assignee name is mostly missing in our patent data. Therefore we cannot define treatment based on the patent portfolio of Standard Oil before the breakup, as we do not know which patents are from Standard Oil. We use the period from 1931 to 1940 to define treatment as there is also little information on the title and abstract of a patent in our data before 1910.

per USPC class.

To measure the impact of the breakup of Standard Oil on patenting, we compare in Figure 8a the total number of patents of US inventors in treated technology subclasses (red solid line) with the total number of patents in control subclasses (blue dashed line) before and after the breakup. From 1895 to 1912, the total number of patents follows a very similar trend for treated and control subclasses. Starting in 1913, the number of patents in treated subclasses starts to grow more than the number of patents in control subclasses.[26] Figure 8b plots the time-varying treatment effects with their 95% confidence intervals. Starting in 1913, subclasses with patents that are useful in the oil industry experience a larger growth in the number of patents than control subgroups. In Appendix D.1, we quantify the effect of the breakup using a difference-in-differences setup. We find that the number of patents increases on average by 9.2 patents (95% CI: [3.2, 15.1]) or 14.9% (95% CI: [5.3%; 24.6%]) in treated subclasses relative to control subclasses. These results suggest that innovation in oil-related technologies increased after the breakup of Standard Oil.

The parallelity of results in the two cases more than 70 years apart lends plausibility to a causal relationship between the breakups and the increase in innovation. Or in other words, it would be quite a coincidence if, in both cases, an unrelated shock increased innovation in technologies affected by the breakup just after it was implemented. Unfortunately, there are too few breakups in US history to test the likelihood of such a coincidences.

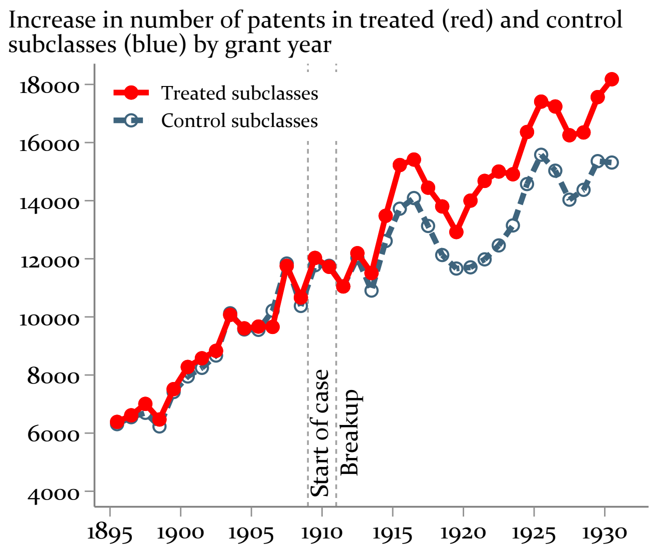
7 Conclusion

Our analysis of the 1984 breakup of the Bell System shows that the rate, direction, and diversity of innovation in telecommunications changed significantly after the

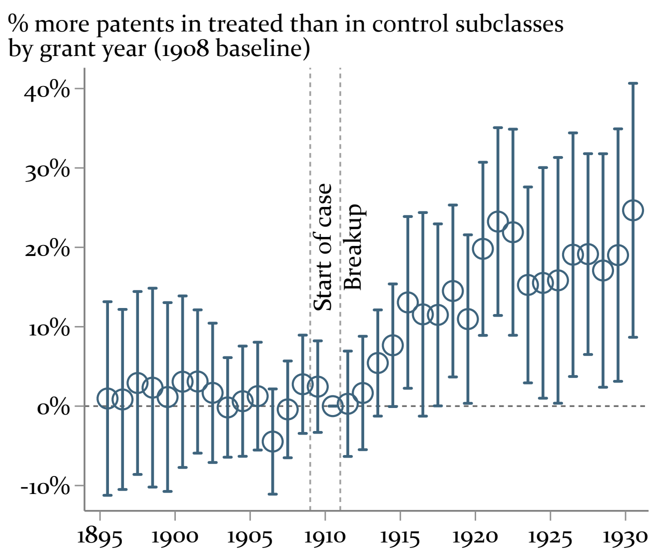
[26] The average difference between filing year and year the patent was granted was 1.42 for patents granted in 1911. This means that the increase in patenting started between the filing years of 1911 and 1912.

Figure 8: The effect of the breakup of Standard Oil on patenting

(a) Total patenting



(b) Time-varying treatment effects



Notes: Panel a) shows the total number of patents in treated technology groups (red) relative to the total number of patents in control technology groups over time by grant year. Panel b) shows the impacts of the antitrust case on Standard Oil on the average difference in total patenting in terms of percentage increases between treated and control technology groups within the same technology subclass. The 95% confidence intervals are based on standard errors that allow for clustering at the CPC technology subclass level. The time-varying treatment coefficients are estimated with a variant of Equation 1. All data is from PATSTAT.

breakup. Although our analysis focuses on one specific case, the core insights extend beyond that particular setting. First, this case shows that exclusionary conduct can harm innovative activity and should therefore be a key concern for antitrust authorities in high-tech sectors (Baker, 2012; Baker, 2019). If a company uses the control of an essential facility to exclude its competitors in related markets, a breakup might increase innovation by ending exclusion. While applying the antitrust laws to single-firm behavior is challenging and may have made antitrust authorities shy away from bringing forward antitrust cases based on Sherman Act Section 2 (Wood, 2021), our analysis emphasizes that the loss for society may be substantial.

Second, the breakup increased the scale of US innovation beyond the effect of the multitudes of regulations already imposed on the Bell System. While some authors argue that further regulation would have sufficed (Crandall and Winston, 2003), our analysis suggests otherwise. Therefore, structural remedies should be in the toolbox of the antitrust authorities and might be more effective than regulation (Gilbert, 2020).

Third, our study suggests that competition increases innovation diversity, even if a monopolist has the best industrial laboratory in the world. Innovation diversity is a significant concern today (Acemoglu, 2020). Our study suggests that promoting competition can be part of the solution.

Fourth, the majority of new telecommunications innovations post-breakup originated from existing companies with known technological capabilities. Therefore, in today's competition cases, the authorities might consider whether other companies are not yet active in the same product market as the company under investigation, but file for patents in the same technologies. This could be an indication of the number of potential entrants post-breakup.

It remains an open question whether the Bell breakup can serve as a model for today's antitrust cases.[27] The case against Bell in 1974 had the aim of isolating the essential facility of the local telephone services from the rest of the Bell System. This was an attractive structural remedy, because local telephone lines were a

[27]The Bell breakup in relation to the breakup of today's technology companies has been discussed in the media, e.g.: `https://www.nytimes.com/2018/02/20/magazine/the-case-against-google.html` and `https://www.wsj.com/articles/the-antitrust-case-against-facebook-google-amazon-and-apple-1516121561`

bottleneck for customer access that Bell could use to exclude competitors producing telecommunications equipment or long-distance services.

The question today is whether a comparable essential facility exists in the cases currently under consideration, and whether this essential facility is used to exclude competitors in related markets (Tirole, 2020). If, in addition, competitors stand ready to enter the market once exclusionary behavior is ended, our paper suggests that US innovation can benefit from the implementation of structural remedies.

It is important to note that the distributional consequences of breakups are beyond the scope of this paper. Before the breakup, most profits accrued to the Bell System. After the breakup, the market was the open to new companies from all around the world. At the time, policymakers recognized that US telecommunications companies lost market share after the breakup. For example, a 1990 report to the US Congress wrote that "The U.S. share of both the U.S. and the world telecommunications equipment market is declining" and that "The U.S. trade balance in telecommunications equipment declined from a surplus of $1.1 billion in 1978 to a deficit of $2.6 billion in 1988" (NITA, 1990). As the reallocation of profits from US companies to companies abroad constitute a significant policy concern, measuring the distributional consequences of antitrust policy is an important area for future study.

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Appendices

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A Appendix to Section 3

A.1 Top 5 classes in the patent portfolio of Bell

Table A.1: Bell System Patent Portfolio before start of the case

Share of Bell's patent portfolio (6406 patents) from 1965-1974 in					
Top 5 classes		Largest subclass within class		Largest Group within subclass	
H01 Basic Electric Elements	24%	H01L Semiconductor Devices	6%	H01L 21 Processes or apparatus adapted for the manufacture or treatment of semiconductor or solid state devices	3%
H04 Electric Communication Techniques	23%	H04Q Selecting	7%	H04Q 3 Selecting Arrangements	4%
H03 Basic Electric Circuitry	13%	H03K Pulse Technique	6%	H03K 3 Circuits for generating electric pulses	2%
G01 Measuring, Testing	6%	G01R Measuring Electric Variables	3%	G01R 31 Arrangements for testing electric properties; Arrangements for locating electric faults	2%
G11 Information Storage	5%	G11C Static Stores	5 %	G11C 19 Digital stores in which the information is moved stepwise, e.g. shift registers	2%
69 other classes	42%	212 other subclasses	70%	754 other main groups	87%

Note: This table shows the five technology classes according to the CPC classification with the largest number of patents in Bell's portfolio of patents that were published from 1965 to 1974. We also show the largest subclass within each class and the largest technology group within the largest subclass.

Table A.1 shows the Top 5 classes in the patent portfolio of Bell for patents published between 1965 and 1974. Bell published 6406 patents during this time period.

A.2 Technology groups assigned to treatment and control for the subclass H04L

As an example, Table A.2 shows the technology groups assigned to treatment and control for the subclass H04L - "Transmission of Digital Information". Seven technology groups with five or more Bell patents between 1965 and 1974 are assigned to treatment and the 18 other technology groups are assigned to control.

Table A.2: Example of treatment and control for subclass H04L

H04L Transmission of Digital Information 251 patents - 4% of Bell's patent portfolio from 1965-1974			
Group	Description	# Bell patents 1965-74	Treated
25	Baseband systems	67	Yes
27	Modulated-carrier systems	57	Yes
1	Arrangements for detecting or preventing errors in the information received	45	Yes
7	Arrangements for synchronising receiver with transmitter	28	Yes
12	Data switching networks	22	Yes
5	Arrangements affording multiple use of the transmission path	19	Yes
13	Details of the apparatus or circuits covered by groups H04L 15/00 or H04L 17/00	5	Yes
43	Arrangements for monitoring or testing packet switching networks	3	No
17	Apparatus or local circuits for transmitting or receiving codes wherein each character is represented by the same number of equal-length code elements, e.g. Baudot code	2	No
23	Apparatus or local circuits for systems other than those covered by groups H04L 15/00 - H04L 21/00	1	No
15	Apparatus or local circuits for transmitting or receiving dot-and-dash codes, e.g. Morse code	1	No
9	Cryptographic mechanisms or cryptographic arrangements for secret or secure communication	1	No
19	Apparatus or local circuits for step-by-step systems	0	No
21	Apparatus or local circuits for mosaic printer telegraph systems	0	No
29	Arrangements, apparatus, circuits or systems, not covered by a single one of groups H04L 1/00 - H04L	0	No
41	Arrangements for maintenance or administration or management of packet switching networks	0	No
45	Routing or path finding of packets in data switching networks	0	No
47	Traffic regulation in packet switching networks	0	No
49	Packet switching elements	0	No
51	Arrangements for user-to-user messaging in packet-switching networks	0	No
61	Network arrangements or network protocols for addressing or naming	0	No
63	Network architectures or network communication protocols for network security	0	No
65	Network arrangements or protocols for real-time communications	0	No
67	Network-specific arrangements or communication protocols supporting networked applications	0	No
69	Application independent communication protocol aspects or techniques in packet data networks	0	No

A.3 Data Sources, Definitions and summary statistics

Table A.3 gives definitions and data sources of variables used in the main text.

Table A.3: Data Sources and Definitions

Variable	Description
Main outcomes and treatment	
# Patents of US inventors	This is the number of patents assigned to US inventors per filing year and CPC technology group. To determine which inventor is a US inventors we use the geolocation of the first inventor in Patstat (Variable PERSON_CTRY_CODE in table tls206). If no geolocation is available we use the geolocation of the first inventor of De Rassenfosse, Kozak, and Seliger (2019) and then of Berkes (2018). If no geolocation of the inventor is available we use the geolocation of the assignee of Berkes (2018). We thank Enrico Berkes for sharing his data. Patstat can be ordered here `https://www.epo.org/searching-for-patents/business/patstat.html`. The current data catalog is available here `http://documents.epo.org/projects/babylon/eponot.nsf/0/225F09FAA60945C2C125855F002797C2/$File/PATSTAT_DataCatalog_Global_v5-17.pdf`. The geolocation of De Rassenfosse, Kozak, and Seliger (2019) is available here `https://www.nature.com/articles/s41597-019-0264-6`. To access the geolocation of Berkes (2018) please contact the author.

Variable	Description
# Patents of US inventors without Bell patents	This is the number of patents assigned to US inventors per filing year and CPC technology group excluding patents of the Bell System. We define the Bell System in the data as having psn_id 2197974 (BELL LABORATORIES) or 32292818 (WESTERN ELECTRIC COMPANY) or 1414759 (AT&T) or if the psn_name contains "AT&T" or "AMERICAN TELEPHONE" or if the psn_name is "AMERITECH SERVICES", "BELL ATLANTIC", "BELL ATLANTIC NETWORK SERVICES", "BELL COMMUNICATIONS RESEARCH", "NYNEX CORPORATION", "NYNEX SCIENCE & TECHNOLOGY", "SOUTHWESTERN BELL TELECOMMUNICATIONS", "SOUTHWESTERN BELL TELEPHONE COMPANY", "SOUTHWESTERN BELL TELEPHONE COMPANY", "U S WEST ADVANCED TECHNOLOGIES", "U S WEST BUSINESS RESOURCES", "U.S. WEST ENTERPRISES", "BELL ATLANTIC NETWORK SERVICES"
# Bell patents	This is the number of Bell patents assigned to US inventors per filing year and CPC technology group.
# Patents of foreign inventors	This is the number of patents assigned to non-US inventors per filing year and CPC technology group.
Treatment	A technology subgroup is treated if 5 or more patents were granted to the Bell System in the years 1965 to 1974.

Patenting experience

No patenting experience	An assignee of a patent has no patenting experience if it filed no patents before 1981. Assignees are identified by their psn_name (table tls206 in Patstat).
Patenting experience	The assignee has at least one patent with filing year prior to 1981....

Variable	Description
in CPC subclass	...in the same CPC subclass (e.g. H04L) under consideration.
in CPC class but not subclass	...in the same CPC class (e.g. H04) but did not file any patent in the CPC subclass (e.g. H04L) under consideration.
in CPC section but not CPC class	...in the same CPC section (e.g. H) but did not file any patent in the CPC class (e.g. H04) under consideration
in unrelated technologies	...in any CPC section other than the CPC section currently under consideration.
Measures for innovation diversity	
# of Bell citations	This is the number of citations to Bell patents per patent. The citation data is from table tls212 from Patstat and we exclude self-citations on assignee level. We drop patents with less than 5 backward citations.
Share of Bell citations	This is *# of Bell citations* divided by the number of all backward citations of a patent. We exclude self-citations on assignee level.
Similarity to earlier patents - 5-year window (Kelly et al. 2021)	This is the 5-year backward similarity from Kelly et al. (2021). To arrive at this variable,Kelly et al. (2021) first calculate for each patent text the TFBIDF, a version of "term-frequency-inverse-document- frequency" (TFIDF) modified to account for the innovation context. Then they standardize the TFBIDF and calculate the cosine similarity between two patents i and j to arrive at the pairwise similarity of patent i and j. To measure the 5-year backward similarity they sum up the pairwise similarity between the focal patent and all patents filed five years before the filing year of the focal patent. We thank Dimitrios Papanikolaou for sharing his data.

Variable	Description
Number of subgroups with a patent filed in a year	This is the number of technology subgroups with at least one patent in a filing year using the CPC classification in Patstat (table tls224). We use the two-dot level subgroup classification for each patent. The file showing CPC levels is available under the link "List of CPC Valid symbols (2021.08)" at `https://www.cooperativepatentclassification.org/cpcSchemeAndDefinitions/Bulk`. The two-dot level is level 9 in the classification file.
Number of subgroups with a patent filed in a year w/o Bell patents	This is the same as the variable *Number of subgroups with a patent filed in a year* but we drop all patents of the Bell System before counting the number of subgroups.
Data on R&D spending from Compustat	
R&D spending	Data item XRD in Compustat North America. This item represents all costs incurred relating to development of new products or services.
Sales	Data item SALE in Compustat North America. This item represents gross sales reduced by cash discounts, trade discounts, returned sales, excise taxes, and value-added taxes and allowances for which credit is given to customers.
R&D/Sales	Research intensity, calculated as XRD/SALE

Table A.4 shows the average value of all variables for treatment and control technology groups for the years before the breakup from 1974 to 1981. For each variable, we describe the source and definition in Appendix A.3. On average, treated technology groups have more patents than control technology groups (row 1). This is true for US inventors as well as for foreign inventors (row 2). If we exclude the patents of Bell, the size of treatment and of control groups becomes more similar (row 3) because by construction most Bell patents belong to treated technology

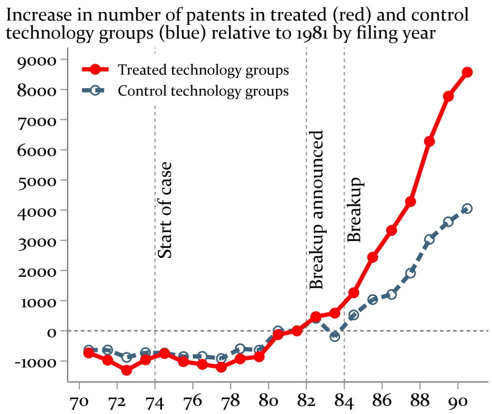
Table A.4: Summary Statistics for filing years 1974 to 1981

Main sample - 75 technology subclasses				
	Treated groups	Control groups	Diff	P-Value
Main outcomes				
(1) # Patents of US inventors	70.95	55.64	-15.31	0.26
(2) # Patents of US inventors without Bell patents	66.36	55.04	-11.32	0.39
(3) # Bell patents	4.59	0.60	-3.99	0.00
(4) # Patents of foreign inventors	40.37	31.58	-8.79	0.22
Measures for direction and diversity of innovation				
(5) Average # of Bell citations	0.28	0.17	-0.11	0.01
(6) Share of Bell citations	0.06	0.04	-0.02	0.03
(7) Similarity to earlier patents - 5-year window (Kelly et al. 2021)	5.99	6.06	0.07	0.38
(8) Average number of subgroups with a patent filed in a year	24.93	25.92	0.99	0.83
(9) Average number of subgroups with a patent filed in a year w/o Bell patents	23.86	25.69	1.83	0.69
Patenting experience				
(10) # Patents of assignees with no patenting experience	6.62	5.42	-1.20	0.35
(11) # Patents of assignees with any patenting experience	93.38	94.58	1.20	0.35
(12) Patenting experience in same CPC subclass	91.26	92.44	1.18	0.38
(13) Patenting experience in same CPC class but not in the same CPC subclass	0.83	0.78	-0.04	0.84
(14) Patenting experience in same CPC section but not in same CPC class	0.84	0.95	0.11	0.79
(15) Patenting experience only in unrelated technologies	0.45	0.41	-0.04	0.81

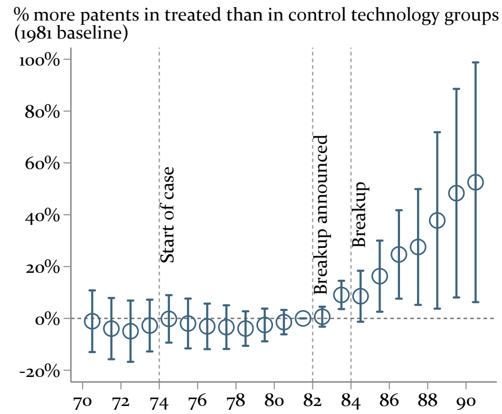
Note: This table shows average values for all variables used in the analysis. Treated technology groups are technology groups with five or more Bell patents in the year 1965 to 1974. Control technology groups are all technology groups within a subclass that are not treated. To arrive at these averages we first aggregate treated and control groups by subclass and then take the average across subclass by treatment status. The p-values result from a t-test with unequal variances. The sources and definitions of all variables are shown in Appendix A.3.

Figure A.1: Alternative Samples

(a) Including foreign inventors - Total patenting



(b) Incl. foreign inventors - Treatment effects



Notes: Panel a) shows for all US patents (US and foreign inventors) the total number of patents in treated technology groups (red) relative to the total number of patents in control technology groups over time. Panel b) shows the impacts of the antitrust case on average difference in total patenting (US and foreign inventors) in terms of percent increases between treated and control technology groups within the same technology subclass. The 95% confidence intervals are based standard errors that allow for clustering on the CPC technology subclass level. All data is from PATSTAT.

groups (row 4). In rows (5) to (15), we show the average values for the measures of innovation direction and diversity and patent experience.

B Appendix to Section 4

B.1 Results including foreign inventors

In our main analysis, we exclude patents of foreign inventors because US patents by foreign inventors might simply reflect a technology transfer of telecommunications technology developed earlier for foreign markets. In Figure A.1, we show the two main graphs for the sample with *all* US patents (independent of the country of the inventor) in Panels a) and b). In both cases the figures similar to our main specification: Up to 1981 there is a parallel trend in patenting and in 1982 the trends start to diverge. The breakup opened up the market for telecommunications equipment not only for US companies but also for foreign companies. For example the New York Times wrote on June 2 1984, that "The breakup of the American Telephone and Telegraph Company (...) [has] opened the market to competition (...) But the opportunities are as inviting to foreign companies - notably the Japanese - as to the American ones."[28]

In Table A.5, we show the effect of the breakup on patenting by country of residence of the inventor. In columns (1) and (2), we use all patents of all inventors as outcome variable. The number of patents in treated technology groups increases by 28.7 patents per filing year or 22.1%. In columns (3) and (4), we show our main results using only US inventors. Here the increase is 14.2 patents per year or 19.0%. In columns (5) and (6), we use the count of patents of Japanese inventors as outcome variable. We find an increase of 11.8 patents per year or 35.8% in treated relative to control technology groups. In columns (7) and (8), we look at inventors from Europe and find a small increase of 1.5 patent per year and technology subclass. Patents of inventors of all other countries increase by 1.2 patents. These numbers indicate that 49% of the total effect is from US inventors, 41% from Japanese inventors and 10% from the rest of the world.

B.2 Additional analysis for the breakup effect on patenting of the Bell System

One key argument voiced by critics against the breakup was that this intervention might destroy the Bell Laboratories and reduce US innovation. The argument is that Bell could no longer appropriate all the returns of its innovation, thus reducing the incentive for R&D, and that synergies within the Bell System would be lost. In the main part of the paper we use the Synthetic Control Method (SCM) to show that patenting of the Bell System decreased. In this section we show that the qualitative results are robust to using the Synthetic Difference-in-Differences method of Arkhangelsky et al. (2021) and we extend the analysis to quality weighted patent outcomes.

[28]Andrew Pollack "Bell Split-Up a Boon to Japan", New York times, June 2, 1984, pates 31,33 `https://www.nytimes.com/1984/06/02/business/bell-split-up-a-boon-to-japan.html` (Last accessed 10-16-2021)

Table A.5: Foreign inventors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	All		US inventors		Japanese		Europe		Others	
	# patents	% increase	# patents	% increase	# patents	% increase	# patents	% increase	# patents	% increase
Treat x I(74-80)	-2.7	-2.1	-1.0	-1.4	-2.2	-6.6	-0.4	-0.0	0.9	0.2
	[-10.3,4.9]	[-7.7,3.5]	[-6.9,4.8]	[-9.0,6.2]	[-6.0,1.6]	[-17.3,4.1]	[-2.1,1.3]	[-0.1,0.1]	[0.1,1.7]	[-0.0,0.4]
Treat x I(82-90)	28.7	22.1	14.2	19.0	11.8	35.8	1.5	0.1	1.2	0.3
	[6.7,50.7]	[6.8,37.4]	[4.5,23.9]	[7.0,31.1]	[0.7,23.0]	[3.4,68.3]	[-1.3,4.3]	[-0.1,0.2]	[0.2,2.2]	[0.0,0.5]
Obs.	2550	2550	2550	2550	2550	2550	2550	2550	2550	2550

***Notes**:* This table shows the result of a difference-in-differences specification using the number of patents of foreign inventors as outcomes. The odd column show the level specification and in the even columns we transform the level results to percent increases using the filing year 1981 and the treated group as baseline. In the first two column we use the number of all US patents in a filing year as outcome. In the following columns we use the number of patents of US inventors, Japanese inventors, European inventors and inventors that are neither based in the US, Japan or Europe as outcome. We report 95% confidence intervals. The confidence intervals are based on standard errors clustered on the subclass level.

Table A.6: Synthetic Control Method

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Number of patents in Top 10% of					
	# Patents		Forward Citations		KPTS Patent Quality		KPSS patent value	
Period	Synth Control	Synth DiD	Synth Control	Synth DiD	Synth Control	Synth DiD	Synth Control	Synth DiD
82-90	-107.2	-196.3	15.9	12.4	14.5	10.0	-22.2	-41.9
	[-147.6, -66.9]	[-241.1, -151.6]	[12.7, 18.9]	[10.3, 14.3]	[1.3, 17.7]	[7.0, 13.1]	[-23.8, -20.5]	[-43.0, -40.8]
Obs.	2615	2615	2615	2615	2615	2615	2615	2615

Notes: This table shows the result from a synthetic control method (odd column numbers) and a synthetic difference-in-differences method (even column numbers) for the Bell System. Each line gives the difference along with 95% confidence intervals between the Bell System and the constructed Doppelganger of the Bell System for the prediction period given in the first column. The Doppelganger is constructed using the outcome data from 1970 up to the prediction years.

Table A.6 shows the results. Each column shows a different analysis with a potentially different Doppelganger. In the first column, we construct a Doppelganger for the unweighted number of patents of the Bell System per filing year using the synthetic control method. As donor pool we use all assignees with 5 or more patents before 1974. We match on the years 1974 up to 1981 and predict the years 1982 to 1990. This is the specification discussed in the main part of the paper. The Doppelganger is 49% IBM, 40% Kodak and 11% General Electric. We find that patenting decreases by 107.2 patents relative to this Doppelganger. In column (2), we use Synthetic Difference-in-Differences instead of the Synthetic Control Method and find a larger decline of 196.3 patents. The Doppelganger is here 40% IBM and 60% Kodak. In columns (3) to (8), we weigh patenting with various quality measures. In columns (3) and (4), we use the number of patents that are in the top 10% in terms of forward citations in the filing year as quality-weighted outcome. We find an increase in the number of patents in the top 10% of forward citations. In columns (5) and (6), we use number of patents in the top 10% of the 10 year patent quality measure of Kelly et al. (2021) in a filing year. This quality measure is calculated by standardizing the sum of a text similarity measure of a patent to patents filed in the following 10 years with the sum of a text similarity measure to patents filed five years before. It thus takes into account how novel the text of the patent is relative to past patent and how future patents are influenced by the patent under consideration. Using this measure we find no impact if we use the Synthetic Control Method and an increase in top patents using the Synthetic Difference-in-Differences method.

One issue with forward citations and the KPTS value in this setting is that if the breakup increased the number of patents the number of potential forward citations and the potential for text similarity goes up. In columns (7) and (8), we use as alternative the number of patents in the top 10% of the Kogan et al. (2017) (KPSS) values as quality-weighted outcome. This measures uses the abnormal stock-market returns around the publication of a patent as a measure of quality. Here, we see a decline in the number of high-quality patents as outcome. Yet, this measure might also be problematic as the breakup introduced competition in the telecommunications market, which may have had a negative impact on the value of Bell's patents.

Taken together, there seems to have been a decline in the absolute number of patents but high quality patents are steady.

B.3 Additional analysis using R&D spending as outcome

In the main part of the paper we show visually that average R&D spending per company in the telecommunications industry group increases relative to a control industry group over time. We define the telecommunications industry group as SIC 3661 "Telephone and Telegraph Apparatus", SIC 3663 "Radio and Television Broadcasting and Communications Equipment" and SIC Code 481 - "Telephone Communications". As control industry group we use all other industries in the two digit SIC code 36 - "Electronic and other Electrical Equipment and Components, except Computer Equipment" and 48 - "Communications" that are not in the telecommunications industry group. If a company is active in the telecommunications and the control industry group in the same year we attribute each industry an equal share of the R&D spending of this company. As data source we use the Compustat North America database, match it to the Compustat Historical Segment Data and deflate R&D spending and sales with the GDP deflator from the Federal Reserve Bank of St.

Louis (FRED). We restrict the sample to the years 1976 to 1990.[29] We include all companies in our dataset that have in all years non-missing R&D spending and sales. Furthermore, we exclude all Bell companies and drop "Telefonaktiebolaget LM Ericsson" as it is a predominately a Swedish company. The final sample includes 78 companies over the 15 years.

To quantify the effect of the breakup on R&D and R&D over sales, we use the following difference-in-differences specification

$$\begin{aligned} R\&D_{f,t} &= \beta_1 \cdot Treat \cdot I[1895-1909] + \beta_2 \cdot Treat \cdot I[1911-30] + \\ &\quad + YearFE_t + Controls + \varepsilon_{f,t} \end{aligned} \tag{2}$$

where the dependent variable $R\&D_{f,t}$ is either the level of R&D or the ratio to R&D to sales of company f in fiscal year t . $Treat_i$ is an indicator function equal to one if company f is active in a treated industry. We interact the treatment indicator $Treat$ with the time periods 1976 to 1980 and 1982 to 1990. All estimates are therefore relative to 1981, the year before the breakup was announced. β_1 measures the average yearly increase in *R&D* per company in treated relative to untreated industry groups from the start of the antitrust case to the announcement of the breakup. β_2 measures the effect of the breakup on *R&D*. We control for year fixed effects and cluster the standard errors on the firm level.

The results are shown in Table A.7. In column (1), we find an increase in the average level of R&D of 55.8 million US Dollar but the estimate is imprecise. In percent terms R&D increases by 46.4 percent (column 2). After the breakup the R&D/sales ratio increases by 1.6 percentage points what corresponds to an increase of 28% (columns 3 and 4). If we control for firm fixed effects in columns (5) and (6), the results are similar. In columns (7) and (8), we include more companies by relaxing the requirement for inclusion in the sample. We include all firms in Compustat that are active in at least 5 of the 15 years but drop companies with an R&D to sales ratio over 25%. The resulting sample has 619 companies. If we use this sample the increase in R&D after the breakup is with 29.2 million about half as

[29] The coverage of Compustat before 1976 appears to be significantly worse.

big as in the balanced sample (column (7). The increase in R&D/sales is similar to our main results (column 8).

B.4 Alternative results by the centrality of a technology for telecommunications

In the main part of our paper we split the sample into terciles according to the number of patents of foreign telecommunications companies has in each technology subcategory. Panel a) in Figure A.2 repeats the results from the main paper. Each tercile contains 33 technology subclasses. In Panel b), we split the sample into deciles instead of terciles. The increase in patenting is mainly driven by the top decile. In Panel c), we split the sample by the number of Bell patents from 1965 to 1974. We find again, that the overall effect of the breakup is driven by the tercile with the most telecommunications patents. Each tercile contains 25 subclasses. In Panel d), we split the sample of Bell patents into deciles and find the that effect is driven by the top 2 deciles.

B.5 Additional results excluding software patents and patents related to data processing

Increase in software patents does not drive the effect

In 1981, in its decision *Diamon v. Diehr* the Supreme Court allowed the patenting of software tied to physical or mechanical processes (Layne-Farrar, 2006; Hall and MacGarvie, 2010). Before that, software was protected by copyright but could not be patented. The Supreme Court ruling led to a large increase in patents related to software. As Bell patents covered a wide range of fields including software this court decision might affect our results.[30] To ensure consistency of patenting standards over time we redo our analysis excluding software patents. We use the complementary

[30]The Bell Laboratories are credited with the development of the Unix operating system and the programming languages C and C++ among many others.

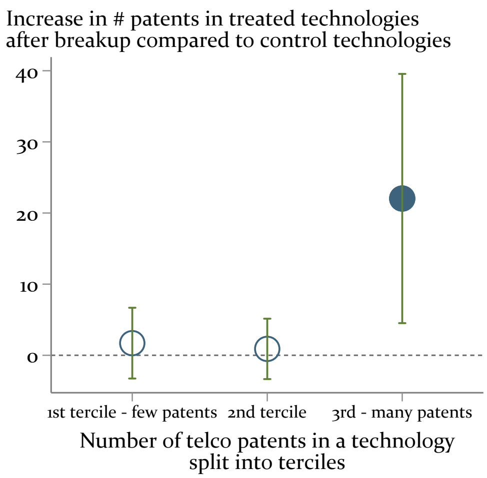
Table A.7: Difference-in-Differences: R&D and R&D/Sales

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Balanced sample				With firm FE		With more companies	
	R&D		R&D/Sales		R&D	R&D/Sales	R&D	R&D/Sales
	level increase	% change	precentage points	% change	level increase	precentage points	level increase	precentage points
Treat x I(76-80)	0.3	0.2	0.3	5.1	-1.3	0.2	7.6	0.2
	[-23.0,23.6]	[-18.8,19.3]	[-0.5,1.0]	[-7.8,17.9]	[-20.0,17.5]	[-0.5,0.8]	[-6.2,21.4]	[-0.4,0.9]
Treat x I(82-90)	55.8	46.4	1.6	28.0	59.0	1.1	29.2	1.8
	[-28.9,140.5]	[9.4,83.4]	[0.2,2.9]	[10.5,45.5]	[-21.7,139.7]	[-0.1,2.4]	[-5.5,64.0]	[1.0,2.6]
Number firms	78	78	78	78	78	78	619	619
Obs.	1244	1244	1244	1244	1244	1244	5891	5891

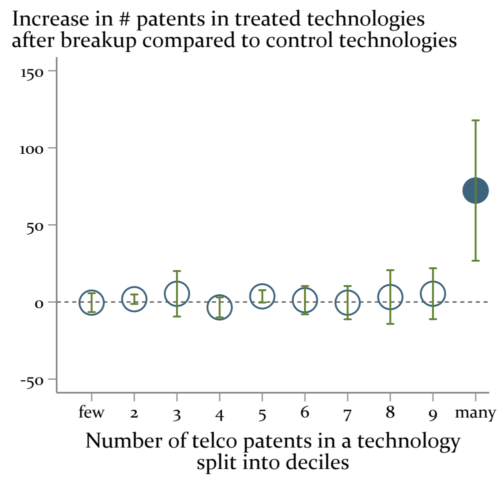
***Notes**:* Columns (1) to (4) show the result of a difference-in-differences specification following Equation (2). The first column shows the result of an OLS regression of our baseline specification. The dependent variable is R&D spending per company. In column (2) we use the OLS estimates in (1) and transform them into percentage increases using the filing year 1981 and the treated group as baseline. In columns (3) and (4) we repeat the analysis of columns (1) and (2), but use R&D over sales per firm as outcome. In columns (5) and (6) we repeat the analysis of columns (1) and (3) but include firm fixed effects. In columns (7) and (8) we include all companies that are for five or more years in our data and that have a R&D/sales ratio below 25%. The confidence bounds are based on standard errors that are clustered on the firm level.

Figure A.2: Alternative specifications for centrality regression

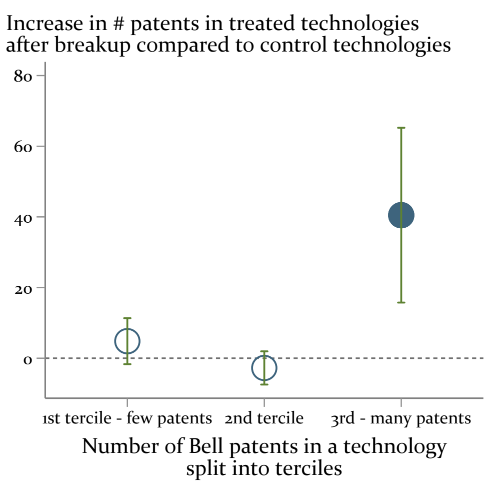
(a) Terciles split by the portfolio of foreign telecom-munications companies



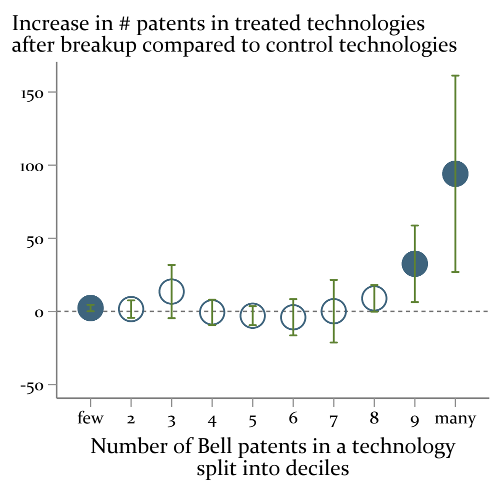
(b) Deciles split by the portfolio of foreign telecom-munications companies



(c) Terciles split by Bell portfolio



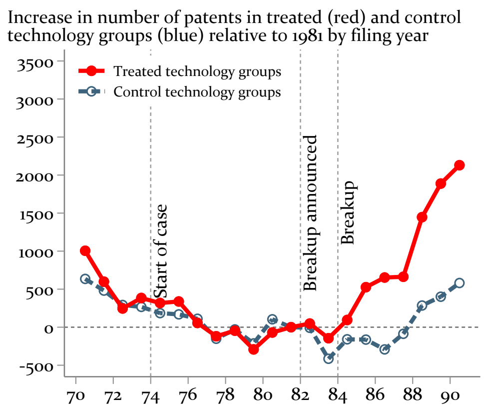
(d) Deciles split by Bell portfolio



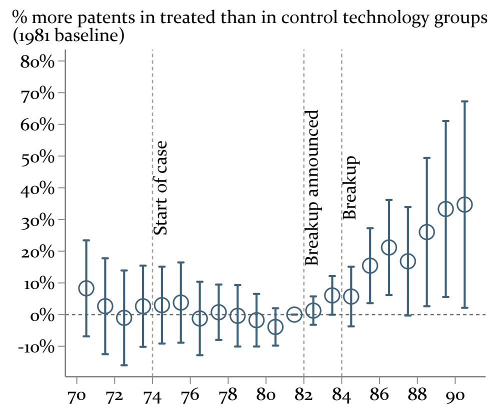
Notes: Panel a) repeats the analysis from the main part of the paper using the patent portfolio of foreign telecommunications companies of patents published between 1965 and 1974 to define the subsamples. Each tercile contains 33 CPC technology subclasses. The foreign telecommunications companies are Nokia (Finland), NTT (Japan), Ericsson (Sweden), Standard Telephones and Cables (UK), Northern Telecom (Canada), Siemens Italy (Germany / Italy), Society Anonyme de Telecommunications (France), CIT (France) and Le Materiel Telephonique (France). Panel b) repeats the analysis of Panel a) with deciles. Panel c) shows the impact of the breakup on patenting after the breakup for different subsamples based on the Bell patent portfolio. To define the subsamples, we divide Bell's patent portfolio published between 1965 and 1974 into terciles by the number of Bell patents. Each tercile contains 25 CPC technology subclasses. The treatment coefficients for the breakup-effect are estimated using Equation 1. Panel b) repeats the analysis of Panel c) with deciles. The 95% confidence intervals are based standard errors that allow for clustering at the CPC technology subclass level.

Figure A.3: Excluding software and data patents

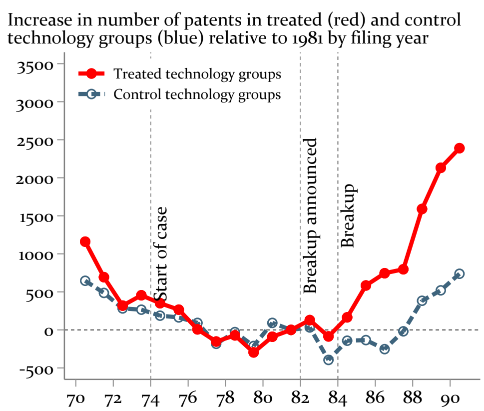
(a) Without software patens - patenting



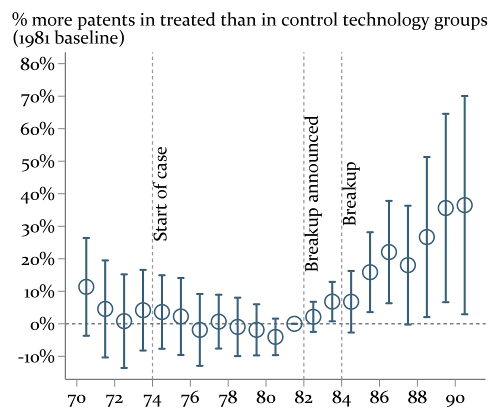
(b) Without software patents - treatment effects



(c) Without data patents - patenting



(d) Without data patents - treatment effects



Notes: In panels a) and b), we exclude software patents from our main dataset. Panel a) shows the total number of patents in treated technology groups (red) relative to the total number of patents in control technology groups over time. Panel b) shows the impact of the antitrust case on average difference in total patenting in terms of percentage increases between treated and control technology groups within the same technology subclass. The time-varying treatment coefficients are estimated with a variant of Equation 1. The 95% confidence intervals are based on standard errors that allow for clustering at the CPC technology subclass level. In Panels c) and d), we repeat the same analysis as in Panels a) and b), but we exclude data related patents instead of software related patents. The definition of software and data related patents are provided in the text.

methods of Graham and Mowery (2003), Graham and Mowery (2005), and Bessen and Hunt (2007) to identify software patents. We then exclude all patents identified as software-related by at least one of the three approaches.[31] Combining all three methods, we identify in total 27,510 patents out of 218,715 patents as software patents; i.e., 12.5% of all patents in our main empirical sample.

In panels a) and b) of Figure A.3, we show our two main graphs excluding software patents. While this suggests that software patents may have contributed to the observed increase in patenting, it confirms that they are not the main driver of the increase in patenting after the breakup. The resulting figures are virtually identical to our main figures.

Computer II does not drive the effect

One key concern throughout the 1970s was that the Bell System would use its control over the local telephone system to extend its monopoly to data communications. Computer II aimed to prevent this by creating two categories of data services: Basic services and enhanced services.[32] "Basic services" is the pure transmission of data. "Enhanced services" are all other services that involve the processing of data such as e-mail or newsgroups. Basic services were regulated while Enhanced Services were not. The Bell Operating Companies could offer Basic Services as part of their regulated services. In contrast, they could not offer Enhanced Services on their own. To do so, they had to establish a completely separate subsidiary instead. The aim

[31] Graham and Mowery (2003) identify the CPC subclasses G06F, G06K, H04L as the subclasses containing the largest number of software patents. Graham and Mowery (2005) use the USPC patent classification system and define patents in class 345, 358, 382, 704, 707, 709, 710, 711, 713, 714, 715, 717 as software patents. Bessen and Hunt (2007) searched the text of all US patents from 1976 to 19977 in three steps to define a software patents. According to this approach, a software patent is a patent where the words "software" or "computer" and "program" appear in the patent description and the words "antigen", "antigenic", and "chromatography" do not appear in the patent description and the words "chip", "semiconductor", "bus", "circuit", or "circuitry" do not appear in the title.

[32] An excellent source on the Computer Inquiries is `https://www.cybertelecom.org/ci/cii.htm` (last accessed 10-12-2021).

of this requirement was to rule out cross subsidization and thus to prevent unfair competition from the Bell Operating companies in the field of Enhanced Services.

The Computer II inquiries were launched in 1976 and ended in 1980. Our estimated breakup effect starts in 1983. To get an indication of how much Computer II might have influenced our measured treatment effect we redo our analysis excluding patents that are related to data processing or the Computer II framework. To identify such patents we search the title, abstract and claims (where available) of all US patents for the words "data", "basic service" and "enhanced service". Using these criteria, we identify in total 24,971 patents out of 218,715 patents as data processing related patents; i.e., 11.4% of the patents in our main empirical sample.

Panels c) and d) of Figure A.3 show our main results excluding the identified data patents. The resulting graphs look again similar to our main graphs. This suggests that the breakup spurred innovation mostly outside the fields related to Computer II.

All these results suggest that neither the introduction of software patents nor the introduction of Computer II can explain the observed size of the increase in patenting after the breakup was announced in 1982.

B.6 Alternative treatment definitions, estimation methods, subsamples, and alternative outcomes in our main specification

This section discusses plausible treatment definitions, estimation methods, alternative samples, and alternative outcome variables.

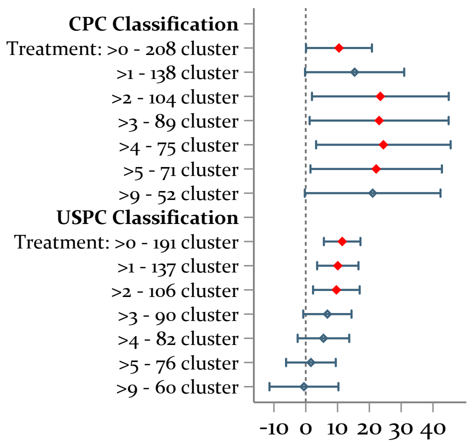
Alternative definition of the treatment In Figure A.4 we show the results of alternative definitions of the treatment. In our main setting we define a technology group as treated if in a CPC technology group there are at least five Bell patents granted in the years 1965 to 1974. Then we aggregate the technology groups to one treated and one control with a CPC technology subclass. In the upper part of Panel a) we vary the cut-off values for the number of Bell patents that define a treated technology subgroup. If we allow for a lower cut-off value the number of subclasses ("cluster") go up. For example if the cut-off is at least one patent (first line) there are 208 subclasses with at least one treated and one control technology group. In contrast if the cut-off value is at at least 10 patents, then there are only 52 cluster. In all specifications, the estimated impact of the breakup is positive, but a bit smaller if we include also subgroups with 1 or 2 patents in the treatment specification. This is plausible as most of the effect is driven by technologies where Bell has many patents (Section 4.2).

In the lower part of Panel a), we use the USPC technology classification instead of the CPC technology classification. The USPC is the technology classification of the US Patent Office. The USPC technology classification was replaced in US in 2013 by the CPC, which was largely based on the IPC that was introduced in 1968. The USPC has technology classes and subclasses. We define a technology subclass as treated if it has more than a certain number of Bell patents in the year 1965 to 1974. Then we aggregate the treated and control subclasses within the technology classes. The results in the lower half of Panel a) show that we find a positive effect of the breakup, but the size of the effect decreases with the cutoff value and is close to zero with a cutoff value of 5. In Panel c), we show one example how the time-varying treatment graph looks like with the USPC classification and a subclass defined as treatment if it contains at least one Bell patent. The graph looks similar to our main graph, but the treatment starts one year later.

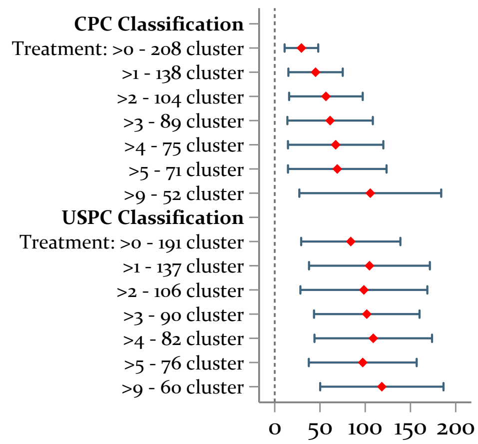
In Panel b) we repeat the exercise in Panel a) but do not aggregate the technology groups (USPC: subclasses) within subclasses (USPC: classes) to one treated and one control observation. This implies that the estimator now gives more weight to subclasses with more treated technology groups. This might make a big difference as the number of treated subgroups within subclasses varies between 1 and 9. The estimated percent increases are generally larger but this is because the average number of patents in a subclass is smaller. The estimated level effects are similar. For example, in our main specification we estimate a total increase of 1065 patents per year (14.2 increase per subclass x 75 patent subclasses). In the disaggregated specification closest to our main specification with a cut-off value of at least 5 Bell patents in the CPC classification, the estimated total increase in the number of patents in 944.2 (4.07 x 232 treated technology groups).

Figure A.4: Alternative treatment definitions

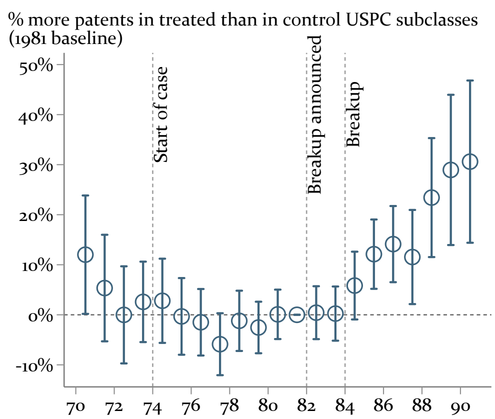
(a) -Tech groups aggregated



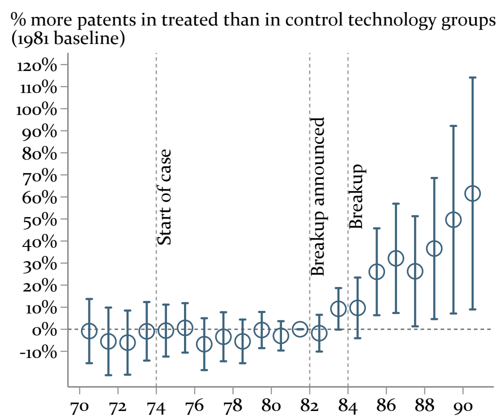
(b) Tech groups not aggregated



(c) USPC classification - aggregated - treatment >0



(d) Drop tech groups with zero Bell patents as control



Notes: Panel a) shows the impact of the breakup on patenting in percent in treated technology classes using our main empirical specification with different treatment definition. In our main empirical specification we aggregate up technology subgroups to one treated and one control subgroup per subclass. In the figure we vary the number of Bell patents above which we define a technology group as treated. We also show at the bottom part of the figure the results for the USPC technology classification system. In panel b), we repeat the analysis from panel a) but do not aggregate the technology groups to one treated and one control technology group per subclass. In panel c) we show the time varying treatment effects for the USPC classification with treatment defined as at least one patent in a subclass. In Panel d) we drop all control technology groups where Bell did not have a single patent granted in the years 1965 to 1974. We define a technology group as treated if Bell had ten or more patents in this technology group in this period.

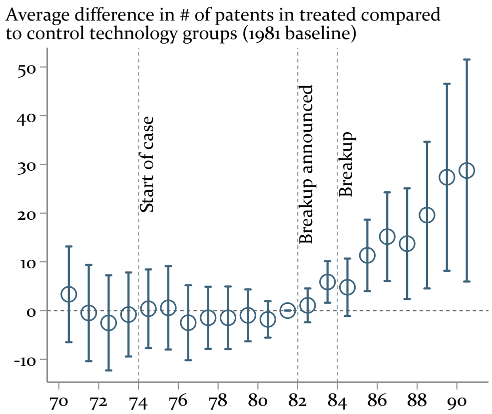
In Panel d) of Figure A.4, we compare technology groups with many Bell patents (≥ 10) in the period from 1965 to 1974 to technologies classes with few Bell patents (> 0 and < 10). This means we drop technology groups with no Bell patents in this period and only compare within technology groups where Bell was active. The idea is that control groups with at least one Bell patent might be a better counterfactual than control groups without Bell patents even controlling for technology subclass. The resulting Figure is again similar to Figure 2a.

Alternative estimation methods In Figure A.5 we show the results of alternative estimation methods. In Panel a) we show Figure 2b in levels instead of in percentage terms. In Panel b) we use the robust and efficient estimators for event studies of Borusyak, Jaravel, and Spiess (2021). Again the outcome variable is in levels and the figure looks similar to Panel a) although with a bit larger standard errors. In Panel c) we use the method of Montiel Olea and Plagborg-Moller (2019) to adjust the standard errors of an event study graph for multiple testing. The 95% Confidence Intervals overlap in some instances with the zero line but most coefficients are significantly different from zero on the 90% level. In Panel d) we estimate the effect of the breakup on the percent increase in patenting as in Figure 2b but we use a Poisson pseudolikelihood regression instead of OLS and convert the estimated coefficient into percentages. The estimated coefficient become more precise but a bit smaller.

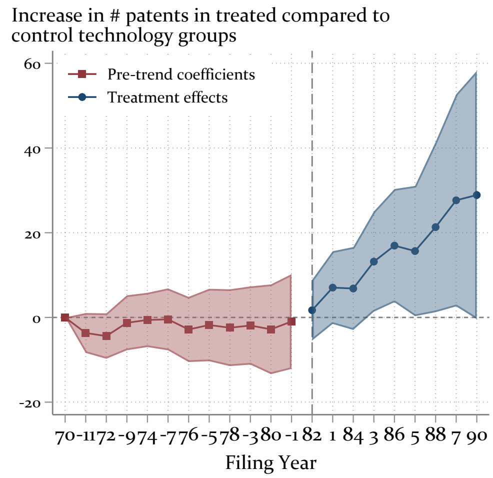
Alternative samples In Figure A.6 we show that our main estimate of the impact of the breakup on innovation does not depend on particular part of the sample. To show this, we drop in turn each technology and report the estimated coefficient. In Panel a) we drop technologies on the CPC section level. Our main estimate is 19% and no matter which section we drop the estimate does not fall below 17%. In Panel b) we drop CPC classes and again no estimate falls below 17% if we drop a single class. In Panel c) we drop each CPC subclass in turn. The most pronounced reduction in the estimate happens if we drop H01L "Semiconductor devices," but the estimate still only drops to an increase of 15%. The strong impact of this class is plausible as semiconductor devices are a key components in telecommunications

Figure A.5: Alternative estimation methods

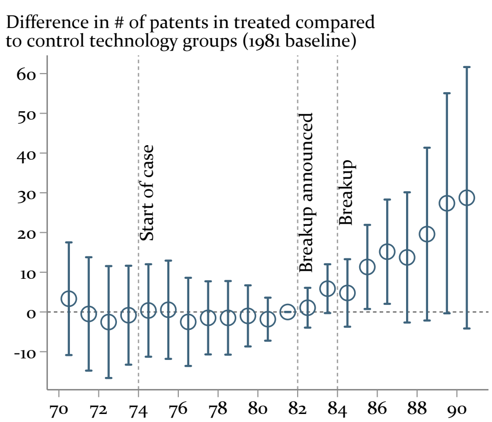
(a) Treatment effects in levels



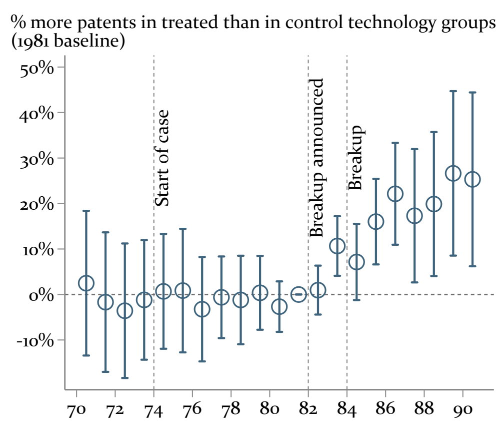
(b) Patent levels with Borusyak, Jaravel, and Spiess (2021)



(c) Standard errors following Montiel Olea and Plagborg-Moller (2019)



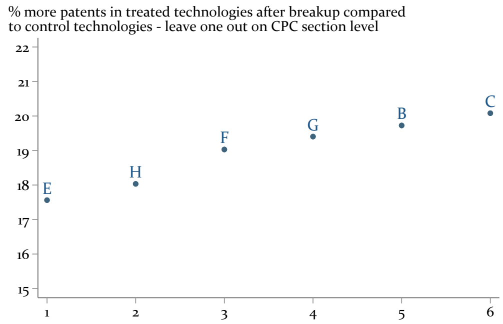
(d) Percent - Poisson pseudolikelihood regression



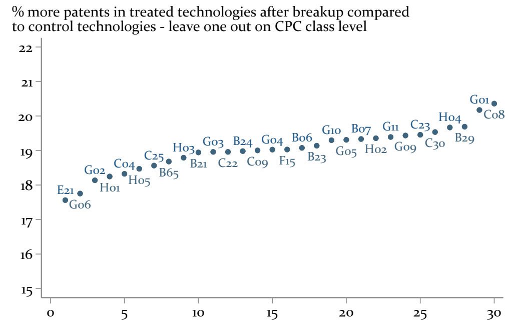
Notes: Panel a) shows for all US patents with US inventors the difference in the number of patents in treated technology groups relative to the total number of patents in control technology groups over time. This is Figure 2b in levels. In panel b) we re-estimate panel a) using the method of Borusyak, Jaravel, and Spiess (2021), that gives robust and efficient estimator for event studies. Panel c) shows the same as Panel a), using confidence bounds based on standard errors that adjust for multiple testing in an event study setting (Montiel Olea and Plagborg-Moller, 2019). In panel d) we reestimate panel a), using a Poisson pseudolikelihood regression. We convert the estimated coefficient into percentage differences and adjust the standard errors using the delta method. The 95% confidence intervals are based on standard errors that are clustered at the technology subclass level.

Figure A.6: Leave-one-out samples

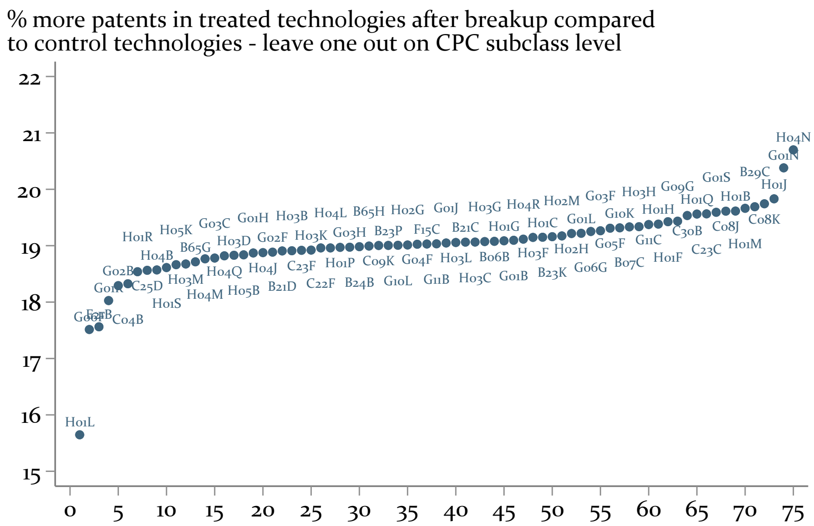
(a) CPC section level



(b) CPC class level

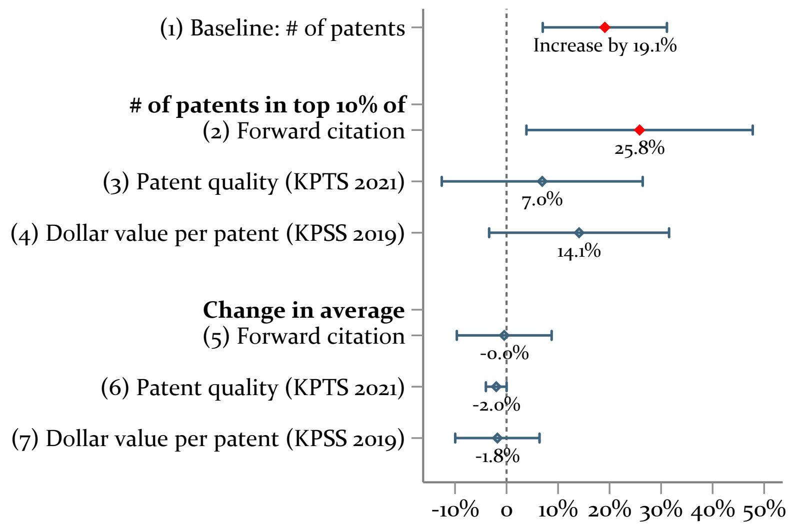


(c) CPC subclass level



Notes: Panel a) shows the impact of the breakup on patenting in % leaving out all patents of one CPC section. In Panel b) we in turn leave out one CPC class and in Panel c) we leave out one CPC subclass.

Figure A.7: Alternative outcomes: Patent quality



Notes: This figure shows the impact of the breakup on different outcome variables in percent in treated technology classes. In the first line, we repeat our baseline specification using the number of patents of US inventors as outcome. In the following three lines we use the number of patents that are in the top 10% according to three different patent quality measures: Forward citations, the 10-year patent quality index of Kelly et al. (2021) and the Dollar values assigned to patents according to Kogan et al. (2017). In the last three lines, we use the same three quality measures but look at average quality.

equipment. These results are stable in the sense that our estimate does not depend on one particular technology. In section 4.2 we show that our results are driven by combination of CPC subclasses, those that are central to telecommunications.

Alternative outcome variables to account for patent quality In Figure A.7, we use alternative outcome variables to account for patent quality. We report again the baseline impact of the breakup on unweighted patenting in row 1. In row 2, we us the number of patents that are in the top 10% in terms of forward citations in the filing year as quality-weighted outcome. After the breakup, we find an increase of 25.8% of impactful patents. This increase is roughly proportional to the increase in patents. In column 3 we use the number of patents that are in the top 10% in terms of the 10-year patent quality measure of Kelly et al. (2021) (KPTS) as outcome. This quality measure is calculated by standardizing the sum of a text similarity measure of a patent to patents filed in the following 10 years with the sum of a text similarity measure to patents filed five years before. It thus takes into account how novel the text of the patent is relative to past patents, and how future patents are influenced by the patent under consideration. Using this measure, we find a positive effect that is of a smaller magnitude than when we use citations as a quality metric. In row 4 we use the number of patents in the top 10% of the Kogan et al. (2017) (KPSS) values as quality-weighted outcome. This metric uses the abnormal stock-market returns around the publication of a patent as a measure of quality. Here, we see again a roughly proportional increase in the number of those high-value patents as outcome.

In rows 5 to 7, we look at the average quality of patents. In row 5 of Figure A.7, we use the average number of forward citations, the average KPTS and the average KPSS value as outcome. In all cases we find a small negative change, suggesting that patent quality decreased on average after the breakup, but not by much.

C Appendix to Section 4

C.1 Additional results on the change of the innovation diversity after the breakup

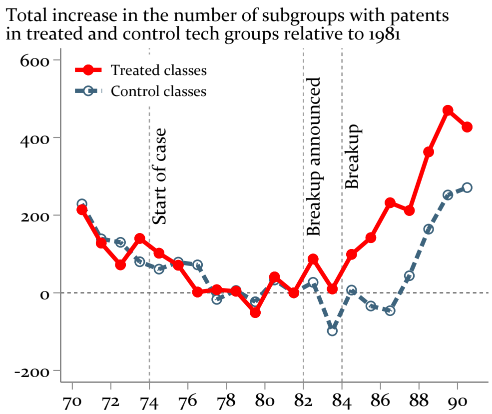
In the main text of the paper we show that after the breakup, the average number of subgroups with at least one patent increases in treated technology groups more than in control technology groups. To do this, we use the definition of CPC subgroups on the two-dot classification level. In the following we visualize the size of the effect and show that our result is robust to sensible alternative specifications.

In Figure A.8 Panel a) we show how the total number of subgroups with at least one patent increases. In 1990 the difference between treatment and control is 157, i.e. there are 157 more subgroups on the two-dot classification with at least one patent in treated than in control technology groups. According to our main result, US inventors filed 2156 patents more in treated than control technology groups in 1990. This suggests there is on average one more subgroup for 13.7 more new patents.

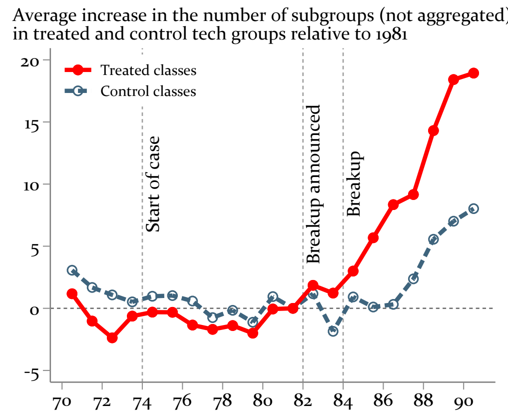
In Panel b) we do the same analysis as in the main part of paper, but do not aggregate subclasses on the two-dot level. Instead, we use the subgroups as they

Figure A.8: Alternative specifications for patent diversity

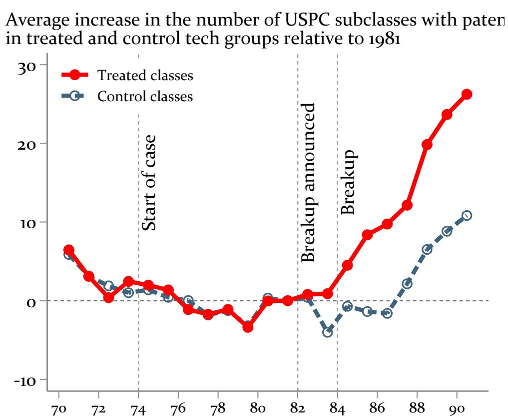
(a) CPC: Total number of main groups



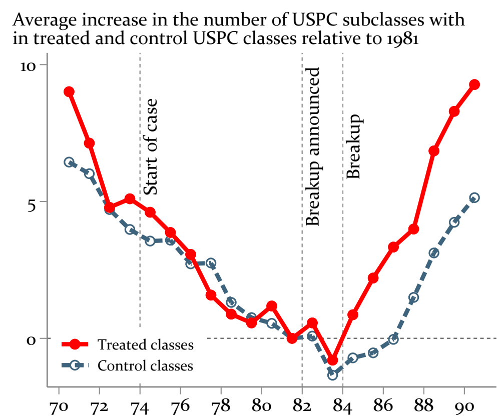
(b) CPC: All groups in the classification



(c) CPC: Unique USPC subclasses



(d) UPSC: Unique USPC subclasses



Notes: Panel a) shows the change in the total number of technology subgroups with at least one patent in a filing year in treatment (red) and control technology groups (blue) relative to 1981 over time. We use the two-dot level subclass classification for each patent. Panel b) shows the average number of technology subgroups in treatment and control technology groups. In contrast to the graph in the main paper we use the subgroups as they are in the data and do not aggregate on the two dot level. Panel c) repeats the analysis in Panel b) but uses the count of USPC technology subclasses in treated and control CPC technology groups as outcome variable. In Panel d) we compare the count of USPC technology subclasses as in c) in treated and control USPC technology classes. We define a USPC technology subclass as treated if there is at least one Bell patent in this subclass from 1965 to 1974.

are in the data. The CPC classification has currently 12 levels below subclasses, this means this graph uses 9 hierarchical levels more than the two-dot classification. The resulting figure looks similar to the graph in the main paper, but the number of unique subclasses increases by about a factor of 3.

In Panel c) we use the count of USPC subclasses instead of CPC subgroups within treated and control technology groups as outcome variable. The count of USPC subclasses give us another measure for innovation diversity, but the resulting figure looks similar to our main figure using CPC subcategories.

In Panel d) we repeat the analysis in c) but use USPC technology subclasses to define treatment and control. We define a USPC technology subclass as treated if there is at least one Bell patent in this subclass from 1965 to 1974. We see again an increase in innovation diversity. In contrast to the figures using CPC technology groups to define treatment and control the difference between treatment and control starts to increase in 1984 instead of 1982.

D Appendix to Section 5

D.1 Difference-in-Differences results for Standard Oil

To measure the impact of the breakup of Standard Oil on patenting, we compare in Table A.8 the change in the number of patents in treated technology subclasses to the change in the number of patents in control subclasses within the same technology class before and after the breakup relative to 1910, the year before the breakup. For this, we use the following regression model:

$$\begin{aligned} \#Patents_{s,g,t} \quad = \quad & \beta_1 \cdot Treat_g \cdot I[1895-1909] + \beta_2 \cdot Treat_g \cdot I[1911-30] + \\ & + Class_s \times Year\,FE_t + \varepsilon_{s,g,t} \end{aligned} \tag{3}$$

where the dependent variable $\#Patents_{s,g,t}$ is the number of patents in USPC class s, subclass g and in filing year t. $Treat_g$ is an indicator function equal to one if subclass g is related to oil and zero otherwise. We interact the treatment indicator $Treat_g$ with the time periods 1895 to 1909 and 1911 to 1930. All estimates are

Table A.8: Quantifying the effect: Difference-in-Differences

	(1)	(2)
	US patents	
	# patents	% increase
Treat x I(95-09)	0.8	1.3
	[-3.9,5.5]	[-6.5,9.0]
Treat x I(11-25)	9.2	14.9
	[3.2,15.1]	[5.3,24.6]
Obs.	13248	13248

Notes: This table shows the result of a difference-in-differences specification following Equation (1). The first column shows the result of an OLS regression of our baseline specification. The dependent variable is the count of all US patents with an US based inventor in a treated or a control technology subgroup. We include technology subclass x year fixed effects. In column (2) we use the OLS estimates in (1) and transform them into percentage increases using the treated group in the pre-period as baseline. We report 95% confidence intervals. The confidence intervals are based on standard errors clustered on the subclass level.

therefore relative to 1910, the year before the breakup was announced. β_1 measures the yearly number of excess patents in treated relative to untreated subclasses from the start of the antitrust case to the announcement of the breakup. β_2 measures the effect of the breakup on patenting.[33] We control for technology subclass x filing year fixed effects to account for differences in patenting rates between technology subclasses over time. We include only patent subclasses that contain both treated and control technology groups.

In column (1), we use the number of all patents in a subclass for a given year the patent was granted as the dependent variable for the time period 1895 to 1930. We find no increase in the period from 1895 to 1909. After the breakup, the number of patents increases on average by 9.2 patents (95% CI: [3.2, 15.1]) in treated subclasses relative to control subclasses. This is an increase of about 1555 patents per year (9.2 more patents per subclass x 169 patent subclasses) for the filing years 1911 to 1930.

[33] We use as start of the treatment period the announcement date of the breakup rather than the date of the actual breakup because we cannot exclude that inventors reacted as soon as they knew of the breakup to be implemented later on.

To get a sense of whether this increase is large or small we calculate the percentage increase using the treated subclasses as baseline. In column (2), we find an increase of 14.9% (95% CI: [5.3%; 24.6%]) in the number of patents in treated relative to control subclasses after the breakup. This suggests that the breakup of Standard Oil increased patenting in oil-related technologies.